

Villanova University

Kinetic Energy Flooring

Group 3

One Step Ahead

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Written Proposal

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Abstract

As the climate crisis worsens, the need for renewable energy has never been more prevalent. Renewable energy sources are essential for a variety of reasons, primarily because they offer numerous economic, environmental, and social benefits compared to traditional fossil fuels. Kinetic flooring, also known as energy-harvesting flooring, is a type of technology designed to convert mechanical energy, typically generated by footsteps or other physical movements, into electrical energy. This type of flooring has various applications, including generating power for lighting, sensors, and other low-power electronic devices in public spaces, walkways, and buildings.

Several different technologies exist for harvesting energy using kinetic flooring, however, to date there have been issues with the cost and effectiveness of these systems, preventing widespread deployment and use. Through this Written Proposal, Group 3 will present and evaluate multiple design solutions for new, cost-effective kinetic flooring systems. A final design, capable of being deployed across the Villanova campus, is depicted and calculations of the average power generated by the system are included.

In summary, the transition to renewable energy sources is essential for addressing climate change, reducing environmental impacts, enhancing energy security, and promoting sustainable economic development. Kinetic tiles offer a sustainable way to generate electricity from human activity and can contribute to energy conservation in public spaces and buildings. They have the potential to reduce the carbon footprint of infrastructure and promote the use of renewable energy sources. Group 3's novel solution for kinetic energy flooring will provide an abundant clean source of power that can be harvested across the Villanova campus and beyond.

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1. Introduction

A major problem that the world is facing is climate change. We need a replacement for fossil fuels as we are in both a climate crisis and an energy crisis. This problem is due to the non renewable resources and harmful processes to obtain energy. This has harmed our planet and the solution can only be found through renewable clean energy.

Global renewable electricity capacity is forecasted to rise more than 60% from 2020 to 2026 [IEA, 2021]. Kinetic Energy Floors have the potential to capture large amounts of lost energy and will play a major role in the expansion of renewable energy. We are creating a floor in which the kinetic energy of one's steps can be converted into electrical energy. This energy will help reduce the usage of fossil fuels and will help fight climate change.

In order to produce a functioning kinetic energy floor, research into prior attempts at kinetic energy flooring were evaluated. This proposal presents various design concepts and prior work that has been done in the field of energy flooring, as well as one company (Pavegen) that is currently manufacturing energy-producing flooring on a “novelty” small-scale today. This proposal points out the issues with past attempts at kinetic energy flooring that have led to the relative failure of kinetic energy flooring to be widely adopted, including the issues with the kinetic energy flooring that is currently being manufactured by Pavegen today.

Building on our analysis of prior and current attempts at kinetic energy flooring, our team realized that a new type of technology for harvesting energy from human walking would be necessary. We began researching solutions that can be used to convert kinetic energy into electrical energy, specifically focusing on research papers

that have been published in the past three years. Our research led us to consider not only electric-generator-type solutions, such as those used by Pavogen, but also newer technologies that show significant improvements over these electric-generator-type solutions.

Three preliminary designs were conceptualized. Our first preliminary design was based on electric-generator-type solutions, but used a different approach than Pavogen and other companies that have attempted to create these solutions in the past. Our second preliminary design was based on piezoelectric generators, a well-known and well-established phenomenon where stresses in certain materials can be converted into electrical power. Our third preliminary design was based on our research of recent discoveries in the field of kinetic to electrical energy conversion, specifically Triboelectric Nanogenerators. These Triboelectric Nanogenerators were only just discovered in 2012 so there have been several recent advances and new research papers around this technology. Our third preliminary design uses recent advances in Triboelectric Nanogenerators that have occurred within the last three years to create a novel kinetic energy flooring solution.

Evaluation of our three preliminary designs against our original requirements was performed and is included in this Written Proposal. A design selection was made from the three preliminary designs, and a detailed design was created based on the preliminary design selection. The specifics of the detailed design are also presented.

A final design depicting our system used in a real-world scenario at Villanova is included in the Final Design section of this proposal. This final design shows multiple individual modules of our system placed underneath the pavers near the Oreo, which is an ideal location for kinetic energy harvesting due to the high pedestrian traffic that passes through the area each day.

2. Formulation of Design

2.1 The Problem

Before our group could discuss and analyze a solution, we first needed to determine the problem. Around the world, countries are starting to experience an energy crisis one by one. Currently, countries like Pakistan, Sri Lanka, Ecuador, and Haiti on top of many others are being ruined by rocketing energy prices and fuel shortages [Jayanti, 2022]. Without a solution to this, one by one, each country will start to fall as we not only start to see our reliance on fossil fuels but also how limited they are. It is predicted that, at this current rate, we will run out of fossil fuels by the year 2060 [Howarth, 2019]. Unfortunately, with the increasing rate of electricity consumption and use of automated devices, it is reasonable to say that 2060 is the best case scenario. With such a short approximation and an even shorter assumed actual year, we need a new solution quickly. Not to mention that this un-updated prediction will become even smaller than it was with the war in Ukraine. Since the war's beginning, we have started to see how little resources we have left and with something as demanding as a war, it has been made apparent in the most extreme way [IEA, 2023]. In addition, as winter is now coming around, Ukraine needs a steady flow of electricity to be able to survive while still being under the pressure of attacks on their energy infrastructure by Russia.

On top of the energy crisis around the world, Group 3 also wanted to make something that was applicable to Villanova. Villanova uses a large amount of energy as it has to provide housing, food, education, entertainment, air conditioning, heating, and additional services to its students. We also wanted this to be a product with a large potential market. Something that could help on not only the small scale, for small

businesses and homes, but also on the large scale, for malls, towns, and entire cities. We set out to create a product capable of providing power to everyone, anywhere.

2.2 Existing Solutions

Today, the common solutions for renewable energy are solar panels and wind turbines. However, these solutions aren't as environmentally friendly as most people would think. Starting on the large scale with solar panels, how many trees had to be cut down so a solar farm could exist? Often only medium scale solar farms require 10-20 acres of land [Pivot, 2019]. This is not even a large size solar farm. Imagine the mass deforestation and repurposing of viable farmland necessary to support the world's massive energy needs – how many animals will lose their homes, how many animals will die, and how will the global food supply chains be disrupted? Furthermore, even once these solutions are deployed, they are still terrible for the surrounding environment. Governments consider solar panels to be toxic waste as they have amounts of heavy metals such as cadmium and lead present. This leads to their disposal being a tedious process while also producing waste that is harmful to the ocean and the general environment. On the smaller scale with solar panels, they cost tens of thousands to install into customers' homes and even after that, they still require maintenance twice a year. On top of that, solar panels ruin the home's visual appeal, potentially leading to it having a lower selling price and losing value overall for the homeowner.

So what about wind turbines? Unfortunately, wind turbines are in the same state as solar panels. On the large scale with wind turbines, again they take up massive amounts of space and ruin our landscapes. So why not move them to the ocean? Well

now the water, its seabed, the marine life, and the surface are all being affected [NOAA, 2023]. On top of that both the water wind turbines and the land wind turbines kill passing birds. At the speed the turbines spin, the birds can't see the blades, leading to them running into the blades or just being impacted by the blades. Lastly, the materials used to build wind turbines still destroy the environment even after they are made. With their concrete-rebar bases, rotting metal, and motor emissions, they are certainly harmful to the environment. Overall, in trying to help reduce the usage of fossil fuels, solar panels and wind turbines are destroying the environment in other ways.

2.3 Determination of Requirements

In designing the requirements for a new type of clean energy solution, we took into account a multitude of factors: it has to generate passive energy, not affect the ecosystem, not lead to pollution, not use fossil fuels, produce stable energy, be affordable, be easy to understand and obtain, and have a large market. After performing a good deal of research, our solution is kinetic energy harvesting flooring. Dissolution obtains electrical energy from flooring and tiles. As people walk on it or even if any pressure is distributed to the tile, it is able to generate electric power. This means that the people will not have to actively try to create energy. Though this is technically not completely passive energy production, it might as well be if these tiles are implemented in the correct, high activity areas. This product will only be deployed in areas of the world that humans inhabit, so we won't need to worry about it negatively affecting the ecosystem. Also, because it converts kinetic energy into electrical energy, we don't need to worry about the use of fossil fuels and associated pollution. Due to its simplest nature of being only a flooring panel or tile, the market will be high, people will be able

to understand it, and it will be obtainable fairly easily. It's just as easy to get as a normal floor tile.

Requirements:

Generates passive and stable energy:

Once implemented, our solution needs to be able to generate consistent energy without any additional active human effort.

Will not affect the ecosystem:

Our solution needs to not sacrifice the ecosystem or any aspect of the world in an attempt to try to help another aspect of the world.

Will not lead to pollution:

Our solution needs to not lead to pollution and must be easily disposed of.

Does not use fossil fuels:

Our solution needs to not be reliant on limited fossil fuels and instead become the reason that we don't need fossil fuels.

Is affordable for us and the customer:

Our solution needs to be cheap enough that it is a desirable solution and well worth the implementation.

Easy to understand and obtain:

While the underlying technology of our solution may be complex, the product itself needs to be easy for the customer to understand and obtain so they are not deterred.

Has a large market:

Our solution must have a large market so that it can have a broad and lasting impact.

3. Analysis of Existing Products

3.1 Pavegen

Flooring capable of harnessing kinetic energy has already been attempted and can be successful in certain circumstances, however, despite certain pros, there are several issues with these solutions. This is why kinetic energy flooring has not yet found widespread use. Pavegen is a perfect example of this. Pavegen was founded in 2009 by Laurence Kemball-Cook [Climate and Capital Media, 2023]. Pavegen seeks to install their flooring into airports, train stations, busy transport sites, sports stadia, and retail destinations. Overall, they are targeting high traffic indoor areas within cities and towns, however the high cost and difficult installation requirements for their flooring have left it as more of a novelty or marketing item than an actual solution for renewable energy.

Pavegen has gone through multiple iterations and produced three different designs for their product. Through this, they have obtained four patents for their product as shown in Appendices A, B, C, and D.

Pavegen's technology utilizes three electromagnetic induction generators, one at each edge of a triangular tile. When someone steps on the tile, it moves down and triggers the electromagnetic generators to spin. This spin through the motor allows for a conversion to electrical energy. An image of the electronics that are used underneath a Pavegen tile are shown in Figure 3A.



Figure 3A: Pavegen's Version 3 (V3) and most recent tile design [Wevolver, 2023].

Overall, Pavegen's product is not bad, however, it is far too expensive to implement for widespread use, and it is currently only for indoor use [Pavogen, 2023]. Pavegen was established over 10 years ago, however their flooring has only been installed 200 times [Pavogen, 2023]. From an electrical standpoint, one step allows the Pavegen tile to generate 3 joules of energy, while 5-7 footstep can produce 20 seconds of light using electromagnetic induction generators [Pavogen, 2023]. Their tile is 500mm by 500mm, has a power rating of 5 watts continuous power from footsteps, has a maximum voltage of 48V (ranging from 12V - 48V), and is made of steel and recycled aluminum [Pavogen, 2023]. Lastly, they have been able to become EMC compliant, CE marked, and UL compliant. However, their product also has numerous downsides, starting with the fact that it costs \$75 - \$160 dollars per tile versus \$0.69 - \$0.99 per tile from a local hardware store [Lowes, 2023].

Like solar panels and wind turbines, Pavegen is not a viable long term solution. Their product only lasts 20 years, which is the exact same lifespan as solar panels and

wind turbines. On top of that, their aptitude for data collection could be portrayed poorly. In a world where data is valuable and powerful, people might not like Pavegen knowing where they are going as they walk on the Pavegen tiles. On top of that, their design is flawed. Electric motors are not cheap, and Pavegen proprietary motors are not weather resistant, causing the Pavegen tiles to only be able to be used indoors. Plus to install their flooring, customers would need to remove their current floor, and then build up the floor height significantly to provide room for the motors, which decreases the effective height of the room. Even after they go through the whole process to install the flooring, it still won't be fun to walk on. When a person takes a step on the tile, it moves down to start the conversion to electrical energy. However, the large travel distance of the tile could easily throw people walking or running off balance, leading to injuries. Furthermore, if someone steps on more than one tile at the same time, it's unlikely that the weight will be evenly distributed so the simple pedestrian will be thrown off by one side of their step being lower than the other. All of this makes the Pavegen floor not realistic for the amount of energy that is produced in the end. Pavegen is working to become established, but if they aren't able to produce energy output at a reasonable cost, and with minimal intrusion to the users, they will most likely continue to stagnate as they have for the past ten years.

3.2 Energy Floors

Energy Floors is another company that produces kinetic energy flooring tiles. Energy Floors was founded in 2007 by Michel Smit and is based in the Netherlands [LinkedIn, 2023]. Similar to Pavegen, Energy Floors harnesses kinetic energy when the tiles move down significantly through electromagnetic generators. However, they took a

different route with the marketing of their flooring. Unlike Pavegen, Energy Floors doesn't seek to be in everyday life. Instead, Energy Floors has three different products: the Dancer, the Gamer, and the Walker. The Dancer, as the name implies, is a dance floor that people use to generate energy. The Dancer comprises multiple products ranging in size, and a typical Energy Floors' 32 tile Dancer system is shown in Figure 3B. As people dance on the tiles, they are able to see how much energy they are generating through a screen displaying the energy numbers.

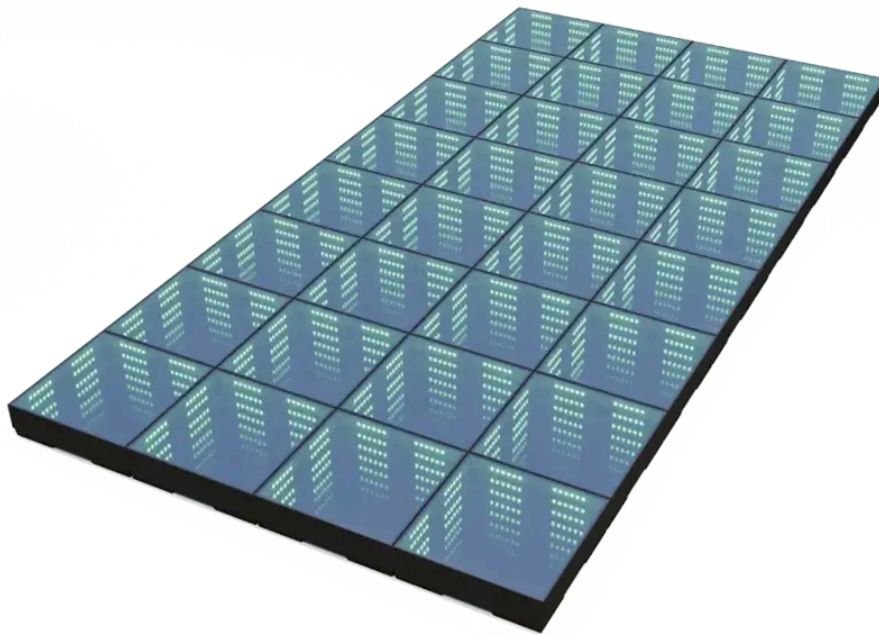


Figure 3B: Energy Floors' 32 tile, Dancer system. It is 600 cm by 300 cm and has a watt peak of 640 [Energy Floors, 2023].

Next, the Gamer is a product that has been mainly used in schools thus far. The tiles light up and children try to hit the areas that are lit up. This impact then generates kinetic energy. Lastly, the Walker is very similar to Pavegen's product. The Walker is a set of indoor tiles meant to harness energy as people walk on them. They have not

specified the locations specifically they would like to implement or have implemented this product, however, like Pavegen's product, this seems like it needs to be indoors to remain functional long-term. Furthermore, it seems like Energy Floors has run into the same problem as Pavegen – given the high price of their product, they are unable to produce enough energy to warrant this high cost, leading to their products being used more as a novelty or a marketing tool. From their reviews, it seems like the product is used as an aesthetic for companies that want to seem like they care about the environment. Sarah Basile states, “During our tours or experiences, the kinetic floor is usually a main focus of our philosophy. The people are always so fascinated by it!” [Basile, 2023]. There is no mention of how much energy they have saved or any positive environmental impact that it has produced. Overall, Energy Floors' solution is very similar to Pavegen in benefits as well as detriments. It still produces minimal energy when compared to its very large cost, and it can throw walkers off balance. However, people using the Gamer or Dancer would be more prepared for the tilting change in the floor tiles. The only significant difference is that Energy Floors has been able to create more products than Pavegen, while Pavegen has been able to perform more installs (although, still only a paltry 200 total).

3.3 EWPanel

Lastly, there is EWPanel. EWPanel took a different approach than Pavegen and Energy Floors, however, they were unsuccessful. EWPanel was formed in 2016 by Lazarus German and Xudong Wang, but they disbanded in 2020. Unlike Pavegen and Energy Floors, EWPanel used triboelectric nanogenerators (TENGs) to generate their energy. TENGs were discovered by Fan and Wang in 2012 [Fan et al, 2012], however,

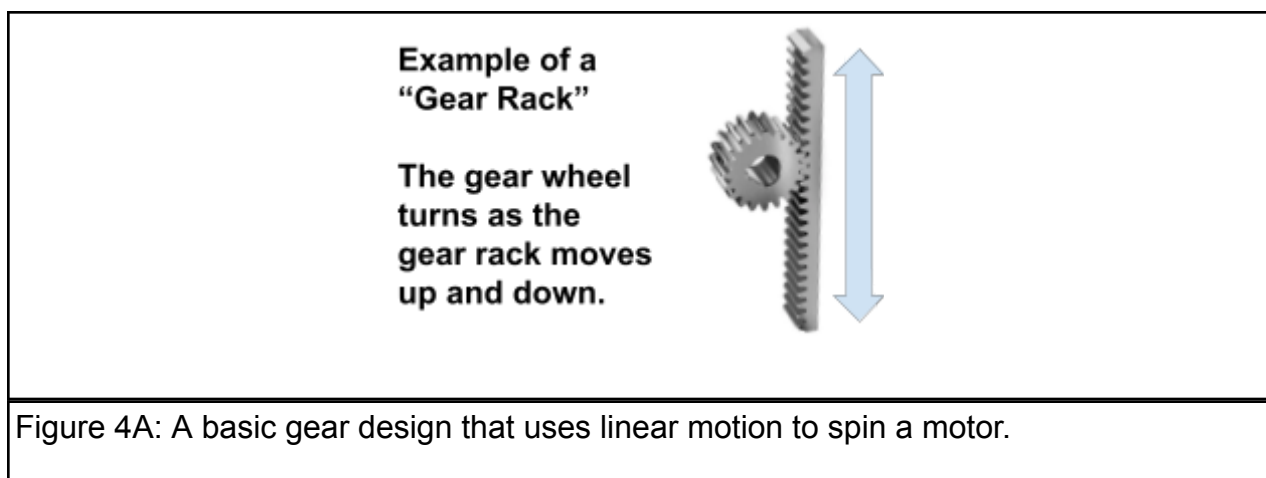
the use of wood pulp as a TENG in flooring was only first created by Wang in 2016. The method used wood pulp embedded in wood flooring to generate energy when pressure was applied. Wang did this to utilize the easy and clear waste removal of a material like wood pulp. It also reduced the cost of the product, since wood pulp and the tape-like array of wood pulp nanogenerators is not costly – nowhere near the cost of electromagnetic induction generators which require massive amounts of money for the motors and the copper in them. Overall, this product was new, cost less, was smaller, was much better for the environment, and didn't move up and down significantly when someone stepped on them. EWPanel was the first company to solve the balance problem. However, they still ran into the same problem of being outside. As a wood panel only, EWPanel's product couldn't be implemented outside because of the weather wearing away at it. Also, as a wood tile only, it couldn't withstand very heavy weight. Finally, while the use of wood pulp a TENG was very environmentally friendly, it was not a very efficient TENG and therefore did not produce enough power to make it a viable solution that would be worth implementing. These factors led to the eventual shutdown of the EWPanel company.

4. Preliminary Designs

4.1 Preliminary Design #1:

Electric Generator Based Human Energy Harvesting Module

One initial design concept that our group considered was using small generators to create electricity whenever a tile is stepped on. Some commonly available DC motors can be used to generate power. While these motors turn when power is applied to them, they can actually create power when their shaft is turned by some external force. For example, a DC 775 motor can produce about 8 Watts of power when turned at 1500 rotations per minute [Electron, 2018]. These motors can be purchased for about \$15 each [Amazon.com, 2022]. The body of the DC 775 motor is 66.7mm long and 42mm in diameter, and it has a shaft with a diameter of 5mm. By placing a round gear on the shaft and connecting it to a gear rack, the DC 775 motor can be turned by a linear movement. An example of a gear rack is shown in Figure 4A.



For our *Electric Generator Based Human Energy Harvesting Module*, we proposed placing four DC 775 motors underneath a 12" by 12" floor tile. The motors would be set slightly inwards from the edge of the tile to allow springs to be placed around the edge of the tile, ensuring that the tile would return to its upward position after being stepped on.

Since the shaft of the DC 775 motor is 5mm in diameter, it has a circumference of 15.71mm. This means that in the best-case scenario where the teeth of the round gear extend all the way into the shaft, the tile would have to travel 15.71mm (or about 0.62 inches) just to turn the shaft of the DC 775 motor once. In reality, the teeth of the round gear will not be able to extend all the way into the shaft, so we estimated that a single turn of the shaft of the DC 775 motor would require approximately a full inch of travel by the tile above it. An image of the DC 775 motors attached to the underside of a 12" by 12" floor tile is shown in Figure 4B.

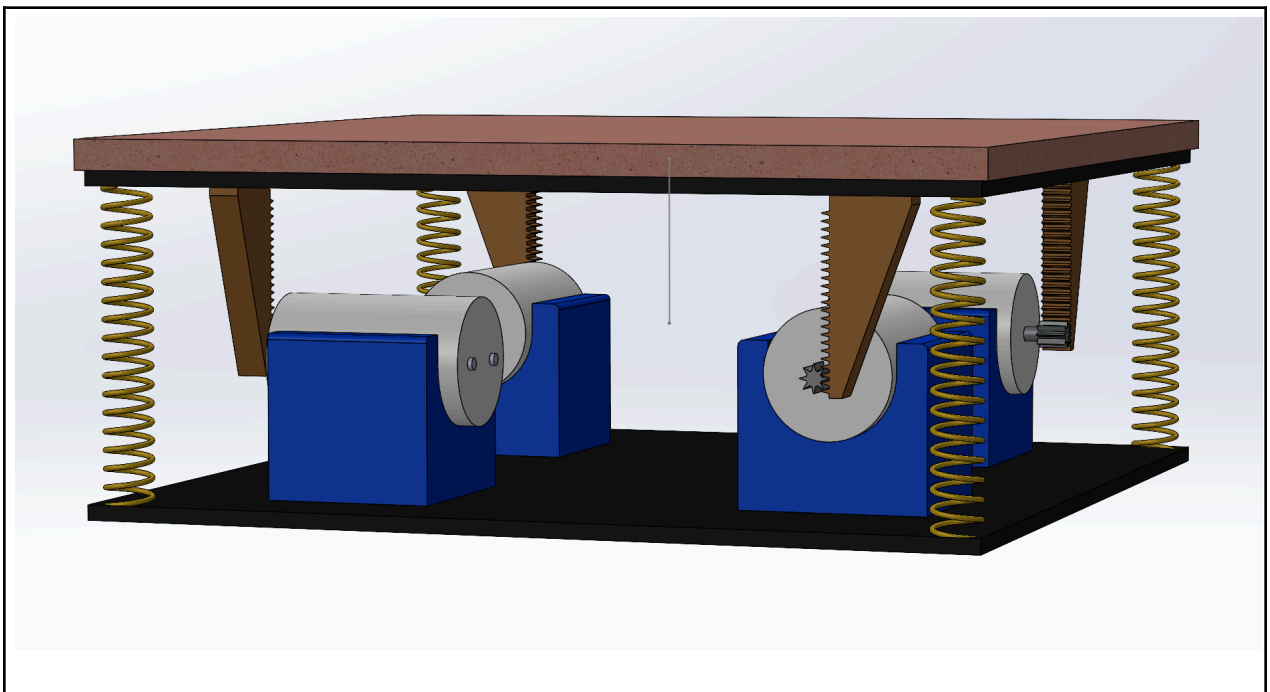


Figure 4B: A simplified SolidWorks CAD rendering of our preliminary design #1. As the tile takes pressure, the springs compress and the gear racks spin the round gears. The

gears spinning leads to the shafts spinning, generating electrical energy from the DV 775 motors.

The design of our *Electric Generator Based Human Energy Harvesting Module* system would require about 4.5" of space underneath the tile to provide room for the motors and the gear racks when they are depressed by a person's foot.

While the example system that used a DC 775 motor to produce energy was able to produce about 8 Watts of power [Electron, 2018], that system was rotating at a speed of 1500 rotations per minute. We decided to calculate how fast our tile would need to be pressed down to achieve this RPM. These calculations are shown in Figure 4C.

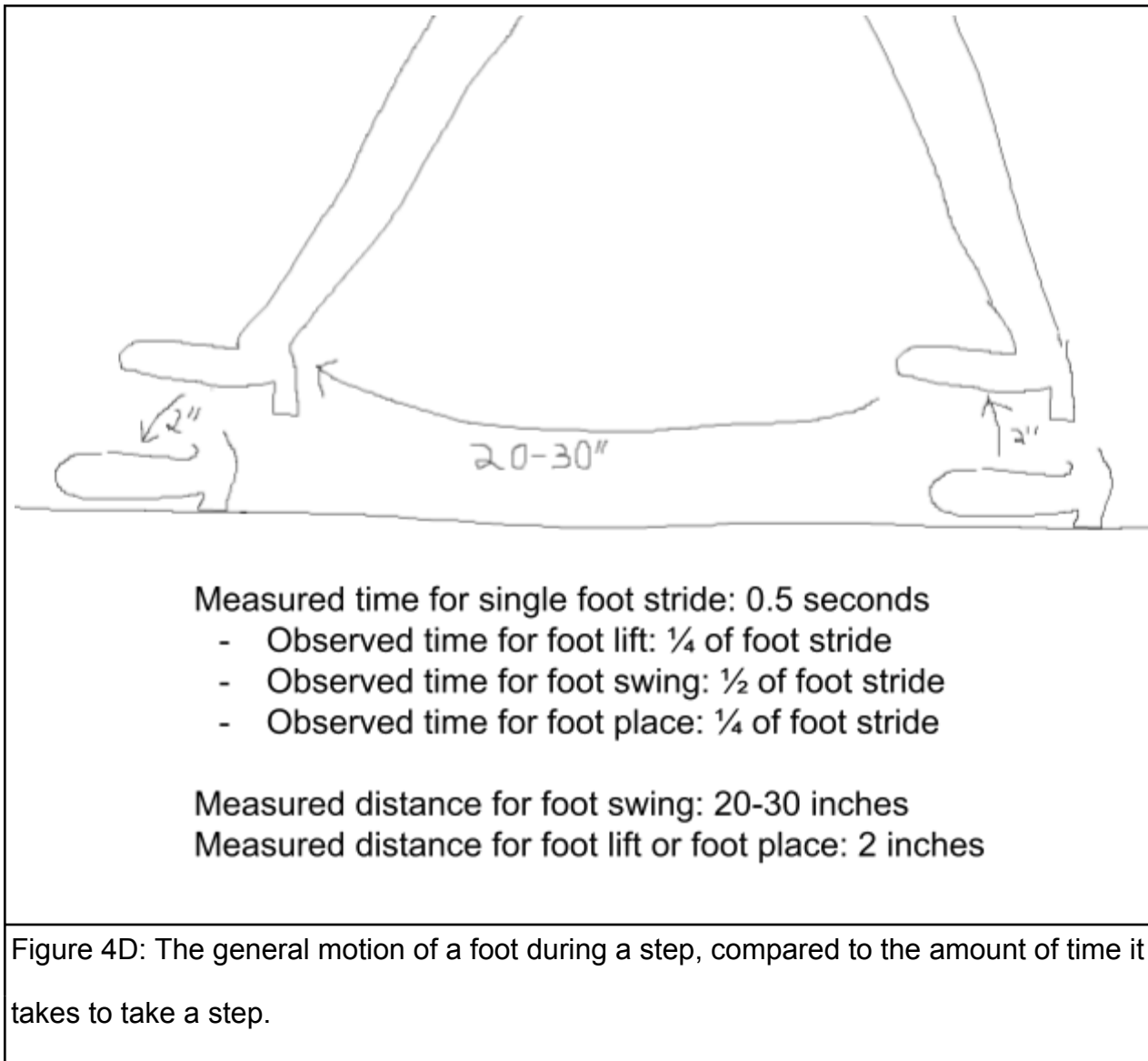
$$1500 \text{ rotations / minute} * 1 \text{ minute} / 60 \text{ seconds} = 25 \text{ rotations / second}$$

Assuming 1 inch of vertical travel is necessary for 1 rotation of the DC 775 motor (as explained in the text above) the RPM can be calculated as...

$$25 \text{ rotations / second} * 1 \text{ in / rotation} = 25 \text{ in / second}$$

Figure 4C: Calculation of linear-motion speed based on necessary rotations per second.

Next, we evaluated a typical walking pattern to see how fast our foot actually traveled when it moved downward toward the ground. We found that a typical foot step, which includes lifting the foot, swinging it forward, and placing it on the ground took approximately 0.5 seconds. A diagram of this motion is shown in Figure 4D.



Using the measured and observed values from our foot stride experiment, we calculated the speed of a “foot place” as shown in Figure 4E.

$$0.5 \text{ seconds} / \text{foot stride} * 0.25 \text{ foot strides} / \text{foot place} = .125 \text{ seconds} / \text{foot place}$$

$$2 \text{ inches} / \text{foot place} * 1 \text{ foot place} / .125 \text{ seconds} = 16 \text{ inches} / \text{second}$$

Figure 4E: The velocity of foot strides.

We then used these values to calculate an estimated maximum power output for our *Electric Generator Based Human Energy Harvesting Module*. We determined that this calculated maximum power output was an overly generous estimate since in reality the motor would need to spin up from 0"/second to 16"/second during the duration of the 1 inch travel. At best, the 16"/second speed might be achieved by the end of the 1 inch travel, so to account for this, we applied an average 8"/second of downward speed to the gear rack. These values were used to calculate an average power produced by the *Electric Generator Based Human Energy Harvesting Module* and the calculations are shown in Figure 4F.

<i>16 in / second foot motion $\Rightarrow$ 8 in / second average speed over 1" gear rack distance</i> <i>25 in / second : 8 Watts</i> <i>8 in / second : 2.56 Watts</i> <i>2.56 Watts * 4 motors = 10.24 Watts</i>
Figure 4F: The energy production of preliminary design #1.

The 10.24 Watts is only produced during the time in which a person is stepping down on the tile. The DC 775 motor will actually produce power while it turns backwards when the springs are bringing the tile back up to its original position, however, any energy obtained from this upward motion would be lost by the fact that the springs will be slowing the person's step on the way down since the springs will be acting against the downward motion. Also, looking at the resistance that the DC 775 motor showed

against hand-turning [Electron, 2018], it was determined that adding additional motors beyond the four in our design would have diminishing returns since they would resist the descent of the tile, causing it to move slower and reducing the overall output.

As a “sanity check” to our calculations, we looked up the value of Pavegen’s power output for their floors and found that they stated that “Pavegen’s patented systems produce around 3 joules of energy per footstep or up to 5 watts of power while someone is walking” [Pavegen, 2023]. This was close to our calculated 10.24 Watts, so we felt that overall our calculations were fairly reasonable.

Some issues were found with our *Electric Generator Based Human Energy Harvesting Module*, similar to Pavogen’s system and others like it on the market. Specifically, the system requires a large amount of room underneath the tiles since it has to account for the 1” travel distance of the tile, as well as the 42mm diameter of the motors, and the space needed for the gear rack when the tile is fully depressed. In addition, the motors are fairly expensive at about \$15 each [Amazon.com, 2022], taking the cost of a single 12” x 12” ceramic tile from \$0.69-\$0.99 per tile [Lowes, 2023] up to over \$60-\$65 per tile. Finally, the mechanical gear rack system is not ideal for outdoor environments where it will be exposed to moisture, causing it to lose its grease and rust, and where pieces of dirt and sand can get into the gear system.

4.2 Preliminary Design #2:

Piezoelectric Based Human Energy Harvesting Module

After doing more research on how to convert pressure into energy, another initial design concept that we considered was using the piezoelectric effect. Piezoelectricity was first identified in 1880 by The Curie brothers, and it is known as the property of

materials to generate electricity from mechanical deformation [Ahmed et al, 2021].

Essentially, the piezoelectric effect allows certain materials to generate electric charge when mechanical stresses are applied to them, and this charge can then be extracted and used to power electric devices or to charge batteries for later use.

Some naturally-occurring materials that have piezoelectric effect and can be used to generate electric charge are berlinite, quartz, cane sugar, rochelle salt, topaz, tourmaline, and even dry bone. It is thought that the piezoelectric effect in bone is actually used as a biological sensor to sense the amount of force that is being applied to the bone [Nanomotion, 2023]. Some examples of man-made piezoelectric materials are barium titanate and lead zirconate titanate.

It should be noted that there are environmental concerns around the use of man-made piezoelectric materials since many of them use lead which is toxic and can pollute the environment, however, recently there has been a push to develop lead-free piezoelectric materials and this has resulted in many new piezoelectrics that are more environmentally friendly [Nanomotion, 2023].

Piezoelectrics are classified into two categories, which are piezopolymer and piezoceramic. Piezopolymers are flexible, however, they have many drawbacks such as low energy conversion rates and low electromechanical coefficients. Piezoceramics are usually brittle, however, they have high energy conversion rates and large electromechanical coupling constants [Khalid et al, 2019]. Since we are looking to generate as much energy as possible, and since the weight of a person is easily borne by ceramics (ex. ceramic tiles are commonly used throughout the world), it was decided that for our preliminary design of the *Piezoelectric Based Human Energy Harvesting Module*, we would utilize piezoceramics instead of piezopolymers. In their work, Zhang

et al found the effective output power density of the stacked piezoceramic when charging a lithium-ion batteries, reached as high as 3.04 mW/cm³ [Zhang et al, 2023].

For our preliminary design of the *Piezoelectric Based Human Energy Harvesting Module*, we calculated that a 12" by 12" floor tile with a 144in² surface area translates to a surface area of 929cm². Stacking piezoceramic layers to a thickness of 1.0764cm would therefore yield a total of 1000cm³ of piezoceramic material per tile, which, using the effective output power density found by Zhang et al, would yield a power output as high as 3 Watts per tile [Zhang et al, 2023]. These calculations are shown in Figure 4G.

$$12 \text{ in} * 12 \text{ in} = 144 \text{ in}^2$$

$$144 \text{ in}^2 * 6.4516 \text{ cm}^2/\text{in}^2 = 929.0304 \text{ cm}^2$$

$$929.0304 \text{ cm}^2 * 1.0764 \text{ cm} = 1000.0 \text{ cm}^3$$

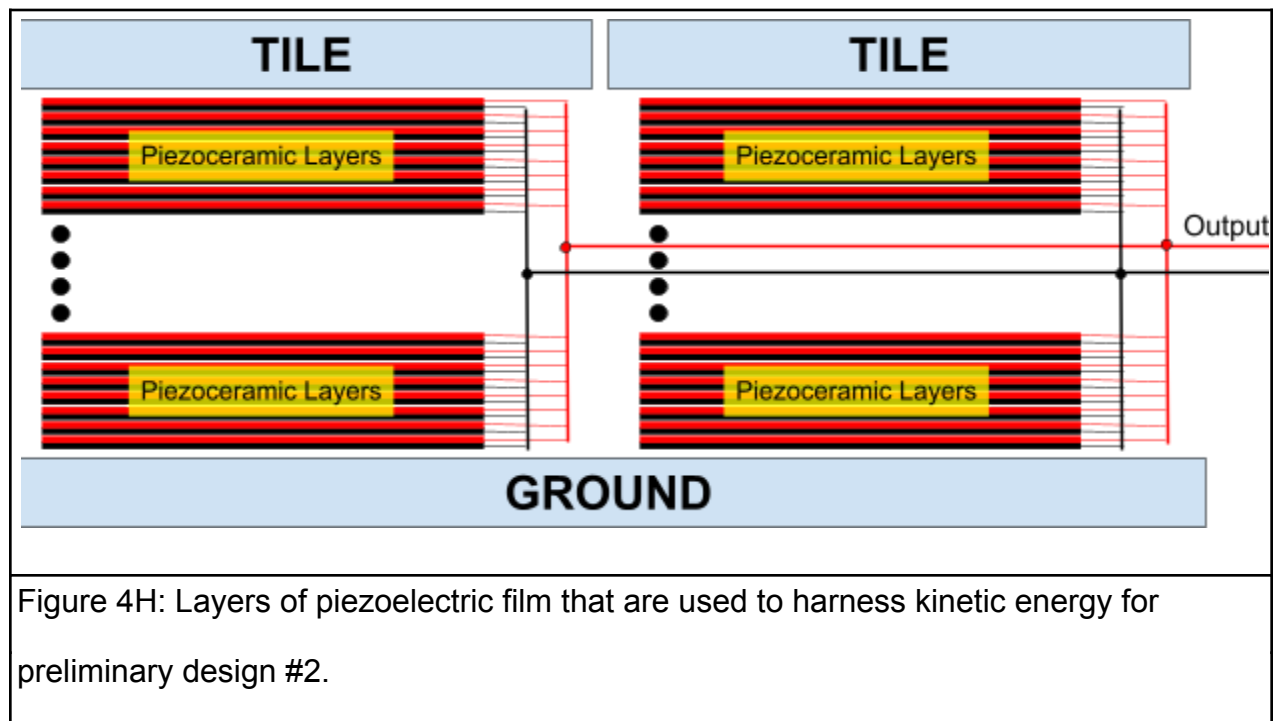
$$1000.0 \text{ cm}^3 * 3.04 \text{ mW}/\text{cm}^3 = 3040 \text{ mW} = 3.04 \text{ Watts}$$

Figure 4G: The energy production of preliminary design #2.

Since a layer of piezoelectric film made of piezoceramic material is .4mm thick [Zhang et al, 2023], it would require 2691 layers of piezoelectric film to create the 1.0764 cm (1076.4mm) thickness necessary to produce the 3.04 Watts.

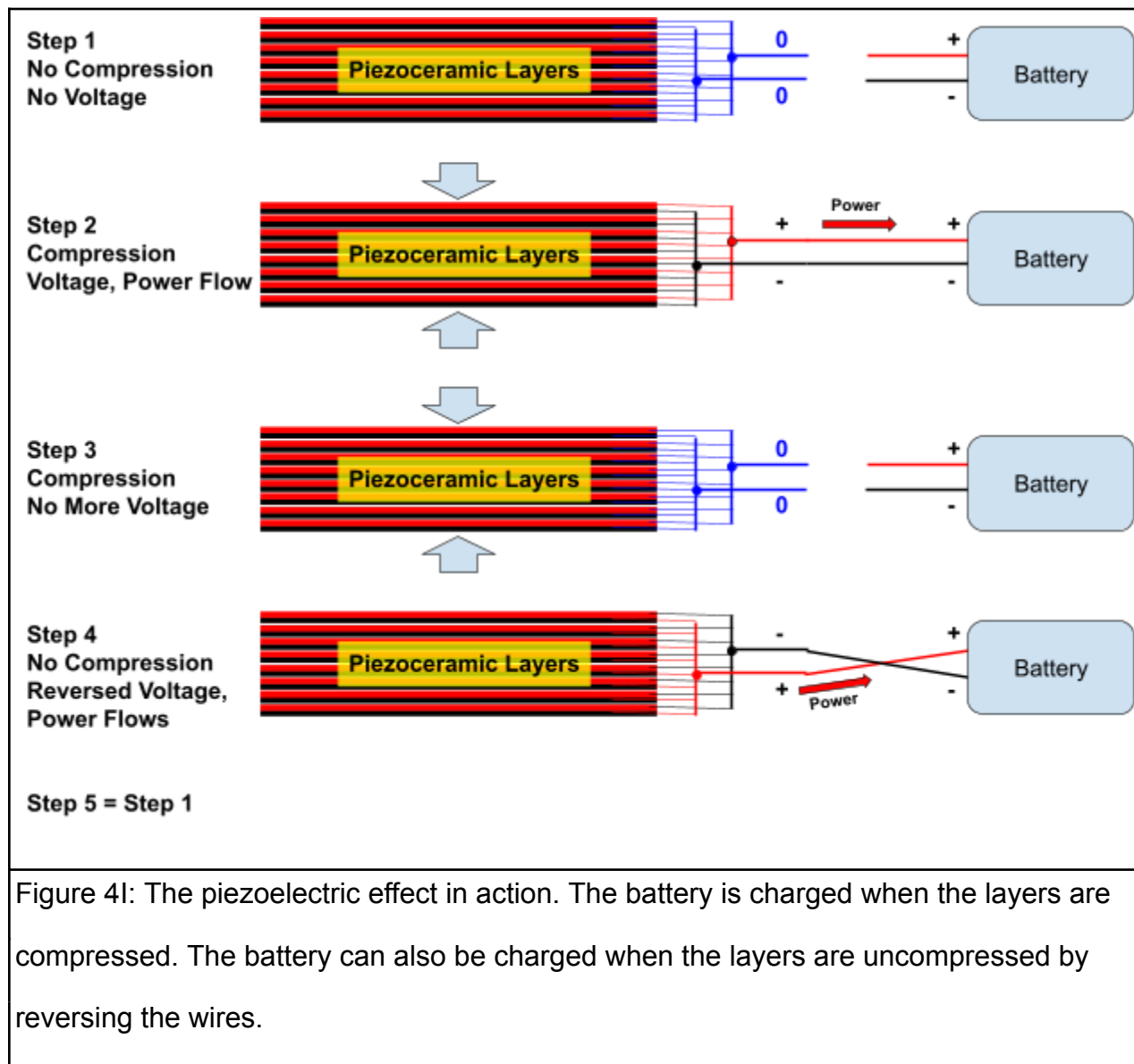
A simplified image of two tiles with layers of piezoceramic film under them is shown in Figure 4H. Note that this figure is not drawn to scale and it does not show other necessary components, such as an encasement to protect the piezoceramic film layers and a battery to store the electrical output of the piezoelectrics. Also, only the top eight layers and bottom eight layers of piezoceramic film are shown in the image, while

in actuality there are a total of 2691 layers of film compressed together between each tile and the ground.



While this system produces a maximum of 3.04 Watts, that power is only produced for the duration of time during which a person's step impacts down on the tile and the piezoceramic material has a change in stress and creates a voltage. Once the piezoceramic material is under full pressure, the energy can be removed by attaching a battery and flowing the energy from the piezoceramic film layers into the battery. After that, the battery can be disconnected and the piezoceramic material will create a negative voltage for the duration of time during which the person's step is removed from the tile and the stress on the piezoceramic material is reduced. Once the person's foot is released, the power generated can be stored into the battery by connecting it to the piezoceramic film layers with the wires reversed since the voltage created by the

piezoceramic film layers would be negative since it was created by reducing the stress on the films. An image of this is shown in Figure 4I.



4.3 Preliminary Design #3:

Triboelectric Nanogenerator Based Human Energy Harvesting Module

Another technology that we found for converting mechanical energy into electricity was the use of Triboelectric Nanogenerators. Triboelectric Nanogeneration is a relatively new technology that is able to convert mechanical energy into electricity. Triboelectric Nanogenerators are based on the Triboelectric Effect, which is the transfer of electric charge between two objects when they contact each other. As these objects are separated, the potential energy between them from these charges increases, which is seen as an increase in Voltage. Triboelectric Nanogenerators harness these charges and can be used to power devices, or to charge batteries for later use.

Triboelectric Nanogenerator technology was invented by Prof. Zhong Lin Wang's group at Georgia Institute of Technology in 2012 [Fan et al, 2012]. By stacking two thin polymer films made of Kapton and polyester (PET), a charge generation, separation and induction process was achieved through mechanical deformation of the polymer film, obtaining a power output density of $\sim 10.4 \text{ mW/cm}^3$ and an output voltage of 3.3 V [Fan et al, 2012].

The Triboelectric Nanogenerator effect works because as two neutrality charged materials, Teflon (FEP) and KATPON, come into contact, they switch charges, attempting to level out. Like magnets, the positive tries to go to the negative and vice versa. When the Teflon (FEP) and KAPTON come into contact, their points of contact will have opposite charges on each side as shown in Figure 4J. Then as the pressure is released, the teflon and KAPTON are separated by the springs. However, their attraction to each other becomes stronger, leading to an increase in potential energy.

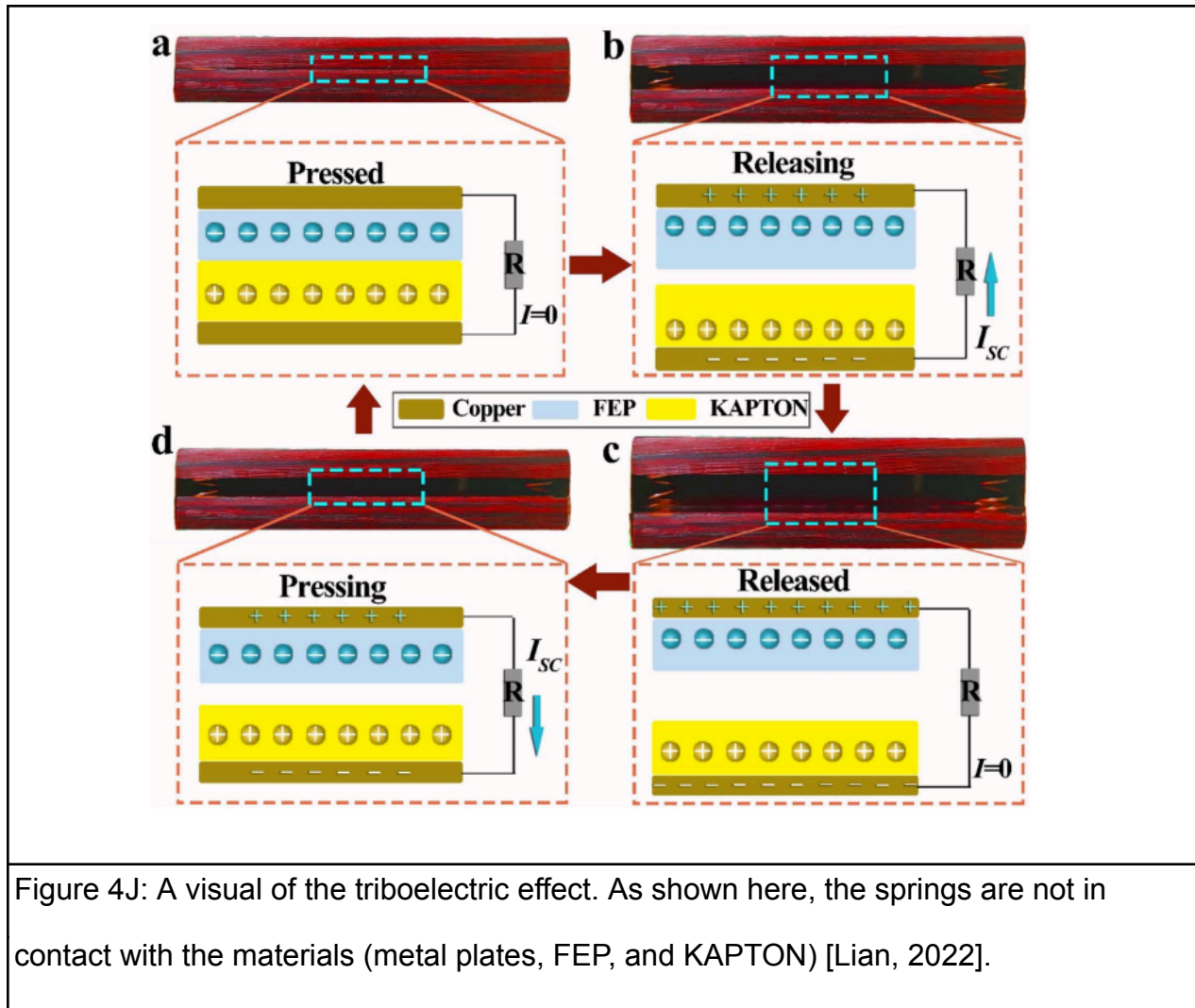


Figure 4L shows a rough diagram of our group's understanding of how Triboelectric Nanogenerators work, and how they would be used in our kinetic energy generating flooring. First, a person steps on the Triboelectric Nanogenerator, bringing the Teflon (FEP) and KAPTON into contact and setting up the charges. Then they remove their foot, causing the Teflon (FEP) and KAPTON to separate and build up even higher energy. The energy is shown in Figure 4L as the 0/100 amounts to show the difference in charge, while the battery is shown with 1000/1000 to simply represent that

it has a lot of electrons that it can give up or accept. The battery then takes the electrons from the material with more electrons as it attempts to even out the charge on the materials. This leads to the battery to become uneven and thus charged as shown in the third step in Figure 4L. When a person steps down again, the Teflon (FEP) and KAPTON will want to move back to their 0/100 state, so electrons will actually flow backwards. This can be used to charge the battery more, as long as the wires to the battery are connected in reverse at this point. As this reaction occurs after every foot press, the battery will become more and more charged. This charge can then be used on an LED light or whatever the battery is powering, since electrons will move through them as the battery tries to even out its charge.

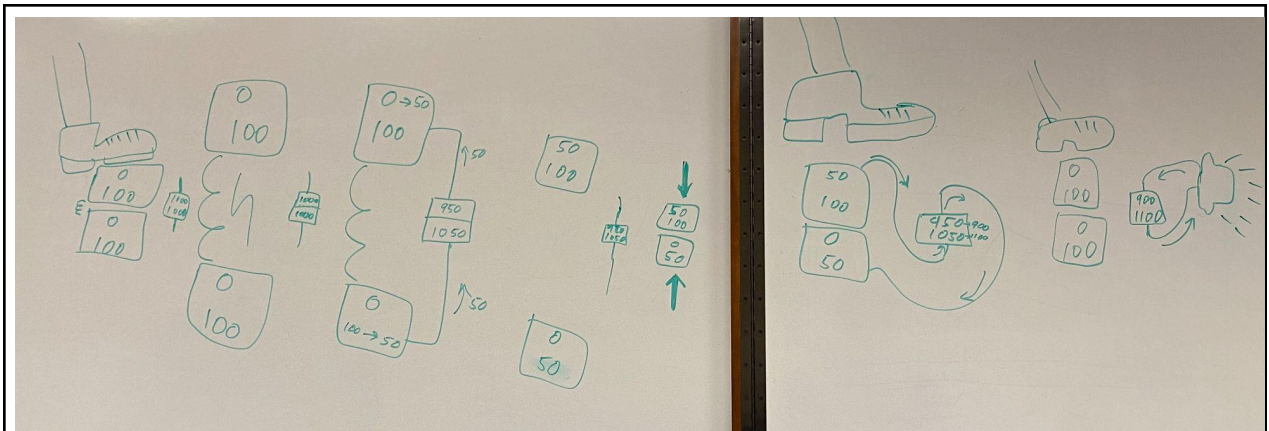


Figure 4K: How the triboelectric nanogenerators work. The higher the number, the more electrons it has. Assume that each material started with a balance of 50/50. In the end, the battery is charged and can be used to light an LED.

5. Idea Selection

5.1 Idea Selection

During our idea selection, we looked back to our requirements that we created before we first came up with our preliminary designs. We did this because we needed to ensure that we met our original conditions. So, we analyzed if each of our designs could generate relatively passive energy, not affect the ecosystem, not lead to pollution, not use fossil fuels, produce stable energy, be affordable, be easy to understand and obtain, and have a large market. On top of that, we learned that a few companies have attempted ventures similar to ours, and we didn't want to make the same mistakes that they did, so we looked at some of the problems and flaws that the other companies ran into and ensured that our product would not have those flaws. Figure 5A shows a chart of our original requirements against our three preliminary designs.

Requirement	Design 1: Electromagnetic Model	Design 2: Piezoelectric Model	Design 3: Triboelectric Model
Generates passive and stable energy	X	X	X
Will not affect the ecosystem	X	X	X
Will not lead to	X	X	X - if using wood

pollution			pulp instead of Teflon (FEP) and KAPTON
Does not use fossil fuels	X	X	X
Can be used outside			X
Is affordable for us and the customer		X	X
Easy to understand and obtain	X		X
Has a large market	X	X	X
Won't have much competition		X	X
Doesn't throw people off balance			X

Figure 5A: Chart of the original requirements against the three preliminary designs.

After that, we compared the technologies against each other and performed additional research on the different forms of energy generation through kinetic energy. First, triboelectric nanogenerators vs electromagnetic generators. Triboelectric costs

less, takes up less room, weighs less and has no competition. However, more people know about electromagnetism, leading to a bigger potential market for that technology as people are more willing to buy what they know they are buying. Next triboelectric vs piezoelectric. Piezoelectric is very similar to the functionality of electromagnetic. However, piezoelectric runs into the same downfall as triboelectric as they are both lesser known, leading to customers being more weary of what they are buying. More tests would have to be done and even after that, customers would probably need to see other people liking the product. Lastly, piezoelectric vs electromagnetic. Piezoelectric is able to generate high-voltage outputs at high capacities. However, unlike electromagnetic, piezoelectric is not very durable [Kalnaskas, 2020]. However, piezoelectric has the capability of higher voltages, smaller sizes, and lower costs when compared to electromagnetic. Overall, in order from best to worst is triboelectric, electromagnetic, then piezoelectric. For the purposes of this product, durability is key. If the product can't survive high pressures on it, then the product will not succeed. This is the sole reason why electromagnetic beats piezoelectric. But electromagnetic still loses to triboelectric because triboelectric doesn't throw people off balance, has no competition, does not require a lot of room below the flooring, and can be used outside with minimal effort, while the gear system in the electromagnetic design wouldn't be able to be outside as it would wear out easily. Triboelectric, on the other hand, is able to handle outside weather since it has no gears, so there is practically no wear. On top of that, using triboelectric, we wouldn't have to worry as much about potentially being sued. If someone were to fall because of the unstable flooring in the electromagnetic design, then it could cause massive problems. Lastly, the cost of a triboelectric nanogenerator is much less than an electromagnetic generator since it is just layers of Teflon (FEP) and KAPTON. This leads to more profits and the ability to implement our

product in more widespread areas. Based on the research and the design requirements chart, we decided to center our design around the triboelectric effect using triboelectric nanogenerators.

Our novel kinetic energy flooring system will use triboelectric nanogenerators based on Plasma Polymer Fluorocarbon Film (PPFC) since it was recently discovered that this material can provide very high output voltage of 200V and can provide 1000 times the power of other triboelectric nanogenerators for a given thickness of material [Cho, 2022]. For example, a 10 cm × 10 cm (.1m x .1m) TENG made of PPFC that is 0.1μm thick can produce 200V and 30μA (0.006 Watts), which is as much power as prior leading TENGs made of Polytetrafluoroethylene that were the same size but 100μm thick [Cho, 2022]. Using some simple math, we realized that this discovery by Cho et al implies that a perfectly layered triboelectric nanogenerator made of PPFC would have a power output of 6 Watts per cubic centimeter as calculated in Figure 5B, which is about 2000 times greater than Piezoceramic power generators, and over 500 times greater than currently existing TENGs, and even farther better than the wood pulp based TENGs used in Wang's EWPanel flooring!

$$.1m * .1m * 0.1\mu m \Rightarrow 0.006 \text{ Watts}$$

$$.1m * .1m * 0.1\mu m * 1,000 = .1m * .1m * .1mm \Rightarrow 0.006 \text{ Watts} * 1,000 = 6 \text{ Watts}$$

$$.1m * .1m * .1mm = 1cm * 1cm * 1cm = 1cm^3 \Rightarrow 6 \text{ Watts}$$

*For a 12" * 12" tile with a 1.0764 cm thick Triboelectric Nanogenerator:*

$$144 \text{ in}^2 * 6.4516 \text{ cm}^2/\text{in}^2 = 929.0304 \text{ cm}^2$$

$$929.0304 \text{ cm}^2 * 1.0764 \text{ cm} = 1000.0 \text{ cm}^3$$

$$1000.0 \text{ cm}^3 * 6 \text{ W/cm}^3 = 6000\text{W}$$

This is about 2000x the power output obtained from Piezoceramic materials!

This is about 577x the power output of Fan et al's Kapton and Polyester based Triboelectric Nanogenerator!

Figure 5B: Calculation of power output of Plasma Polymer Fluorocarbon Film (PPFC) based Triboelectric Nanogenerators (TENGs).

While Plasma Polymer Fluorocarbon Film (PPFC) would not be as environmentally friendly as wood pulp based triboelectric nanogenerators, causing construction workers and homeowners to have to properly recycle the modules if they are ever removed in the future, this was seen as an acceptable tradeoff for the greatly increased power output that could be obtained. Furthermore, we did not want to make the mistake that EWPanel, Pavegen, and Energy Floors made by creating a product that does not produce enough power, or that is too expensive for the amount of power it produces. By using Plasma Polymer Fluorocarbon Film (PPFC), we determined that we would not be as environmentally friendly during disposal of our product, however, we could produce a flooring that met all of our other requirements, and which would be a viable product that we can sell, allowing this new form of renewable energy to be used across the world. Furthermore, once we are successful, we can establish recycling centers where we will buy back any used modules, ensuring that no PPFC will be released into the environment.

5.2 Hardships faced

Throughout the design process, we had to do a lot of research to come up with a product that was innovative and that would generate enough electricity to cover the cost of buying and installing it. This also needed to be something new that wouldn't have much competition. Going with an electromagnetic design did not make sense as there would be existing competitors, and we knew that the companies that made these electromagnetic-based kinetic floor systems had not grown significantly over the 10+ years that they were in business. While designing our electromagnetic-based kinetic floor systems for our prototype design #1, we had to try to reduce the travel distance of the tile so people could keep their balance and avoid falling and getting hurt. With a mechanism such as a triboelectric nanogenerator, we were able to solve that problem since it is so small and the flooring won't need to travel downwards significantly. Alternately, the concept of triboelectricity has been around for literally thousands of years, but customers still had a high chance of not knowing what it was. This could present issues when we try to sell our product. However, with the new advances in triboelectric generators, we determined that they solved the problem of both cost and required power output, while also solving the problem of people losing balance when they take steps since they do not need to go down as far as tiles that are based on the electromagnetic generator design, so we chose to go with this technology and we use marketing to educate people about triboelectric generators when we sell our product.

Then we had to worry about wear and tear. EWPanel, who had used wood pulp based triboelectric nanogenerators, couldn't implement their product in outdoor areas since the wood would be affected by weather conditions. We were able to overcome this challenge, by not making our device out of wood, and by making our device a separate

stand-alone module that is fully self-enclosed and weatherproof. This module can be placed underneath any existing tile or paver, which also solved the problem of allowing people to choose their own tiles and flooring.

After that, we had to look more into the marketability of our product. We looked at the energy output, its affordability, how much it would cost us to make, how light it was, and if it could really be put everywhere we wanted. We research the materials needed to create the energy output using the triboelectric effect. We also looked at our potential competitors and the economics associated with their products. Pavegen's flooring can cost up to 160 dollars per tile, which is why they are failing to grow their business, so we had to ensure that our system would cost significantly less than that. By choosing triboelectric generators, our system will already cost less than Pavegen's and Energy Floors' systems since they are using expensive electromagnetic generators.

Lastly, dealing with size and weight were issues that we spent time addressing. Eventually, by using triboelectric nanogenerators we were able to achieve a small size, so we can be certain that it can be put under any floor without requiring major excavation. This also means that it will be weight efficient because most of the weight will be in the actual flooring itself.

6. Details of Design

Our design uses triboelectric nanogenerator technology similar to that depicted in Figure 4J. The design is made up of a tile, a sheet of Plasma Polymer Fluorocarbon Film (PPFC) (replacing the FEP in Figure 4J), a sheet of KAPTON, 4 springs, two sheets of plastic, and 2 sheets of aluminum (replacing the copper in Figure 4J). The tile is on top of the insulator which is on top of the aluminum which is on top of the PPFC which is on top of the KAPTON which is on top of another insulator. Then there are 4 springs connecting both insulators. When someone steps on the tile or when anything puts force on the tile, it gets pushed down. However, unlike Pavegen and Energy Floors, the tile will get pushed down so little it will be unnoticeable. The tile then compresses the mechanism as shown in “Step a” of Figure 4J. During this, the KAPTON touches the PPFC. Then when it is released, the energy generated gets transferred to the aluminum and then to a battery (replacing the “R” component in Figure 4J). The process then repeats.

Solidworks CAD drawings of our triboelectric nanogenerator based kinetic flooring solution are shown in Figures 6A, 6B, and 6C. In these CAD drawings, a 12” x 12” ceramic tile sits on top of our device. Our device consists of two plastic plates (shown in dark gray color) outside of two aluminum plates (shown in silver color). These plastic plates are insulators that will not absorb the charge from the aluminum, while the aluminum plates acts as “wires” to bring the charge away from the device.

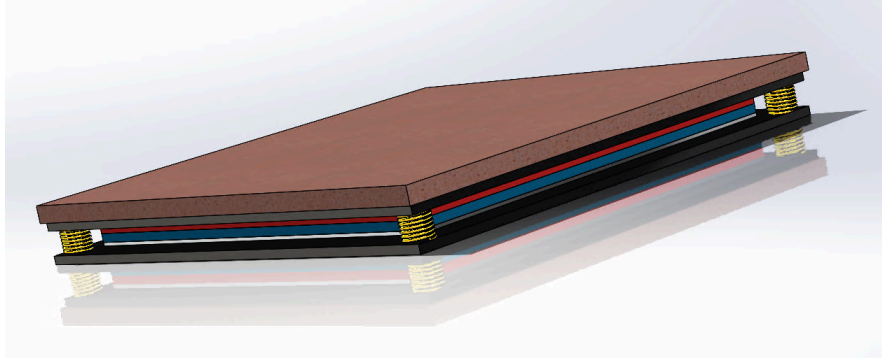


Figure 6A: A top slanted side view on the final design. This brown on top represents the tile, the black is the plastic insulator, the silver is the aluminum, the red is the Plasma Polymer Fluorocarbon Film (PPFC), the blue is the KAPTON, and the gold are the springs. Not drawn to scale.

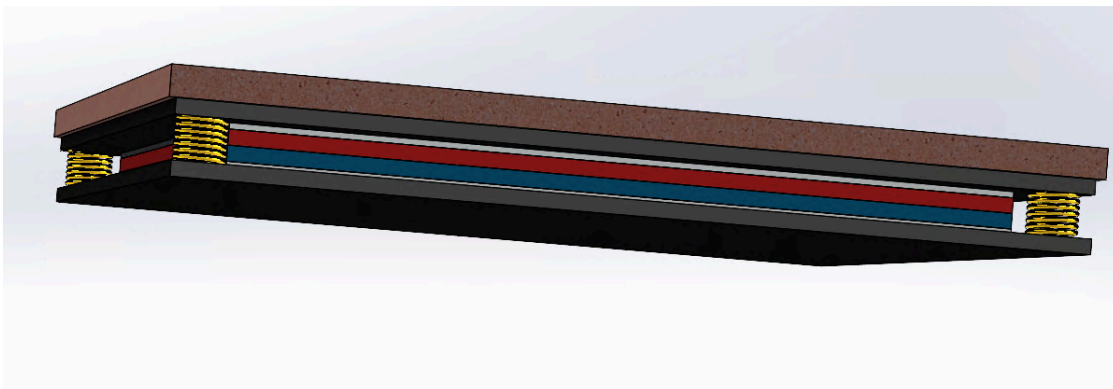


Figure 6B: A side view of the tile. Not drawn to scale.

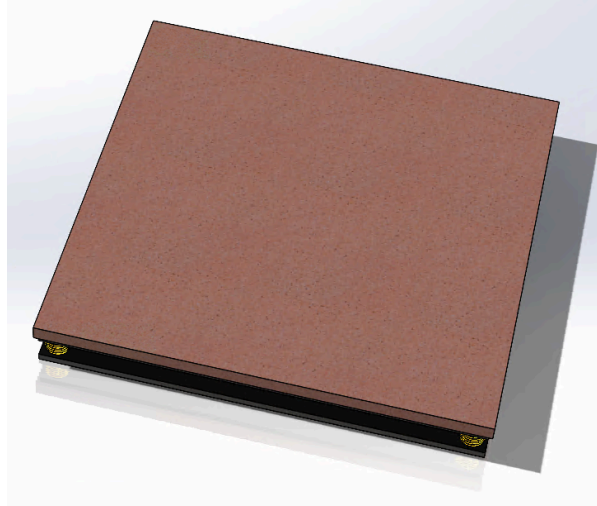


Figure 6C: A top-down view of the tile. Not drawn to scale.

Our design is flexible leading to a much greater market. Unlike prior attempts at kinetic flooring, which limited customers' choices of tiles and flooring to only those made by the company, our system works by going underneath any existing flooring. Using this design, all we have to change is the length, width, and spring constant (spring stiffness and resistance) to apply this to any customer's tile or flooring.

Our design can also be applied to roadways where we can harness the compression force from cars and trucks. We can embed large versions of the system into asphalt and concrete, using a very high spring stiffness so the mechanism doesn't get crushed. Alternatively, on everyday flooring such as around cities, gyms, homes, towns, malls, etc, we will use different shapes as needed for each, while using a lower spring constant..

The only changes needed to apply this system to any scenario are the length, width, and spring constant – all versions of our products will still use the PPFC,

KAPTON, aluminum, and hard plastic plates. PPFC and KAPTON were chosen as they are the most effective pair for the triboelectric effect, generating up to 6 Watts per cubic centimeter in recent breakthrough studies [Cho, 2022]. Plastic was chosen as it suffices as an insulator and is durable enough in most circumstances. Of course, if these end up getting used in very high-pressure inducing settings, then the plastic can be changed to another stronger insulating material as needed. For the metal used, we were between copper and aluminum as potential conductors for the electron current. We settled on aluminum as the massive reduction of cost was well worth it [Diehl, 2023]. Copper has a price of \$3.729 dollars per pound, which is significantly more expensive than aluminum at a price of only \$1.0693 dollars per pound [DailyMetalPrice, 2023]. Lastly, we decided on a 4000 mAh lithium battery, such as the Samsung 40T 21700 (40T3) battery. These rechargeable batteries hold a lot of power and are fairly inexpensive at about \$1.00 each in bulk [Alibaba, 2023]. With one battery this big per module, it's unlikely that there will be an overflow of power. On top of that, these are small enough to not have a large effect on the design.

7. Final Design

The final design is a fully enclosed configurable module that comes in various sizes, with various spring compression constants to allow for use under a variety of tiles and flooring configurations. A CAD rendering of a 12" x 12" module is shown in Figure 7A.

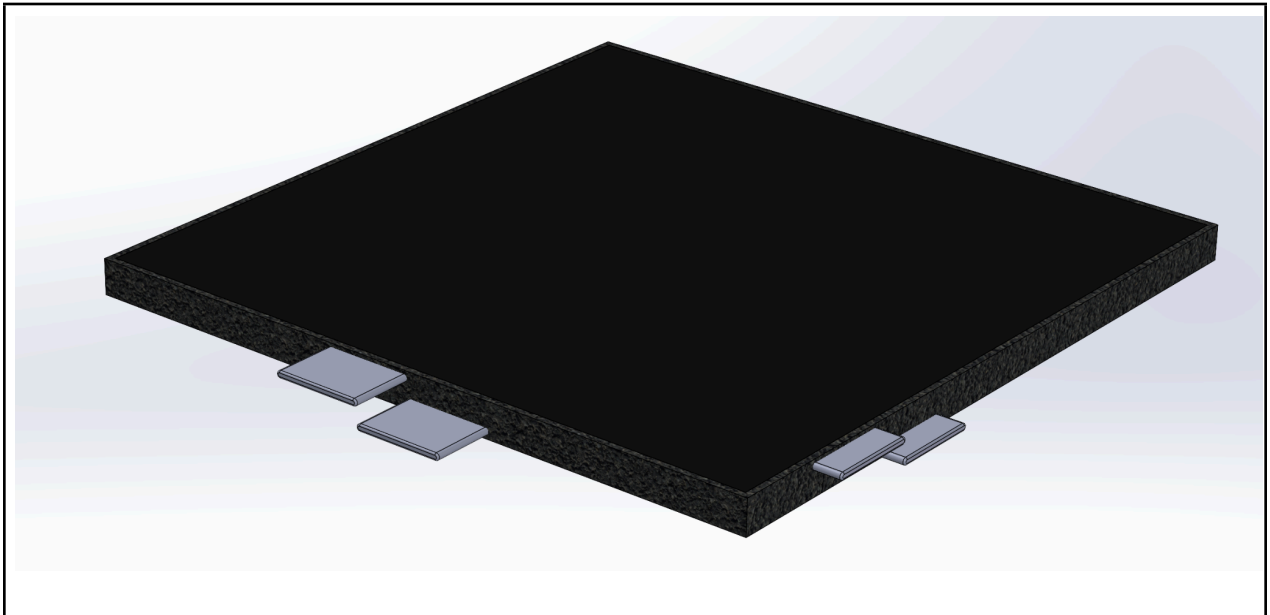


Figure 7A: A single module of the final triboelectric nanogenerator kinetic flooring design.

The module is comprised of two hard plastic plates, one on top and one on bottom. In order to seal the system from outside weather elements, while still allowing it to compress, a flexible rubber seal is attached around the outside of the plastic plates. The inside of the module contains the layers shown in the detailed design section, specifically, the two sheets of aluminum attached to the inside of the plastic plates, with the layers of Plasma Polymer Fluorocarbon Film (PPFC) and KAPTON attached to the sheets of aluminum, and four springs to hold the layers apart until the module is

compressed from above. The module also contains a battery and simple electronics to connect the battery correctly when pressure is applied or released from the top of the module.

Coming out of the sides of the module are spring-loaded connectors that can be temporarily pushed into the module to allow it to be slid down in between other neighboring modules when it is installed. Once in place, these spring-loaded connectors pop back out and extend into the next module to form one giant system from all of the interconnected modules. Figure 7B shows the back side of the module which has slits where the spring-loaded connectors from the neighboring modules enter into the module. These slits are cut through the flexible rubber which forms a seal around the connectors, preventing any moisture or dirt from entering the module.

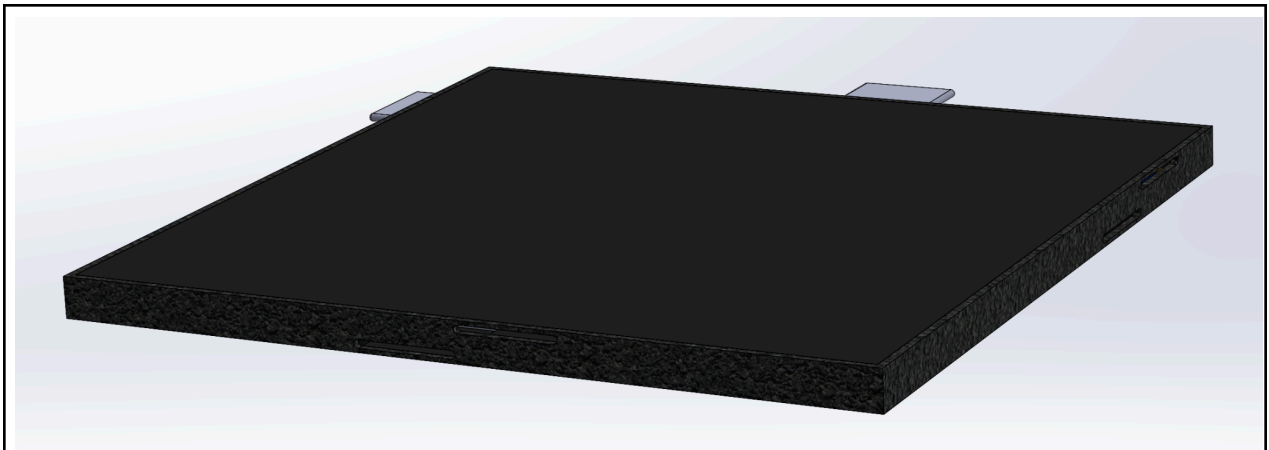
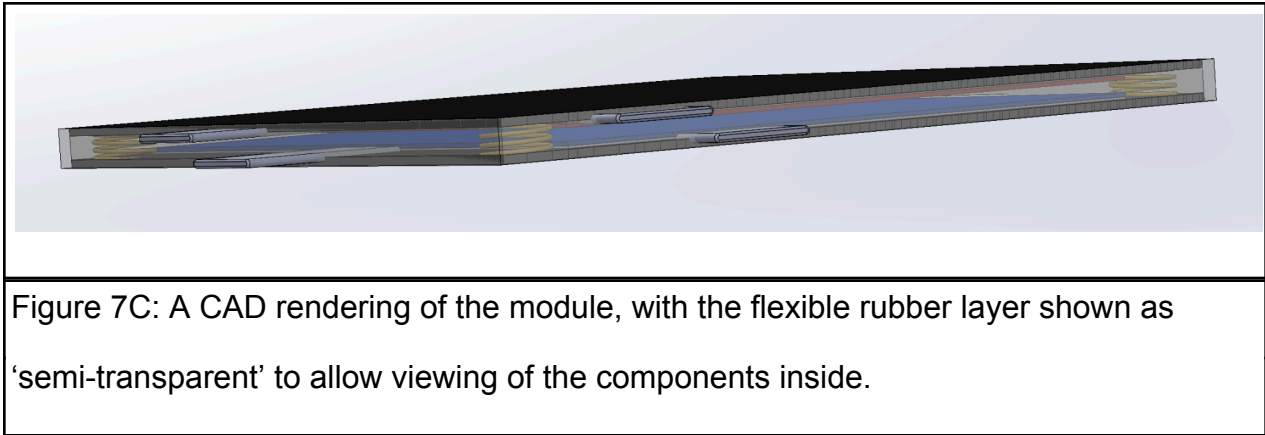
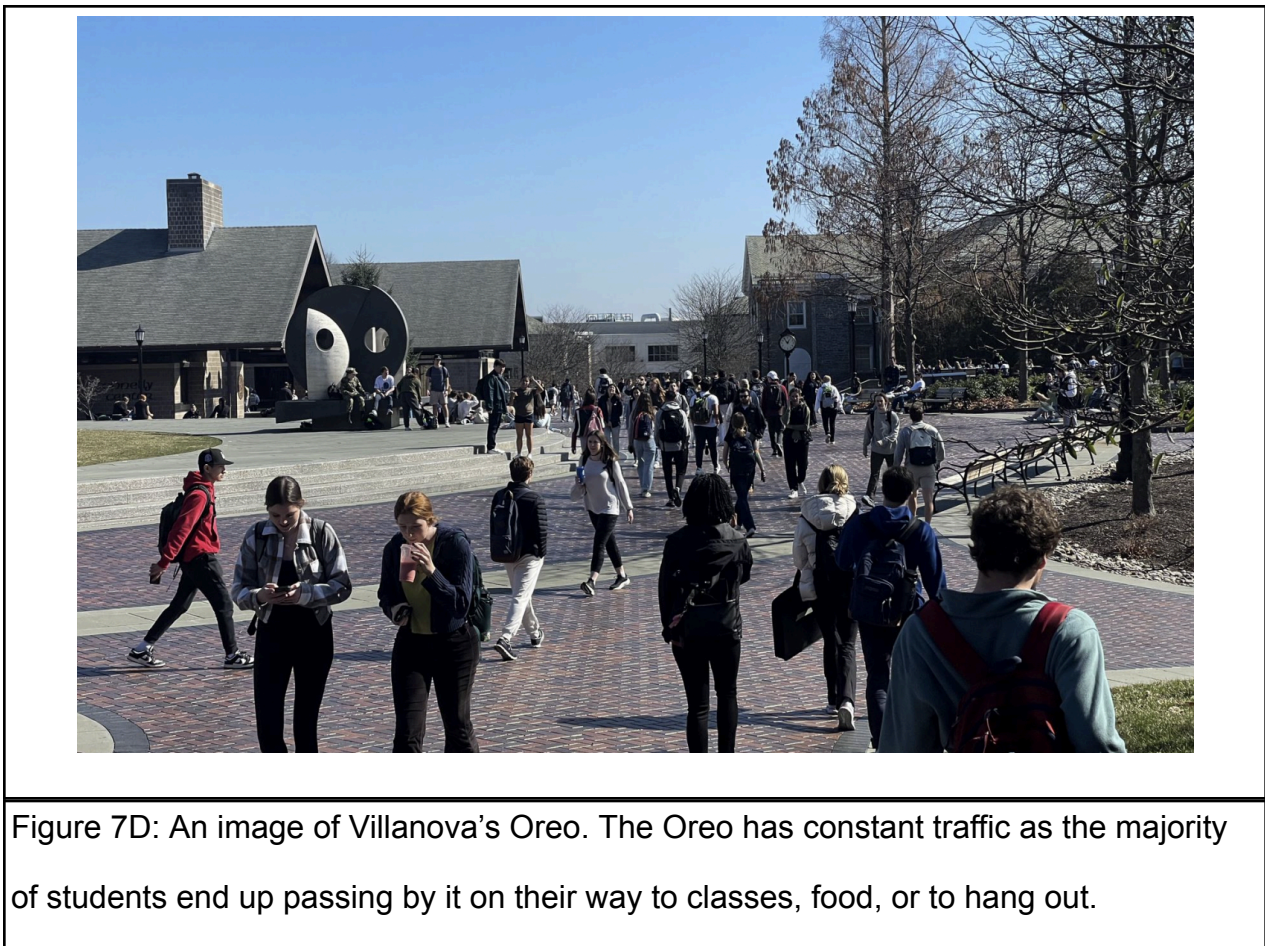


Figure 7B: Back side of module showing slits in the flexible rubber to allow connection of neighboring plates, while protecting from moisture and dirt.



The final design was applied to the pavers near the Oreo on our Villanova Campus. As seen in Figure 7D, this location has a lot of pedestrian traffic, so there is a lot of human-generated kinetic energy that can be harvested.



This area around the Villanova Oreo is also ideal since it contains paver stones. In fact, we estimated that there are about 10,000 paver stones in just the area around the Oreo alone! Each of these paver stones is able to be lifted up using a “Paver-Puller,” or by simply using two screwdrivers [Admin, 2020] [Villeneuve, 2020]. This allows each paver to be lifted up and retrofitted with the version of our final design that is specifically shaped to the size of a paver stone.

We measured a paver stone to be 4” x 8” so the version of our final design has been modified to match this size. There is a small amount of excavation that will need to be performed after each paver stone is removed, however unlike motor-generators systems like Pavegen that require 1 - 2 feet of excavation, our system only requires 2 cm of height so the area can easily be dug out with just a hand shovel.

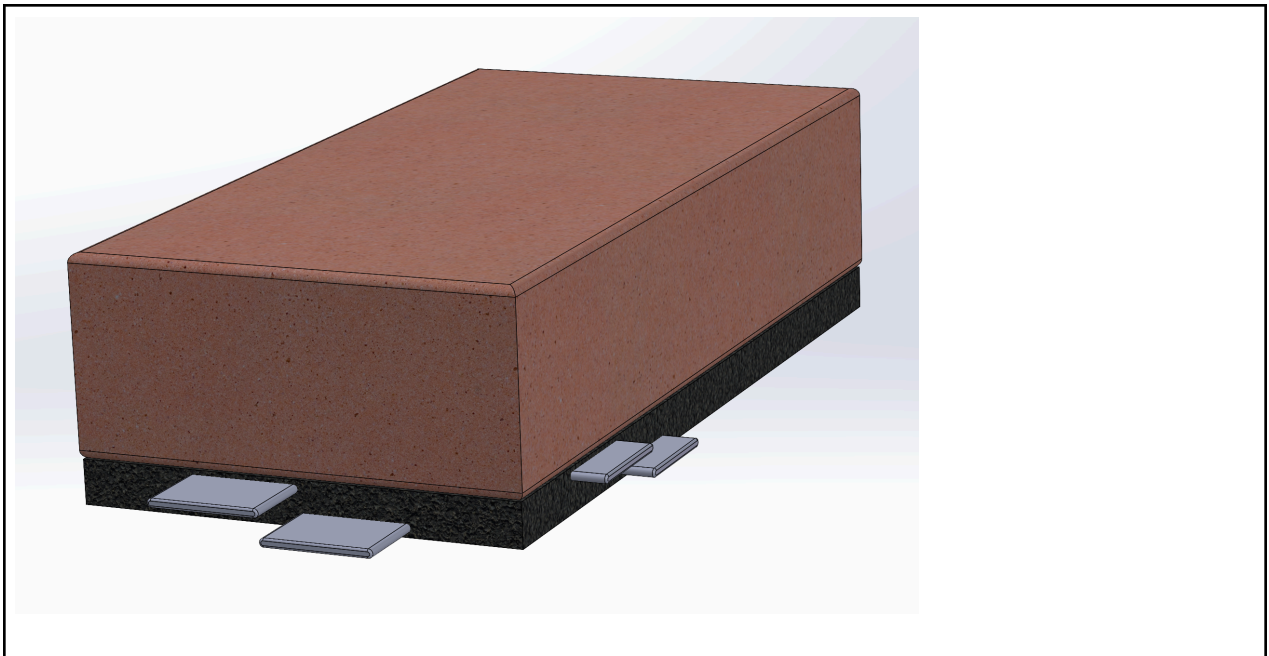


Figure 7E: Version of the final design that has been scaled and tailored to the pavers used near the Villanova Oreo. The area where the triboelectric reaction takes place is enclosed in plastic and flexible rubber so that the Plasma Polymer Fluorocarbon Film (PPFC), aluminum, and KAPTON are not affected by weather.

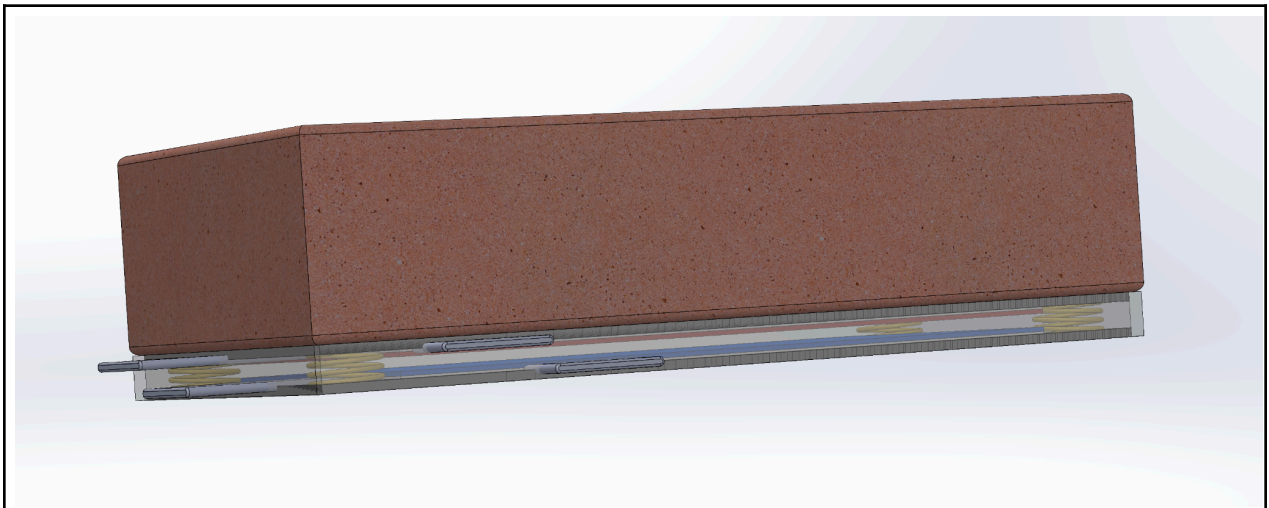


Figure 7F: Like Figure 7E, this is tailored to the Oreo and a better representation of the size. The plastic enclosure is shown as “semi-transparent” and the Plasma Polymer Fluorocarbon Film (PPFC) is not in contact with the KAPTON in this CAD drawing.

Figures 7E and 7F show a version of the final design created for use under one of the pavers used in the area around the Villanova Oreo. The spring stiffness of this module has been adjusted to account for the weight of the paver stone.



Figure 7G: A photo of the “wishbone” paver pattern used throughout the Villanova campus.

Finally, it can be seen that the connectors of the module shown in figure 7E are not both centered. This is to allow for use in the “wishbone” pattern that the pavers are laid out in throughout the Villanova Campus as shown in figure 7G.

8. Societal Impact

A major issue our society will have to face is the question of how we can limit the use of fossil fuels. Fossil fuels have gotten us very far as a society but we need to step away from them as they are very harmful to our environment. Fossil fuels are nonrenewable and dangerous to produce. While they also create both air and water pollution, and contribute to global warming.

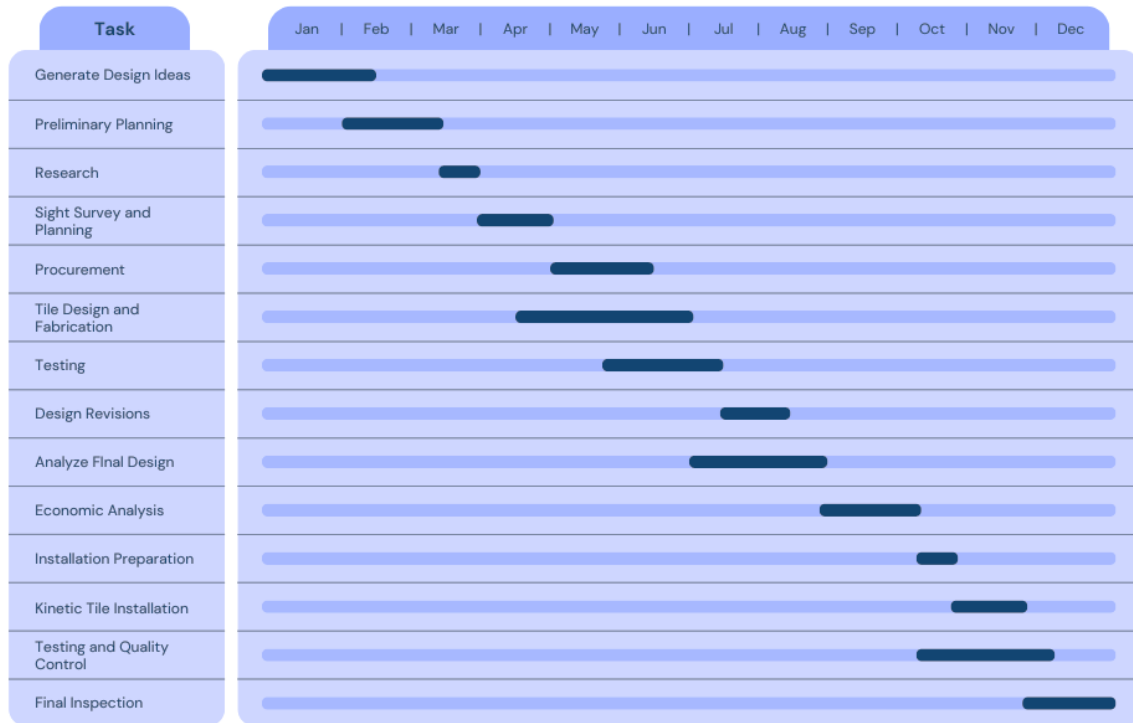
Our society has already developed technologies that use alternatives to fossil fuels like solar energy and wind energy. The creation of solar panels and wind turbines produce energy using renewable resources. These technologies have become increasingly popular over the last couple of years. However just as these products are avoiding the use of fossil fuels they are also harming our environment. The International Renewable Energy Agency predicts that in four years solar panels will contribute about 315,000 metric tonnes of waste, just due to residential installations [Atasu et al, 2021]. Wind Turbines are predicting a similar issue with their technology. “Experts expect that more than 720,000 tons worth of gargantuan wind-turbine blades will end up in U.S. landfills over the next 20 years.” Even though these sustainable technologies are beneficial to the bigger picture of not having to heavily rely on fossil fuels, they are still contributing to the waste, which harms our environment.

Our technology of Kinetic Energy Flooring will use our steps as a renewable energy source. The use of kinetic energy as a clean energy source will allow us to decrease the use of fossil fuels and fight against climate change. The technology we will use will be able to be used under any type of flooring. Placing this technology in areas with high foot traffic areas will allow us to harvest an efficient amount of energy. Our

floors continue the mission of stepping away from fossil fuels and other harmful processes through renewable energy.

9. Gantt Chart

Kinetic Tiles : Gantt Chart



10. Budget

1. Labor and Location

Salaries and Labor- \$20,000

Outside Services- \$3,000

Rent- \$5,000

Food- \$500

Utilities- \$700

Insurance- \$615

Maintenance- \$50

2. Research and Development

Patents- \$8,000

Software- \$700

Technology License- \$600

3. Total Cost

One Prototype- \$400

Materials- per 100 modules at scale

Aluminum sheets- \$30

Plastic- \$10

KAPTON - \$20

Plasma Polymer Fluorocarbon Film (PPFC)- \$30

4000 mAh Batteries - \$100

Landscaping crew installation cost for 10,000 pavers around the oreo- \$20,000

Cost for 10,000 kinetic energy modules for around the oreo- \$19,000

11. Conclusion

In the end, we decided to use triboelectric nanogenerators for our design. This has shown to allow for a lower price, lesser weight, safer approach, and more applicable design. On top of that, it allows for a safer and more stable source of energy. We won't have to worry about cutting down countless forests to create a flat land capable of housing acres on top of acres of solar panels. Furthermore, we can save bird's lives by causing less wind farms to be made. Birds will be able to fly safely, without having a fear of being killed out of nowhere. Lastly, this design has allowed us to achieve our goal of reducing the usage of fossil fuels. With this passive source of energy that isn't reliant on the weather, like solar panels and wind turbines, we can turn away from the destructive and limited reliance of fossil fuels. Triboelectric nanogenerators were overall a better design technology than that of electromagnetic generators and piezoelectric generators. They are able to generate the same amount of energy, if not more, due to how widespread we plan to implement these, at a fraction of the cost and size.

Using Pavegen and Energy Floors' current product pricing, we can decide on a price for our system that is appealing to the public's eyes. Furthermore, we can make deals and discounts based on mass purchases. Lastly, while tile and wood flooring typically costs anywhere from \$1.00 to \$25.00 per square foot, we estimate that the additional price per square foot to add our modules will only be about \$2.00 to \$3.00 per square foot, which will be easily paid for over time by the power they will produce. This is much less than the \$75 - \$160 dollars per tile currently charged by our competitors. Most importantly, the low cost will allow our kinetic energy flooring to be quickly adopted and used in many situations, and it will create a new viable clean energy solution.

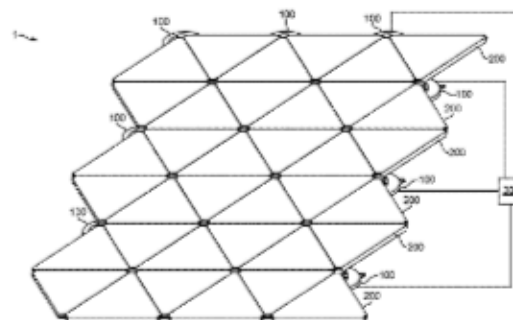
Based on the simplicity of the modules, we believe that production of this product will not be difficult, and our solution will be used in many homes, retail areas, small businesses, towns, and cities before we significantly raise the price. Since our technology can just simply be added onto the bottom of the tile to start producing energy, we expect that it will be able to help countless people all over the world by saving costs on energy for them on top of stopping the usage of fossil fuels.

12. Appendices

Appendix A: Pavegen patent showing the layout of their kinetic energy flooring system.



(12) United States Patent Webster	(10) Patent No.: US 10,333,370 B2 (45) Date of Patent: Jun. 25, 2019
(54) FLOORING SYSTEM (71) Applicant: PAVEGEN SYSTEMS LTD , London (GB) (72) Inventor: Craig Webster , Cambridge (GB) (73) Assignee: Pavegen Systems Limited , London (GB) (*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.	(58) Field of Classification Search CPC G08B 13/10; E04F 15/02; F03G 7/08; 1102K 7/1853 (Continued) (56) References Cited U.S. PATENT DOCUMENTS 6,515,586 B1 2/2003 Wymore G08B 13/10 6,707,386 B1* 3/2004 Pruissner 307/116 (Continued)
(21) Appl. No.: 15/759,783 (22) PCT Filed: Sep. 14, 2016 (86) PCT No.: PCT/GB2016/052845 § 371 (c)(1), (2) Date: Mar. 13, 2018 (87) PCT Pub. No.: WO2017/046587 PCT Pub. Date: Mar. 23, 2017	FOREIGN PATENT DOCUMENTS CN 202012029 10/2011 DE 102007001225 7/2008 (Continued) OTHER PUBLICATIONS Steinhage et al., "Monitoring Movement Behavior by means of a Large Area Proximity Sensor Array in the Floor", Workshop on Behavior Monitoring and Interpretation, Jan. 1, 2008, pp. 15-27.
(65) Prior Publication Data US 2018/0342929 A1 Nov. 29, 2018	<i>Primary Examiner</i> — John A Twoel, Jr. (74) <i>Attorney, Agent, or Firm</i> — Jason P. Mueller, Adams and Reese LLP
(30) Foreign Application Priority Data May 10, 2016 (GB) 1608200.0	(57) ABSTRACT The present invention relates to a flooring system for generating electricity from users as they walk. A flooring system (1) for characterizing a footstep (2), comprising: a plurality of tiles (200) for supporting one or more people; and a plurality of sensors (100x, 100y, 100z), each sensor (100x, 100y, 100z) arranged to generate a signal representing a force applied thereto, wherein each tile (200) is supported by at least three sensors (100x, 100y, 100z), the flooring system (1) further comprising a data processing system (1001) in communication with each sensor (100x, 100y, 100z) for receiving the signal generated thereby, wherein for each tile (200) the data processing system (1001) is arranged to produce output data by comparing the signals received from (Continued)
(51) Int. Cl. H02K 7/18 (2006.01) F03G 7/08 (2006.01) (Continued) (52) U.S. Cl. CPC H02K 7/1853 (2013.01); E04F 15/02 (2013.01); E04F 15/22 (2013.01); F03G 5/06 (2013.01); (Continued)	



Appendix B: Pavegen patent showing construction of the kinetic energy flooring system and the location of electrical generators under the vertices of the triangular-shaped tiles.



US010557460B2

(12) **United States Patent** **Webster et al.**

(10) **Patent No.:** **US 10,557,460 B2**

(45) **Date of Patent:** **Feb. 11, 2020**

(54) **FLOORING SYSTEM**

(71) Applicant: **PAVEGEN SYSTEMS LIMITED**,
London (GB)

(72) Inventors: **Craig Webster**, Cambridge (GB);
Phillip Tucker, Brighton (GB)

(73) Assignee: **Pavegen Systems Limited**, London
(GB)

(*) Notice: Subject to any disclaimer, the term of this
patent is extended or adjusted under 35
U.S.C. 154(b) by 2 days.

(21) Appl. No.: **15/759,741**

(22) PCT Filed: **Sep. 14, 2016**

(86) PCT No.: **PCT/GB2016/052844**

§ 371 (c)(1).

(2) Date: **Mar. 13, 2018**

(87) PCT Pub. No.: **WO2017/046586**

PCT Pub. Date: **Mar. 23, 2017**

(65) **Prior Publication Data**

US 2019/0048858 A1 Feb. 14, 2019

(30) **Foreign Application Priority Data**

Sep. 14, 2015 (GB) 1516234.0

(51) **Int. Cl.**

F02B 63/04 (2006.01)

F03G 7/08 (2006.01)

F03G 5/06 (2006.01)

E04F 15/02 (2006.01)

H02K 7/18 (2006.01)

H02N 2/18 (2006.01)

(52) **U.S. CL**

CPC **F03G 5/06** (2013.01); **E04F 15/02044**
(2013.01); **F03G 7/08** (2013.01); **H02K**
7/1853 (2013.01); **H02N 2/18** (2013.01)

(58) **Field of Classification Search**

CPC **F03G 5/06**; **F03G 7/08**; **E04F 15/02044**;
H02N 2/18; **H02N 2/183**; **Y02T 10/641**;
Y02T 10/7072

USPC **290/1 R**, **1 A**, **1 E**; **322/3**
See application file for complete search history.

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Primary Examiner — Tulcidas C. Patel

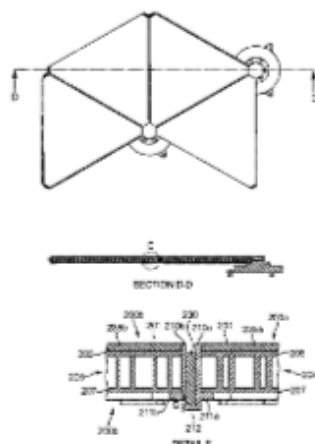
Assistant Examiner — Thomas K. Quigley

(74) Attorney, Agent, or Firm — Jason P. Mueller, Adams
and Reese LLP

(57) **ABSTRACT**

The present invention relates to a flooring system for generating electricity from users as they walk. A flooring system (1) for generating electricity, comprising: a plurality of generators (100), each generator (100) having a support, each generator being arranged to generate electricity from linear motion of the support in a first direction; and a plurality of tiles for supporting one or more people, wherein each support supports a plurality of tiles.

15 Claims, 15 Drawing Sheets



Appendix C: Pavegen patent showing the design of their proprietary electric generator that converts the kinetic energy to electrical energy.



US011309769B2

(12) **United States Patent**
Webster et al.

(10) **Patent No.:** **US 11,309,769 B2**
(45) **Date of Patent:** **Apr. 19, 2022**

(54) **METHOD AND SYSTEM FOR GENERATING ELECTRICITY FROM FOOTSTEPS**

(71) Applicant: **PAVEGEN SYSTEMS LIMITED,**
London (GB)

(72) Inventors: **Craig Webster,** London (GB); **Ben Gordon,** London (GB)

(73) Assignee: **PAVEGEN SYSTEMS LIMITED,**
London (GB)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 755 days.

(21) Appl. No.: **16/300,505**

(22) PCT Filed: **May 10, 2017**

(86) PCT No.: **PCT/GB2017/051296**
§ 371 (c)(1),
(2) Date: **Nov. 9, 2018**

(87) PCT Pub. No.: **WO2017/194936**
PCT Pub. Date: **Nov. 16, 2017**

(65) **Prior Publication Data**
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(30) **Foreign Application Priority Data**
May 10, 2016 (GB) 1608199

(51) **Int. CL**
H02K 7/06 (2006.01)
H02K 7/18 (2006.01)
H02K 7/02 (2006.01)

(52) **U.S. CL**
CPC **H02K 7/1853** (2013.01); **H02K 7/025**
(2013.01); **H02K 7/06** (2013.01)

(58) **Field of Classification Search**
CPC H02K 7/025; H02K 7/06; H02K 7/1853
See application file for complete search history.

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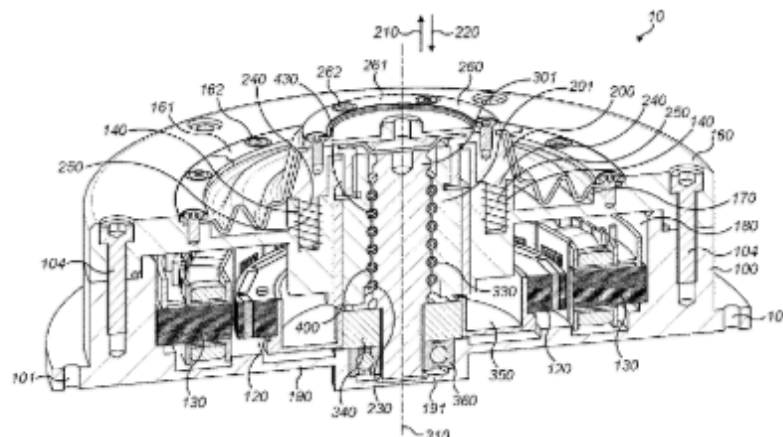
Primary Examiner — Ramon M Barrera

(74) *Attorney, Agent, or Firm* — Jason P. Mueller,
FisherBroyles, LLP

(57) **ABSTRACT**

A disclosed electrical generator includes a housing, an actuator, a rotatable member, a stator, a rotor, an electrical circuit, and a current controller. The actuator is movable relative to the housing and the rotatable member is also rotatable relative to the housing. The rotatable member cooperates with the actuator such that movement of the actuator causes rotation of the rotatable member. The stator is fixed relative to the housing and the rotor receives rotational kinetic energy from the rotatable member. Movement of the rotor relative to the stator generates electromagnetic induction in the rotor and/or the stator which produces a three-phase alternating current. The electrical circuit includes a rectifier that converts the alternating current to a direct current. The current controller regulates the direct current to thereby generate a fixed constant direct current.

17 Claims, 4 Drawing Sheets



Appendix D: Pavegen patent showing the tile assembly and their method for harvesting kinetic energy, specifically the conversion of linear progression into rotational motion.



US008736088B2

(12) **United States Patent**
Kemball-Cook et al.

(10) **Patent No.:** **US 8,736,088 B2**
(45) **Date of Patent:** **May 27, 2014**

(54) **ENERGY HARVESTING**

(56) **References Cited**

(75) Inventors: **Laurence Kembell-Cook**, Harbledown (GB); **Philip Tucker**, Harbledown (GB)

(73) Assignee: **Pavegen Systems Limited**, Canterbury, Kent (GB)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 47 days.

(21) Appl. No.: **13/642,093**

(22) PCT Filed: **May 4, 2011**

(86) PCT No.: **PCT/GB2011/000686**

§ 371 (c)(1),
(2), (4) Date: **Dec. 5, 2012**

(87) PCT Pub. No.: **WO2011/138585**

PCT Pub. Date: **Nov. 10, 2011**

(65) **Prior Publication Data**

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(30) **Foreign Application Priority Data**

May 5, 2010 (GB) 1007497.9

(51) **Int. Cl.**
F02B 63/04 (2006.01)
F03G 7/08 (2006.01)
H02K 7/18 (2006.01)

(52) **U.S. Cl.**
USPC **290/1 R**

(58) **Field of Classification Search**
USPC **290/1 R**
See application file for complete search history.

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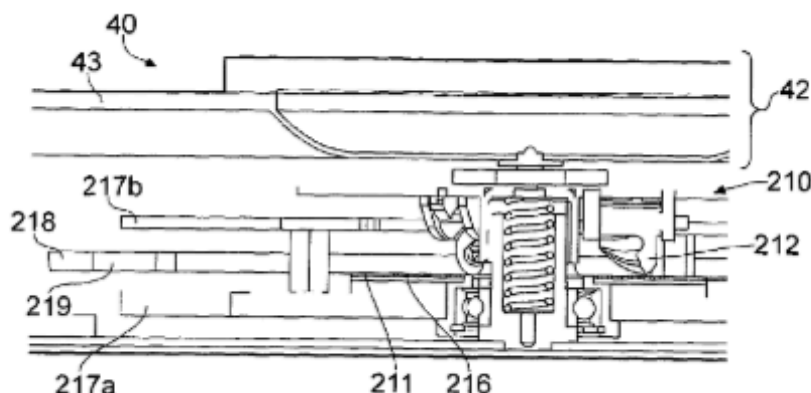
Primary Examiner — Pedro J Cuevas

(74) Attorney, Agent, or Firm — Mossman Kumar & Tyler PC

(57) **ABSTRACT**

The present application describes techniques for the harvesting of kinetic energy from the movement of people and/or vehicles. A motion converter is discussed which converts linear progression caused by traffic-related impulse forces, to be converted to rotational motion for driving the rotor of an electricity generator. An assembly for harvesting energy including the motion converter and a floor unit are also described.

19 Claims, 6 Drawing Sheets



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