Project Name:

Smart Energy Harvesting Tiles

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1. Executive Summary

This project is aimed at the design of Energy Harvesting Floor Tiles, a new and eco-friendly technology for converting footfalls into electrical energy through the use of piezoelectric sensors in the tiles. The primary objective of this project is to harness the kinetic energy caused by human movement, store it in batteries, and use it for low-energy applications like LED lighting, USB charging, and IoT-based real-time monitoring. The technology facilitates smart city projects through energy efficiency and sustainability, thus also being a credible choice for shopping malls, railway stations, airports, and sports stadium public infrastructure.

One of the fundamental characteristics of this system is the addition of a plucking mechanism, which dramatically increases piezoelectric energy harvesting efficiency. In contrast to other pressure-based piezoelectric systems where only direct compression is used, the plucking mechanism uses a spring-loaded actuator or a flexible cantilever beam that drives the piezoelectric material by plucking or vibration as a reaction to foot impact. This creates numerous oscillations rather than one compression event, hence a greater energy output per step. Through optimization of mechanical deformation, the plucking mechanism provides high efficiency of conversion of mechanical to electrical energy, thereby optimizing the system's effectiveness in practical applications.

This project was initially conceived within the context of ECTE250, where teams of students designed innovative technological solutions. Team 8 received the project upon the completion of Deliverable 1, and was responsible for conducting additional research, refining, and deploying the Energy Harvesting Tiles.

This report is an overall project review, from mechanical and electrical design to IoT integration and energy monitoring. It employs Tinkercad testing to simulate rectifier circuits and energy storage and then prototypes it for validation. Budget breakdown and marketing strategy are also included in the report, which further indicates the system's viability for practical application.

2. Introduction

The Energy Harvesting Floor Tiles project is an innovative way of capturing and converting the kinetic energy generated by walking footfall into electrical energy. The system captures mechanical stress as a source of electricity using piezoelectric sensors in the flooring tiles, which is stored in batteries for use in low-energy applications like LED lighting, USB charging ports, and IoT-enabled monitoring systems. This solution aligns with international sustainability efforts and smart city efforts, providing a renewable energy supply for high-density locations such as shopping centers, train stations, airports, and sports stadiums.

Apart from this, the project further incorporates the 3R's – Reduce, Reuse, and Recycle principle. Through the utilization of renewable sources for construction in the form of tiles, the product reduces dependency on traditional sources of energy, recycles kinetic energy produced due to the footfall otherwise lost, and reuses electric power to power low-power applications, thus minimizing the overall environmental impact.

2.1 Project Theme

The project deals with sustainability and alternative energy by harnessing piezoelectric materials for the generation of energy from typical human motions. The system translates mechanical energy from walking into electric energy, providing a sustainable and clean source of energy, with reduced dependency on the traditional power grid and the environment, respectively.

Furthermore, with the incorporation of the 3R principles, the project encourages the utilization of recyclable material in the manufacture of tiles, reducing electronic waste and encouraging long-term sustainability. The tiles are made to show durability and reusability, with low maintenance requirements and optimum energy efficiency.

2.2 Functional Outline

The Energy Harvesting Floor Tiles system requires various components:

- **Piezoelectric Sensors:** Installed in the tiles, the sensors produce electric charges when they are subjected to mechanical stress due to foot movement.
- **Energy Storage Devices:** The electricity generated is accumulated in batteries, which facilitates effective energy management and offers a consistent power supply to the connected devices.
- **Power Management System:** The system controls the storage of energy, delivering a stable output that is ideal for low-power applications like LED lighting and USB charging points.
- **IoT-Based Monitoring:** An integrated IoT module enables real-time monitoring of energy generation and consumption, allowing for data-driven insights and optimization of the system's performance.

2.3 Unique Advantages and Impact

The incorporation of a plucking mechanism is what distinguishes this system from conventional piezoelectric energy harvesters. This mechanism entails a dynamic interaction whereby a plectrum comes into contact with piezoelectric beams periodically, thereby inducing vibrations to enhance energy output. In research studies, it has been shown that plucking mechanisms can enhance efficiency through the provision of several oscillations for each footstep, as compared to the single compressions in conventional designs.

2.4 Project Framework and Objectives

Objective: To design and implement a floor tile system that has the capability to harvest and store electrical energy from footsteps, with a plucking mechanism for high energy conversion efficiency and the use of 3 R's

Scope: The design, prototyping, and testing of the Energy Harvesting Floor Tiles, along with the integration of energy storage solutions and IoT-based monitoring systems with respect to the 3 Big R's

Stakeholders: The major stakeholders are the urban planners, green organizations, commercial real estate developers, and the public, all of whom stand to gain from the sustainable energy solutions offered by this technology.

Timeline: The project schedule is organized over a period of six months and separated into distinct phases, which include research, design, prototyping, testing, deployment, and innovation fair. The development of incremental deliverables enables progress to be monitored well over the course of the project.

Budget: An estimated budget has been allocated for materials, prototyping, testing equipment, and personnel, to complete the project successfully. The allocated budget that we received was AED900 Approximately with AED 250 for the Arduino kits and the other AED 650 for our project components.

Success Criteria: The success of the Energy Harvesting Floor Tiles project hinges on effective energy conversion, durability from foot traffic, and the use of recyclable materials for sustainability. Pilot deployments' end-users and stakeholders' favourable response will also validate its success. The project aims to foster clean energy solutions and support the development of smart, green urban infrastructure.

3. Design

3.1 Flowchart

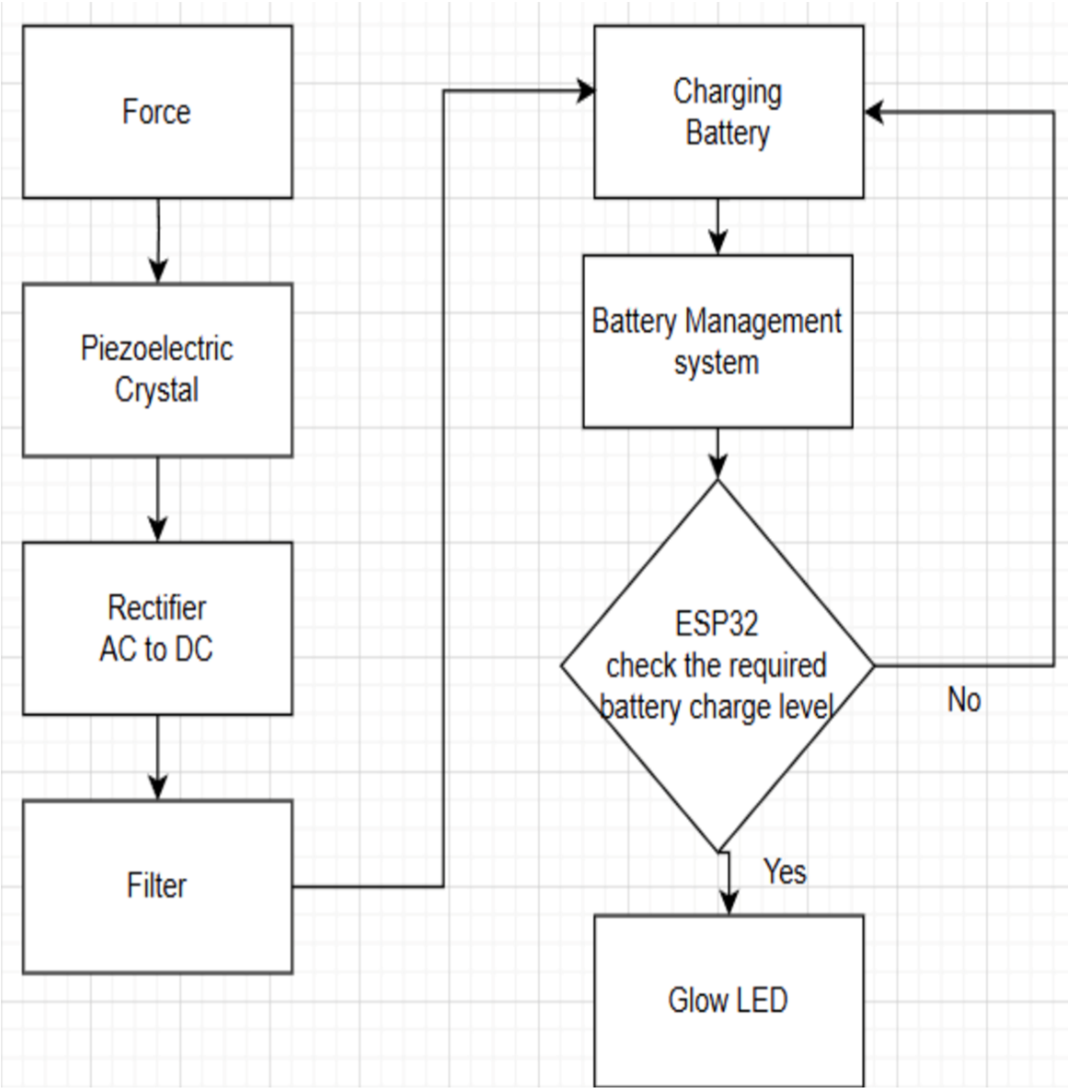


Fig. 1: Flowchart for SEHT outlining the functionality

3.2 Block Diagram

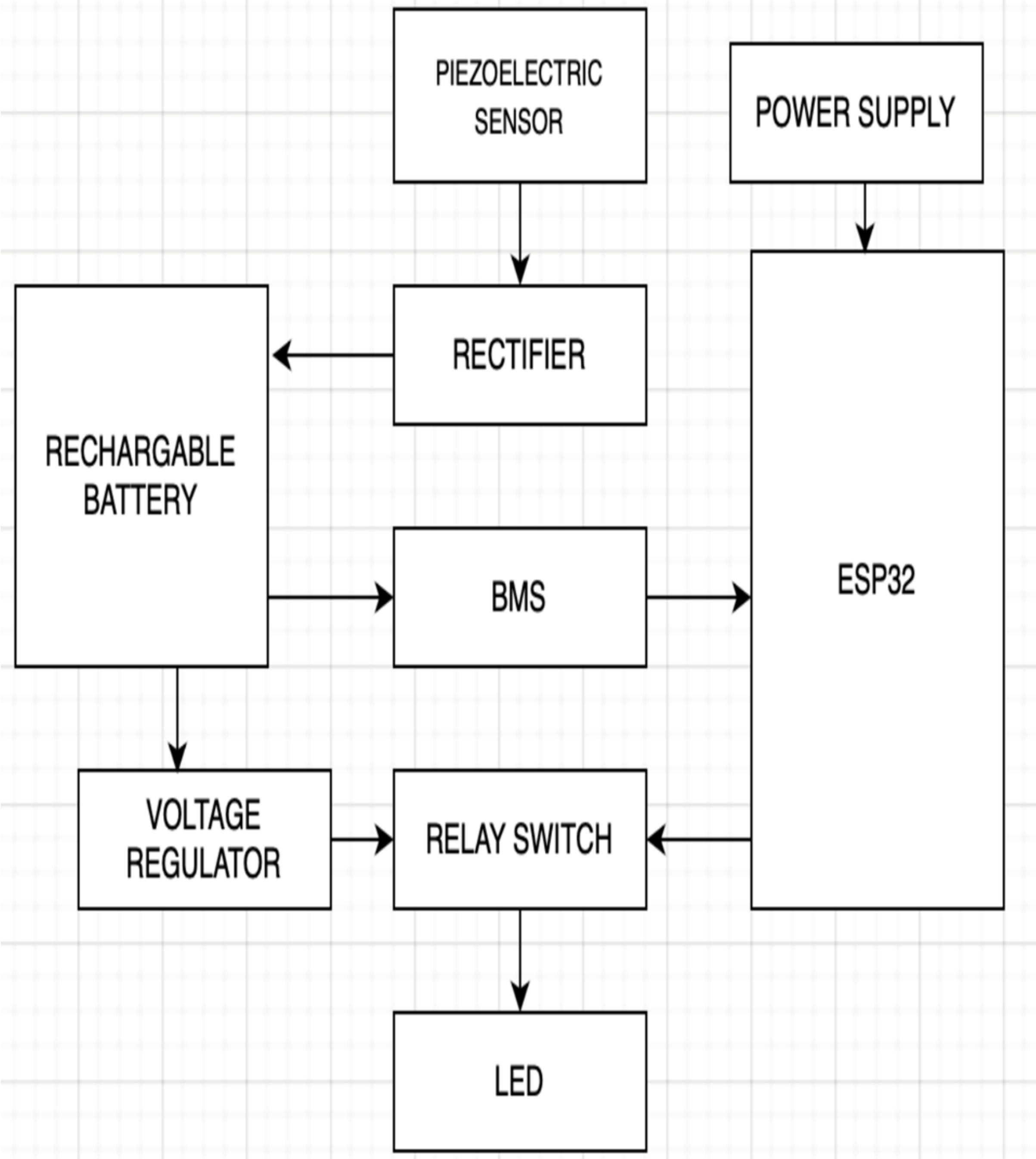


Fig. 2: Block diagram showing components

3.3 Tinkercad Design

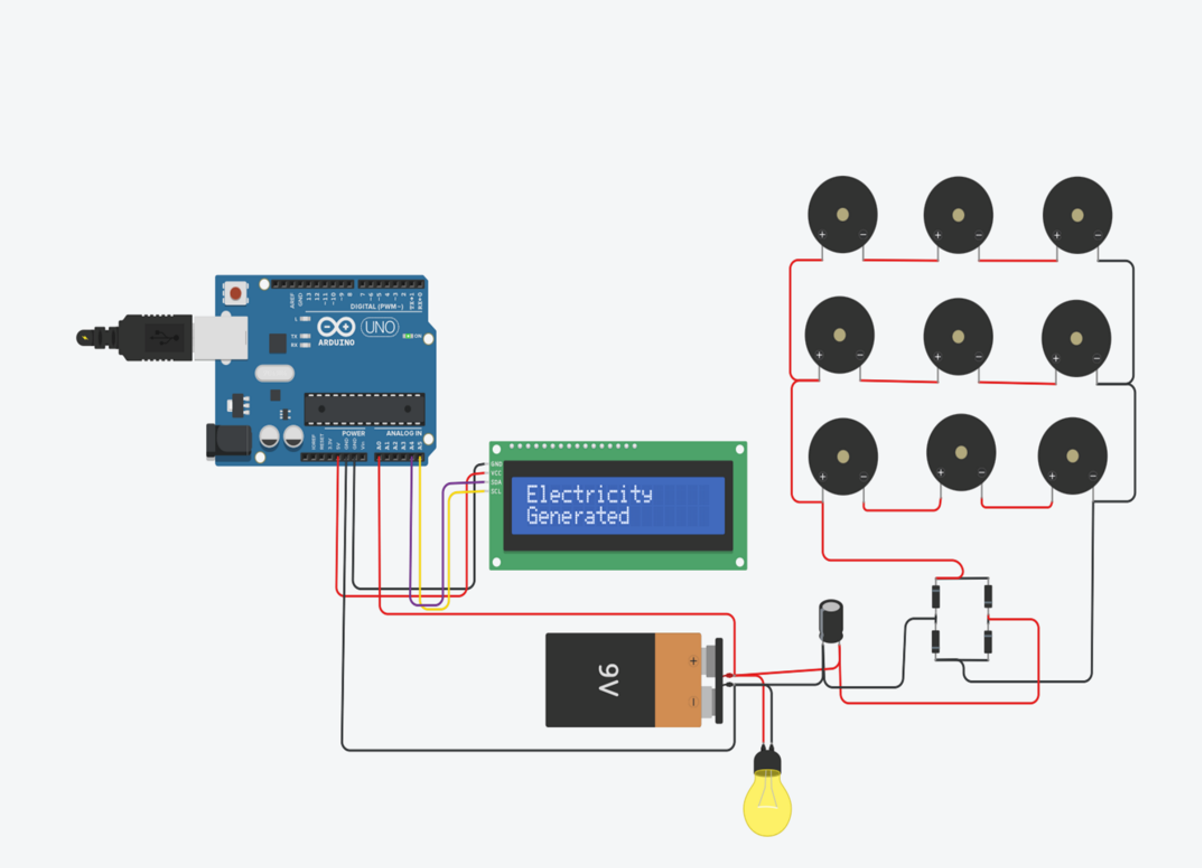


Fig. 3: Tinkercad circuit Design showing simulation

Description

In our Tinkercad model, we arranged nine piezoelectric sensors in a 3×3 configuration three parallel and three series to increase voltage and current. The produced voltage is sent to a full-wave bridge rectifier that changes AC to DC. The DC voltage is then filtered by a capacitor for stability. Rechargeable batteries hold controlled voltage, which is overseen by a Battery Management System (BMS) that is combined with an ESP32 microcontroller to allow real-time monitoring and energy distribution. The energy is mainly used to power streetlights that function according to set conditions in the ESP32 program. The lights only come on at night and upon walking on the tiles, thus saving energy. The system only consumes 5% of the energy stored in lighting, which makes it more efficient and sustainable.

4. Alignment

The Energy Harvesting Floor Tiles project aligns with contemporary trends in IoT-based energy management and sustainability. The proposed design meets the objectives of the project requirements, particularly the smart city and renewable energy solutions domain. Our system utilizes piezoelectric transducers for converting mechanical energy into electrical energy, which is stored and tracked in real-time using IoT technology. The tiles can be placed in high-traffic areas such as malls, airports, and footpaths, where frequent movement can generate a huge amount of renewable energy

The project adheres to the fundamental principles of energy efficiency, economic viability, and environmental conservation. The incorporation of an IoT-enabled monitoring system enables round-the-clock logging of data, thereby providing optimum performance and timely identification of faults in the system. A benefit of the project is that it is scalable; an array of such tiles can be deployed at various locations, thereby making a significant contribution to urban energy conservation initiatives.

4.1 Constraints

The project is subject to several constraints that must be resolved in design and implementation. The first challenge is optimizing the energy conversion efficiency of piezoelectric transducers. While the materials do have the ability to convert pressure into electricity, the output voltage is low, and an efficient energy storage and regulation system is required. Piezoelectric materials also pose limitations regarding durability and mechanical stress tolerance, which must be resolved to realize long-term reliability.

Cost is another consideration. Microcontrollers like the ESP32 that are capable of IoT and piezoelectric materials add upfront cost and may lengthen the breakeven point. Good design of the system and affordable sourcing of materials will be important in reducing this. Furthermore, wireless transmission of data is required to incorporate IoT elements, which can add latency and connectivity issues where there is no good network coverage. Iterative prototyping to improve design and rigorous component selection will be required to mitigate these drawbacks.

4.2 Design Improvements

For greater operational efficiency and capacity of the Energy Harvesting Floor Tiles, various design improvements have been integrated. While an initial single-layer piezoelectric design was suggested, continued research and testing added the application of a multi-layered stacking approach aimed at amplifying energy output. The process provides for greater mechanical stress distribution and electrical efficiency without incurring substantial material costs.

Another improvement includes the integration of a sophisticated battery management system (BMS) that works to manage the build-up and distribution of generated energy. This system reduces the possibility of overcharging and improves the overall lifespan of energy storage components. Further, the Internet of Things (IoT) infrastructure has been improved to include an energy-saving transmission protocol that reduces data loss while allowing real-time monitoring with low energy consumption.

The system consists of piezoelectric transducers, an ESP32 microcontroller, a battery management system, voltage sensors, capacitors, and a mechanical structure composed of durable composite layers to withstand prolonged foot traffic. These improvements address key concerns such as durability, affordability, and system reliability, thus ensuring that the final design aligns with both technical requirements and sustainability goals.

5. Testing

5.1 Piezoelectric Sensor Testing

- To test the performance of the piezoelectric sensors, we will record the voltage and current produced at different pressures and step frequencies. The tests allow for the assessment of the performance and reliability of energy generation.
- Piezoelectric materials undergo mechanical stress under repeated force, which can cause degradation over time. This test ascertains the stability of voltage and current output after extended use, thereby estimating the lifespan and durability of the sensor.
- The response time of a piezoelectric sensor is the duration it takes to produce an electric output when force is applied. Fast response time is essential in applications that demand instant generation or real-time sensing capability.

5.2 Battery Management System (BMS) Testing

- Efficiency in charging determines how effectively the piezoelectric energy harvesting system converts mechanical energy into electrical energy stored in the battery. Such an analysis helps in determining energy losses and optimizing the system to ensure maximum power retention.

- Load distribution testing evaluates how efficiently the Battery Management System (BMS) allocates power to connected devices. A well-balanced system ensures stable voltage and current delivery, preventing power fluctuations, overloads, or underperformance of devices.

- The Battery Management System (BMS) plays a key role in avoiding overcharging and deep discharge of the battery, conditions that may result in battery life loss, heat production, or system failure risk. This analysis ensures that the BMS operates to regulate the charging and discharging processes to ensure safe operating conditions.

5.3 Integration and Sytem Testing

- Energy transfer efficiency measures how much energy generated by the piezoelectric sensors is successfully transferred to and stored by the battery, including rectifier, BMS, and wiring connection losses. Having knowledge of these losses is crucial for optimally performing a system and reducing inefficiency.

- Successful operation of interconnected piezoelectric tiles as a collective system is paramount to the maximization of power output and uniform energy distribution. This analysis investigates the degree to which the tiles operate in harmony in energy production and transmission processes, reducing losses and upholding stability.

- Backup power sources and fail-safe mechanisms keep the piezoelectric energy harvester functional across a sequence of circumstances, such as power surges, system failure, or unplanned disconnections. This test examines the system's capacity to preserve operational integrity, safeguard attached devices, and avert power losses at critical points.

5.4 Durability Testing

- Fatigue testing is used to test the life and durability of springs in the piezoelectric system by subjecting them to a series of successive cycles of relaxation and compression. Fatigue testing is imperative in ascertaining if the springs will have the ability to sustain their mechanical properties over prolonged operation, hence delivering a steady force and energy transfer to piezoelectric sensors.

- It is crucial to select the right materials for the piezoelectric energy harvesting system to maintain longevity, efficiency, and durability. Since the system would constantly be subjected to mechanical stress and environmental factors, the materials must be corrosion-resistant, wear-resistant, and structurally stable over long periods of time.

- Spring rate consistency is required to keep the force required to compress the spring constant with time. This helps in maintaining a constant energy transfer to the piezoelectric sensor for efficient power generation and system reliability. Material fatigue, deformation, and environmental factors can make the spring behavior vary with time, thereby decreasing performance.

- Wear and tear testing checks for the surface degradation of the piezoelectric system components, including sensor casings, springs, and mechanical contact points, due to repetitive stepping and pressure application. The test ascertains material endurance, structural strength, and long-term operation.

- It is crucial that the piezoelectric energy harvesting tile will operate in outdoor or wet environments for long-term durability and reliability. The test evaluates the system's degree of protection against water ingress, dust accumulation, and exposure to the environment in order to prevent electrical breakdown, corrosion, or mechanical deterioration.

6. Project Planning

This project's entire design timeline involves eight deliverables to be finished in two semesters.

6.1 Project Deliverables

Deliverable 1 - Project Proposal Presentation (Winter Week 3)
The team presented two project proposals, outlining their objectives, feasibility, expected outcomes, and implementation challenges. Judges reviewed both proposals and selected Energy Harvesting Floor Tiles as the final project.

Deliverable 2 - Detailed Design Report (Winter Week 7)
This phase involves refining the system architecture, selecting appropriate components, and conducting an initial feasibility study. The report includes key elements such as problem statement, system overview, design specifications, materials selection, circuit schematics, mechanical structure, IoT framework, and power storage mechanisms. Additionally, it covers risk assessments, cost analysis, and projected implementation feasibility.

Deliverable 3 - Design Simulation (Winter Week 10)
Virtual simulations are conducted to validate the theoretical design. This includes analyzing energy conversion efficiency, mechanical stress tolerance, and IoT communication feasibility before moving to physical prototyping.

Deliverable 4 - Breadboard Prototype (Spring Week 6)
A working prototype is assembled on a breadboard to test the piezoelectric transducers, rectifiers, voltage regulation, and energy storage systems. This phase validates that the components function as expected and provides insights into potential improvements.

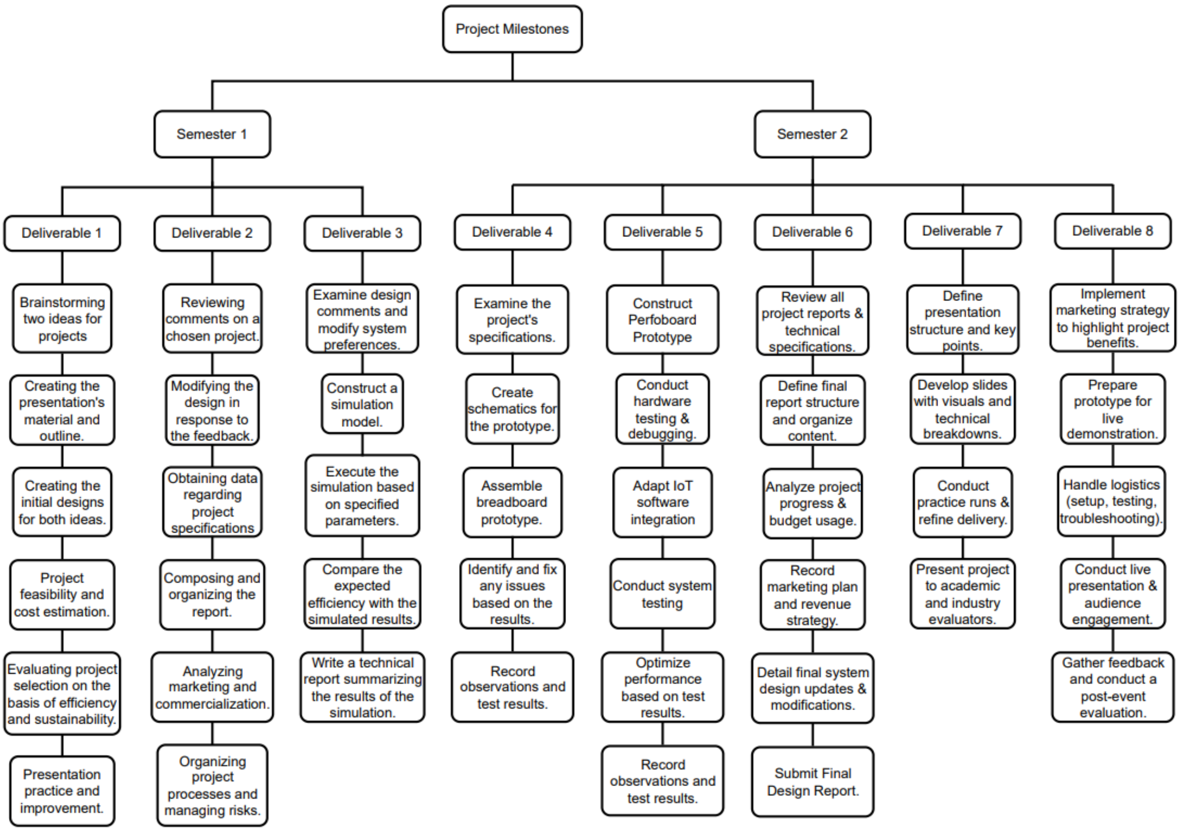
Deliverable 5 - Perfo Board Prototype (Spring Week 8)
A more durable and optimized prototype is developed on a Perfo board, improving circuit layout, mechanical integrity, and overall system stability. The prototype undergoes extended testing under simulated real-world conditions.

Deliverable 6 - Final Design Report (Spring Week 10)
This document consolidates all findings, covering system performance, energy output data, durability testing, and efficiency improvements. The report also provides recommendations for future enhancements and scalability.

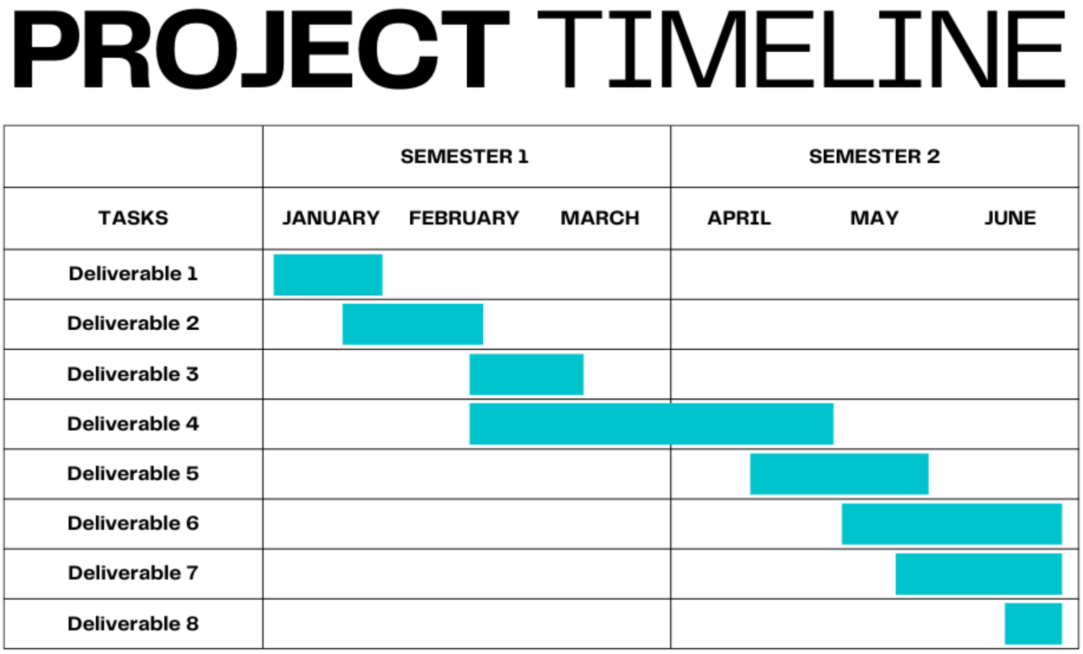
Deliverable 7 - Final Project Presentation (Spring Week 10)
For the final presentation, The team prepares and delivers a professional presentation to academic and industry evaluators, highlighting the project’s objectives, methodology, results, and real-world applications.

Deliverable 8 - Innovation Fair
The final working prototype is showcased at the Innovation Fair. The live demonstration features real-time energy harvesting, IoT monitoring, and insights into the project's potential applications in smart cities and sustainable infrastructure.

6.2: Work Breakdown Structure (WBS)



6.3: Gantt Chart



6.4: Managing Risks

Risk management is critical to the success of the Energy Harvesting Floor Tiles project. Component failure is a significant risk because faulty piezoelectric transducers or IoT sensors would impact performance. To mitigate this, we have backup components and will conduct regular testing. There can be IoT integration issues, e.g., data transmission delays and power instability. Pre-testing and fail-safes like on-site data storage will ensure seamless performance. Network connectivity is also a problem; the system will cache offline and send when connected. Budgets are managed through prudent cost planning and an emergency fund if required. Foot traffic durability problems will also be addressed with stress testing and reinforced materials. With these steps, we aim to provide a resilient, low-cost, and scalable system with minimal downtime.

7. Budget

The total allocated budget for the project is 900 AED. However, due to certain components and instruments being provided by the university and the decision to use an ESP32 led to substantial reductions in expenses due to its versatility compared to the alternatives hence making it sustainable in cost cutting. The total expenditure on parts came to just around 441 AED with a remaining budget of 459 AED.

The utilization of the ESP32 has played a crucial role in the project's implementation. It is a powerful and versatile platform that serves as the main controller allowing the team to deliver high-quality products while leaving plenty of room for upgrades. The leftover money allows us to find opportunities to create additional features and refine products so it meet expectations.

7.1 Prototyping Parts

Component	Quantity	Cost (AED)
ESP-WROOM-32 with Terminal GPIO Expansion Board	1	47
Lithium Battery BMS	1	27
Voltage Sensor	1	10
Relay Switch	2	23
Voltage Regulator	1	10
Voltage Booster	1	20
Bridge Rectifier	10	42
1n4007 Diode	10	17
Capacitor 1000uF	5	10
Piezoelectric Transducers	10	25
1800mAh Rechargeable Battery	1	74
Wire kit	1	15
LED Diode	10	8
Acrylic Sheet 3mm	1	18
Polycarbonate Printer Filament	1	54
Spring Stainless Steel	10	16
Stainless Steel sheet	1	25
	TOTAL COST (AED)	441

7.2 Labor Cost

Our labour costs differ for each deliverable depending on the task.

Item	Hours / Team Member	Total Cost (AED)
Deliverable 1	7	40 x7 x6 = 1680
Deliverable 2	10	65 x10 x 6= 3900
Deliverable 3	5	50 x 5 x 6=1500
Deliverable 4	6	70 x 6 x 6=2520
Deliverable 5	19	50 x 19 x 6=5700
Deliverable 6	30	55 x 30 x 6=9900
Deliverable 7	3	60 x 3 x 6=1080
Deliverable 8	4	4 x 6 x 45=1080
Consultation	10	4500
	Total (AED)	**31860**

These labor and consultation costs have been carefully calculated to ensure that the project benefits from the necessary expertise while maintaining a reasonable budget. By utilizing a combination of team members' skills and expert consultations, the aim is to optimize project outcomes while managing costs effectively.

7.3: Sales Cash Flow

The Sales Cash Flow Forecast shows how much money is expected to be made and spent over the next five years. By knowing what is predicted to be earned and spent, the team can make smart choices about how to use the resources effectively to make more profit.

The product is planned to be sold for 60 AED each, however it costs 441 AED to make each one with 20kWh of energy generated per day (1kWh per tile).

As the components to manufacture the tiles will be bought in bulk, a huge reduction in price of components can be expected as buying in bulk leads to substantial savings. After surfing and looking through multiple sites we have calculated the price of a single unit tile to be 60 AED.

Total Production Cost:

20 tiles × 60 AED/tile = 1,200 AED

Selling Price with Profit:

Profit per tile = 25% of 60 AED = 15 AED

Selling price per tile = 60 AED + 15 AED = 75 AED

Total selling price = 20 tiles × 75 AED/tile = 1,500 AED

Daily Revenue from Energy Generation:

Electricity cost in UAE: 0.293 AED per kWh ***(United Arab Emirates Electricity Prices, June 2024 | GlobalPetrolPrices.com, n.d.)***

Daily savings = 20 kWh × 0.293 AED/kWh = 5.86 AED

Monthly Revenue:

5.86 AED/day × 30 days = 175.8 AED

Break-even period = 1,500 AED / 175.8 AED/month ≈ 8.5 months

Cash flow Projection:

Month	Cumulative Revenue(AED)	Cumulative Profit(AED)
1	175.8	-1324.2
2	351.6	-1148.4
3	527.4	-972.6
4	703.2	-796.8
5	879.0	-621.0
6	1054.8	-445.2
7	1230.6	-269.4
8	1406.4	-93.6
9	1582.2	82.2
10	1758.0	258.0
11	1933.8	433.8
12	2109.6	609.6

The assumption of ideal conditions of energy generation was crucial in creating this projection. Actual performance may vary due to environmental factors.

According to the data, we can assume a consistent profit over a 5 year period after getting through the break even point which comes around 8.5 months.However, several factors can affect the sales flow such as market demand, competition, economic conditions, etc.

8. Marketing

8.1: Overview

The global shift to sustainable and ecological energy is causing a growth in the market of energy harvesting tiles. According to an article, the market for energy harvesting tiles was valued at USD 146.47 million in 2024 and expected to increase to USD 216.84 million by 2030, increasing at a compound annual growth rate (CAGR) of 6.5% (360iResearch, 2025).

The increase in global warming and overall reduction in fossil fuels, such a method of generating energy with minimum effort, other than installation, provide a sustainable yet useful alternative to generate energy. Upon installation in highly populated and commercial places it provides a simple and cost-effective way to generate energy.

8.2: Marketing Strategy

Since the target area for these tiles are commercial and densely populated areas, the marketing will be focused for them. As the key selling point is to feature an innovative and sustainable way to generate energy, smart cities will be included. The marketing will be focused on how such a simple and cost-effective gadget / tool can be used to generate energy and not require extra human effort other than the energy exerted by people walking on them. The lights to signify the working of the tile while also lighting up the area during later times of the day may also be a relevant factor. One last factor that will be mentioned is the durability of the materials used.

Following the physical demonstrations, multiple digital marketing strategies will be implemented. Social media will play a key role in providing the public and companies with advertisements for the product. The creation of blog posts, articles, research papers and other digital tools will help in increasing the reach of the product and reaching our target audience.

The sales cash flow for the next 5 years is outlined as follows:

Year	No. of Items Sold	Total Investment (AED)	Total Revenue (AED)	Profit (%)	ROI (%)
1	80	19,660	24,000	18	22.08
2	50	12,288	15,000	18	22.08
3	80	19,660	24,000	18	22.08
4	85	20,894	25,500	18	22.05
5	90	22,181	27,000	18	21.72

According to the data, there is a consistent profitability over the 5-year period, with a stable profit margin of approximately 18% for each year. Even though there is a fluctuation in the number of items sold, the profit percentage remains constant which results in a steady cash flow from sales. However, several factors can affect the sales flow such as market demand, competition, economic conditions, etc.

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