Group 9 – Harvesting Energy from Large Groups of People

Rabia Aslam
20271652
r2aslam@uwaterloo.ca

Tom An An Chu
20274220
aachu@uwaterloo.ca

Kevin Kwong
20246727
k3kwong@uwaterloo.ca

Yahya Remtulla
20281411
yremtulla@uwaterloo.ca

Yiling Wang
20285973
y257wang@uwaterloo.ca

Vanessa Yip
20224263
vyip@uwaterloo.ca

Abstract

A vast amount of human kinetic energy produced by large groups of people is still considered an untapped energy source as currently few technologies are available to efficiently harness it and convert it to a usable form. The most important needs identified were the safety of the product, its durability, and its self-sustainability. The proposed solution is a tile that compresses as a result of human footsteps. This will be implemented in transit systems in densely populated cities. Problems impeding the success of current systems include the inconsistency of human traffic and the lack of economic feasibility to implement them. The product converts the mechanical compression from footsteps into electrical energy, which will be stored in a battery for future use. Ergonomic, economic and environmental factors were also taken into consideration during the design process. The power generated per tile was approximately 10.5 W per step, which is roughly 10 times greater than what the current state of art products can achieve. Most of the requirements outlined at the metrics and benchmark stage were achieved.

1. Introduction

There is great potential in harnessing the kinetic energy from large groups of people moving through bottle necked areas. Currently there are very few technologies available in the market that are able to effectively and efficiently accomplish this.

The public transit systems located in densely populated cities is the main target area for project. Stakeholders who are directly or indirectly affected by the implementation of the system that would harvest energy from the individuals using the public transit system would include the commuters themselves, transit employees, the government, and sponsors/special interest groups.

A difficulty with harvesting human kinetic energy is the inefficiencies associated with converting the mechanical translational energy into a usable energy form such as electricity. Another difficulty is the consistency or regularity of human traffic sufficient for energy production. Human traffic varies from day to day, thus this form of energy would not be reliable for applications that require a constant power source and would have to be supplemented with an additional power supply as backup. In the past, implementation of the state of art systems cost more than the value of the energy generated from them in a reasonable time frame, therefore the payback period for such a system would make it unreasonable to mass implement.

The product that the group designs focuses strictly on harnessing the kinetic energy from footsteps and converting it into electricity. Out of scope topics are applications that the electricity can potentially power.

1.1 State of the art

Throughout the years, there have been many attempts to harvest human kinetic energy; however, no plans have ever been mass-implemented due to high costs and limitations of technology.

One attempt to generate energy from crowds comes from the East Japan Railway Company (JR East). This company came up with the idea to retrofit their Tokyo train stations with piezoelectric energy generating floorboards that harvests the kinetic energy generated by crowds to power the station's ticketing gates and display systems. From the total amount of piezoelectric floor space of 25 cubic meters, JR East can generate over 1400 Watts per day, which is more than enough to power their systems [1].

Although this solution shows the possibility of utilizing the energy generated from crowds in useful implementations, it is still limited by the availability and cost of current resources. For example, as of now, one piezoelectric transducer, with overall dimensions of 2mm x 2mm x 3mm costs around $100-200 (USD) each [2]. The cost to create one tile of piezoelectric flooring that is 1m x 1m would cost a few thousand dollars.

The goal of this project is to find ways to decrease the cost of harvesting energy from crowds and use the generated energy towards a self-sustaining device to assist the present human population

2. Problem statement

The human body generates kinetic energy but only a small percentage of it can be captured. According to NASA's Defense Advanced Research Projects Agency (DARPA), a footstep could provide 1 to 2 watts if harnessed correctly [3]. However, if you turn this single footstep into millions of steps in a crowded and constantly populated area such as a subway station, the energy generated can be utilized to power many useful devices. Therefore, the aforementioned theory gives this project justification to address the following problem statement:

"Large groups of people generate energy through interactions with their environment via movement and essentially produce significant amounts of kinetic energy. This supply of energy is still a relatively untapped energy source as current solutions aren't effective in harnessing it due to cost, durability and scalability factors. The desired end state is to establish a system to harvest energy from human movement while addressing current deficiencies."

3. Customer Needs & Product Requirements

The customer of the product is the Toronto Transit Committee (TTC), Toronto's public transportation authority. The TTC operates busses, subways, streetcars, and rapid transit lines. The number of passengers who used the TTC in 2009 was 471,233,000. At Bloor station, which is the most frequently used stop, 205,500 passengers flow in and out daily [4].

Due to the large number of people that the TTC attracts, it becomes an ideal customer for the product. The product will be able to convert the footsteps from large groups of people in the subway station into electricity, and use the electrical energy generated to power an application to aid in making TTC commuters' experience with TTC more enjoyable.

The customer statements were gathered from a variety of sources. These include: TTC commuters, TTC janitor, TTC electrical and safety standards engineer, TTC green projects buyer. Summarized below are customer statements that were translated into customer needs, and this generated our product requirements, which defines our product design:

1. The product must meet electrical and safety standards
2. The product is unnoticeable when stepped on
3. The product is durable

4. The product is easy to clean

5. The product generates a sufficient amount of electricity to support an external application

6. The product is self-sustained in terms of electricity usage

The next step in determining our product requirements was to systematically weigh the translated needs and determine what metrics were needed for its design. The following table embodies this.

Table 1: Metrics

Metric #	Metric	Imp	Units
1	Total mass for one complete unit	4	kg
2	Floor depression if any	5	mm
3	Manufacturing cost	4	CAD$
4	Product lifespan	5	years
5	Energy harnessed from commuter steps	5	Watts
6	Flooring unit length	4	M
7	Flooring unit width	4	M
8	Flooring unit depth	4	M
9	Total floored area	4	m^2
10	Time to recover implementation cost	4	years
11	Level of protection product enclosure provides against hazardous parts	5	IP Code
12	Level of protection of the equipment inside product enclosure against harmful ingress of water	5	IP Code
13	Level of resistance to mechanical impact	5	IP Code

Note for Table 2: IP code can be interpreted as International Protection Rating or Ingress Protection Rating.

The next step we took was to benchmark these metrics against our competitors, JR East Railway Company and the Sustainable Dance Club. This helped us reach some marginal and ideal values for our final product requirements. Extracting only the ideal values, our final product requirements were determined.

The following table are the final product requirements for our product

Table 2: Final Specifications

Metric #	Metric	Units	Value
1	Total mass for a complete unit	kg	2.5
2	Floor depression (if any)	mm	0
3	Manufacturing cost	CAD$	250
4	Product lifespan	years	15
5	Energy harnessed from commuter steps	Watts	15
6	Flooring unit length	m	1.5
7	Flooring unit width	m	0.5
8	Flooring unit height	m	0.1
9	Total floored area	m^2	0.75
10	Time to recover implementation cost	years	5
11	Level of protection product enclosure provides against hazardous parts	IP Code	5
12	Level of protection of the equipment inside product enclosure against harmful ingress of water	IP Code	7
13	Level of resistance to mechanical impact	IP Code	10

4. Concept Generation, selection, and testing

4.1 Concept Focus

The chosen concept area was selected to be harvesting kinetic energy from people in large gatherings within the transit system and converting that energy into usable electricity. Potential designs for this concept could be split into two different areas:

- Design for spaces inside the transit system, for example, subway handles inside each section of a train.
- Design for general areas where people gather, for example, flooring in an area where many people traverse across.

4.2 Concept Generated

The final method of energy generation was decided to be electromagnetic induction because it was a cheaper alternative to most other methods, such as piezoelectricity and because it could potentially generate more electricity. When a magnet is passed through a conducting metal solenoid, a current is induced through the coils. The faster the magnet is passed through it, the stronger the current that is induced. This would cause a potential difference between the terminals of the conductor. The resulting voltage and current through the solenoid can be run through an electric circuit, and can ultimately be used to power applications that contain light bulbs or LEDs. The following are the initial conceptual sketches of each design that the group created, followed by a description of how each concept is supposed to work in an ideal situation.

Concept 1: Hanging Handle

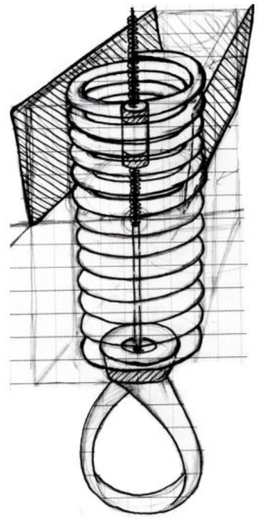

Figure 1: Hanging Handle

This design was intended to be implemented in a vehicle. Passengers would use the handles to secure themselves as the vehicle moves. The release of the handles exert an upward force, similar to a force released after a tension spring has been stretched, propels a magnet located in the center of the coils to oscillate, thereby inducing an electrical current to create electricity. The strength of this design is that it is easy to maintain; however, its durability is compromised by the numerous directions it can be pulled at, and the safety of this design is compromised because of the magnetic in the circuitry is located very close to the user's head. In addition, this concept has a limited potential of how much energy it can generate because there are only a few people on a vehicle who actually use handles.

Concept 2: Teeter Totter Tile (T-T Tile)

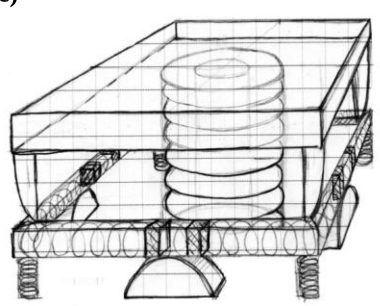

Figure 2: T-T Tile

This concept was designed to be implemented as a replacement for the current tiles in areas of high people traffic. When people step on the tile, the spring at the center would compress, and cause the teeth at the edges of the tile to push two of the four teeter-totters down. When these teeter totters are pushed, a magnet inside would slide up and down it's the teeter-totter's length; this would create a current through the conducting wires wrapped around the teeter-totters, thereby generating electricity. The strengths of this concept are that it is very durable and can function long enough to power useful application for long periods of time by a large number of people. This design is safe because all the circuitry that converts kinetic energy to electrical energy is hidden underneath the floor, away from the users; however, this design's weaknesses are that it could be a tripping hazard if people are not careful.

Concept 3: Rolling Floor

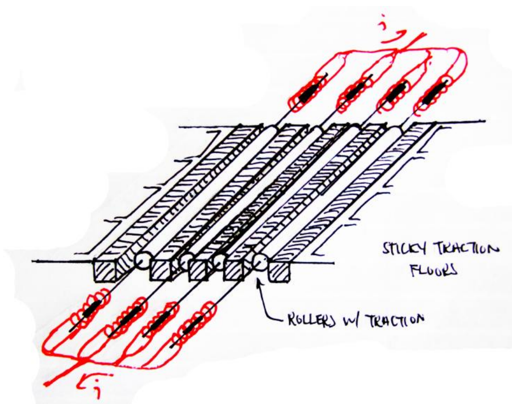

Figure 3: Rolling Floor

The final concept is also meant to be implemented on the ground. When people step across a floorboard, they cause the rollers inside the floorboards to start rolling. These rollers are connected to magnets that rotate to create a magnetic field around conducting coils, which create electricity. This concept is more durable than the others because of the usage of rollers rather than springs; however, potential water damage greatly reduces the durability of this design as the metal bars would have to be exposed to the environment and dirt. This design also poses some safety hazards as certain shoes, such as stilettos, or clothing dragging on the floor might get trapped into the corners where the rollers and the tile meet. The energy that can potentially be generated from this design is also limited because each roller can only roll at most a few times before it is stopped by friction or someone else stepping on it, allowing only a small amount of energy to be generated from each step.

4.3 Concept Selection

To select our final concept we decided to use a decision matrix. Each concept was weighed on five different criteria, where a weighting of 0 is 'unsatisfactory', and a rating 4 is 'very good'.

Table 3: Weighted Decision Matrix

		Concept Alternatives					
		Hanging Handle		T-T-Tile		Rolling Floors	
Criteria	**Importance Weight (%)**	**Rating**	**Weighted Rating**	**Rating**	**Weighted Rating**	**Rating**	**Weighted Rating**
Ease of Maintenance	10	4	0.4	2	0.2	2	0.2
Durability	15	2	0.3	4	0.6	3	0.45
Noticeable	15	3	0.45	2	0.3	1	0.15
Price	10	3	0.3	2	0.2	3	0.3
General Safety	20	2	0.4	3	0.6	1	0.2
Electricity Generated	30	3	0.9	3	0.9	3	0.9
Total	**100**		**2.75**		**2.8**		**2.2**

From the decision matrix, the concept to be selected is the ‘T-T-Tile’. This decision was based mostly on the safety of the device and the amount of energy the device can generate. Because the T-T-Tile can be implemented in a safe manner, and can potentially generate more electricity than the other concepts, its concept was chosen to be the design.

4.4 Concept Testing

The purposes of these surveys were to determine the concept’s feasibility and the public’s acceptance to the idea. The chosen concept was tested through surveys of potential users, focused on the Waterloo region. People who were interviewed were mostly students, faculty of the university, and the TTC and GRT commuters.

The format of the test was in an interview process and also through a survey. People who were tested were asked about what they thought about the tile, its feasibility, and any problems they foresee that might be encountered. The concept was described to the interviewees through verbal communication and through a concept drawings of the device.

Individuals chosen in the survey population were asked to take an online survey where they were asked about if they felt that the device would hinder their daily activities, and about what they feel would be good potential applications for the generated energy. In addition, a janitor for the TTC and two TTC statistical officers were interviewed on their opinions on the effectiveness of the device, and if our proposed location of the device is correct (ie. The chosen location will generate the most electricity).

The results of the surveys indicated that the selected concept was accepted a wide all the surveyed individuals and verified that the device is feasible. It was verified that the device would able to harvest the most energy at bottlenecks of the transit system, and that a depression of less than 1.3 centimetres would be relatively unnoticeable to people walking across the tile.

5. Concept Prototype - Analysis & Synthesis

5.1 Functional Decomposition

The objective of the device was identified as harvesting human kinetic energy and converting it into a usable energy form to be utilized by a local application. Electrical energy was chosen, as it could be used to enable virtually all applications in the transit system which requires electricity. Human kinetic energy is converted to electrical energy, stored, then transmitted to the application when required. Determining how much energy is currently stored in the device was also considered important as insufficient amounts of power may always be a problem due to the inconsistency of human traffic. In this case a backup power source could be triggered as a supplement.

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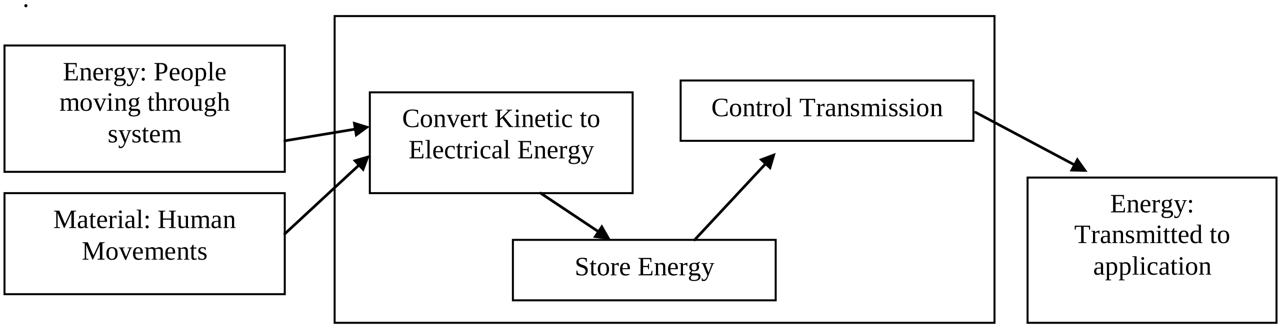

Figure 4: Simplified Function Decomposition

5.2 Prototyping

A prototype was created with the functional decomposition as seen in Figure 4 and the selected concept in mind. Solid Works was used to create a 3D model to assist with dimensioning and visualization of the prototype. The actual prototype internals were built to scale with the 3D model.

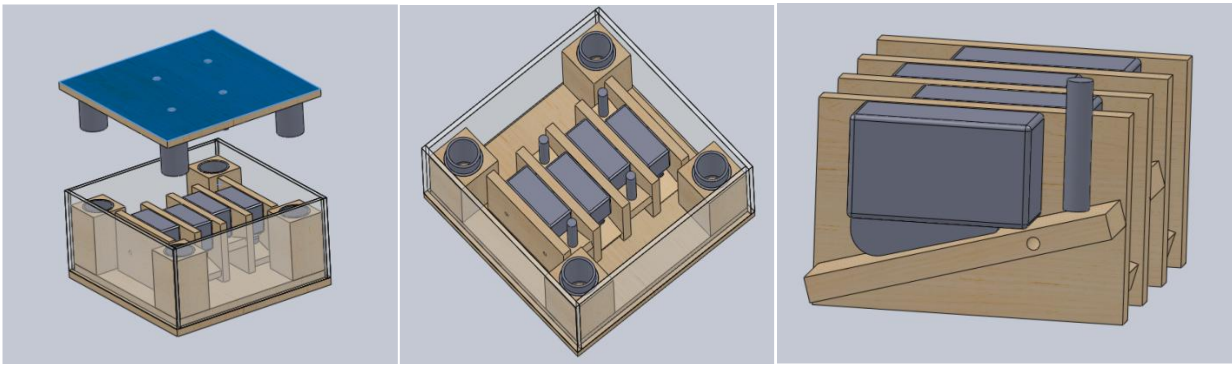

Figure 5: Virtual Prototype Model

Dynamo flashlights were used as the generator to produce a DC voltage. The circuit for the design places all four generators in series, hooked up to a storage device similar to a rechargeable battery. If more than one tile is being used to harness human kinetic energy, the tile generators would be placed in parallel with each other to charge the storage device. In the situation where insufficient power is in storage, a fallback circuit will connect the device to the regular power grid. Figure 6 displays the internal schematic and two external schematics depending on the number of tiles installed.

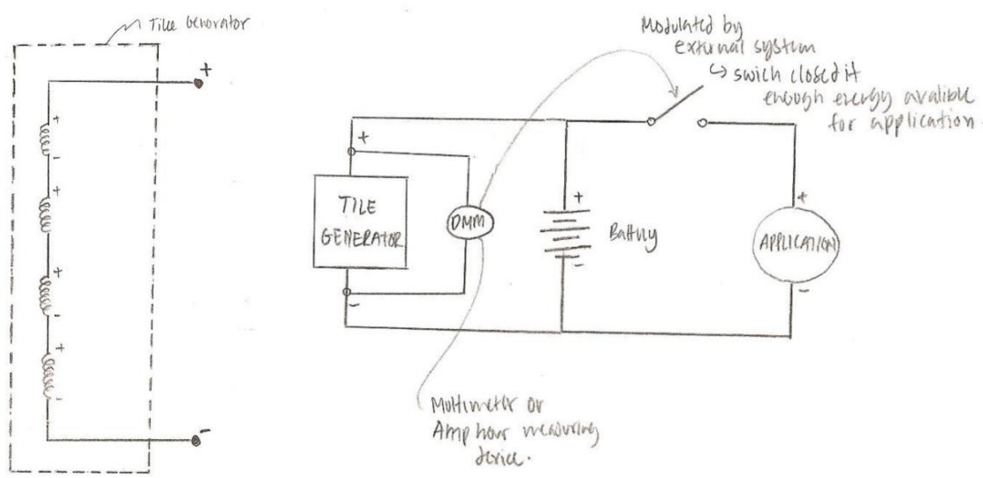

Figure 6: Internal and External Schematics of the Tile Generator

The dynamo generators would be triggered by human steps through a lever mechanism and a pin attached to the ceiling of the internal compartment of the tile. This mechanism transforms a small depression from a step into a large displacement to actuate the dynamos increasing power generation.

5.3 Mathematical Analysis

A bond graph can represent the energy transformations in a dynamo mechanism. A dynamo is a proven model with higher conversion efficiency than other types of coil/magnet generators since induction can occur from the spinning flywheel after force is applied. The physical representation and bond graph model are shown below in Figure 7 and Figure 8.

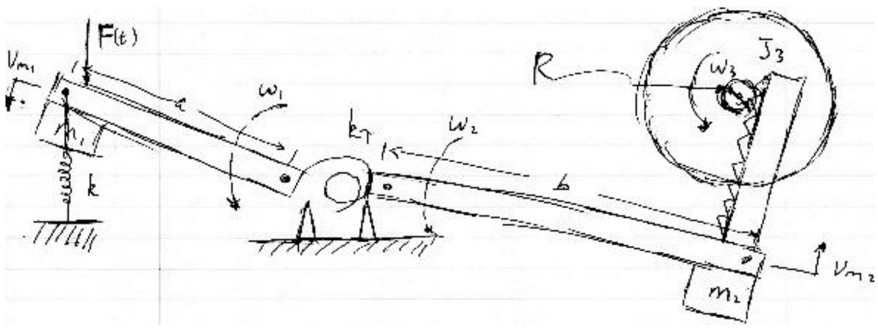

Figure 7: Device Components

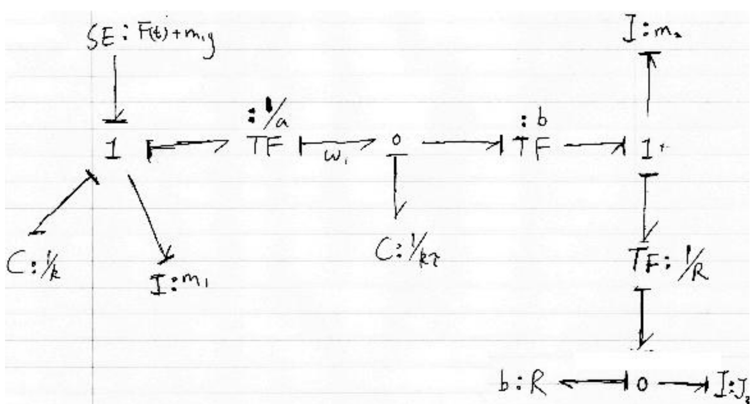

Figure 8: Bond Graph

Data obtained from measuring the dynamo's output during use was obtained through experimentation. The dynamos were compressed once per second to simulate moderate to heavy foot traffic. The data found was that:

DC voltage/dynamo = 1.5V	DC power/dynamo = 90 mW
DC current/dynamo = 60 mA	Power generated/tile = 13.5 W

Furthermore, a Matlab simulation using state equations derived from the bond graph and the physical parameters of the prototype revealed that the power generated per tile was approximately 10.5 W. The metrics and benchmarking report calls for a minimum power rating of 1 W and an ideal power rating of 15 W. Both experimental result and Matlab simulation demonstrated values closer to the ideal power rating, which meets and exceeds customer expectations. It should be noted that analysis done on the prototype will closely match the physical form, as the actual generators to be used in the prototype were used for experimentation.

5.4 Environmental Impact

The surfaced area consisting of the floor tiles will be covered with a special type of matting. It is highly slip retardant and can mitigate the risks of slips and falls in high traffic areas. The soft rubber base acts like anti-fatigue flooring, making it ideal for the transit industry. With the covering on top of the tile, the device will be less exposed to environmental factors, hence extending the lifetime of the product. The longer the product life is, the less frequent the device has to be replaced, reducing the amount of waste to the environment. Although not officially tested, it can be assumed that the materials used in the prototype are very similar to the ones used in the actual product, therefore the remaining analysis on materials used are based on what was used in the prototype. All materials are recyclable or biodegradable with the exception of PVC pipe. For PVC pipes, there may not be a recycling program available in the city; therefore, it may be required to be disposed as garbage. Of course, a large-scale project involving large quantities of tiles would likely involve a recycling program with the tile retailer.

5.5 Economics

As previously stated, it is assumed that the materials for the actual product will be very similar to the prototype; therefore, analysis will be based on the materials used for the prototype. Of course, economies of scale from mass manufacturing the product would severely reduce costs in all areas.

Table 4: Material List

Part	Material	Quantity	Cost ($)
Dynamo Generator	Dynamo Flashlight	4	60
Inner Partitions	Plywood	5	5
Base	Plywood	1	5
Telescopic Pillars	Plywood PVC Pipe, diameter 1 PVC Pipe, diameter 2	4 4 4	10 5 5
Springs	Spring	4	16
Actuators	Aluminum Rod	4	10
Housing Walls	Acrylic Sheets	4	6
Tile Top	Plywood	1	5
Lever	Aluminum Bar Bolt	4 4	20 3
Miscellaneous Assembly Components	Nuts, Screws, Washers Glue	- -	10 -

5.6 Physical Prototype

The physical dimensions of the prototype differ from the proposed dimensions of the device. The primary reason for this was that these dimensions of the prototype depended on the size and number of the generators being used. Also, the area required for the generator trigger mechanism to operate was also an important factor in the decision to modify the dimensions.

The specification for tile depression was also modified from 0 cm to 12.5 mm for the prototype. This decision was primarily depended on how human kinetic energy would be harnessed by the device. The method chosen was based on transforming mechanical translational motion into rotational into electrical energy. Due to this reason some depression was required in order for the dynamo generators to be triggered by human footsteps.

Lastly the area of a single tile was changed to be variable for the purpose of the prototype, which differs from the actual device has an area of 0.75 m2. The team determined that depending on the amount of energy required by the application that would use the generated power, a certain number of tiles can be customized accordingly to the power generation needs. Refer to Figure 9 for an overview of how one tile looks like.

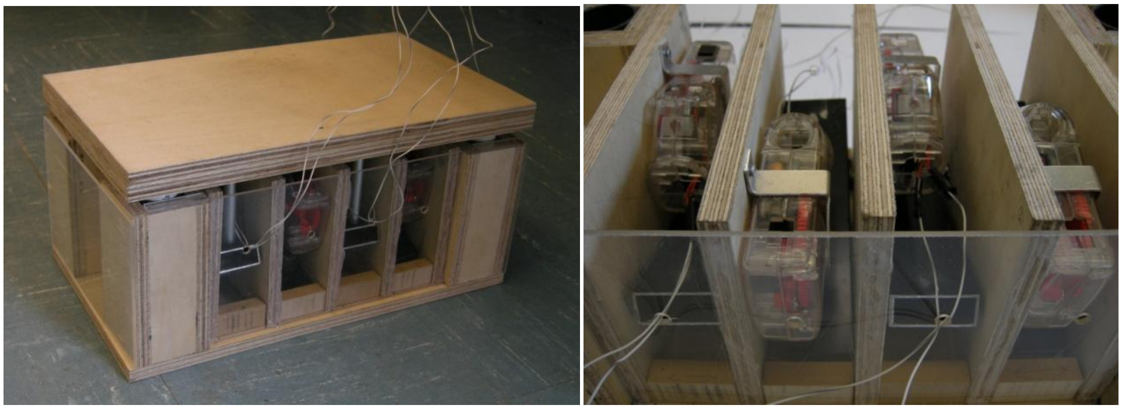

Figure 9: Finished Prototype

6. Discussions – Conclusions & Recommendations

6.1. Conclusions

At various stages of design process, feedback was solicited from experts and potential end users. The information gathered showed general positive attitude toward the concept of using floor-based mechanism to harness energy. Stakeholders interviewed were mostly students; concerns identified relate to comfort and safety.

The symposium provided an opportunity for the targeted audience to physically interact with a working prototype. Everyone was very impressed by the functionality and surprised by the lack of unpleasant feeling associated with depressible surfaces. There were some comments regarding the tile mechanism being too unstable. However, this is simply a deficiency associated with the prototype and constrained access to precision machined shock absorption devices.

The prototype was able to achieve most of the requirements outlined in the metrics & benchmark stage. In particular, the amount of energy generated exceeded expectation and is roughly 10 times better than what the current state of art product on the market can achieve. The form proved to be robust and stable over repeated usage.

That said, the comfort and user interface aspects fell short of expectation. The extent of the depression was more than what was specified. It does not pose any major safety issue, but was noticeable enough to raise concerns from some users. The material used for building the prototype is heavily influenced by time and resource constraints, and is not reflective of what an actual implementation will use.

One important feature of the selected concept is scalability. The prototype is constructed with this in mind by encapsulating mechanical elements in self-contained packages; interaction with systems is accomplished by wire harness carrying power to load. This is an important proof of concept and confirms the ability for individual tile modules to be arranged and connected in customizable series/parallel combinations.

6.2. Recommendations

The scope of the project has not changed significantly from what was first proposed. However, it has been realized that given the current implementation, questions remain as to what specific practical application should be powered. There is currently a conflict between where the device resides and where localized application is found within the transit system. The interim solution is to divert the generated power to a battery pack, which can then be rewired to the intended application.

One major next step is to investigate the material and manufacturing process required to mass produce the system for commercial applications. The height dimension restriction is of particular concern because a feasible solution would be impossible using the current.

7. References

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