FootY - Energy harvesting while walking

Ben Zaquin Arthur Meyer, Ben Hamouda Mohamed Brahim, Vidal-Aragón Jacobo, Bandeira Eguiraun Íñigo, Calvaruso Claudio, Luong Émile Minh-Son

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Prof. Yves Bellouard
Prof. Edoardo Charbon
Group 8

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Part I
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Part II

Product concept

1 Introduction

The subject of renewable energies is a recurring topic and finding a way to produce green energy is a big challenge for humanity.
Although various ways of collecting renewable energies already exist (photo-voltaic panel, wind turbines etc...), we wanted to explore another area and that would be the subject of our project: energy harvesting from walking.
As an unavoidable daily activity and a human function, we will try, throughout this project, to make the best of the energy produced during human walking motion.

2 General description

Energy harvesting from walking is a subject which is opened to lots of possible interpretations. From portable wearable devices for personal use to a more collective way of doing so, our team decided to attack the project on the educational point of view and target population groups by designing a floor that would collect energy from people's steps.
The possibility to adapt this floor to different installations allows to target several companies and sectors which makes its use versatile (for exemple in public places, schools, etc..).

3 Brief market analysis

The target market is renewable energies and education. We are proposing a mean of sensitization regarding the importance of this topic for educational institutions, universities and population mainly.
More than 10 universities in Switzerland and 200 in Europe could host and benefit from our project. Public authorities in Switzerland, and for further perspectives Europe, are also part of the marker we want to target.

4 Unique selling point of your product

The product is very didactic and easily accessible for people, in addition to its durability which makes it perfect for the role it will be playing in the awareness about renewable energy.
Its interactive aspect is one of its key features.

Part III
Technical solution

5 Specifications

The product has two main functions: energy harvesting and sensitization. Thus the specifications of the tile shall be related to these main themes:

1. Energy harvesting
   - The product shall convert mechanical energy to electrical energy
   - The product shall store energy in a battery or a super-capacitor
   - The product shall supply the showing-off system used for sensitization as a first goal
   - The product should, in the long term, reduce energy consumption in public spaces and schools using the energy stored
   - If the product uses active electrical components, it shall be able to supply them
2. Sensitization
   - The product shall be accessible in public spaces
   - The product shall be esthetically attracting to adults and children
   - The product shall be didactic and simple to use
   - The product shall have a fun showing-off system
   - The product shall be tough enough and durable to sustain attempts of over-trying it
   - The system shall have accessible information about our product, how it works and why it exists
3. Other specifications to take into account
   - The product shall be adaptable to any space it's installed in
   - The product shall be waterproof
   - The product shall have a modular structure
   - The product shall be comfortable for general use by kids, adults and elderly

6 Design phase : solutions explored

The options we were considering were a mechanism inspired of the *autoquartz* systems in mechanical watches (Figure 1) and a mechanism relying on the deformations caused on piezoelectric materials.
The complexity of the first option resided in its practical implantation, that's why we decided to explore the piezoelectric solution. The scaling laws would have also had an impact on the power generated.

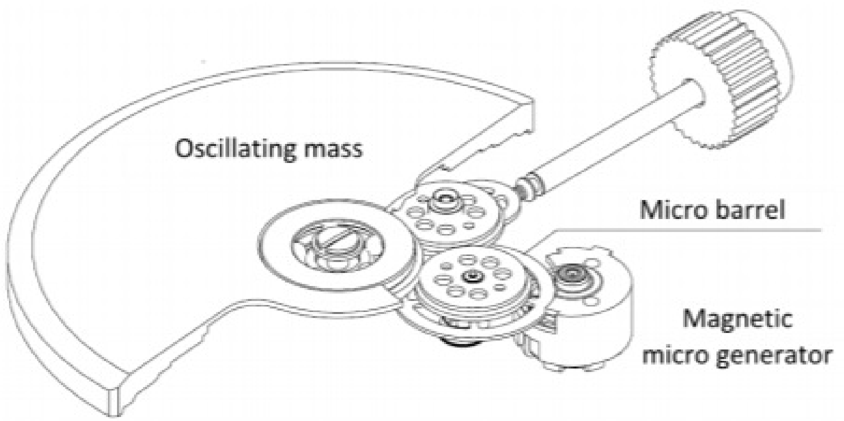


Figure 1: 3D view of the Autoquartz system in a watch

At its actual scale, the continuous production of milliwatts (mW) is enough to supply power for the watch. Further simulations would have been needed on a larger scale and the incertitude on the efficiency as well as the deadline constraint worked in the favor of the piezoelectric implantation, although this mechaical system remains to be studied further in a future time in order to test its efficiency.
The piezoelectric solution takes advantage of the properties of piezoelectric materials. By deforming, those materials can produce a high voltage. Combined with the right mechanical implantation and electronic circuits, we could produce enough energy to fulfill the interactive functions of our product as well as storing some of the energy inside a capacitor for later use.
A short test period has been made as a study for our future design. Depending on the pressure applied on the piezoelectric material, we can generate high voltages (see Figure 2).

We first decided to go for the mechanical system below (Figure 3). The pressure force applied on the moving part pushes it downwards and causes the bending and deformation of the piezoelectric layers. The damping material (in this case a foam) is used for the comfort of the user and guarantees a shock absorption in case of a brutal impact.
The advantage of such implementation is the possibility to put multiple piezoelectric layers.

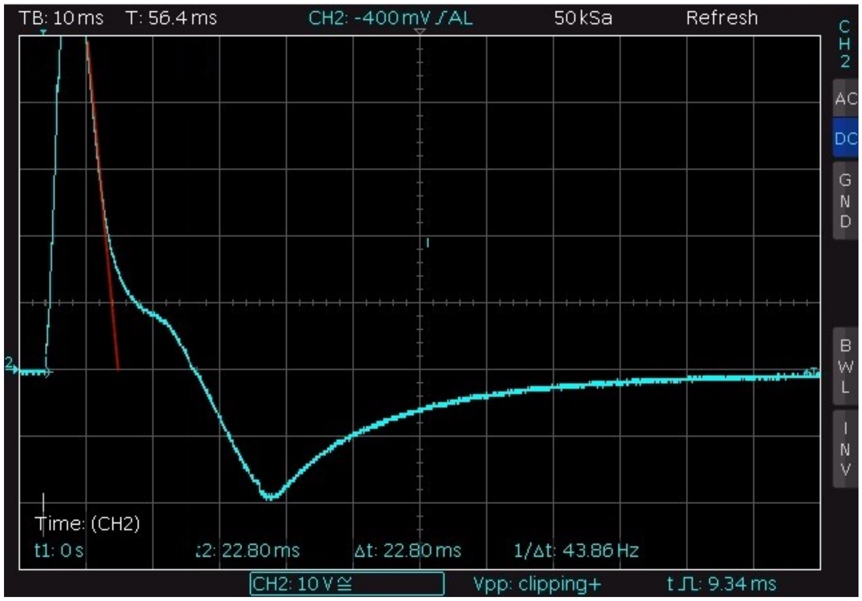


Figure 2: Peak voltages on a pressed piezoelectric element can reach more than 80V but for a very short period. That's why we chose a vibrating mechanism

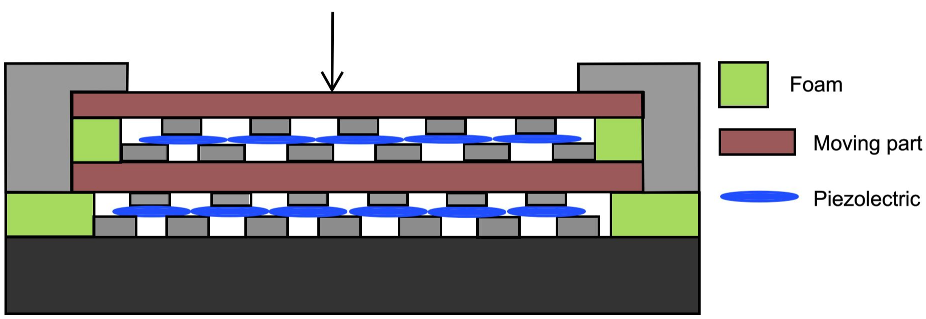


Figure 3: Simplified diagram of the first mechanical system idea

Our experiments and further researches showed that deformations and induced vibrations on these elements were more efficient than rapid impacts on the surface.
We consequently decided to go for an oscillating system (Figure 4). The choice of a hard ceramic piezoelectric material was done over a flexible composite piezoelectric material (MFC for example) due to the generated energy efficiency.

7 Technical choices made

7.1 Selected design

As said in the previous section, an oscillating mechanism based on the plucking of beams was chosen. The mechanism presented in the Figure 4 works as follows: pushing the tile downwards causes the plucking of the beams by the central pointy structure. Their release after bending to the maximum displacement calculated causes the beams to oscillate at its resonant frequency.
The intrinsic stress at the surface of the beams causes the piezoelectric materials to deform (extension or compression) which generates electrical energy for us to use.

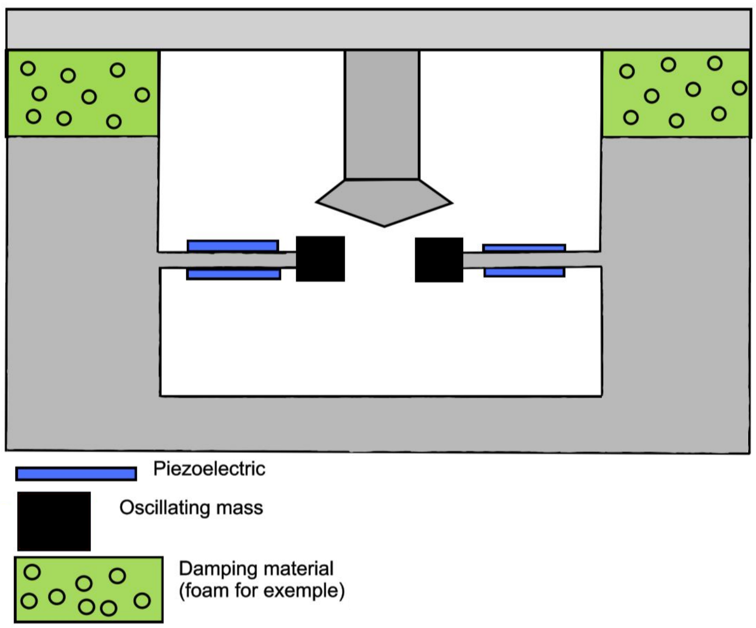


Figure 4: Simplified diagram of the mechanical system chosen

The comfort of the user, related to the amount of difference in height felt, being also one of our concerns, we installed a damping material (a foam) under the pressable surface.
An initial prototype using foams was realized in the locals of Robopoly. By experimentation, walking on such tile felt nice and smooth and the height difference (maximum estimated at 2cm) should not bother future users.
The foam also absorbs any shocks within the structures and stabilizes the press-able surface.
The electrical energy is to be treated by an electrical circuit connected to the piezoelectric layers. Since the signal generated is not a DC signal, it needs to be rectified before being stored in a component.

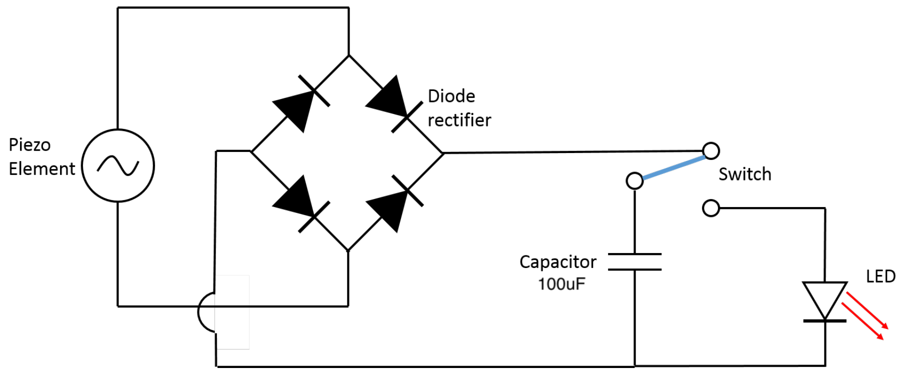


Figure 5: A simple rectifier circuit, after further considerations and studies we decided to use other components, with active elements

In order to get the best efficiency when it comes to the harvesting of energy the team decided to go for a circuit that uses active components. Although it consumes energy, these losses are minimal (estimated to be in range of nA) at certain working regimes if we refer to the datasheets of the components that we plan to use.

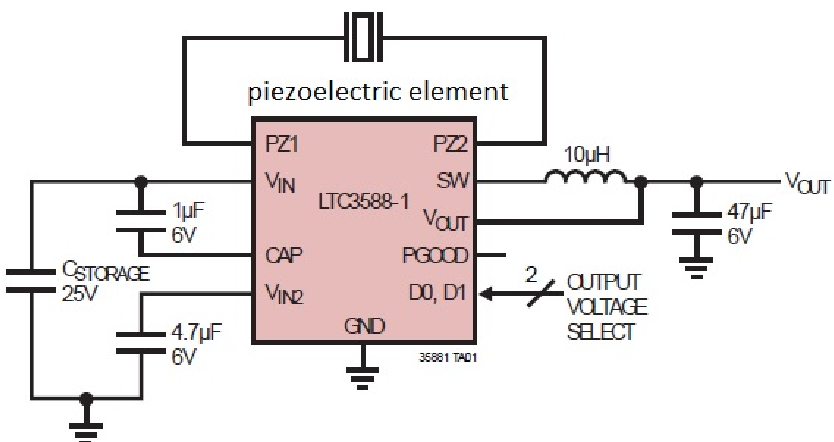


Figure 6: This is the first stage of the circuit used, the LTC3588-1 chip rectifies the signal, converts it to DC and stores it in a Capacitor $C_{storage}$ until a certain value. $C_{storage}$ then supplies the chip and the battery charger via other chips

The working principle is to profit from the piezoelectric elements' motion to charge a capacitor to a certain potential through a chip that has an integrated diode Recompile rectifier bridge. Once the maximum charging value is reached (refer to datasheet), the chip is switched to its second mode to supply the charging circuit with a constant current up to 100 mA and a voltage chosen by us depending on the pin connected (we chose 3.6 V of continuous output).
This would allow us to continuously provide P=V·I=360 mW and charge an external battery. When the input capacitor's voltage drops under the charging value chosen we restart charging it by switching the chip mode again.
This way proved to be more efficient than just using passive electrical components because of the low current generated by the piezoelectric elements (μA) despite the high peak voltage that could be reached, and the fact that the energy calculated would only take the RMS voltage value during the short generation time which is nowhere near the peak value observed on the oscilloscope (Figure 2).

7.2 Analysis / Modeling of the key functions related to the unique selling point

The product suggested by our team is based on a very simple model that everyone can relate to. Our goal is to make it as accessible, didactic and intuitive as possible. It is based on the vibration of the piezoelectric elements which in our mechanical design is similar to just plucking a ruler: a kids' game.

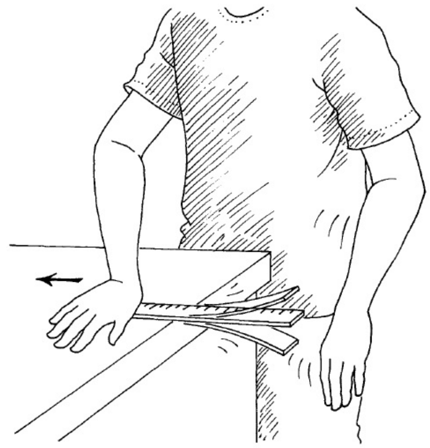


Figure 7: Modeling of the mechanical principle used

This damped vibrating motion (see oscilloscope figure) is representative of the energy generated by the piezoelectric elements that could be used by us.
The rectified version of the real profile (see figure) will be the one used to calculate the energy generated by one step and that will be displayed to the user of our platform.
In order to calculate that, we just integrate the surface under the curve over the period of oscillations. The energy produced will be supplying our electrical circuits that will help charge batteries and supply the show-off system.

7.3 Key elements in the design and how they could further optimized

7.3.1 Mechanical elements

The mechanism is very simple and straightforward as presented in section 7.1. It is mainly based on the clamping of the beam and how much energy could be generated by its plucking as presented below.

The vibration depends on the vertical movement of the farthest part of the beam. The tile box is 50 mm tall approximately, which constraints the vertical movement of the hitting piece. In order to obtain a bigger vertical displacement of the beam with a lower vertical displacement of the tile a leveraged mechanism is used. This mechanism is shown in the following pictures.

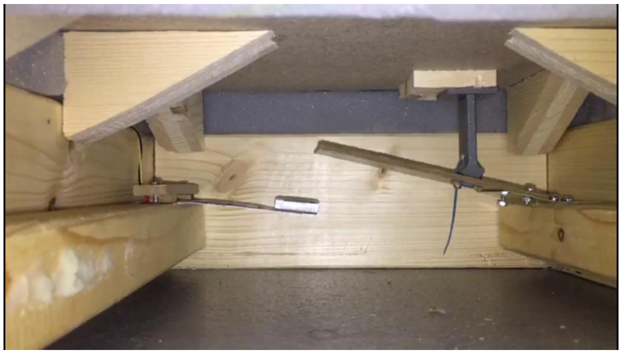


Figure 8: Before and after stepping on the tile

Figure 9: While stepping on the tile

In order to maximize it we need to take many factors into consideration:

1. External factors
   - The actuating element
   - The external damping
   - The clamping
2. Internal factors
   - The piezoelectric element placement
   - The vibration frequency
   - The internal damping

The actuating element will be a pointy object with curved boundaries in order to apply a local punctual force at the tip of the beams. This element will have a vertical movement which will bend the beams to maximum displacements in order to improve the frequencies of vibration (Figure 11).

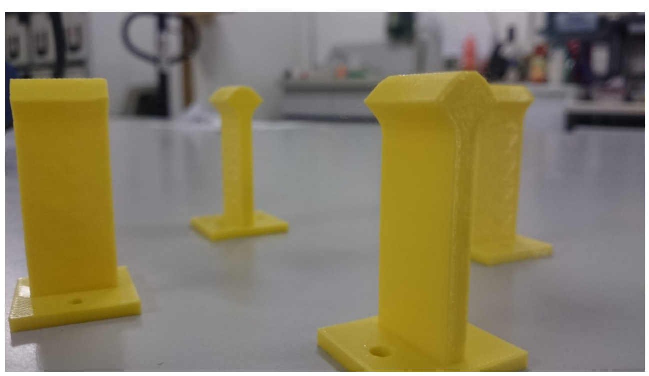


Figure 10: A series of 3D printed actuation elements

The external damping assured by the foams is done mainly to avoid sudden impacts, for the comfort of the user and also for security purposes as the amount of energy that could be transmitted in a single step onto the beams could break the piezoelectric elements since the kinetic energy would be very high (E=$\frac{1}{2}m.v^2$). We need to be very careful with clamping as it is a big source of energy dissipation and an important parameter in preventing the beams from breaking. It has also a direct impact on the beams' length and thus vibration frequency.

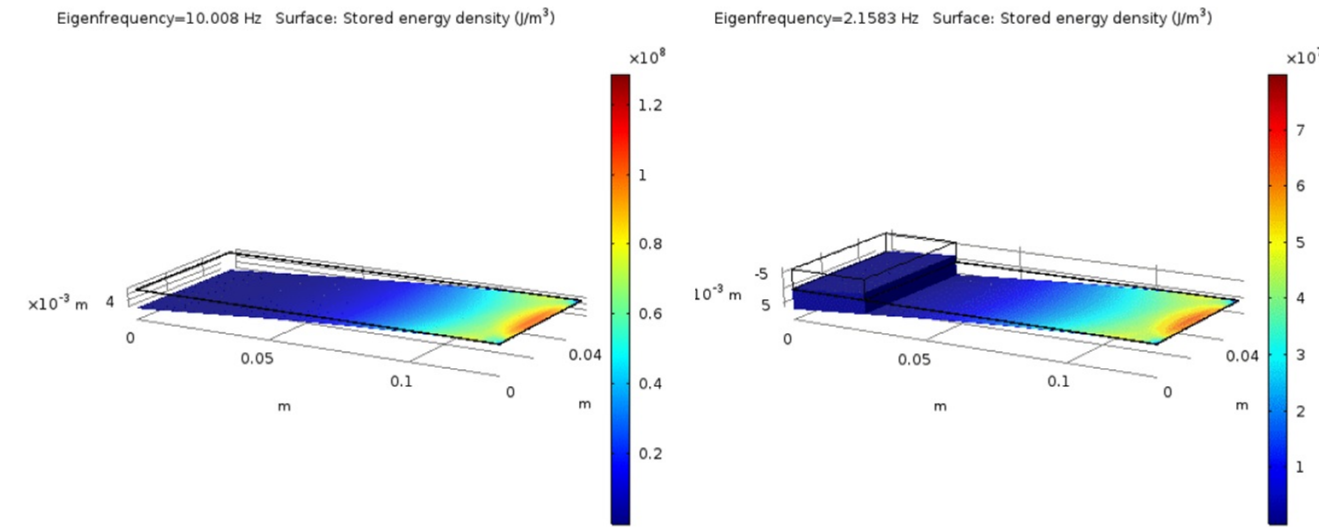


Figure 11: Energy concentration along the vibrating clamped beam and the natural frequency (eigenfrequency) variation: The resonance frequency drops when the beam is tuned with a tipped mass

As seen in the previous figures, the maximum stress (thus energy) is concentrated at the clamped end of the structures. That is why the piezoelectric elements will be fixed near the clamped part.
The goal vibration frequency is the resonance frequency of the structure. This frequency ensures a maximum displacement of the tip of the beams and the larger deformation of the piezoelectric element, which translates into higher produced energy. If the maximum displacement is reached, the vibration is going to be at the proper first mode of the beam regardless of the force applied. We will try to take advantage of this independence. Since we need the vibrations to extend on a large period of time, we decided to adapt the vibration frequency to lower levels (At lower levels the maximum displacements generated are higher which means more electrical energy harvested). That can be done by putting a mass on the tip of the beams. We tried different settings during our experiments (see Figure 7) to get the best efficiency. An optimization regarding the tipped mass will be done in the future.
The internal damping is the most difficult part to optimize. In order to have more vibrations, we need the damping to be minimal. Whereas, the electrical energy collected from the deformations generated represents in itself losses and damping factors. There is then a compromise between the energy obtained and the oscillations period.

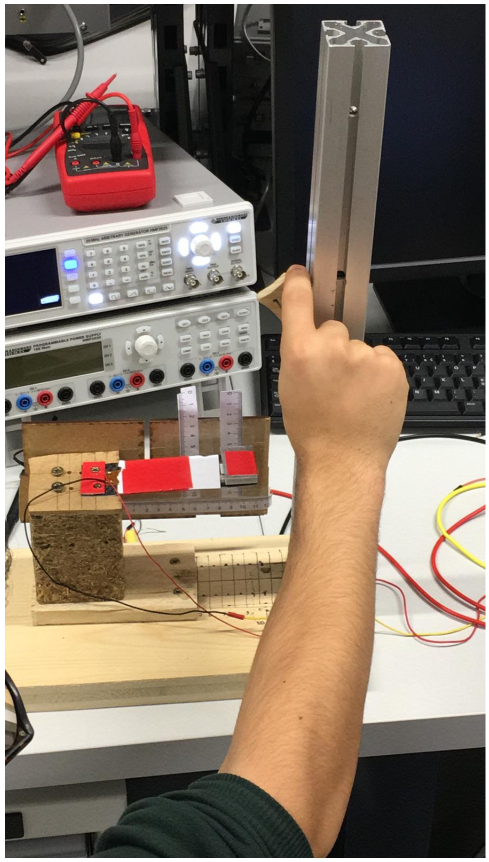


Figure 12: Experimentation phase to find the best compromise between different tipped masses and different beam lengths

Empirical optimization The amount of energy generated by the vibration of a piezoelectric element attached to a beam depends on several internal and external parameters (material, vibration frequency, actuating element, placement of the piezoelectric element, shape of the beam, etc..) and these parameters are often cross correlated. Some parameters has hence to be arbitrary chosen.

For this experiment, the assumption that the influence of the position of the piezoelectric component on the harvested energy is independent from the others parameters has been made.

An experimental setup showed in fig.12 has been made to test various combinations of parameters. The material of the oscillating beam has been fixed. As shown in fig.11, an important parameter is the position of the clamping on the piezoelectric piece. The parameter f is defined in eq.1 from the distances presented in fig. 13.

$$f = \frac{Lpiezo - Lclamping}{Lpiezo} \quad (1)$$

The fig.14 present the measure of the energy harvested in a capacitor for various f values using the experimental setup (fig.12). The energy harvested is calculated from the output voltage of the capacitor loaded through a simple rectifier as presented in fig.5. The harvested energy follow the equation 2.

$$E[Joules] = \frac{C[Farads] * V[Volts]^2}{2} \quad (2)$$

These results show that for a fixed set of parameters, it exist an optimal position of the piezoelectric element. Here the best f value is 0.7 which means that the maximum of energy harvested is obtained when 70% of the piezoelectric component if free and 30% are clamped.

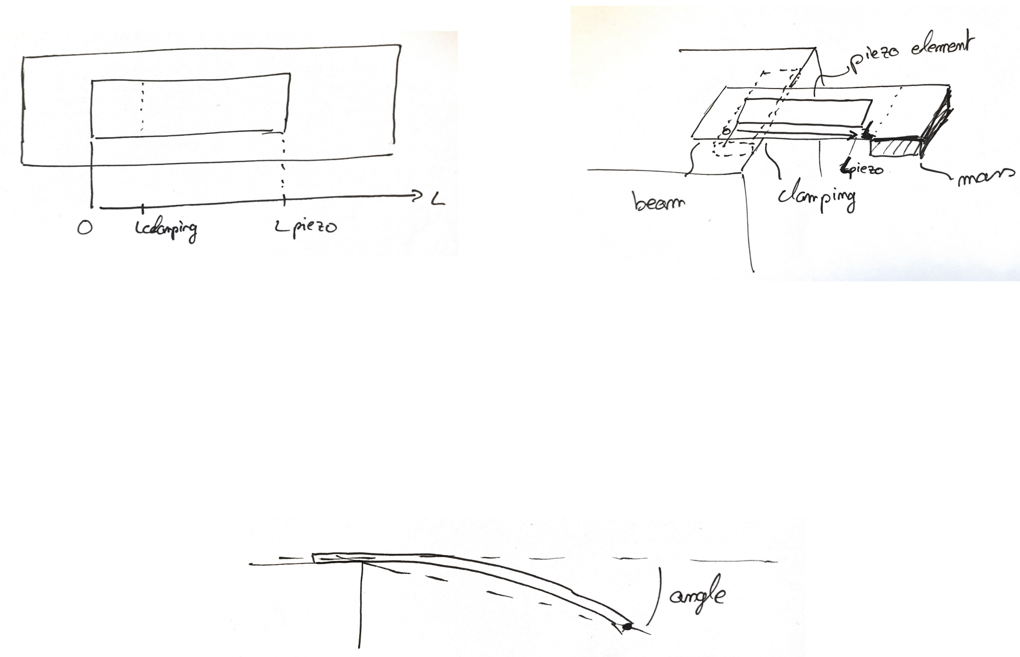


Figure 13: Drawing definitions

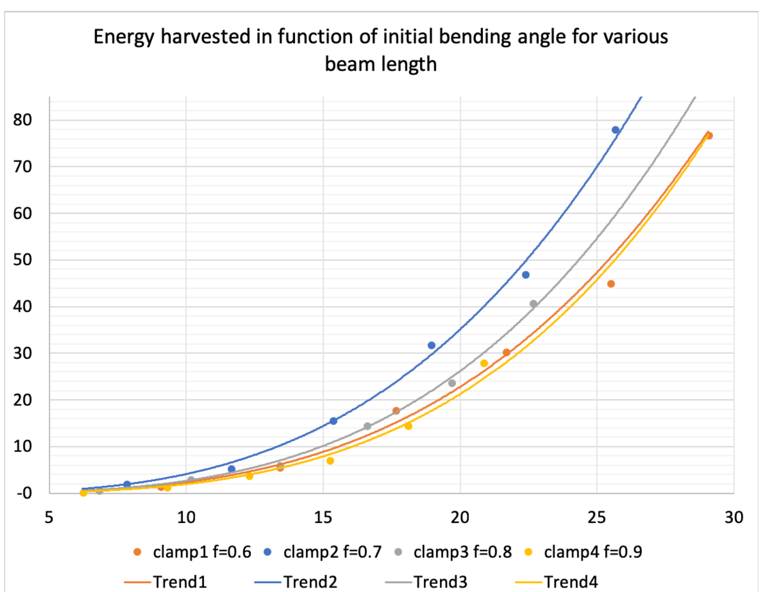


Figure 14: Energy harvested (MicroJoules) in function of the angle (angle in degree defined in fig.13) at initial displacement for various f (see eq.1)

7.3.2 Electrical elements

The electrical part of the mechanism could also be divided in 4 main parts:

1. Generating piezoelectric elements
2. Central component: the chip
3. Intermediate element: storage capacitor
4. Output elements: battery charger

As seen in the previous subsection, the piezoelectric elements' deformation generates an oscillating damped electrical signal. Although clamped to the same structure, the piezoelectric elements might have slightly different resonant frequencies, signal amplitudes, and phases. The signal generated would have the following profile (see fig.15. This can be an issue as a system containing multiple piezoelectric components connected in parallel would oscillate and lose some power in energy transfer across piezoelectric materials. To resolve this issue, the simplest solution is to add a rectifier circuit to each of the piezoelectric components and then only have additive influence between curves. This is what has been implemented in the prototype.

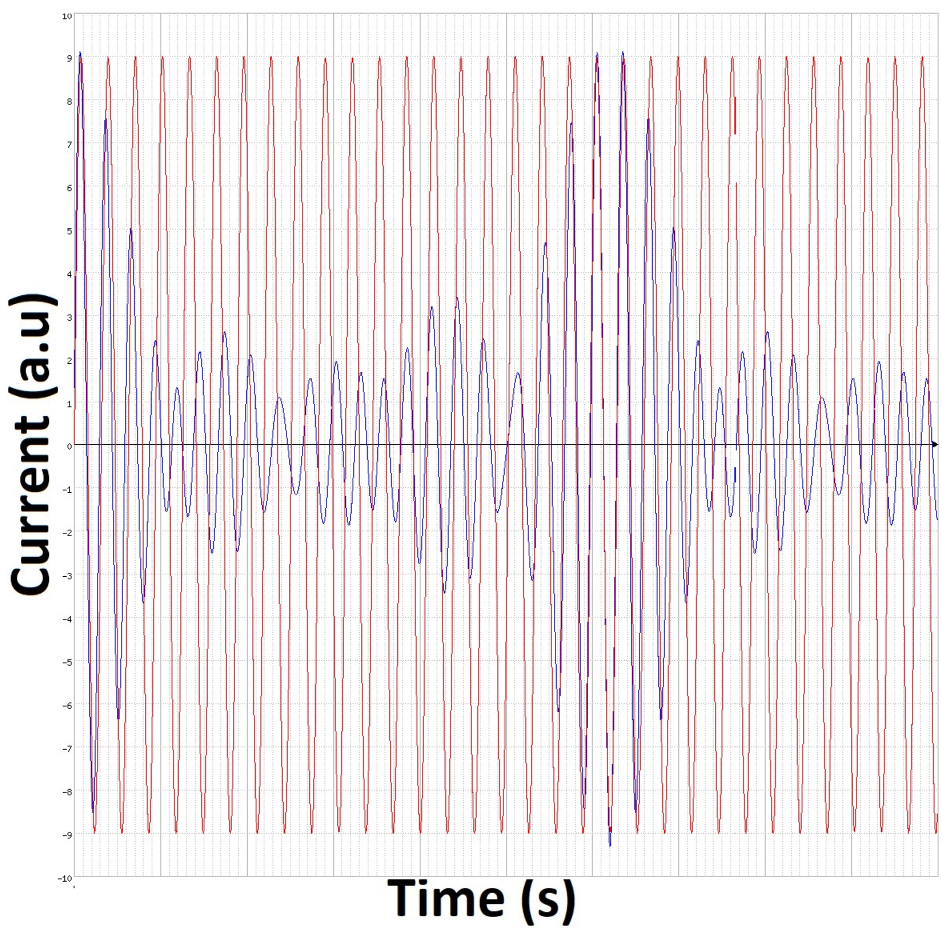


Figure 15: Red curve : the ideal signal generated by 5 piezoelectric elements with a 2Hz frequency over a period of a 100s; Blue curve : the real current containing a distribution of frequencies and phases.

With a goal of charging a battery, some active electronics components are needed. The signal presented in Fig.15 gets through the central electrical component of our circuit, the LTC3588-1 chip, and gets rectified and converted in a DC signal.

The DC signal is then stored in the intermediate element: $C_{storage}$. Unfortunately this capacitor is designed to be charged up to only 20V, so the piezoelectric motion that generates a surplus voltage is lost.
Once charged to the 20V, the LTC3588-1 chip's buck converter efficiently transfers a portion of the stored charge to the output elements.
This process is repeated everytime the $C_{storage}$ capacitor's voltage drops and only consumes nano-Ampers to keep the output signal going.

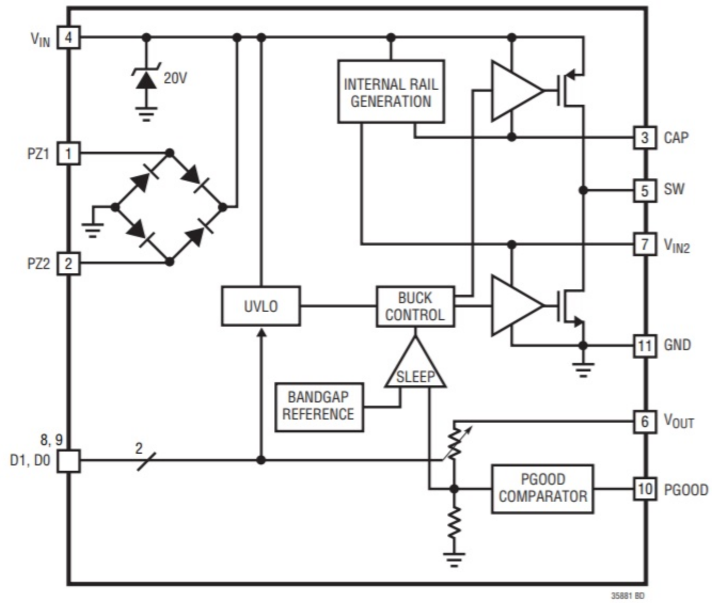


Figure 16: The LTC3588-1 block diagram

The use of such active components improves the conversion efficiency as the output voltage pin is regulated on 3.6V with a 100mA continuous current, which results in a constant output of 360mW over large periods of time.

It is to be noted that such process could further be optimized since the total efficiency is still bad on the long term, so a direct use of the stored energy in $C_{storage}$ on LED lighting is a more interesting application as shown during the demonstration on the 21st of December 2018.

8 Manufacturing choices and proposals for future production

8.1 Prototype fabrication

8.1.1 Structure

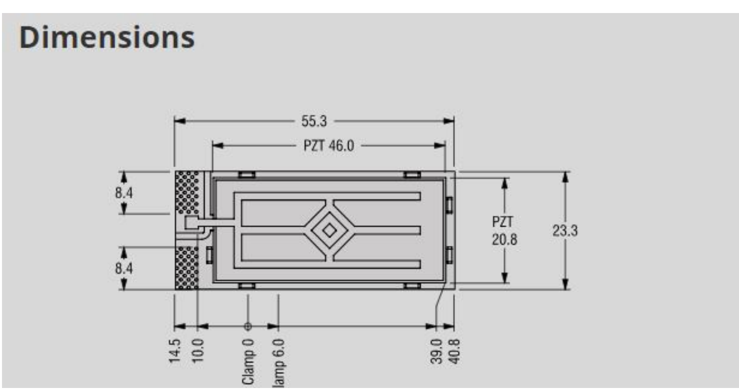
Our prototype is composed of 4 different parts:

1. The structure/mechanical support
2. The clamping and vibrating system
3. The electrical system
4. The show off system

The mechanical support was the casing for the whole mechanism. For the prototype and due to budget limitations, we used wood to build it (see the following section).
The mechanical support also represents the surface of the tile and contains a damping made of foam and a guiding system to limit the play when stepping on the said tile.
The clamping and vibrating system consisted of beams on the structure's inner border fixed at one end and free on the other end. The beams' plucking is induced by an actuator clamped similarly at the other inner end of the mechanical structure and bound with a simple string to a piece glued on the tile's back that moves vertically causing therefore the actuation movement.
The electrical system used in the prototype is slightly different to what is going to be implemented at later stages of the product as the battery charger was not present. For the first tile it consisted of a series of rectifier bridges (one bridge for each beam) connected to a storage element (a capacitor) and to a series of leds that would light up with the capacitor's discharge.
For the second tile, and in order to implement the modular aspect, the electrical circuit was the same and connected to a magnetic conducting material that would link both structures. This allows a wireless connection and less electrical wires minimizing the risk of tangling with the inner mechanical system.
The show-off system was a wooden board connecting the leds between them with a copper wire and to the electrical circuit of the first tile, as well as a panel with the same connections.

8.1.2 Materials

The most important compromise was between the budget allowed for the prototype and the quality of the material that we wanted to use for the manufacturing.
We knew from the beginning that the piezoelectric materials would be the most expensive elements of the prototype. We wanted one that had the best performance/price ratio. The piezoelectric materials that we bought are shown on the Figure 17.



Layer Specifications

Layer Material	Thickness mils / mm
Polyester	2.0 / 0.05
Copper	1.4 / 0.03
PZT 5J	6.0 / 0.15
Stainless Steel 304	6.0 / 0.15
Polyimide	1.0 / 0.03

Figure 17: Piezoelectric in PZT *S118-J1SS-1808YB*

The price was still high but the efficiency of the S118-J1SS-1808YB was good enough to prove our concept. This material can also be used for the mass production because the price goes down with the quantity :

Quantity	1	5	25	100
Price($/unit)	60	36	24	18

To make 2 tiles, and not to go over budget, we bought 5 piezoelectric materials for $\simeq$ 250 CHF, that took half of our budget.
For the structure, wood was appropriate because it filled the following criteria:

- Cheap
- Tough
- Eco-friendly
- Easy to manufacture

The clamping system, and the panels for the showing-off system was also made in wood due to its accessibility thanks to Robopoly and it was easy for the testing period.
As for the damping system, we used a foam. The foam was cheap and provided a nice and comfortable feeling while stepping on the tile.

Figure 18: The final prototype realized

8.2 Final product (Estimated costs for manufacturing of your product)

Wood as material for the structure can be a good/cheap alternative. Another possibility could be to use recycled plastic (PET) like the society EcoDom (http://www.ecodom.mx/). In addition to fulfill the same characteristics as wood, plastic is waterproof and can protect more easily the electrical circuit. Comparing the young modulus of wood (spruce) and PET, there is no risk of break for our structure.

	Wood	PET
Young's modulus (GPa)	10 to 13	8.3 to 14

The quantity of the production is related to the number of contracts and also the quantity of tile ordered by the costumers. Below are two tables of different quantity production, both with wood and PET, to compare the prices. The two main hypothesis are a production of 5'000 tiles (little production) and 100'000 tiles (massive production). The price for 1 meter of wood for the upper part of the tile is 7.95 - CHF, sor for 1 tile, it's around $\simeq 1.10-$. The price for the structure is $\simeq 15.-$- per tile
Little production :

Elements	Cost(CHF)
Wood	75'000
Piezo (3/tiles)	270 '000
Clamping & vibrating system (wood)	5000.-
Clamping & vibrating system (plastic)	2500
Electronic components	25'000
Machine for casting	50'000
Mold (estimation)	30'000
Manufacturing cost	40'000
PET	$\simeq 15'000$
Cost/tile (wood)	83
Cost/tile (PET)	86.5-

Massive production :

Elements	Cost(CHF)
Wood	1' 500' 000
Piezo (3/tiles)	5'400'000
Clamping & vibrating system (wood)	100'000
Clamping & vibrating system (plastic)	50'000
Electronic components	500'000
Machine for casting	50'000
Mold (estimation)	30'000
Manufacturing cost	800'000
PET	$\simeq 300'000$
Cost/tile (wood)	83.-
Cost/tile (PET)	71.3

The choice of the material used for the tile will depend on the quantity of production. For a massive production, the choice of recycled PET would better regarding two points : the first one is the cost production per tile and the second one is ecologic. A massive production using wood could have an impact on the massive farming of tree, so the use of already existing plastic would be more eco-friendly. All those number are calculated without any "mass production reduction". The cost per tile is the highest price for the manufacturing of the tile. There is possibilities to negotiate price, demanding of the amount a materials needed.

8.3 Quality analysis and control

Our product has two keys aspects : its durability and the easy accessibility of the energy produced, the environmental impact, and other important criteria.

Control of the quality of the structure : The diversity and range of weights inside a population must be sustained by FootY tiles. A test of durability shall be done. FEM softwares and materials studies help improve the efficiency of the pre-test phase.

Control of the quality of the show-off system :
As an educational product, FootY's key features rely heavily on the show-off system. The tiles must be able to generate enough energy from just a few steps (as an experimentation process) to light up enough leds for a demonstration. The light intensity and duration through time could be a quality assessment and is easily checked during the prototyping phase.
Such tiles also represent a long term investment so their toughness, resistance to exterior impacts and longevity are also important parameters to be checked and controlled. To do so, a FEM software study and a materials study must be done in order to ensure as less deterioration as possible on the long term. As for the electronic elements, we must check the components lifetime with the suppliers.
Finally, an efficient battery charging process must be achieved. A performance test over few hours is effortlessly achieved for that purpose.

9 Intellectual property (IP) analysis

The aim of this section of the report is to analyse the IP of our FootY. For doing so a prior state of the art has been done to check already existing patents for similar products. The potential market and future opportunities have also been explored and discussed by the group.

9.1 Introduction

The protection of our ideas, our "intellectual property", is very important. There are different ways of doing it, for example "keeping it secret" whenever it is possible like the famous brand Coca-Cola. This occurs when the entry barriers are very large so the company does not go for additional protection. In this case considering an entry barrier the difficulty of finding the exact ingredients and quantities.

In our case, the technology is already well known and can be easily copied. The competitor just needs to buy it, disassemble it and easily understand how it works. Hence in our case from a strategic point of view it is interesting to go for further protection such as publications or patents.

9.2 Prior art search (Before patenting)

Consists on checking the existing inventions in order not to incur in Copyright while developing our product. For that firstly we defined our product in the so called claim. Secondly with the main characteristics that differentiate our product we perform a research in the patent engine. This can be Top-Down or Bottom-up in our case we have combined them in order to focus faster on our target.

9.2.1 Main characteristics and patent family

In order to do an accurate research we set the main words that define FootY. The one we have checked in the Patent Scope and EspaceNet database to identify the patent family were:
<tile> <energy> <piezoelectric> <modular> <walking> <generator>
<education>
The main families and subfamilies where to find some other related patents are:

- Mechanical engineering > Lighting > NON-PORTABLE LIGHTING DEVICES; SYSTEMS THEREOF; VEHICLE LIGHTING DEVICES SPECIALLY ADAPTED FOR VEHICLE EXTERIORS > Lighting devices intended for fixed installation. Family code: F21S 6/00
- Physics > Education > Educational or demonstration appliances > Electrically-operated educational appliances (working with questions and answers; simulators; advertising or displaying in general). Family code: G09B 5/00
- Electricity > Generation. Family code: H02

Using the tool of ESPACENET Patent Search inside this families or using the key words we found some competitors that can have some similar products. This are the two main competitors:

9.2.2 Flooring System from PAVEGEN SYSTEMS LTD

"A flooring system 1 for generating electricity from pedestrians, comprising a plurality of generators 100, each generator having a support which supports a plurality of tiles 200. Each generator generates electricity from linear motion of the support in a first direction. Also disclosed are several related inventions, whereby sensors are used in place of the generators and combined with a processor. The system is arranged to estimate the location of a footstep, direction of a users motion based on time differences, or direction of a users motion based on magnitude of the signal. Two further disclosed inventions include electromagnetic receivers and transmitters associated with a mobile communications device for transmitting information from the sensors. The tiles are preferably triangular, are supported at each corner and may include a frame around the periphery of each tile."

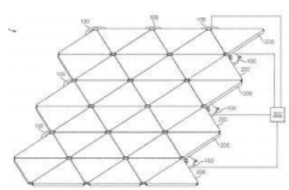


FIG 1a

Figure 19: Pavegen

The similarities with our project are the tiles on the floor with generator to product energy with people's motion. The difference are the application. In this patent, the intention is to localize the person walking on it and estimate his direction. The generating system is also different. They use motors instead of piezoelectric.

9.2.3 Printing head for tile decoration from INGEGNERIA CERAMICA S R L

"The invention relates to a printing head for decorating tiles, comprising at least a hollow element, internally of which a conduit is afforded, destined to contain pressurised glaze. The conduit exhibits at least an outlet nozzle for the glaze. An obturator is associated to each nozzle and is mobile between a closed position of the nozzle and an open position of the nozzle. The obturator is activated by a relative piezo-electric actuator, arranged internally of the conduit, to which it is solidly constrained."

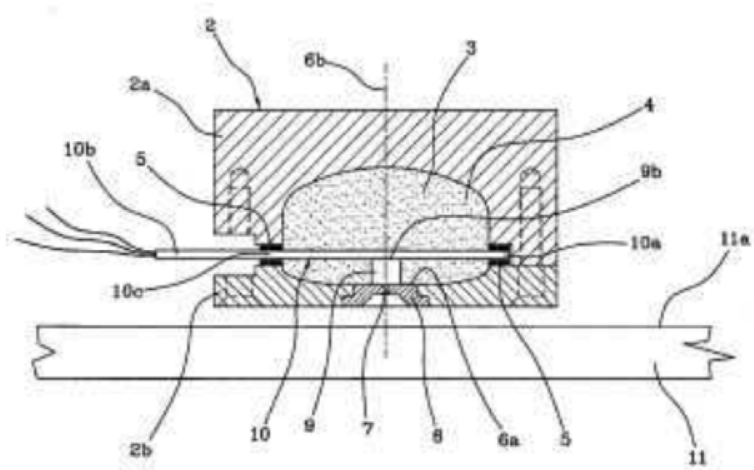


Figure 20: INGEGNERIA CERAMICA S R L

In this case the idea is to light a tile, using the energy of a piezoelectric.This is almost the same idea as our project, but we would use other ways to produce light, like using basic LED's, and not necessarily on the tile itself, but perhaps next to it. The vibration of the piezoelectric material is the main difference.

9.2.4 Piezo-luminescent decorating floor tile

"The utility model provides a piezo-luminescent decorating floor tile which is composed of a transparent plate layer, a piezoelectric plate, light emitting diodes, a storage battery, a single-chip microcomputer, a power source data transmission module and a power source data receiving module. Deformation energy generated when people walk through the ground with the piezo-luminescent decorating floor tile laid is collected through the piezoelectric plate, and is converted into electric energy to be stored in the storage battery, and the light emitting diodes are lightened. Meanwhile, the light emitting diodes with different colors can be combined freely on a certain piezoluminescent decorating floor tile. The piezo-luminescent decorating floor tile can be produced into the size of a common floor tile, and the light emitting decorating ground is formed. The piezo-luminescent decorating floor tile is easy to produce and manufacture, is assembled modularly, and is convenient to use and low in cost, power is supplied in two modes, energy is saved, the piezo-luminescent decorating floor tile is environmentally friendly, and can be ordered according to the specific needs of a user or laid creatively."

This case might be the patent that have the most common points with our idea. From people motion, they harvest the energy with piezoelectric material and use the energy for a lighting system. The differences with our project is the way that we deform the material. In this study, they use direct deformation, whereas we use a pivot to make vibrate a beam. Also the signal conditioning system differs as the requirements are different.

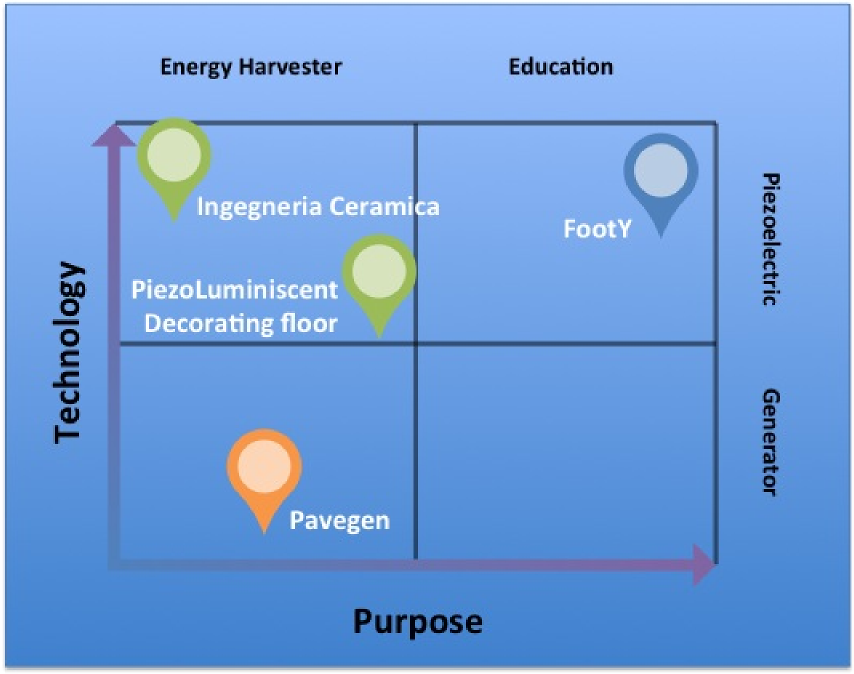


Figure 21: IP Benchmark

9.3 IP ANALYSIS OF OUR PRODUCT

9.3.1 The claim

"FootY is an energy harvesting tile that transforms mechanical translation into electricity using the piezoelectric principle"

"An actuator induces the vibration of the oscillating system consisting of bimorph piezoelectric beams"

"The energy harvested can be directly consumed or stored in each tile"

"A foam is used as a damping system to reduce the impact and improve the feeling when using it"

"Each tile is independent and fully autonomous and thus modular structure can be realized"

9.3.2 Abstract

The present application describes a device that harvests energy produced by people when walking, running or jumping over it. The conversion of the energy will be through piezoelectric material, using a vibrating system. The electricity produced will be stocked in batteries or be directly use for a show-off system (with LED's for example). The product is user-friendly and shows how much amount of energy has been stocked. In order to achieve a smooth lowering, a layer of foam is used so that the user doesn't feel any shock.

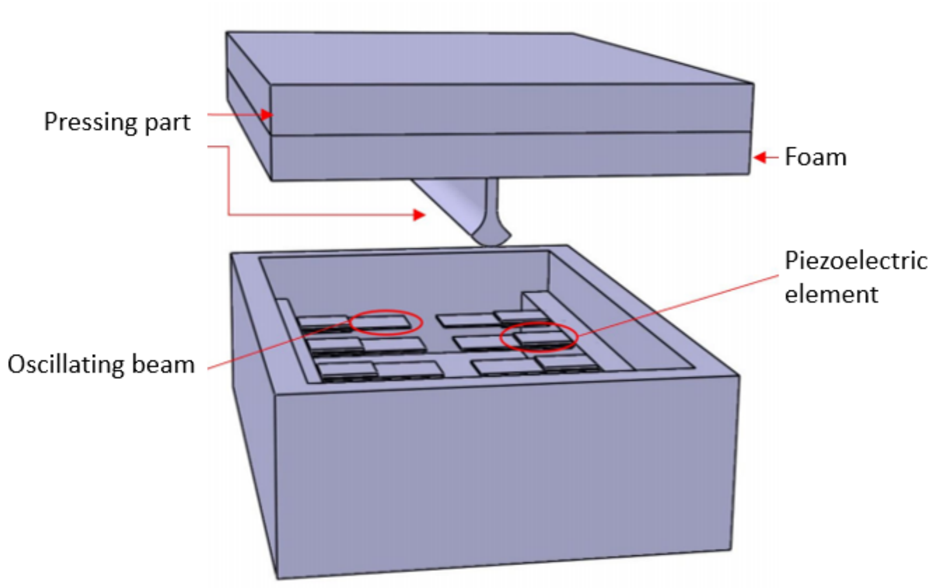


Figure 22: CAD tile

Our project has two main innovative part : the vibrating system of the piezo, that allows more power production efficiency, and the whole product, as presented before.

9.3.3 Strategy

Our business plan can be divided into three main phases :
1. Education and sensitization of population in Switzerland
2. Expand our market to Europe
3. Enter in the marker or renewable energy with new approaches

In terms of IP Phase 1 will require a patent for the Swiss market. Once we get established in this market and a year before entering phase 2 we should start procedures for a patent expansion to other countries in Europe for example France, Germany, Spain... For the phase 3 our aim will be to diversify the possible applications by developing new products and the possible patents for them. We have to keep in mind (especially between Phase 1 and 2) that as soon as our company starts making money, competition will be interested in our product and steal our concept. To prevent it, we will directly patent our outline, in order to work on it and improve it quietly later. Make a patent could have different reasons.

In our case, the competition doesn't exist yet, thus the left part of the graph in 9.2.4 can be forgotten. As discussed before, we have two ideas on which we can make a patent : the vibrating system and the whole device. The strategy for the whole project is defensive, because we want to be able to sell our product without paying for it. For the vibrating system, we patent it for having the exclusivity for our product.

9.3.4 Conclusion

As it has been checked and after some investigation, we find that none of the patents uses or has exactly the same characteristics as ours. And none of them mixes the idea of generating energy with piezoelectrics and with tiles.For our product there are many different possible applications, in our case with Footy we want to get focused on Education and sensitization. Knowing that, we can use it as a selling point and use our personal characteristics as our piezoelectric generation system to be different than our competitors.

Part IV

Pre-Business plan

10 Market

As previously stated, the target market mainly the educational market and particularly in Switzerland as it is yet to be reached by companies working on such tiles.

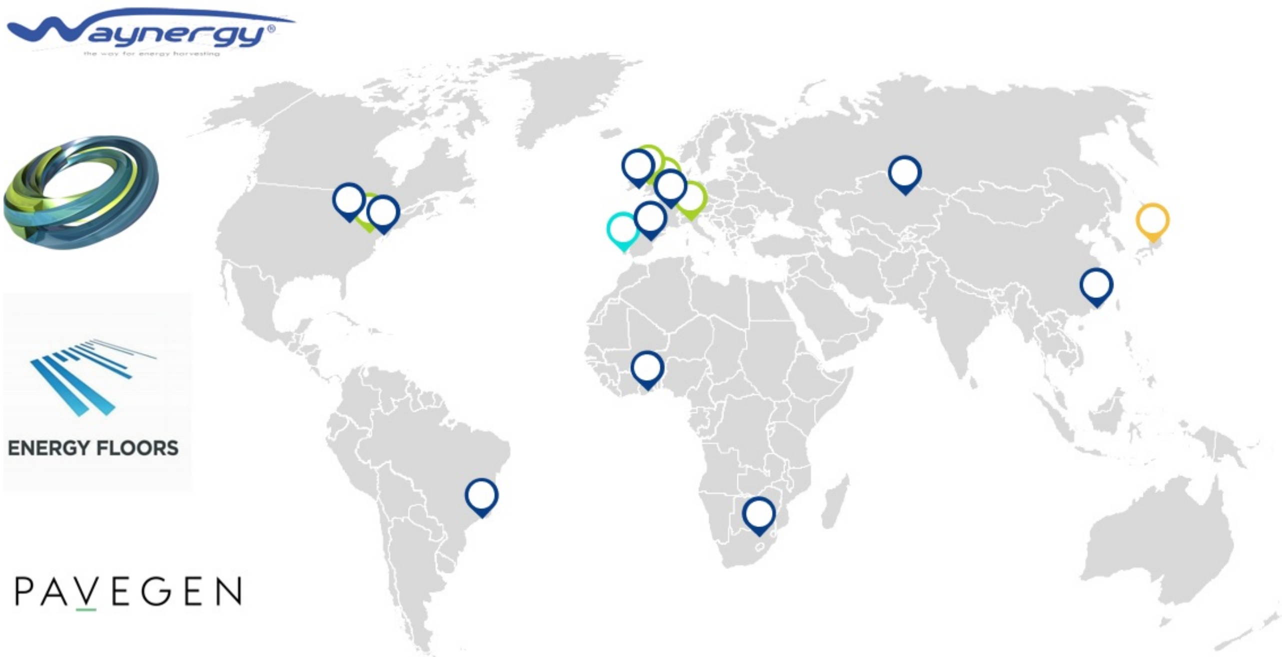


Figure 23: Potential competitors: Waynergy (light blue) in portugal, Soundpower (yellow) in Japan, Energy Floors (green) based in the Netherlands but also present in the UK, France, Italy and the US and Pavegen based in the UK and the most present on the world market of the energy harvesting tiles

It is important to note that these companies work on a different market and also use different technologies than ours.
We also plan on expanding on the governmental and public institutions (train stations, airports etc...), but our first target will be the educational public and private institutions, mainly in Switzerland, where we are based.
A part of our marketing strategy would rely on the exposure of our product (see later sections). That's why we plan on putting our first test period on the EPFL campus, EPFL being renowned for the innovation projects as well as promoting ecological researches.
A successful testing period could mean the expansion on other campuses and schools throughout Switzerland and maybe Europe. This will promote our product as well as credit EPFL.

11 Strategy towards commercialization

12 Your organization

For the first year of organization, we would rely mainly on a heavy cooperation with EPFL laboratories in order to improve the product. A serious IP procedure would be taken in order to protect our idea while pushing the research work further, spreading the idea in the educational institutions and negotiate contracts with public Swiss institutions in canton de Vaud for a first testing period on our prototypes, advertising for our product and for a future first installation when the product is finished.
In a 2 years milestone the final version of the product shall be finished, the product will enter the market. We would also aim for further exposure in the Swiss market and participate in international events.On the managerial side we would have gathered an executive team and create different departments for marketing, research, executive work and financial work.
Original team members would move to foreign countries for the expansion of the company if the project is successful in the Swiss market after 5 years and a HR (Human Resources) department would be opened by then.

13 Financing of your project

Being a green and educational project, FootY can receive funds in different ways. One of those possibilities would be **contracts** with different public authorities in Switzerland, like "le canton de Vaud" for example. Signing some contracts could be already a part of our financing. Another possibility are people called *"Angels"*. There are affluent people, generous, who are ready to support ecological/social project. The last possibility to get money is from start-up contests and from the European commission.
In order to have an idea of the future perspective and the financing needs for Footy we present the 10-years projections for the company as well as the main assumptions.

Projections (CHF)

Year	0	1	2	3	4	5	6	7	8	9	10	Terminal
EBIT growth: Revenues growth		10%	13%	17%	16%	14%	11%	8%	6%	3%	3%	#
Revenues		32400	35640	40344	47122	54473	62100	68829	74352	78489	78489	#
Margin		30%	31%	32%	33%	34%	35%	36%	37%	38%	40%	#
EBIT		9720	11048	12910	15550	18521	21735	24778	27510	29826	31395	#
EBIT(1-T)		7776	8839	10328	12440	14817	17388	19823	22008	23861	25116	#
Amortization		2268	2459	2743	3157	3595	4036	4405	4684	4866	4709	#
Investment	30000											#
Inc Working Capital		8100	8910	10086	11781	13618	15525	17207	18588	19622	19622	#
ROA(return on assets)		20%	22%	24%	26%	28%	26%	24%	21%	19%	15%	#
IR (investment rate)		50%	60%	70%	60%	50%	42%	34%	26%	18%	20%	#
FCF	-30000	1944	2388	2985	3817	4794	5899	7021	8104	9105	10204	#
Terminal Value												68023
PV	-30000	1647	1715	1817	1969	2095	2185	2204	2156	2053	1950	12997
VAN	**2788**	> 0										

VAN (CHF)		
	Investment	30000
	Ru	18%

Figure 24: Projections

As shown in the excel sheet the VAN(18%) is positive for an investment of 30000 CHF and the following assumptions.

Sales 1st year	CHF
Tiles per client	60
CHF/Tile	180
Total/client	**10800**
Nº Of clients/year	3

Production 1 st year	CHF
Nº of pieces to be produced	300
Cost/Tile	80
Minimum initial investment	**24000**

Assumptions	CHF
Initial ROA	20%
Final ROA	15%
Initial IR	50%
Final IR	20%
Initial revenues	32400
Initial Margin	30%
Final Margin	40%
Taxes	20%
Depreciation	10%
Working capital	25%

Figure 25: Assumptions

14 Planning

We have to start producing the FootY tiles in large quantities as soon as possible in order to decrease the price per unit, since it's a modular product. However, before launching mass production it is important to collect as much feedback from users as possible. During the first year we will conduct our researches for product improvements in parallel with prototype testings and feedback in public places. This will help us to get in touch with the public and improve our final design.
We shall focus on one product version and study the future improvements (such as a possible implantation in crosswalks) in the future. This would allow us to enter a continuous flow of production and help to reduce the cost.
We will take care of the production and get the electronic parts and raw materials from other suppliers. Later on we might start producing our own electrical circuits in order to reduce the production cost even more.
Since FootY is not meant for personal use but rather for community use, our company will experience slow growth in the beginning which leads to a high risk of an early failure. That's why we would try to negotiate many contracts and multiply public experimentation of our prototypes in order to get as much exposure and investments as possible during the first year.
It is important during that period to further study the market in order to avoid early competition which would threaten the sustainability of our company.

15 SWOT analysis (Strengths, Weaknesses, Opportunities, Threats)

Figure 26: SWOT graphic

In order to achieve a good SWOT analysis, a detailed list of strengths, weaknesses, opportunities and threats related to our product, has been listed in Fig.26.
Listing the strengths first, we want to draw attention to the innovative aspect of our concept, as it solves a described problem in a non-common, original way. When asking for a product designed to 'harvest energy while walking', the first idea that comes to mind is the use some wearable device that a pedestrian utilizes for individual purposes like for instance charging his phone battery.
However, we have redefined the idea to create something useful for a whole community of people and for profiting in an effective way from any crowded zone, especially in rush hours.
Another strength is its sustainability and its commitment towards the environment. Our product harvests free and clean energy using the pedestrians' movements and steps.
Also, the modular design that we thought of as well as the option to be scalable makes our product a great invention not only for the educational purposes that we had set (main goal), but also for further uses in the future.
The weaknesses of our product reside in the low amount of energy that is possible to harvest due to the efficiency of the piezoelectric elements and the frequency of steps. In addition, it requires a high fixed cost to its implementation. The product is not meant to make a big margin of profits, at least not on the short term.
However, it opens future opportunities in research or further studies. As it is a really innovative and didactic product, it can takes us to lead the educational market.
Finally, the threat to our product is the possibility for it to be seen as a useless product.

Part V
Project Management

16 General strategy

An ideas exchange and personal research was conducted during the brainstorming phase. We tried to get the best out of the creativity of each team member. Once the idea was chosen, the team was split in two groups: one for electrical design and the other for mechanical design for more work efficiency. Of course communication between both teams was required for feedback, for researches and possible new ideas.
We made weekly PVs in the first period with chairman and secretary roles taken each time by different team members.
The PVs were important to decision making and were used as a reference for task distributions, due tasks and important informations to be researched in order to guarantee time efficy and keep the team members updated.

17 WBS - Work breakdown structure

The WBS was done at the very beginning to provide an overview of the whole project. We have redefined it all along the different phases in order to divide tasks more efficiently. Here we present the latest version.

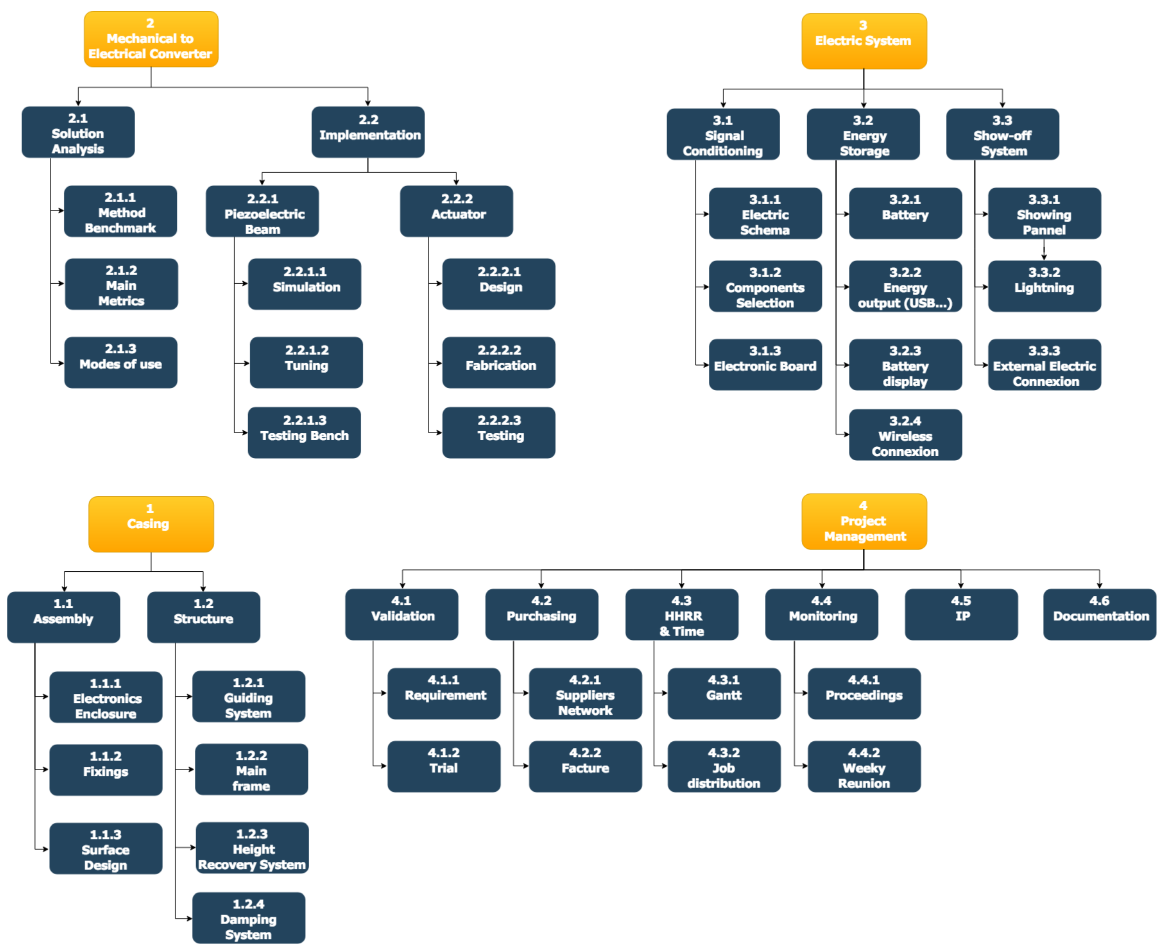


Figure 27: WBS Diagram

18 Stakeholder analysis

External	Universities	Expected level of safety, a product that is fully ready-to-use for educational purposes and open to improvements in the future
	Industries and companies	Expected level of safety, delivered on time, great amount of harvested energy to meet the investment in the product, well designed, durability
	The state and government	Expected level of safety, durability, eco friendly, must be open to integration to power grids, need to satisfy legal constraints
	Cars and traffic	Expected level of safety, weight resistance, should not increase the energy consumption while crossing it
	People walking	Should be used by everyone, people with disabilities included
	Suppliers	Well defined requirements, they sell goods and materials
Internal	Team members	Tasks assignments between the members, role playing (chairman and secretary), research work, have to provide the working prototype, get final grade
	Professors	Clear instructions given to the group members, expected delivery on time of the prototype and final report. Gave advises and feedbacks, explanations and potential implementation for the group and idea
	Teaching assistant	Weekly feedback, advises and explanations for what is asked in the project
	EPFL labs	Components and locals supply and help, expects respect for schedules and organized work with the machines, expects the groups to use the machines correctly and not damage them
	Swiss communes	Expects respect of the government norms, provides investment and necessary equipment for potential implementation of the project
	EPFL	Provides money, supervision and spaces. Expects an innovative concept from the students, provides equipment for potential implementation of the project

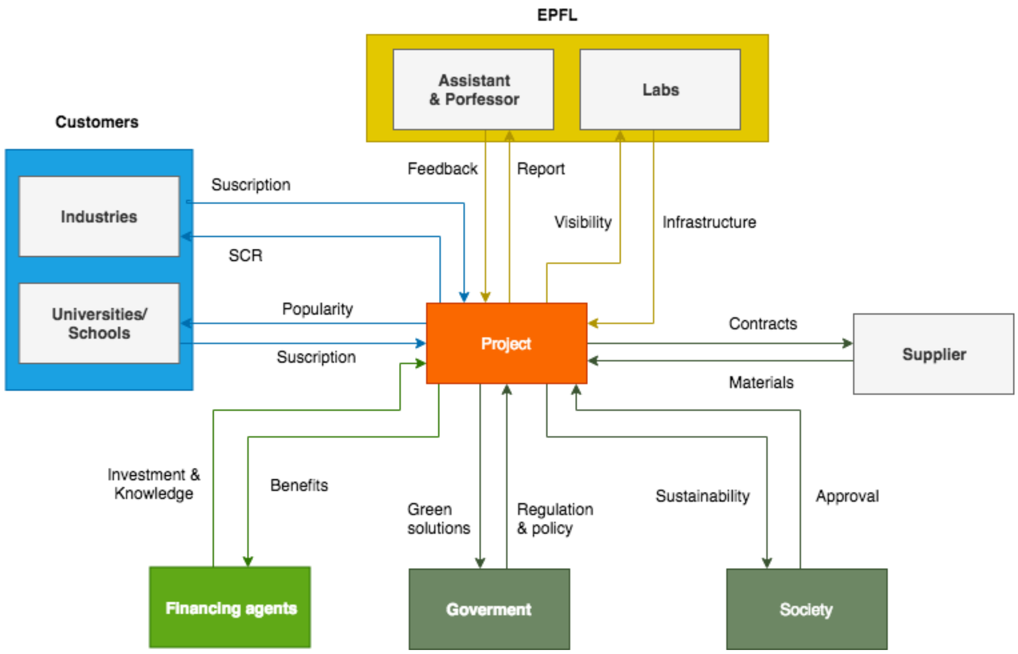


Figure 28: Stakeholders Analysis

19 Gantt chart

We divided the important tasks over the time given to us by following a Gantt that we set. The Gantt chart is presented below:

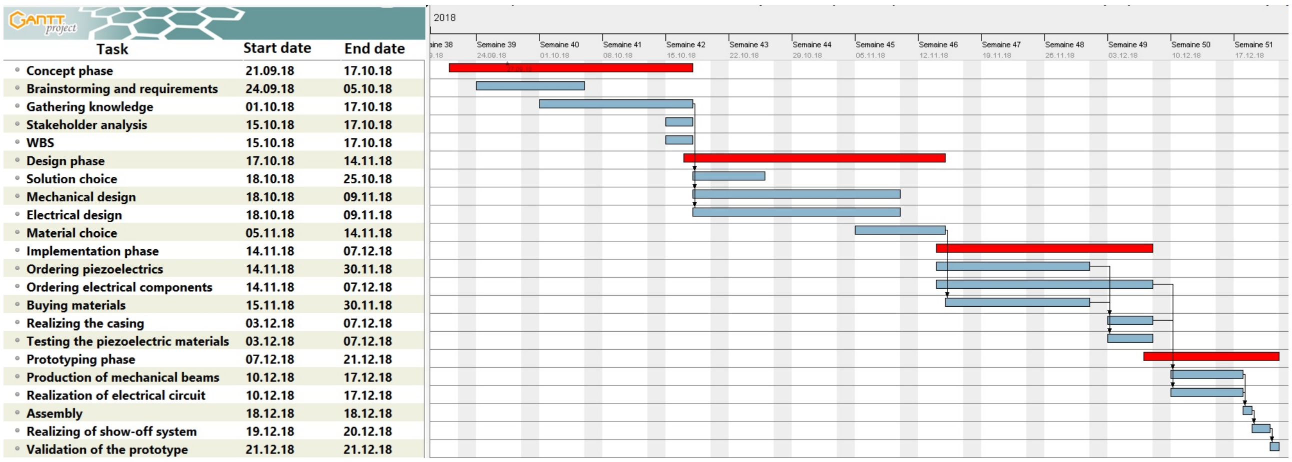


Figure 29: Gantt chart with tasks and due dates. The arrows represent dependencies between tasks. We managed to stick to this chart througout the semester

19.1 Initial Plan

The project started with the "Concept Phase", that lasted until the 17th of October, in which a brainstorming phase was made.
At the end of this phase we settled with the idea of an energy harvesting floor.
After exploring few possible solutions in the (such as: electromagnetic conversion, pneumatic conversion, etc...).
The "Design Phase" started with two main plans in which we worked in parallel, until the midterm presentation: autoquartz movement (Mechanical solution) and piezoelectric materials.
Ideas of possible mechanisms, materials, optional and working solution were considered and analyzed.
The final solution retained by the group was the piezoelectric proposition.
During the "Implementation Phase", the group was split in two, half of the members worked on the realization of the electrical part and the other half on the realization of the mechanism and the outer structure. A series of tests was conducted in order to optimize the mechanism and test the feasibility of the prototype in time.
In the end, the "Prototyping Phase" was the assembly phase and the show-off system realization.

19.2 Deviation from the original Plan

As explained in sections 6 and 7 the mechanism knew radical changes going from changing the use instant impact on the piezoelectric materials to abandoning the idea of relying exclusively on passive electrical components.
The other deviations encountered were related to the number of piezoelectric elements in a single tile. Initially we aimed for 2 rows of bimorphs (beams with on layer of piezoelectric elements on top and at the bottom) which meant an implementation of 12 piezoelectric elements per tile. The mechanical constraints and budget limitations saw us modify our system to host only 3 piezoelectric elements mounted in half bimorphs (one single layer on top of the beam).

19.3 Difficulties encountered

The difficulties encountered during the project can be divided into two main parts: mechanical and electrical. The mechanical difficulties resided in mainly a compromise between the beams' lengths and the frequency of oscillations generated by the vibrations.
As explained in 7.3.1 we solved the problem by tuning the oscillations with tipped masses.
The electrical difficulties represented our main challenges. First the piezoelectric elements produce very low electrical current, and their parallel implantation could be a source of an interference lowering the efficiency of the system even more.
As for the components used, the capacitor is a component that has inevitable leaks that we had to minimize. As for the battery, a continuous current supply was necessary and thus we had to use active components that would consume some of the energy produced. The last point is not very problematic since the consumption of such elements is negligible, but still, it is something that have to be considered when one deals with nano or micropower harvesting solutions.
Although the battery was successfully charged, studies in the energy harvesting domain as well as our experimentation led us to conclude that a direct/short term application (lighting LEDs, corridors, paths) could be more advantageous than long term applications (charging a battery).

Part VI
Conclusions

With a company-like structure of the course (random team members on a subject with a deadline) we had a brief experience of what the industrial world looks like, starting a project from scratch and ending up with a functional prototype.
The project of energy harvesting while walking was very interesting and open to lots of ideas that led us to building a tile able to harvest energy from people's steps.
The most interesting part of this idea is its ability to target huge populations and not single customer and the chosen market for that was the educational and institutional one, because we thought that an additional goal of sensitization concerning renewable energy systems would be important.
From the two main solutions between using Autoquartz movement or piezoelectric material the second one was chosen because it was found more interesting and Autoquartz have a scalability problem.
In the end, the product was realized on time, it satisfies the purpose to be functional, modular, educational with its show-off system, durable and tough. It is able to harvest energy and produce an continous output DC current of 100 mA, enough to charge a battery.
The show-off system as well as the tile itself have ready-to-go implementations and innovations. The tile can be used in multiple scenarios and places by the use of waterproof and stronger materials or recycled materials like PET. By coupling it with PV-pannels in outdoor and crowded scenarios, the harvesting efficiency of the two systems coupled can be increased to the point that a mini-grid can be built. A foot sensitivity, an information collecting, a display system and a changeable texture under feet are possible innovations. More possible scenarios consider the use of FootY-similar system in roads used by heavy trucks or on highways.
The implementation and spread of FootY could have a larger impact in future years also considering the 2050 World CO_2 emissions and renewable energy production goals.
We believe that starting from the sensitization of future generations, even by the use of a simple showing-off demonstrating the harvested energy with led lights, we could make a greener world where humans' steps can light up the future.

Figure 30: On the left the team 8 during the final presentation. On the right the final prototype

Part VII
Annexes

19.4 Branding

Where does FootY come from? The name can be separated in two different parts FOOT and an additional Y. This second part stands for the word YOU, making the user the principal character in this new energy adventure. The other part is related to the products nature, a tile or a generating floor. Like this joining these two ideas we came up with the brand of FootY.

Figure 31: Designing evolution

For creating the logo and the name of our product, a large process of brainstorming and design was done.In the previous figure it can be found as a summary some of the principal ideas that we came up with to create the most accurate logo for our company. A rounded shape with our name inside of it and a vertical sharpen figure on it. This last figure represents the one of the key parts of our product. is the small piece that transmits the impact of the tile to the generating system.

With this logo our product key parts of our product are represented and can create a positive and exceptional good impresion on the clients.

19.5 Promotional Banner

Figure 32: Promotional Banner used for the final presentation

19.6 Details of cost of manufacturing

Wood : Here are the possible site where we can get the wood necessary for the construction of the strcture : https://www.bricoetloisirs.ch/construction-renovation/bois/panneaux-de-bois-decoupe-du-bois/panneaux-de-fibres-de-bois/panneaux-de-fibres-dures/panneau-de-fibres-dures-brut/p/3890986

https://www.bricoetloisirs.ch/construction-renovation/bois/bois-de-construction-bois-profile/chevrons/chevron-rabote-oecoplan-115x75-mm-1-m/p/4130445?template=productpage1_new&box=box1

From the first site, we can get 9 tiles with one plate so $\simeq$ 1.10-/tile. Coupling this with $\simeq$ 14.- for the rest of the structure, we get 15.-/tile.

Piezoelectric : From the site www.piezo.com, we got for an order of minimum 100, a price of 18$/piezo.

Clamping system: It is composed of a plate fixed by two screws. We need 3 of them per tile, so the estimation of the price is 1.- per tile if it is built with wood and the half for 3D printing or PET.

PET: If we want to replace fully the wood by the PET, we would need 12Kg of PET for each tile. We know from structural mechanics that there is the possibility to get a strong structure without the necessity to have a full one. With the hypothesis that only 25% of the total volume is needed, we finally get 3kg/tile. Knowing from the site www.plasticker.de that the price for 1Kg of PET can be maximum 0.87€ ($\simeq$ 1 CHF), we finally fet 3 CHF/tile.

Machine for casting and Mold: Discussed in the course "*Physics of manufacturing*", the price of a mold vary around 30'000$. For the price of the machine, we get the information from this site : https://french.alibaba.com/product-detail/pet-preform-injection-molding-machine-price-in-plastic-injection-machines-1988631141.html

Manufacturing cost: For the construction of each tile, we need to pay someone. If we pay 24 CHF a person that can produce 3 tiles in one hour, we get 8 CHF per tile.

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