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Pedestrian Energy Harvesting System from Walkway of Addis Ababa City

By

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Abstract

Addis Ababa is a primate city that needs enormous amount of energy to up keep the socio-economic development. The frequent black out are signs for looking other alternatives of energy. One of the on-site energy alternatives could be harvested from the pedestrian flow in the city. This flow could be used to harvest and augment its energy supply. Thus, in this work a mechanism that utilizes the dense pedestrian flow for energy generation has been sought for and tested at laboratory scale. After analyzing the pedestrian flow at Aratkilo, Piassa and Mexico and determining their number of pedestrian with in a specific set of time or the Pedestrian Level of Service (PLOS), a machine has been constructed. Parts of the selected streets with PLOS level 'D' (15-20) pedestrian foot per minute(PF/M) and 'E' (20-25 PF/M) were found to be fit for the system Since PLOS of "A", "B" and "C" are not dense enough and "F" is too congested for the system.. Street vending, street furniture, queuing and platooning affected walking experience and speed of pedestrians as well as the feasibility of the system. The prototype has been tested and modified at the laboratory and the result has shown that an average of 0.21 (p=2.50954E-20) electric volt for the first group with weight range of 49 -78 kg and 0.2 (p= 1.1495E-25) for the second group of weight range of 54-76 kg has been harvested. This work has demonstrated that pedestrian flow in the main and secondary centers of the city if channeled properly could be a good source of on-site renewable energy for a city aspiring to be sustainable. It also indicates the need for integrated urban design solution for urban challenges.

Key Words: *Electric energy harvesting, Pedestrian flow, PLOS, Urban Design, Weight, Sustainable.*

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List of Acronyms and Abbreviations

AAU	Addis Ababa University
AASTU	Addis Ababa Science and Technology University
CBD	Central Business District
CHP	Combined Heat Plant
CSA	Central Statistics Agency
EEA	Electric Economic Association
EEPCO	Ethiopian Electric Power Corporation
EiABC	Ethiopian Institute of Architecture Building Construction and City Development
GDP	Gross Domestic Product
GTP	Growth and Transformation Plan
HCM	Highway Capacity Manual
HEP	Hydro Electric Power
LED	Light Emitting Diode
LOS	Level of Service
LPG	Liquid Petroleum Gas
MCC	Main City Center
MIT	Massachusetts Institute of Technology
PLOS	Pedestrian Level of Service
PFM	Pedestrian Foot Minute
PV	Photo Voltaic
WEC	World Energy Council

1. Introduction

1.1.Background of the study

Energy is the ability to do work and the cause for every change in the universe. Broadly, there are two types of energy forms; kinetic and potential energy. Kinetic energy is due to movement and potential energy is due to change in place of an object. Electrical, mechanical, radiant, thermal, motion and sound energy are forms of kinetic energy. potential energy includes forms like gravity, elastic, nuclear, stored mechanical and chemical energy. Based on their recyclability, energy sources are divided into renewable and non-renewable. Renewable sources are those that can be naturally replaced such as hydroelectric, solar energy, biomass, wind, geothermal, heat and ocean energy sources. Non-renewable energy sources are those which cannot be naturally replaced such as coal, petroleum, natural gas and nuclear energy.

Production of energy from different sources started since the dawn of urbanization. Currently, energy has become the part of any city development and cities have started generating energy efficiently. Efficient energy generation has many advantages. Employment creation, energy saving, adjusting greenhouse gas emission, energy security, consistent energy delivery, reduction of energy price, macro-economic impacts, increased industrial productivity, poverty alleviation, health and wellbeing of society, decreased local air pollution, resource management, balanced public budget, and increased asset values are some of them (IEA, 2014).

Cities are dependent on continuous energy supply for their existence. According to the 2008 survey (Eurostat, Energy Yearly Statistics, 2010), energy dependency of most European cities which is defined as imported energy divided by the gross energy consumption of the nations ranges from 20% (Poland) to 81 % (Spain) and the World Energy Resources Report (2013) stated that 1.2 billion people were out of commercial energy access. Lack of access to energy sources forces people to lead difficult way of life. Major energy sources for cities are fossil fuels accounting up to 82 %. Renewable source amounts only 11 % (other than large hydrogen). The rest are nuclear (5%) and hydro power, less than 10 MW (2%).This figure changes to 76 % of fossil and 16 % of renewable sources, 6% nuclear and 2% of hydro power in 2020 (World Energy Council, 2013). More than 50 % of world's population now resides in cities which account for 75 % of energy uses, this will increase to 70 % of population that is 90 % growth and 80 % of carbon dioxide emissions in 2050 (UNFCCC Bonn, 2015). In Europe, 40 % of the greenhouse gas emission comes from urban mobility and 36 % from buildings (CoMO, 2012). If the world's development continues like this, achieving sustainability is going to be a hard task. The energy demand in sub-Saharan Africa has also increased by 45 % from the year 2000 to 2012 (Stefano *et al.,* 2015). In Ethiopia, the low level of alternative renewable energy source adoption is mentioned as one of the limitations of the energy sector (EEA, 2008 EC).

There have been numerous interventions towards renewable energy consumption at micro- scale, meso-scale and macro scale throughout the world (Han *et al*., 2012). The urban forms and development patterns are related with energy provision capacity (Urban Block Design Guide line, 2009). Urban design as a place making process. tries to accompany the lives of the society by utilizing resources present in the urban setting itself (Moughtin and Peter, 2005).

As the need for alternative and sustainable energy sources in cities grow, the idea of using different renewable energy harvesting mechanisms has also increased. Bright field development to revitalize the existing brown field using solar energy (Lori, 2006) and generating electricity from walking in cities by the application of piezo electricity concept has already been underway in Europe (Pavegen, 2016). The use of green technology sources is also being emphasized following the severity of climate change effects. Green technologies provide solutions that are environmental friendly, safe, healthy, renewable and efficient towards achieving sustainable development. Solar array, reusable water bottle, solar water heater, wind generator, rainwater harvester, residence insulation and green buildings are proved to be beneficial in increasing income and reducing energy costs (Ghanshyam, 2015). When people walk, they generate and discard energy to the ground which they step on due to their weight. This energy can be transformed into electrical energy and other forms as well. This study has therefore sought for ways to harvest renewable energy from large pedestrian flow by making energy harvester prototype from locally available materials.

1.2.Problem statement

Addis Ababa city is highly dependent on hydroelectricity. However, the high dependence on electrical power and existing supply problem is the energy paradox of the city's performance (Yohannes, 2015). The city still depends on liquid petroleum gas (LPG) which is not supplied consistently by the sector; moreover, there is supply discrepancy of electricity (Dawit, 2008). Dwellers experience electric power cut out frequently and most residential tasks are dependent on the electric power supply due to rise in the price of kerosene gas recently. Therefore, the city needs to look for additional energy supplies such as adding alternative and renewable sources. The city dwellers lead relatively modern way of life and are highly dependent on the supply of electricity (Fantu *et al*., 2015). The society continually complains about the unreliable energy supply system by its intermittent nature. It is hard to be certain if there will be electric power supply the whole day, it can run out any time. Therefore, reserving energy in the form of cow dung, wood, diesel generator, battery and solar PV is becoming common.

The city's development has brought in congestion and densifying of the central business district areas. Even though motorized transport seems to be dominant in the city, 70 % of the dwellers are still foot travelers (Improving pedestrian mobility through bottom-up strategies, 2014). The transport sector hasn't given attention to pedestrians. Only 35% of the roads in Addis Ababa were built with walkways (Fantahun, 2012). Walkability is one goal of urban design and has many advantages (Llewelyn, 2000). A recent and new perspective about walking in relation to energy advocates walking as energy harvesting mechanism (Mateau and Moll, 2005; Cottone, 2011; Pavegen, 2016).

The unreliable electric power supply in Addis Ababa needs to be addressed by active energy sensitive urban design solution. Among the different options, dense pedestrian flow in places with high pedestrian flow of the city can be tapped as an alternative energy source. The city itself can be a potential source of renewable energy. This study has sought for designing a pedestrian energy harvester prototype that harvest energy from the city's pedestrian flow to augment the energy supply of the city.

1.3. Objectives of the Research

General objective

- To design, construct and test on pedestrian energy harvester that can harvest energy from dense pedestrian flow in Addis Ababa.

Specific objectives

- To design pedestrian energy harvester that harvest energy from dense pedestrian flow.
- To construct a pedestrian energy harvester prototype from locally available resources.
- To identify street segments of large pedestrian flow volume based on the pedestrian level of service where the selected prototype can be scaled up.
- To test the pedestrian energy harvester prototype at the laboratory for its validity.

1.4. Research Questions

General research question

- How can a pedestrian walkway energy harvester that harvests energy from dense pedestrian flow be designed, constructed and tested at a laboratory level in Addis Ababa?

Specific research questions

1. How can the pedestrian flow in the city be changed to a useful energy source?
2. How can a pedestrian energy harvester be constructed using locally available resources?
3. Which street segments in Addis Ababa are fit for the pedestrian energy harvester prototype to be scaled up?
4. How efficient is the pedestrian energy harvester prototype for different pedestrian flow?

1.5. Scope

This study was confined to places having dense pedestrian flow in Addis Ababa, especially the CBD, and tried to use locally available resources as much as possible to construct the energy harvester prototype and test it at a laboratory level.

1.6.Significance

The study will contribute to the society by providing sustainable energy source in the city. It will inspire the scientific community to work on integrated urban design solutions towards urban challenges and it hints the government to focus on development directions towards a sustainable and renewable energy harvesting and generation from the environment.

1.7.Limitations

The prototype generates low output due to factors such as material specification, length of wires and stepping point by pedestrians on the prototype. The weight of pedestrians was acquired through observation due to difficulty to count and interview them about their weight at the same time and also not to interrupt the flow of pedestrians.

2. Literature Review

2.1.Energy and Urban Design

Energy is the core for existence of life and it is endless. The law of conservation of energy is basically derived from this nature of energy. The history of energy conversion goes back to the emergence of human civilization at around 5,000 BC. The development of new energy conversion mechanisms through time can in fact be used to understand history of human development and major events in time.

Energy has affected the settlement pattern of early cities, civilization and development of nations throughout the world. People have tried to control and fought over main energy sources such as water bodies and are still rebelling over nuclear power. The traditional usage of energy includes exploiting animal muscle for agricultural field, hunting, gathering and pasturing. Modern energy consumption started during the invention of the steam engine in England at the end of 18^{th} century. Because of this, cities in Europe were located near to water resources for industrial and economic advantages (Mazia, 2010). Mazia also stated that the turning point in energy harvesting sector was the industrial revolution that accelerated the dynamics of city structure. The industrial revolution has marked the change in human development through energy possession, industrialization, and GDP of nations **(**Jan De Vries, 2000; David and Astrid, 2000; Allen, 2006).

The fossil fuel that was incessantly used without limit and the ever-increasing human population has resulted in environmental degradation through time (Mazia, 2012). Climate change, acid rain, global warming, greenhouse effect, melting of glaciers relate to energy crisis impacts. These effects can only be mitigated through paradigm shift in energy production and consumption. One of the idea is the *'Next Revolution'* idea where renewable energy source takes over the non-renewable at large scale (Mazia, 2012). This idea is further enhanced by Roberto

> *"every city, every industry, every manufacturer wants to be, somehow, "sustainable", hence the "extensive sustainability"* (Roberto, 2010*).*

Energy plays an important role in the realm of urban design. Many scholars have suggested the advantages of energy in urban design and sustainable development. It is noted from Llewelyn (2000) that there are levels of using renewable energy sources in the environment including the sun, rain water, ground water, wind energy and other alternative sources. Energy consumption in urban environment can be classified into three major forms which are embodied (energy found in the particles of the infrastructure), operational (energy needed for the infrastructure to function) and transport energy which is the energy required to transport the infrastructure (Michael *et al*., 2009). There are two types of energy embodiments as stated by Moughtin (1996) energy capital (energy employed in constructing infrastructure in urban setting) and energy revenue (energy consumed throughout the life span of an infrastructure). Relating urban design and energy consumption of cities, Moughtin described it as,

> "*Urban design is the pursuit of more sustainable form that decrease the energy capital of urban forms"* (Moughtin, 1996).

There are many tools in urban design practice that helps to design a better environment where energy consumption is reduced and efficiency is increased. This will help to bring stability in a neighborhood that otherwise would have created violence and crime due to lack of consistent energy supply. There are three scales for intervention in energy generation (Han *et al*., 2012). The macroscale includes large hydropower, wind, solar, biomass and geothermal plants. The meso scale includes district level Combined Heat Plant (CHP), mid-scale solar collectors such as photovoltaic cells and open or closed medium geothermal plants and the micro scale consist of individual building energy recycling, such as PV, solar boilers and Small CHPs (Han *et al*., 2012).

Among the aspects of urban design, re-using of resources is essential to reduce cost and increase efficiency as well as to decrease environmental degradations (Llewelyn, 2000). Designing the landscape in a way that balance natural and manmade resources allows proper utilization of energy. Robust design principles and application of energy treatment principles are ways towards resource management and energy conservation. Clean energy mechanisms are also advocated by adding more infrastructure in cities and settlement areas. In some cities Combined Heat Capacity (CHP) are installed to provide energy to neighborhoods. Among the ten principles of '*one planet living'* concept which are:

"zero carbon- reducing energy use and supplying energy sustainably, Zero waste, Sustainable transport, local and sustainable material, local and sustainable food, sustainable water, natural habitats and wildlife, culture and heritage, equity and fair trade and helath and happiness "(Roger *et al*., 2007).

minimizing carbon emission and waste generation, sustainable pedestrianized transportation system and applying local sustainable ingredients in design practice are some aspects related to energy sensitive urban design mechanisms. It is also suggested that policies need to target sustainability (Roger *et al*., 2007). Densifying urban areas with proper infrastructure provision allows reducing consumption and applying human centered energy supply. It also mitigates pollution and preserve spaces while depressing urban sprawl (Llewelyn, 2000).

As a discipline, urban design is a comprehensive field that is concerned with designing the public realm and advocates pedestrian friendly environment. The public realm hosts a variety of activities one of which is walking for different purposes. Previous practice of urban design neglected the performance of the city in relation to energy production and consumption and impacts. It only focused on the place making, but a public place can only be lively when people are involved in it and when they do, their activities involve energy transformation. If sustainability is to be realized, then public transport, bicycling and pedestrianism should take the major role and motorized modes especially private motor vehicles should be discouraged and public transport encouraged (Moughtin, 1996). Sustainability has important intersection with urban design as it is the goal of urban development. The need for integrated urban design practice has been long marked by scholars as it is the way towards achieving sustainability. Sue (2010) suggests that solving energy crisis is not a concern for one sector, it rather needs gathering different disciplines to come up with a solution. The following statement describes how it is important to integrate energy in urban design.

> *"Today urban design practice is developing an integrated approach to a wide range of factors including resources, emissions, health, people, culture and habitat, and how the relationships between them can shape urban form. Although this agenda may seem complex, common sense application of urban design principles and collaborative working can deliver quality places". We can design places to help minimize the use of energy and scarce resources, and to adopt to predicted climate change. coping with climate change calls for more than just token wind turbines or solar panels. It requires an understanding and biodiversity make a place more or less sustainable. Much can be achieved at the neighborhood and*

building scale. Developments should be designed to influence the micro climate, minimize the use of energy, and maximize energy efficiency through local supply and the use of renewables" (Roger *et al*., 2007).

2.2. Mechanical Energy Sources

Energy harvesting system widely uses kinetic energy (wind, waves, gravity, vibration), electromagnetic energy (Photovoltaic cell, radio frequency), thermal energy (solar-thermal, geo thermal, combustion), atomic energy (nuclear, radioactive), and biological energy (biofuel, biomass) sources (Mateau and Moll, 2005; Paulo and Gaspar, 2010). Different scholars classify energy sources in different ways but agree that energy is mainly gathered from the environment through various activities such as mechanical, air flow, heat, temperature differences. Sojan and Kulkarni (2016) add sound and human energy as other sources of energy and point out that there are three types of mechanical energy sources. These are;

a) Steady state sources (i.e., fundamentally from fluid flow).
b) Intermittent sources (i.e., gathered form vehicle movement over energy harvesting prototype or repeated human activities like walking).
c) Vibration sources (i.e., vibration).

The choice of suitable energy sources is still arguable among different scholars. Sojan and Kulkarni (2016) stated that vibration sources yielded an output of 10-100mW and are applied in few areas like self-powered sensors and low power electronics. Yildiz (2009) mentioned machine vibrations, mechanical stress, high pressure motorized strain, industrial machines, and rotation as additional sources of mechanical energy. Classification of energy harvesting devices is presented in Mateau and Moll (2005).

They classified energy sources based on their input for the conversion as human and environment energy devices. Human energy devices use share of the energy from the consumer (Shenck and Paradiso, 2001). Starner and Paradiso (2004) generalize the ways to extract electricity from human power through '*exploiting, cranking, shaking, squeezing, spinning, pushing, pumping and pulling*'. Human energy is divided into two - active and passive human energy. Human active energy uses the direct involvement of human as energy input. Radio receivers, electric torches and phone battery chargers are some to be mentioned (Mateau and Moll, 2005 stated from A. Jansen *et al*., 2000). Human passive energy gathers energy from the indirect involvement of human activity. Its cost of conservation is very low showing a development of interest in recent years. Wrist watches, miniature thermos electric generators and remote controls are some examples listed in the review of Mateau and Moll (2005). Environment energy device gains the input energy from the surrounding potential sources such as kinetic, solar and thermal energy sources (Mateau and Moll, 2005). Yildiz (2009) classified them based on their characteristics as natural, mechanical, thermal, light, electromagnetic, biological and chemical energy sources.

Human beings need energy to do everything in life both at rest and at work even to think (Morton, 1952; Okuno *et al.*, 1986). According to Paulo and Gaspor (2010) human beings generate power between 81W while sleeping to 1630W while sprint walking. They also stated the major factors for this variance of power to be temperature, humidity, air swiftness, ecological, physical activity, body area subject to and heat padding factors like clothing and fats. Another study from energy harvesting network (2011) revealed that human movement generate power. The report shows that human arm motion can produce greater than 60W, finger motion 6.9-19mW, footfall or heel strike 67W of power. It has also been known that human body burns nearly 10.5 MJ or

121W daily which is dissipated through various activities (Yildiz, 2009). Moll and Rubio (2000) used bio mechanical model to compute energy involved in human stride and found it to be around 40J.

2.2.1. Mechanical Energy Harvesting

The process of harvesting energy from the surrounding and converting to functional and useful forms of energy is known as energy harvesting (Viswanath *et al*., 2015). Energy harvesting is a mechanism that gathers free energy from the surrounding through different forms and to use it for betterment of human life and provide alternate energy sources **(**Sojan and Kulkarni, 2016). The central idea of energy conversion is to increase the efficiency of energy forms to be stored and used. Energy harvesting started from the early times when solar energy was converted to electrical energy and developed through technological advancement **(**Sojan and Kulkarni, 2016). There are mechanisms experimented on private, semipublic and public places and their corresponding energy outputs are still being analyzed (Minazara *et al*., 2006).

Natural way of energy conversion transforms energy without the fabrication of new material. Artificial energy conversion technique requires human beings to intentionally manufacture energy convertors in order to perform the process for them to use it for different activity. Simple energy harvesting system uses available energy sources in the surrounding ecosystem in general to convert it to more applicable forms. A typical simple energy converting system consists of several parts to function as shown in Fig-1. Sojan and Kulkarni (2016) discussed the conventional energy harvesting model from the micro-electronics comprised of input, detection, storage part and the load part. Yildiz (2009) suggested that the overall process was comprised of power scavenging and distributing.

In this model, it is obligatory to store the energy before using it to reduce loss of energy through heat and other forms.

The energy fields illustrated in Fig- 1 are the sources of energy to be harvested whereas the energy harvester elements are three. The first one is the transducer that convert one form of energy to another form like the prototype constructed under this study. The conditioning are the materials used to regulate the energy output and the third part is the storage used to store the energy before the final use such as batteries.

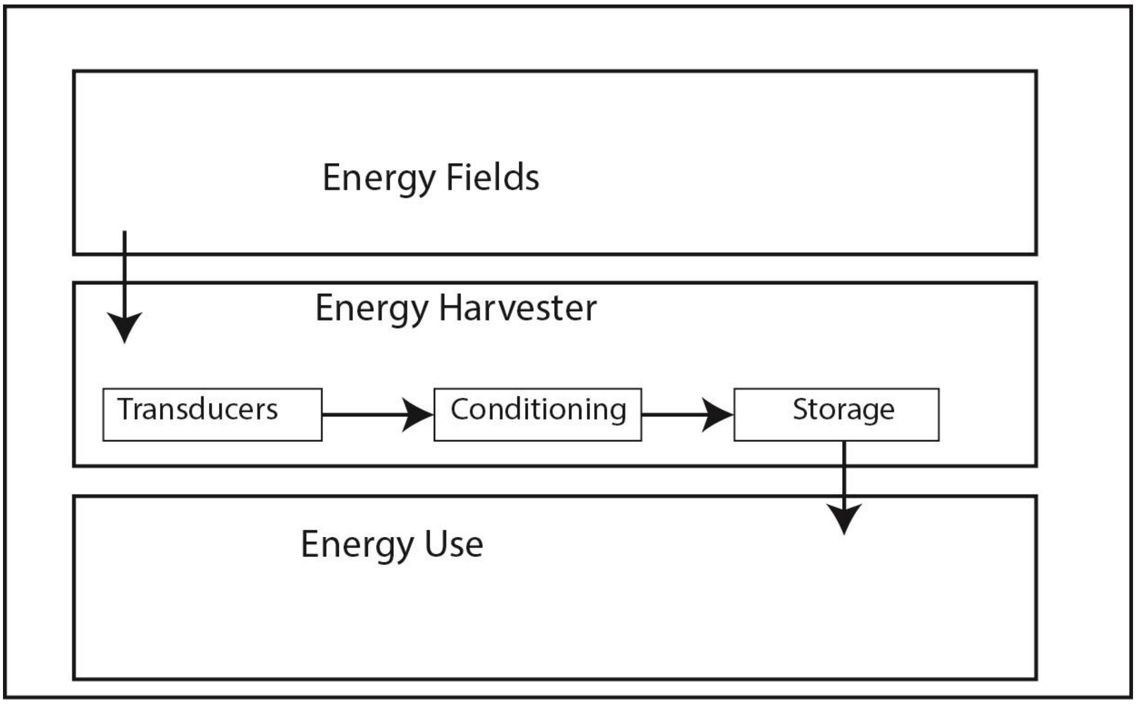

***Figure 1**:* Simple energy harvesting mechanism *source:(Bickerstaff, 2011.)*

2.2.2. Techniques of Mechanical Energy Harvesting

There are different ways to convert kinetic energy into electrical energy. Scholars suggest three methods - piezoelectricity, electrostatic energy and magnetic induction (Mateau and Moll, 2005; Cottone, 2011). Berdy (2014) detailed the method by adding, magnetostrictive and transduction as mechanisms to generate electric energy form mechanical movement or vibration. There are two kinetic energy transducers (materials that convert energy forms). These are, inertial transducers (vibrate at a specific regular rate) and non-inertial transducers (exert force to be converted to elastic energy to bring deformation). Other forms are:

a) Piezoelectric: uses the electrical polarization nature of certain materials (piezoelectric materials) when exposed to mechanical force to generate electricity or vice versa.
b) Electrostatic: principled by the movement of a transducer opposite to an electric field to generate energy
c) Magnetic induction: uses the difference of magnetic flux with in an electric circuit to bring electric field or intensity to generate energy.

Sojan and Kulkarni (2016) generalized the characteristics difference of the above techniques and energy yields as presented in Table-1. Piezoelectricity was found to generate more energy output than the other two methods but limited by its shorter life span, depolarization, charge leakage and brittleness.

***Table 1**:* Comparison of mechanical energy harvesting techniques.

Parameters	**Electrostatic**	**Electromagnetic**	**Piezoelectric**
Complexity of the process flow	Low	Very High	High
Energy density	4mJ cm^{-3}	24.8mJ cm^{-3}	35.4mJ cm^{-3}
Size	Integrated	Macro	Macro
Problems	Very high voltage and need of adding charge source	Very low voltage output	Low output voltage

Source: Sojan and Kulkarni, 2016

It has been experimented that mechanical energy sources can generate 4-800W of electrical energy (Yildiz, 2009). Mechanical energy harvesting from different sources like vehicles, large building structures, road and rail line, human activities and ocean waves is showing a great advancement as the need for renewable energy sources especially for urban areas is increasing (Zuo *et al.*, 2013). Free energy from human walking is converted to electrical energy using different techniques. Paradiso *et al.,* (1998) tried to integrate a mechanical energy harvesting prototype in a shoe sole with complicated small circuits and gained 1W electrical power enough to charge a radio. This prototype was not adapted for its limited application which only works on pendulum equipped shoes and its discomfort for use. Hayshida (2000) modified the electromagnetic convertor by adding more magnets and gears to yield more energy, but its complexity led to demerits in applications and shorter life time. Paradiso and Shenck (2001) argued that previous electro mechanical conversion power output on the shoe mounted devices were very low (1.3-8.3mW) and introduced an "*elastomer generator*" on shoe sole to improve the capacity. Kornbluh (2002) used an electrostatic generator by compression of dielectric elastomer technique. Wearable energy harvester introduced by MIT engineers was claimed to be the best due to its dependability and flexible adaptation in daily human activities. This prototype converts energy from human walking by installing it in the heel strike of shoe sole (Yildiz *et al.,* 2011). Joydev *et al., (*2013) constructed a prototype which uses electromagnetic induction to cut magnetic flux by coils. When a body weight is exerted on the plate, the downward movement of the plate rotates series of gears that produced electricity and yielded 80-95V or 40-50A of electricity. The above scholars have tried to harvest energy from human walking using shoe mounted prototypes.

Extensive methods such as the compact size piezoelectric harvester have been developed to increase the voltage output (Korla *et al.,* 2010). Pavegen has installed pavement energy convertors in streets of London using piezoelectric materials to produces average power of 2.1W from each tile (Tom *et al*., 2013).

2.3. Pedestrian Level of Service

Pedestrians are the core part of the overall traffic system and a principal element of urban design. Traffic congestion and the struggle to solve it by different stakeholders can be one indicator for this issue. The increased human density in city centers has resulted in the emergence of the level of service concept.

Pedestrian level of service is the qualitative valuation of quantitative factors like speed, volume of traffic, formal structures, traffic disturbances, delays and freedom to move (Ian, 2008). It is comprised of six levels that range from A- F. 'A' means there is very small number of pedestrians and "F" shows the most congested type of pedestrian movement. Level of service was first established in the traffic engineering sector after observing that capacity design has indirectly resulted in deliberate congestion (Watson *et al.,* 2003). It advocates that pedestrians should be able to bypass other slow-moving pedestrians in front of them. This is mainly related to the width of sidewalks and flow of people within a certain part of sidewalk in specific travel time. The general bench mark of the Level of Service (LOS) analysis is to determine the necessary factors when designing a pedestrian space such as, scale and time of peaks, lines caused by traffic light and the economic results of space deployment (Watson *et al.,* 2003). The different levels of PLOS as shown in Table 2, 3 and 4 have their own distinct behavior.

Table 2: Pedestrian Level of Service classification.

Level of service	**Average pedestrian area of occupancy**	**Average flow Volume (Pedestrian Foot/Minute)**
A	3.25 m^2 or greater	7 PF/M
B	2.3-3.25 m^2	7-10 PF/M
C	1.4-2.3 m^2	10-15 PF/M
D	1-1.4 m^2	15-20PF/M
E	0.46-1 m^2	20-25 PF/M
F	0.46 m^2	Variable up to 25 PF/M

Source: Watson et *al.*, 2003

Table 3: Average PLOS criteria for pedestrian.

LOS	**Space(ft^2/p)**	**Flow Rate (p/min/ft.)**	**Speed(ft./s)**	**Volume /Capacity V/C/Ratio**
A	>60	< /= 5>7-10	>4.25	< / = 0.21
B	>40-60	>5-7	>4.17-4.25	>0.21-0.31
C	>24-40	>7-10	>4.00-4.17	>0.31-0.44
D	>15-24	>10-15	>3.75-4.00	>0.44-0.65
E	>8-15	>15-23	>2.00-3.75	>0.65-1.00
F	</ = 8	Variable	< / = 2.50	variable

Source: Bloomberg and Burden, 2006

Table 4: Tabularized presentation of the PLOS reconstructed for this study.

PLOS	Characteristics	Possible locations
A	Pedestrians can select their route and there is no conflict between them. They can pass slow walking ones and can turn back on the same route as well.	Public buildings or plazas without space restrictions.
B	Normal walking speed exists. Pedestrians can bypass slow moving ones. Minor conflicts and slight lowering of speed is expected.	High quality transport terminals.
C	Pedestrians cannot select route and bypass each other. There is high probability of conflict. Mostly fluid flow but little friction and interaction between pedestrians would occur.	Heavily used transport terminal, open spaces with severe peaking.
D	Normal speed is restricted and reverse flow is expected to occur due to absence of by passing and slow speed. There is conflict on this leveled side walk way. Fluid flow is expected to occur.	Crowded public areas where alteration of movement and direction is needed
E	Normal speed is restricted. high shuffling due to congestion. Limited adequacy of pedestrian holding areas at critical design sections. All supplementary pedestrian facilities must be evaluated.	Sport stadium gates and rail transit facilities.
F	Pedestrian Speed is extremely restricted. High shuffling and unavoidable contact. Forward movement is dependent on those at the front and no reverse movement. There is no control and complete breakdown of pedestrian traffic.	More of queuing than a normal flow. It is not suggested for walkway design.

Source: Watson *et al*., 2003

The classification methods described in Table 2 and 3 have similarity of naming the levels from A- F and both depend on the number of pedestrians and pedestrian space or occupancy. Their difference is that Bloomberg and Burden added other attributes such as volume to capacity ratio and speed and also studied factors affecting pedestrian speed.

There are different perspectives for side walkways width standard. Watson *et al.*, (2003) suggests that walking speed, pedestrian spacing and conflict chance of traffic agglomerations are the basics while proposing the effective width of the side walk from any kind of obstacle (buffer width) to be 41 cm in order to avoid conflict with different stationary and moving objects including other pedestrians. This distance has shown some variations according to other researchers. Stucki (2003) suggested that separation of 1.5 feet from walls, 1.14 ft. from fences, 1 ft. from tiny obstacles should be maintained for proper pedestrian operation. Hoogendoor and Daamen (2005) put 1.5ft. separation for holdup areas. The Highway Capacity Manual (HCM, 2010) recommended 1.5-2 ft. In general, it shows how the side walk width affect the pedestrian level of service. There have been arguments on the attributes of the level of service standards. Muraleetharan *et al.*, (2002) suggested that level of service should not only focus on the motorized mode of transports and added attributes like width and separation of pedestrian from vehicular lane, obstruction level, bicycle events as part of the walkway activities. Watson *et al.*, (2003) have also tried to improve this by focusing on the average pedestrian area of occupancy and flow volume.

There are many tools of pedestrian movement analysis in the realm of urban design and transport engineering. Muraleetharan *et al.*, (2002) have used conjoint analysis to determine how users rate the service features. The HCM (2006) used flow of pedestrians for side walkways using space (ft^2/p), speed (ft./s) and volume to capacity ratio. For pedestrian side walk ways, the HCM (2006, 2010) used platooning effect as one factor affecting the PLOS based on previous work by Pushkraev and Zupan (1975). The technical report from city of Melbourne (2014) had come up with techniques in relation to the pedestrian movement and its connection with the CBD. It emphasized on cluster of jobs in the surrounding area and the travel time matrix with effective job density to describe the pedestrian movement Bloomberg and Burden (2006) on their extensive summary on the HCM has generalized that the Platoon adjusted PLOS is a level lesser than the normal average PLOS. One of the factors affecting PLOS level in relation to energy harvesting prototype designed under this study are the pedestrians step and stride length. There are different stride length depending on factors such as gender, body weight health condition and height (Saunier *et al.,* 2010). According to the Oklahoma university, The Average standard stride length of a normal person is 62cm for male and 52cm for woman (*www.LIVESTRONG.com*). This helps to design a machine that pedestrians step on to generate electrical energy.

The primary use of pedestrian level of service analysis is to understand the character of the walkway in relation to the pedestrian movement pattern. According to Ian (2008), LOS can be used as a measure of performance of the side walkways. For this study, the pedestrian level of service was used to identify streets with larger pedestrian flow volume in order for scaling up the harvester and extrapolate the quality of energy produced.

2.4. Energy in Ethiopia

Ethiopia has a vast potential of hydro, wind, geothermal and solar energy source but small part of it has been utilized so far. The introduction of modern energy source in

Ethiopia is a recent phenomenon. For instance, the first electric generator arrived in 1890 from Germany during the reign of Emperor Menelik II which was used to light the palace (Dawit, 2010). The first street light system was introduced in 1930 (EEA, 2007). The per capita energy consumption of the nation is still relatively low which is 200kwh per year and the total energy stability relies on outdated sources such as wood fuels, crop residues, and animal residue (Fantu *et al.*, 2015).

Household energy consumption had the largest share out of the gross energy consumption accounting 89 % in 2006 out of which 74% was consumed by rural and 15% by urban households (EEA, 2007 EC). Generally, out of the total energy produced, 34% is consumed by households, 40% by industries and 26% by the service sector. This is why energy is understood to be one of the socio-economic enablers by the government (EEA, 2007 E.C). Learning from the GTP I, the second phase has given emphasis for building climate resilient green economy among which accelerating human development and technological capacity building and ensuring its sustainability are the major ones (GTP II, 2016). In order to achieve these goals, an alternative and renewable energy source is needed to balance the energy demand with the increasing rate of urbanization.

Urbanization has brought both potentials and challenges for the development of the nation. One of the challenges of urbanization is the ever-increasing demand for constant energy supply. The continuing population growth together with urbanization is likely to change the domestic energy demand in the future. The current energy policy framework strongly emphasizes on renewable energy source and efficient power distribution (Berlin energy Transition Dialogue, 2017).

2.4.1. Energy Sources in Ethiopia

By the year 2020, the power demand of Ethiopia will reach to 17,000MW. Ethiopia from its 45,000MW hydroelectric potential, only exploits 3810MW. The current hydroelectric source of Ethiopia is summarized in Table-5.

Table 5: Hydroelectric power projects in Ethiopia

Constructed DAM	Year	Power at peak level (MW)
Koka	1960	43.20
Awash I and II	1996 and 1971	64
Fincha Dams	1973 and 2003	134
Melka Wakena	1988	153
Tis Abay I and II	1964 and 2001	84
Gilgel Gibe I and II	2004	605
Tekeze	2009	300
Beles	2010	460
Fincha Amerti	2011	97
Gelgel Gibe III	2015	66.8

Source: Energy Report Ethiopia, 2016.

The Grand Ethiopian Renaissance Dam, which is 1,800m long and 145m high expected to have a volume of 74,000 million^3 when finalized, will be the largest in Africa with a capacity of 6,000MW (i.e.15,200 GWH per year) (Berlin energy transition dialogue, 2017). Ethiopia exports electrical energy to Djibouti (230KV) and has signed agreement to sell 400MW to Tanzania and 100MW to Sudan annually (Energy Report Ethiopia, 2016; Samson, 2016). The Geothermal energy potential of Ethiopia is estimated to be from 500-10,000MW (Samson, 2016). From this potential, only 3.5MW (Aluto langano) has been utilized. Tendaho (100MW) and Aluto langano (75 MW) are in the pipeline (Energy Report Ethiopia, 2016).

The solar power potential is estimated to be 5.5kw/m^2/day (Berlin energy transition dialogue, 2017). GTP II desires to deliver 150,000 solar homes and 300,000 solar lanterns (Energy Report Ethiopia, 2016). Their application is to bring small scale supply using off grid Photovoltaic cells for domestic uses. The estimated wind energy potential is 1000GW with average wind speed of greater than or equal to 7m/s at 50m above ground level (Berlin energy transition dialogue, 2017). Table-6 shows the different wind energy projects and their power at peak level.

Table 6: Wind power projects in Ethiopia.

Project name	**Power at peak level (MW)**
Ayisha	300
Debre birhan	100
Assela	100
Adama II	153
Mesebo Harena	42
Galema I	250
Ashegoda	120

Source: Energy Report Ethiopia, 2016

The Ashegoda project has started generating 30MW with the help from a French company known as Vergent Group (Energy Report Ethiopia, 2016). Other sources of energy are wood (1,120 million tons per year), agricultural wastes (estimated to be 15-

20 million tons per year), natural gas (up to $113Bm^3$), coal (up to 300 million tons) and oil shale (up to 253 million) (Samson, 2016).

2.4.2. Energy in Addis Ababa

Addis Ababa established in 1887, had an abundant forest cover that took years to grow but were cleared for fuel and construction purpose (Araya and Yishak, 2012). Due to this, Emperor Menelik was nearly forced to move the capital from Entoto to Addis Alem. It is due to the adaptation of the fast-growing eucalyptus tree that satisfied the city's fuel demand in short time, made the city permanent to settle where it is now (Briggs and Blatt, 2009). Araya and Yishak (2012) have mentioned actions taken by both governmental and non-governmental stakeholders to increase the forest cover of the city as well the country so as to sustain reliable fuel wood supply.

Now a day, the high price of charcoal and liquid petroleum gas (LPG) has shifted the city's main energy stock to hydroelectric power supply of electricity. From the work of Araya and Yishak (2012), house hold energy sources in Addis Ababa are classified in to two categories. The first one is traditional energy source which comprises of charcoal, fuel wood, sawdust, and dung. The second is modern energy source that consists LPG and HEP generated electricity. The increasing energy demand of the city necessitated the exploration of more options to meet its energy hunger, one of which is utilizing its dense pedestrian flow.

3. Materials and Method

3.1.Description of the study area

The study areas are located in Addis Ababa, the capital city of Ethiopia, which has an elevation of 2300 m above sea level and located at 9°1′48″N and 9°1′48″North 38°44′24″East. Established in 1886 during the reign of Emperor Menelik II and empress Taitu, the city has now 10 sub cities namely Akaki Kaliti, Nefas Silk-Lafto, Kolfe Keraniyo, Gulele, Lideta, Kirkos, Arada, Addis Ketema, Yeka, and Bole sub-city. The study selected three areas from Arada, Lideta and Kirkos sub cities. The street segments were selected from Arat kilo, Piassa and Mexico areas as shown in Fig – 2.

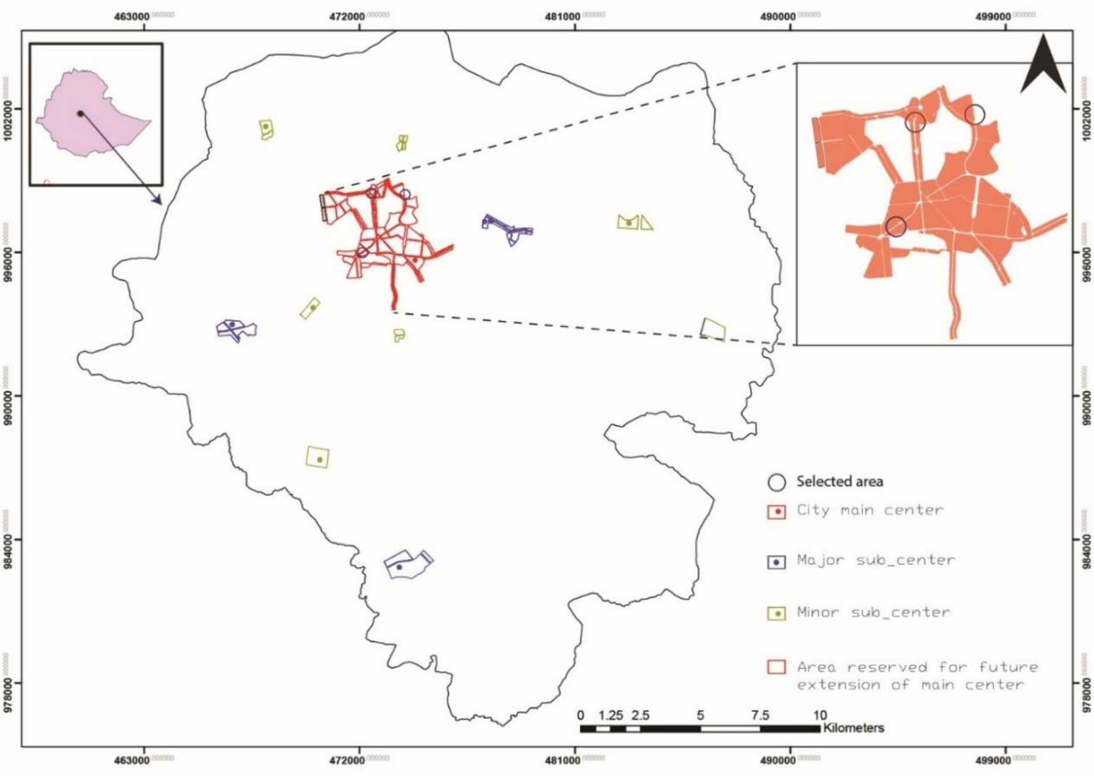

Figure 2*:* Location map of the selected street segments in Addis Ababa

3.2.Research Design

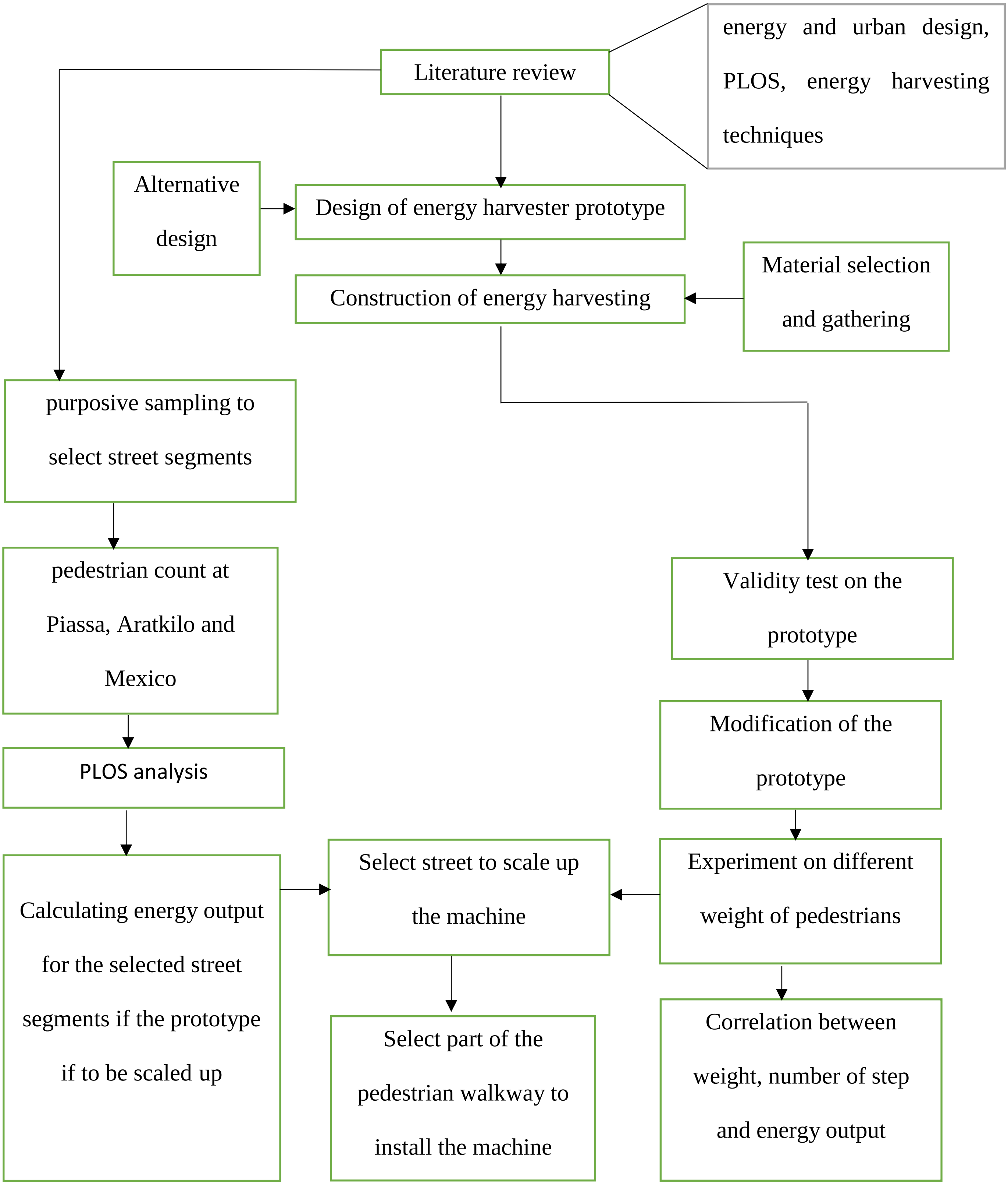

Figure 3: Research design

The Research design presented in Fig-3 shows a combination of instrument design and quantitative correlation research design carried out under this study. The instrument design part included designing and constructing one energy harvesting prototype, testing and modifying it at the laboratory. The construction had different phases. The first prototype was tested in the laboratory and it was modified three times to come up with one final energy harvesting prototype. The correlation research design part included analyzing relation between the electric voltage output, weight of participants and number of pedestrians from PLOS analysis. The test was carried out to check the validity of the machine. The study focused on relation between the average energy output, weight and the PLOS of the selected street segments.

3.3.Designing and constructing the prototype

By designing an energy harvesting system that use active involvement of human walking, the study tried to demonstrate that the large pedestrian flow in the main city center of the city has a potential of becoming alternative renewable energy source. The design considered the average stride length of a normal person to be 62cm for male and 52cm for female (www.LIVESTRONG.com).

The system functions by changing vertical motion from pedestrian foot step to rotation. The machine stress downward when weight is exerted up on it. The straight gear, that is connected to the circular gear changes the vertical motion to rotation so as to spin the dynamo which finally generate electric volt. The maximum carrying capacity of the machine was set to 300 kg to carry significant amount of weight.

The materials employed to construct and modify the prototype were:

- Four compression springs (14cm long and spring constant 0.86 N/M)

- Two rack gears with 96 teeth.
- Two small circular gears or pinon (36 teeth and 3.8cm diameter)
- Two small dynamos
- 5 cm thick (55x55cm) square metal frame.
- 5cm thick (50x50cm) square metal frame
- Metal box to put the machine (62*62*35cm)
- Light wood Plate (75*75cm) and Plastic rubber

The materials employed in constructing the prototype were gathered from locally available resources as much as possible. Regarding the stepping plate of the prototype, light metal was used which was later cladded with a light wood plate to absorb the sound created by the machine when stepped on. The length of the springs also needed to be short not to compromise the comfort of the pedestrian flow since pedestrians will notice the downward stress if it is long. The spring length was first 10-15cm, but after repeated experiment it was minimized to 5- 8 cm on the modified machine. The two dynamos under the stepping plate at the opposite sides balance the energy conversion process and increase the output. The square shape for the machine is selected so as to get significant weight from a foot step at random point on the machine. The pre-modified prototype had wood support system at the bottom corners and under the legs to avoid the swinging vertical motion of the rack gear. The wood support system was later replaced by metal rods (see Annex D). It was placed at the corners of the prototype to inhibit both the vertical and horizontal swinging movement of the steeping plate and also save space. The prototype was put in a metal box to increase the aesthetic quality and protect the machine from external damage and also to absorb the disturbing sound created while stepping on it. An opening at the side of the machine allows to maintain and modify it when required and a rubber band was used to decrease the sound as well as fill the opening between the upper part (stepping plate) and the lower part (holding metal box) of the prototype.

3.4. Selecting street segments fit for energy harvesting

Purposive sampling was used to select the street segments by setting 4 parameters, proximity to the main city center (MCC), representativeness of other pedestrian walkways in the city, prevalence of large pedestrian flow along the segment and presence of separate pedestrian walk way. Scholars agree that the central business districts are areas where there is large pedestrian flow (Bloomberg and Burden, 2006). Based on the site observation, three areas have been selected out of six primarily selected segments for further study. They have been ranked out of 5. Rank of 1 is least suited and 5 is for suited (see Annex C). The study was conducted at EiABC (Ethiopian institute of Architecture Building Construction and City development).

Pedestrians on the selected street segments were counted for 15 minutes which was then used to calculate the PLOS for the selected street segments. The pedestrian count was carried out from 10:00-12:00 local time (4:00 PM – 6:00 PM) on weekdays from Monday to Friday where the pedestrian flow was expected to be high. Side by side with the pedestrian count, the size of pedestrians was identified through observation. For this study, the weight of individual pedestrian was identified via observation and estimating their weight from their size (HCM, 2010). The three weight groups identified were categorized as small (approximately below 50 kg), medium (approximately 50-70 kg) and large (approximately above 70 kg) (see Annex A and B). The variation on weight of pedestrians was aimed to see the weight distribution on the selected street segments.

$$V=S/t \tag{1}$$

where,

V= speed

S= distance

t= time

$$\text{Flow Volume}(P)= \text{Average Speed}(S) * \text{Average Density}(D) \tag{2}$$

$$\text{Ped Volume}(P)= \text{Average Ped Speed } (S)/ \text{ Average Ped Area}(D) \tag{3}$$

The speed of pedestrians to cover the selected street segments has been recorded and average pedestrian speed for the specific segments was calculated using Equation-1. The PLOS level was calculated using the Equation-2 and 3 (Watson *et al.,* 2003) respectively. The Pedestrian flow volume was first calculated then the Pedestrian Flow volume was generated after.

The effective walkway width was calculated using the Equation - 4. The total walkway width is the total width of the pedestrian walkway including all features such as Street furniture, outdoor activity areas. The obstacle width is the width of the street segments where the flow of pedestrians is restricted by different obstacles that are likely to inhibit normal pedestrian flow.

$$E.W.\ W= T.W.W - O.W \tag{4}$$

where,

E.W.W= Effective walkway width

T.W.W= Total walkway width

O.W= Obstacle width

3.5.Testing the Prototype

To understand the efficiency of the machine four trial tests were done at the laboratory. The three tests were mainly aimed to check the validity of the, machine and the fourth and final test was aimed at finding the average electric output of the machine. It was carried out to measure the electrical voltage output using a voltmeter. The prototype was put in a convenient leveled surface and human subjects were allowed to step on the machine. The Three tests have a sample size of 51 pedestrians each in order to compare the result throughout the test using same sample size. The first test was primarily aimed to check the working mechanism of the prototype for different weight. The second test, after modification of the first prototype, set up included human subjects of different weight to step on it and used a voltmeter to measure the output voltage (see Annex D). The third and fourth tests were carried out at EiABC using the same procedure as the previous tests. After the trial tests an experiment was done on different pedestrians on the machine to find the average energy output of the machine. There were two groups of pedestrians randomly selected with sample size of 24 and 26 each. The total electric output that would be harvested from the street segments was calculated using Equation-5. For better understanding the prototype test has been given a name on different tests: P-1 for the first, P-2 for the second, P-3 for the third and P-4 for the final test on the prototype

$$T.\ V = V.\ sing. * T.n.p \tag{5}$$

where,

T. V.=Total voltage output

V. sing. =voltage output for a single person

T.n.p.=Total Number of pedestrians

3.5.Analysis

3.5.1. Design and Construction of the Prototype

In order to design the pedestrian energy harvesting machine, the factors weight, step and stride length, spring constant and stepping area were considered as parameters. The weight of pedestrians on the selected street segments gathered through observation is presented in Table-7.

***Table 7**:* Frequency of weight distribution of sampled pedestrians

Area of seleted street Segement	Frequency of pedestrians weighing Below50 (kg)	Frequency of pedestrians weighing 50-70 (kg)	Frequency of pedestrians weighing Above 70 (kg)
Piassa	53	245	53
Arartkilo	30	150	120
Mexico	125	156	31

The pedestrian step length was acquired from international literature review. A stride length of 62 cm for male and 52 cm for female was taken (www.LIVESTRONG.com). Taking this figure in to consideration 55cm of step length was used to design the prototype.

3.5.2. Selecting Street Segments and PLOS analysis

The top 3 areas; Piassa, Aratkilo and Mexico as shown in Table-8 were selected for further study. These areas were further observed and a single representative pedestrian walkway has been selected from each area to undertake the PLOS analysis (See Annex c).

Table 8: Selected sites

Criteria for grading	**Megenagna**	**Mercato**	**Piassa**	**Arat Kilo**	**Mexico**	**Bole**
Proximity to the main city center	1	5	5	5	5	1
Representativeness of other walkways	4	4	4	4	4	4
Prevalence Large pedestrian flow	3	1	4	4	5	5
Presence of separate pedestrian walk way	5	5	3	3	4	2
Grade	3.25	3.75	4	4	4.5	3

The total number of pedestrians that is gathered through observation and pedestrian count from the selected street segments is shown in Table -9.

Table 9: Weight of Pedestrians

Street Segment	**Pedestrian count (No)**	**Pedestrian/foot/minute(No)**
Piassa	350	24
Aratkilo	300	20
Mexico	312	21

The effective walkway width of the street segments presented in Table-10 shows that physical features such as street furniture, vegetation and activities such as begging, vending transport lines and extended activities from adjacent buildings consume the pedestrian walking space. This dictates that the placement of the machine if it is to be scaled up needs to be in the section of the pedestrian walkway where there is relatively uninterrupted movement of pedestrians.

Table 10: Effective walkway width and area.

Segment location	Effective walkway width (m)	Total walkway width(m)	Total Segment length
Piassa	1.2	3	80
Aratkilo	4	12	103
Mexico	2	5	125

The Average speed of pedestrians in Table-11 shows whether the pedestrian flow is continuous or interrupted. It affects the pedestrian flow volume which is the major factor to select street segments in order to scale up the energy harvesting machine. The presence of luggage tabularized in Table-12 shows majority of the pedestrians on the walkways were not carrying significant luggage.

Table 11*:* Average speed of pedestrians.

Segment location	Average speed (m/s)
Piassa	1.7
Aratkilo	2.11
Mexico	2.3

Table 12: Pedestrians with and without luggage

Segment location	**Pedestrians with luggage**	**Pedestrians without luggage**
Piassa	140	210
Aratkilo	120	180
Mexico	125	187

4. Result

4.1.Design and Construction of the Prototype

This study found that the dense Pedestrian flow in Addis Ababa can be used to harvest energy by designing a technology that convert mechanical energy from human walking in to electrical energy. The construction of the prototype machine shown in Fig-4 and illustrated in Fig- 5 used light metal plate, compression or load bearing springs, copper wires and metal box. Number of pedestrians on the selected street segments, weight of pedestrians and stride length are the major factors incorporated in the design and are needed in order for the machine to function. A step length of 55cm (see Annex D) was ideal to design the foot step energy harvester. The maximum carrying capacity of the machine was 300kg with an area of 0.56m^2 (75*75cm). The materials employed for the construction of the prototype were gathered from local markets.

***Figure 4**:* Close up view of the prototype

***Figure 5**:* The prototype illustrated (P-4)

4.2.Identifying Street Segments for Energy Harvesting

The identified street segments with dense pedestrian flow were Piassa, Aratkilo and Mexico area streets. A Total of 962 pedestrians were counted on the selected street segments. 54.4 % were male and 45.6 % were female. The pedestrians were found to be dominantly weighing from 50-70 kg. Presence of luggage in all the selected streets segments has not shown a significant impact on the pedestrian flow. Piassa street segment had the highest and Aratkilo the lowest pedestrian flow directing that Piassa street segments could yield more output using the energy harvesting machine than Aratkilo and Mexico. All the three street segments were categorized under PLOS level of 'E' with a platoon adjusted PLOS level of 'D' (see Table-13). The pedestrian occupancy area on Piassa and Mexico segment was 40% and on Aratkilo it was 33.3%.

Table 13: PLOS level of selected street segments.

Street Segment	Pedestrian/foot/minute	PLOS level	Platoon adjusted PLOS
Piassa	24	E	D

Aratkilo	20	E	D
Mexico	21	E	D

Factors affecting the pedestrian flow volume were street obstacles. Pedestrian movement obstacles observed at Aratkilo street segment were que attractors and street vendors. The walkway was paved with asphalt and earth materials. Pedestrians were observed choosing the asphalted part to walk which created concentration of pedestrians on the small portion of the walkways. Queue attractors like transport lines at the upper end and advertisement boards at the lower end of the segment were found to be the major ones. Street vendors located at the middle of the segment were other elements that forced pedestrians to stop and wait in order to pass. Pedestrian movement obstacles at Piassa street segment were improper installation of street furniture, street vendors blocking the way and activities from adjacent commercial buildings. The surface was paved with cobblestone at the upper end and the rest of the segment was asphalted. The pedestrian movement obstacles observed at Mexico segment were que for transport facility and platoon due to street venders, beggars and platoon at street crossing. The effect of adjacent buildings is minimal on this segment since it is located adjacent to a fenced civic compound.

Generally, the major factors affecting pedestrian movement and the PLOS level on all the identified street segments were Street vendors, Street furniture, queuing and platooning effect due to transport facilities.

The side walk way analysis showed that the pedestrian walkway for the selected streets segments was divided in to three quarters. The first was the **activity quarter** where pedestrian movement was inhibited due to activities such as vending, begging, sitting and outdoor activities from adjacent buildings. The second was the **walking quarter** where pedestrians were relatively free to walk with minimal interruption from street activities and installed furniture. The third was the **que quarter** where pedestrians were lined for transport facilities. On the que quarter, a mixed activity (vending, begging) took place together with the que which also inhibited the pedestrian movement. The second (walking) quarter was best suited for the machine to be installed and to get large pedestrian number for the energy harvester to be efficient.

4.3.Efficiency of the Prototype

The Average electric output of the prototype was 0.09 V before and 0.64V after the first and second modifications. After the third modification prototype yielded an average of 0.37 V. The final experiment showed an output of 0.21 V for the first group and 0.2 V for the second group. All the tests have shown that an increase in number of steps will increase the energy output. The material specification, resistance due to length of the copper wires, Friction between the stepping plate and supporting metal rods were factors affecting the energy output in addition to the stepping speed.

The tests on the prototype showed that dense pedestrian flow from side walkways in Addis Ababa could be used to harvest energy using such active mechanical energy conversion prototype constructed from locally available materials. The study also has proved that a PLOS level of ‘D’ and ‘E’ were sufficient for the machine to work efficiently.

Assuming all pedestrians from the three selected street segments weighing above 50 kg would step on the prototype, a total of 147.53volt electric output would be harvested from the first machine and 484.78volt output from second the modified machine. The third modified machine would yield 279.35 volt for the same number of pedestrians and the final modified machine would yield 158.5volt. Table -14 shows the PLOS level and electric output of the selected street segments for the prototype. It shows the difference in the output throughout the modifications of the prototype and the efficiency of the system in relation to the street segments studied under the study. The electric volt out put is related with the number of pedestrians from the selected street segments for the average output recorded on the four prototypes tests.

Table 14: Electric volt output for the selected street segment's PLOS level

Segment	PLOS	Pedestrians number (No)	P-1	P-2	P-3	P-4
Piassa	E	298	58.23	190.72	110.26	62.6
Aratkilo	E	270	52.76	172.8	99.9	56.7
Mexico	E	187	36.54	119.68	69.19	39.2
	mean values	252	49.18	161.07	93.12	52.8
Total			147.53	483.2	279.35	158.5

The voltage output for the first test (P-1) illustrated in Fig-6 shows a positive relation (relation coefficient of 0.9) with the weight. The available space on the machine for more dynamos and the need to increase the output were the reasons for modifying the prototype. The modification included adding dynamo at the other side of the machine. The voltage output of the second test (P-2) is presented in Fig - 7.

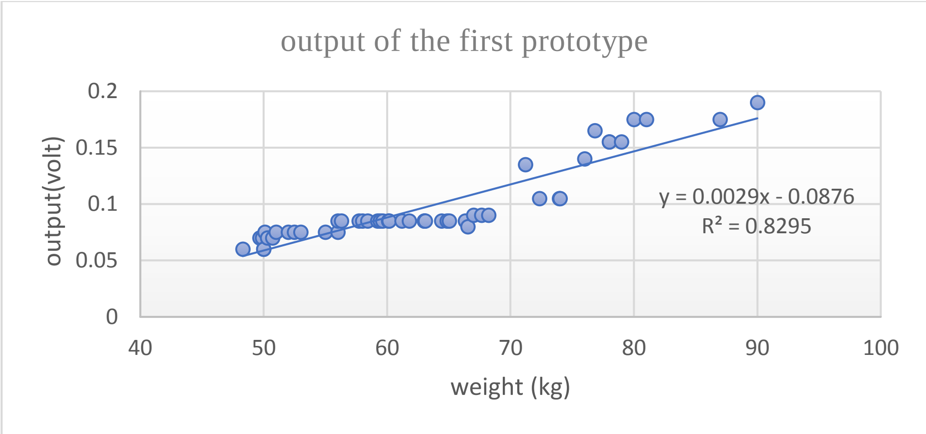

***Figure 6**:* Energy output of first test.

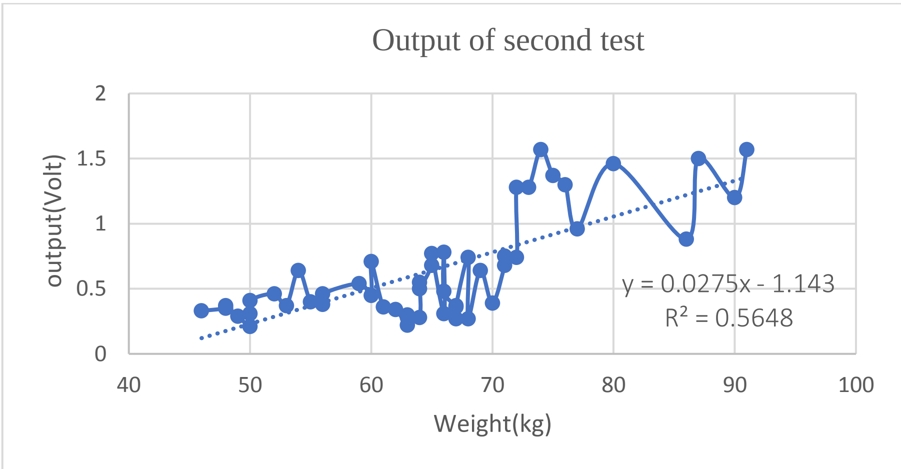

***Figure 7**:* Energy output for second test

The weight and electric output during the second test (after the first modification) also showed a positive relation (relation coefficient of 0.75) but slight differences were observed on the output after the modification. The fluctuation in the output was due to factors such as stepping speed (the speed with which the machine stress downward and upward) and resistance due to the length of the copper wires. The average output however increased after the modification. The minimum and maximum weights recorded during the first test were 48.3 and 90 kg respectively. The second test, for the modified prototype, was done on participants weighing from 46-91kg.

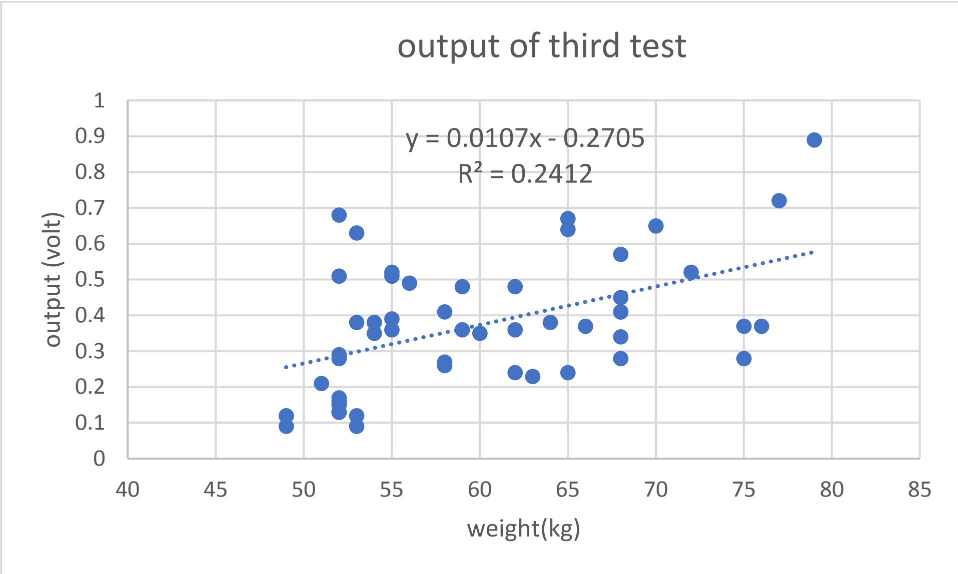

Figure 8: Output of the third test (P-3)

The third modification included replacing the wood system with a metal rods to avoid horizontal motion of the steeping plate, constructing a metal box to contain the machine and plastering square tiles (30*30cm) on the steeping plate to increase its aesthetics and decrease the loud noise of the machine by absorbing it in to the synthetic and the result is shown in Fig-8.

The minimum and maximum weight of participants during this test was 49 and 79 kg respectively. The result showed that weight and electric volt has a positive relation (relation coefficient of 0.5). During this test the same weight has been seen to yield varying output because of difference in the steeping speed, resistance due to length of the copper wire and friction between the stepping plate, supporting metal rods at the corner of the machine and the way of stepping by pedestrians or simply put due to the modification of the machine.

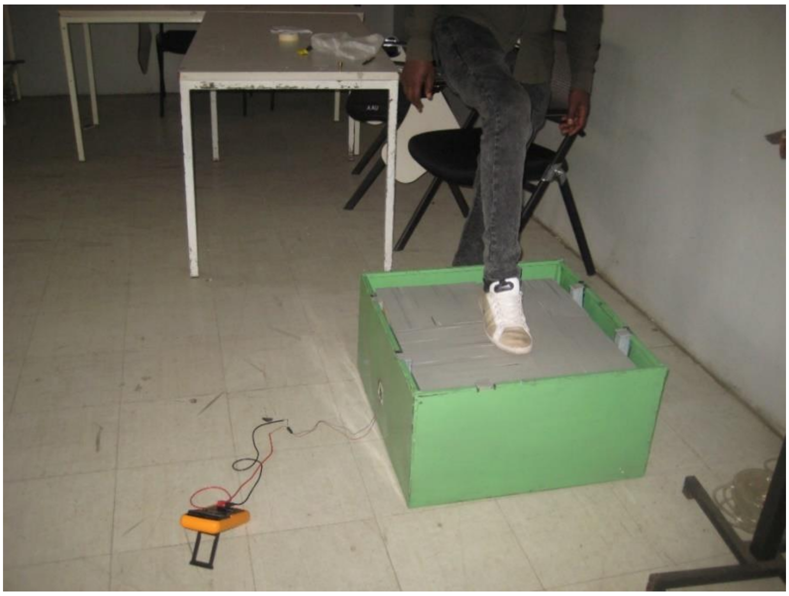

***Figure 9**:* Prototype test set up (P-3)

The final modification was aimed to resemble the machine as if it would be placed on an actual pedestrian walkway. Cladding the machine with a square wood plate of length 75*75 cm and plastic tiles (30*30cm) so as pedestrians would not fall while stepping on the machine and shield the machine from any external materials that will defunctionalize it as shown in Fig-9. The first group of sample size 24 was experimented on the prototype with weight ranging from 49-78 kg. the *t*-test showed a (*p* value of *1.1495E-25).* An average output of 0.21 volt was recorded as indicated in Fig- 10.

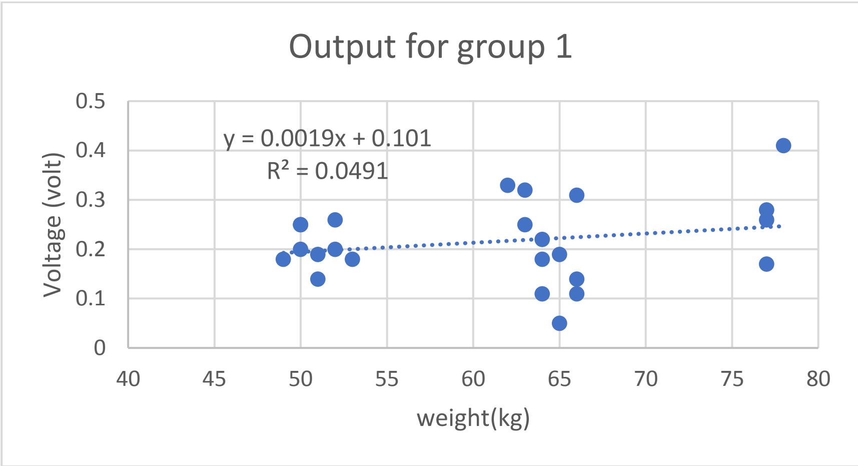

***Figure 10**:* Output of the experiment(P-4)

After the experiment a two tailed unpaied *t*- test has been conducted and a value of (*2.50954E-20)* show there is a significant difference in the electric output for different weight of pedestrians. The second group of different weight ranging from 54-76 kg. For this group an average output of 0.20 (see Fig- 11) volt was recorded showing that the similar weight the electric output was close to be same.

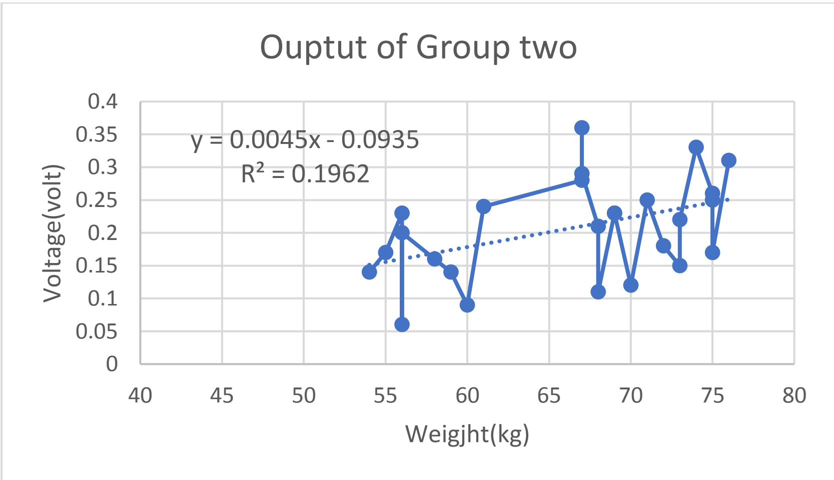

***Figure 11**:* Experiment result of group two.

The loud noise produced by the machine has been greatly decreased after this modifiction due to the attachment of the rubber band around it. The output has shown a reduction in value which was 0.21 volt. The pedestrian weight and voltage has been recorded to be postively related on this test (relation coefficient of 0.3).This reduction in output was the result of the new modifications which increased the friction between the stepping plate and the supporting metal rods in side the machine. Cladding it with additional wood plate also increased the weight on the machine that reduce the downward stress of the plate.

The average output value of the machine has changed in the progression of modification so has the physical appearance as shown in Fig-12. The trendline disclosed a slightly increasing pattern in the average output of the machine. The average of the mean values from the prototype tests has a value of 0.33 volt for an average weight of 66.25 kg (see Annex E). The difference between the first and fourth test result which is 0.12 volt shows the modification on the machine has increased the energy yield.

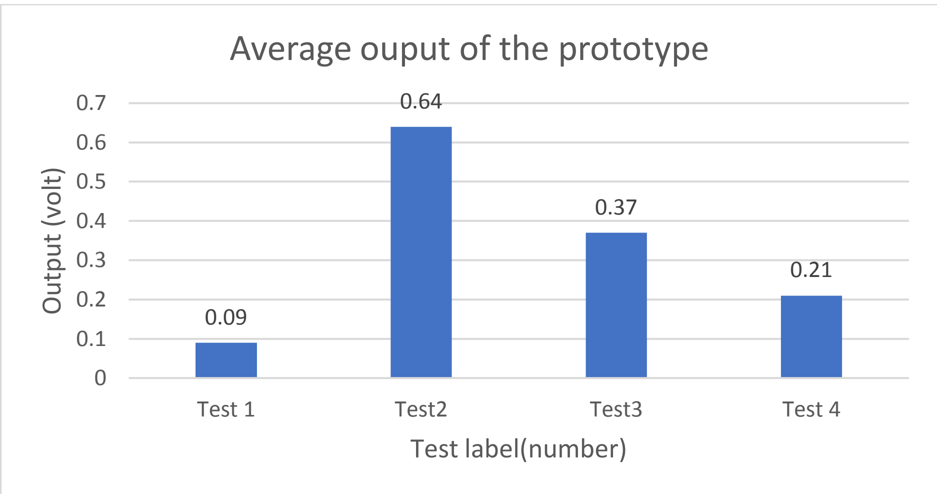

Figure 12: Average output of the prototype

5. Discussion

5.1. Design and Construction of the Prototype

The design of this technology used active mechanical energy harvesting technique consuming an intermittent energy source from human walking activity to harvest energy. Paulo and Gaspar (2010) mentioned the factors affecting energy harvesting from human as temperature, humidity, air stiffness, ecological and physical activity, body are subject to padding. This energy harvesting mechanism is directly and indirectly affected by these events since these factors affect the number of pedestrians. The prototype design and construction has tried to minimize the effect of these factors by using locally available materials and avoiding complex system that need more effort from pedestrians. Since the machine is to be placed below the side walkways, pedestrians are only expected to step on it in order to exert weight, no other interaction is required. The system uses this pedestrian weight to harvest and generate electrical energy. The designed technology used a simple electro - mechanical system that uses energy fields involving human walking as a transducer comprised of rack and pinon gear and a conditioning part that is the electrical system composed of dynamos. The output volt can be easily stored using batteries.

5.2. Identified Street Segments with large Pedestrian Flow

The street segments at Piassa, Aratkilo and Mexico area have a PLOS level of 'E'. As Watson *et al.,* (2003) explained in their work, normal pedestrian flow was also restricted on these street segments. Reverse flow and bypassing slow moving pedestrians was inhibited in these segments. Due to the presence of street obstacles high shuffling and platooning were also observed as discussed in the HCM (2006, 2010). Factors affecting pedestrian number and movement on the walkways included street obstacles such as street vendors, street furniture, queuing and platooning due to transport facilities which affected the overall pedestrian flow. This has also decreased the effective width of the walkway pointing that the identified street walkways were malfunctioning. The "E" PLOS level of the segments proves their capacity to accommodate dense pedestrian flow though the necessary infrastructure is not well provided. A PLOS level more than "E" is likely to over congest the walkways. It will also inhibit the movement of pedestrians which challenge the need for a dense pedestrian flow in order to harvest energy.

5.3.Efficiency of the Prototype

The weight and the energy output has shown a strong positive relation. This dictates that if all sampled pedestrians of weight group above 50kg would step on this prototype, energy (158.5 volt) could be continuously harvested within 15 minutes during peak hours of week days. The average output of the machine was relatively low but, using the dense pedestrian flow as a multiplying factor, more energy can be harvested from densely pedestrianized street walkways in the city. Physical factors that affected pedestrian's experience are likely to affect the efficiency of the machine because a reduction in the number of pedestrians implies less weight which yields low energy output.

This energy harvesting prototype differs from works of Hayshida (2000) in simplifying the complex gear systems used in previous work. This machine has a similar concept to magnetic induction generators stated by Sojan and Kulkarni (2016). Previous works by Kymissis (1998), Hayshida (2000) and MIT engineers stated in (Yildiz *et al.,* 2011) used a wearable system on human body (muscle), but this new system does not require people to wear any item on their body. It only requires pedestrian's weight to press the machine down while stepping on. The work by Ghosh *et al*., (2013) has harvested 80-95 V using more gears and magnetic flux system where as this machine differs in using small gears to generate small output. The work by Tom *et al.*, (2013) used similar rack and pinon techniques to light a lamp installed in the pavement. The prototype machine constructed under this study has a wide space for electrical adjustment and can accommodate more dynamos on all directions under the stepping plate. It is easy to measure the output voltage and repair it once installed. The pavegen green walkways concept used piezoelectric materials to generate energy. Even though their application is similar the prototype from this study uses electromechanical system to generate 0.21 volt (approximately 0.42W) of electric power. The difference in the output is attributed to the modifications on the machine and difference in the weight of the pedestrians

5.4.Application of the Prototype

This technology can be used to light LEDs, street lights, charge electric equipment after storing the energy yield. It can be scaled up in areas where there is large number of pedestrian such as stadiums, large public open spaces and transport stations in addition to walkways with large pedestrian flow with PLOS level of 'D' and 'E'.

The electrical energy output from the machine can be stored in battery. It allows a range of weight up to 300kg. It can be easily constructed and installed. It can also accommodate relatively wide electric system and have space for additional mechanical system (Gear system). In spite of all these advantages the stepping plate creates little noise when stepped on it. This creates discomfort for pedestrians when installed on actual walkways. The machine occupies relatively small space ($0.5625m^2$).

6. Conclusion

Street segments at Piassa, Aratkilo and Mexico areas with PLOS level ‘D’ and ‘E’ were found to be fit for the well-functioning of the prototype. The laboratory test showed that the prototype harvested an average of 0.21volt for weight group between 49-78kg (average weight of 66.25 kg). The efficiency of the prototype was affected by number of steps of pedestrians, the speed of compression of springs, friction between the stepping plate and supporting metal rods and resistance due to length of wire. Since the experiment was limited to a laboratory scale, it cannot be certain to conclude for the street segments in the city.

The prototype can be scaled up on public and semipublic urban areas for further study. Aesthetics and disturbing sound of the prototype were the major drawbacks of this system that calls for further modifications.

The findings from this study showed that by harvesting energy from the environment, cities can save more energy. This study opens an avenue for further exploration in the link between human movement and energy harvesting mechanisms in cities.

7. Recommendations

Harvesting renewable energy from the surrounding urban area is essential to build sustainable city. Urban design as an interdisciplinary field should focus on exploring the potential of different energy sources from the environment. Energy sensitive urban design solutions, such as this energy harvesting system, should be encouraged. Design of such systems should also incorporate urban design elements that are readily available in the environment and the urban public realm itself.

Pedestrian friendly streets need to be promoted in the city so as to improve the pedestrian flow in order to generate more energy output from this technology. This machine need to be scaled up on areas with dense pedestrian flow and streets with PLOS level of ‘D’ and ‘E’ such as Piassa, Aratkilo and Mexico as identified in the study.

Further study is compulsory to modify the comfort and efficiency of this machine. Experiment on pedestrian walkways is necessary to investigate the link between this system and pedestrian flow in detail.

Two installation mechanisms are recommended for the prototype when scaled up, single machine installed at the center of sidewalk way (walking quarter) as shown in Fig-13 and 14 and multiple machine installation in all the quarters of the side walkway in order to increase the energy output as illustrated in Fig-15 and 16. The prototype when scaled up should be placed below the level of side walkway.

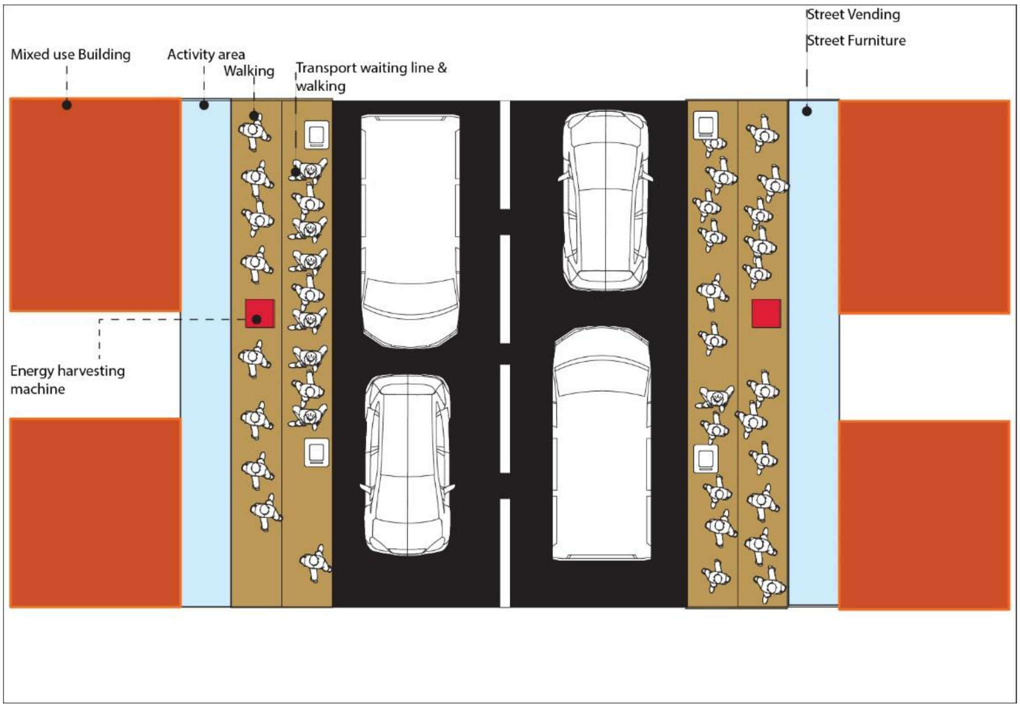

***Figure 13**:* Alternative one, single machine installation.

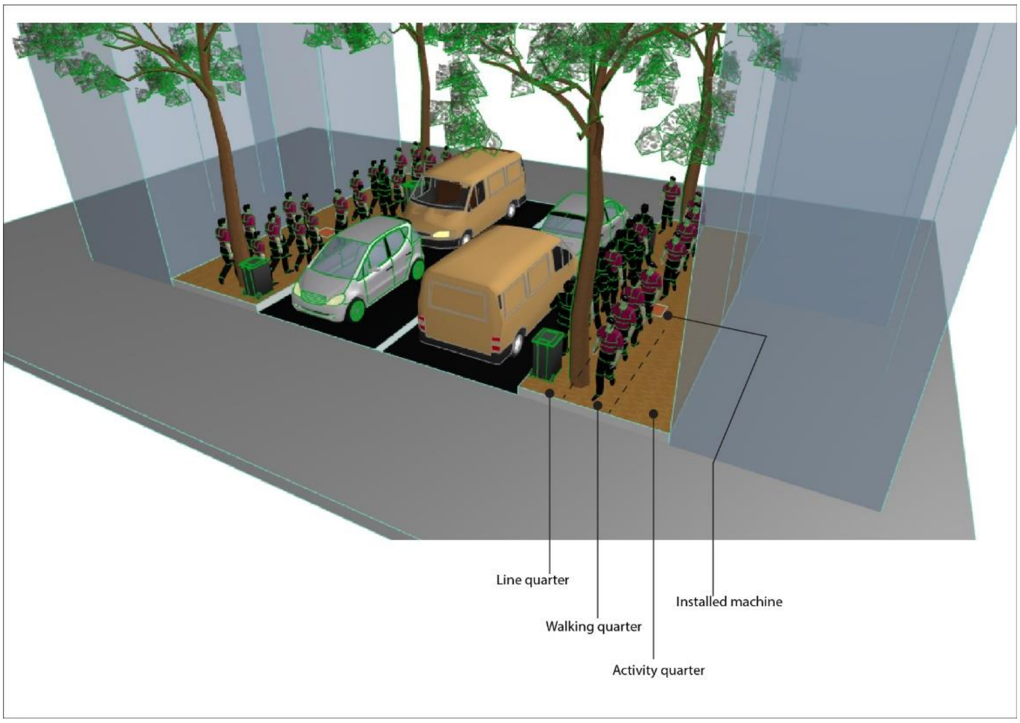

***Figure 14**:* Alternative one 3d view

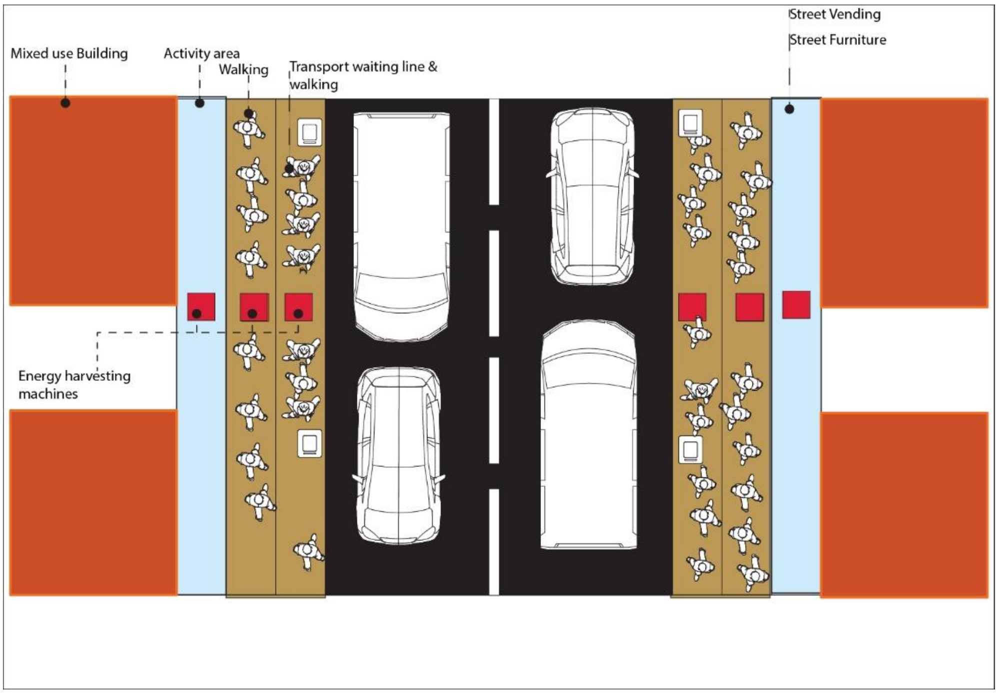

Figure 15: Alternative two, Multiple machines installation

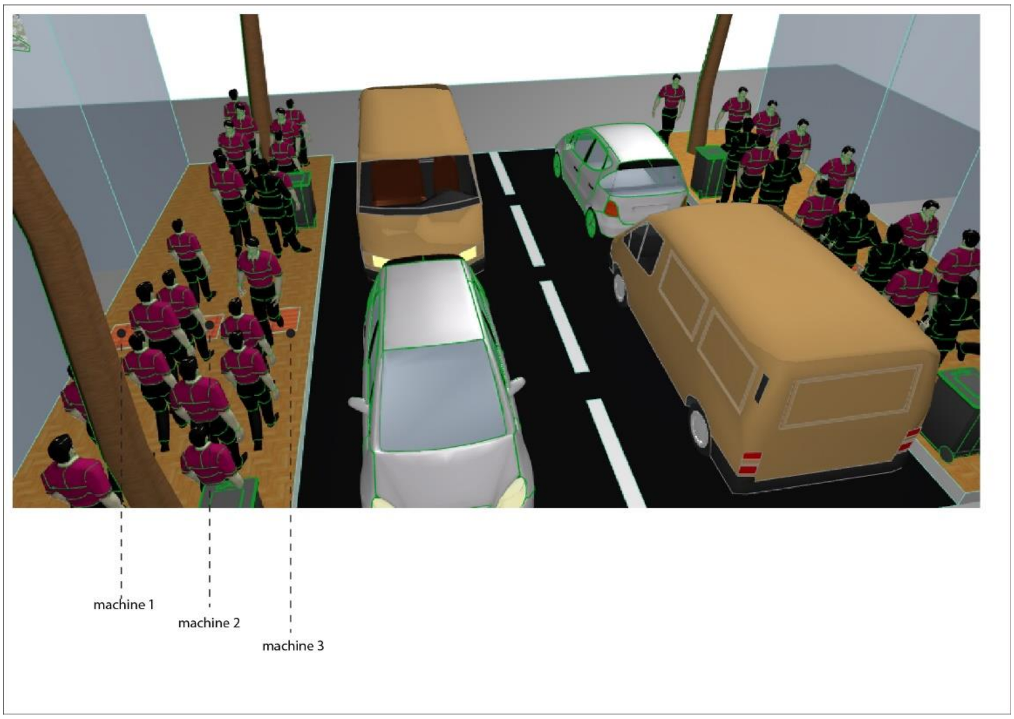

Figure 16: Alternative two 3d view

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8.2. Annexes

A. Pedestrian speed Count Sheet

Ethiopian Institute of Architecture Building Construction and City Development (EiABC)

PEDESTRIAN SPEED COUNT SHEET

Name [ ]
Location [ ]
Adjacent land use [ ]
Direction [N/S] [E/W] [S/N] [W/E]
Total Street Width [ ]
Effective Street Width [ ]

Platooning [Yes] [No]
Reason for platooning: Signal [ ] Street Geometry [ ] Vendors [ ] Others [ ]

Side walk pavement: Asphalt [ ] Coblestone [ ] Earth mat. [ ] Gravel [ ] Other [ ]

Side walk pavement: Very bad [ ] Bad [ ] Fair [ ] Gravel [ ] Very good [ ]

Date [ ]
Day [ ]
Weather [ ]
S.Time [ ]
E.Time [ ]

Pedestrian roll number (#)	Gender	Age	Size	Luggage	Disability	S.Time	E.Time	
	M [ ] F [ ]	<15 [ ] 15-50 [ ] >50 [ ]	small [ ] Medium [ ] Large [ ]	Y [ ] N [ ]	Y [ ] N [ ]			

B. Pedestrian LOS Count Sheet

Ethiopian Institute of Architecture Building Construction and City Development (EiABC)

PEDESTRIAN LOS COUNT SHEET

Name [ ]

Location [ ]

Adjacent land use [ ]

Direction [N/S] [E/W] [S/N] [W/E]

Total Street Width [ ]

Effective Street Width [ ]

No. of Building Entrances and exit [ ]

Obstacle [Yes | No]

Obstacle Type

Tree [ ]
Furniture [ ]
Vendors [ ]
Others [ ]

Que [Yes | No]

Que Attractors

Facility [ ]
Public scene [ ]
Others [ ]

Date [ ]

Day [ ]

Weather [ ]

S.Time [ ]

E.Time [ ]

Street ID	Time interval(minute)												Remark
	5	10	15	20	25	30	35	40	45	50	55	60	

C. Site selection criteria

Criteria for grading	Megenagna	Mercato	Piassa	Arat Kilo	Mexico	Bole
Proximity to the main city center	1	5	5	5	5	1
Representativeness of other walkways	4	4	4	4	4	4
Prevalence Large pedestrian flow	3	1	4	4	5	5
Presence of separate pedestrian walk way	5	5	3	3	4	2
Total sum	13	15	16	16	18	12
Grade	3.25	3.75	4	4	4.5	3

1. **Proximity to the main city center**

1= Located inside the main city center of the city(MCC).

2=Located within 5 km radius from the MCC.

3=Located within 10km radius from the MCC.

4=Located within 15km radius from the MCC.

5= Located within 20km or more radius from the MCC.

2. **Representativeness of other walkways.**

1= Very good

2=. Good

3= Fair

4=bad

5= Very bad

3. **Prevalence Large pedestrian flow.**

1=Small pedestrian flow throughout the day.

2=Average pedestrian flow Only on peak hours

3=Average pedestrian flow throughout the day.

4=Large pedestrian flow only on peak hours.

5=Large pedestrian flow throughout the day.

4. **Presence of separate pedestrian walk way**

1= No clear demarcation of walkway from vehicular path along the segment.

2= No continuous demarcation of walkways from vehicular path along the segment.

3= Demarcation of walkways from vehicular path along the segment exist but not

4= Good demarcation of walkways from vehicular path along the segment.

5=clear demarcation of walkways from vehicular path along the segment.

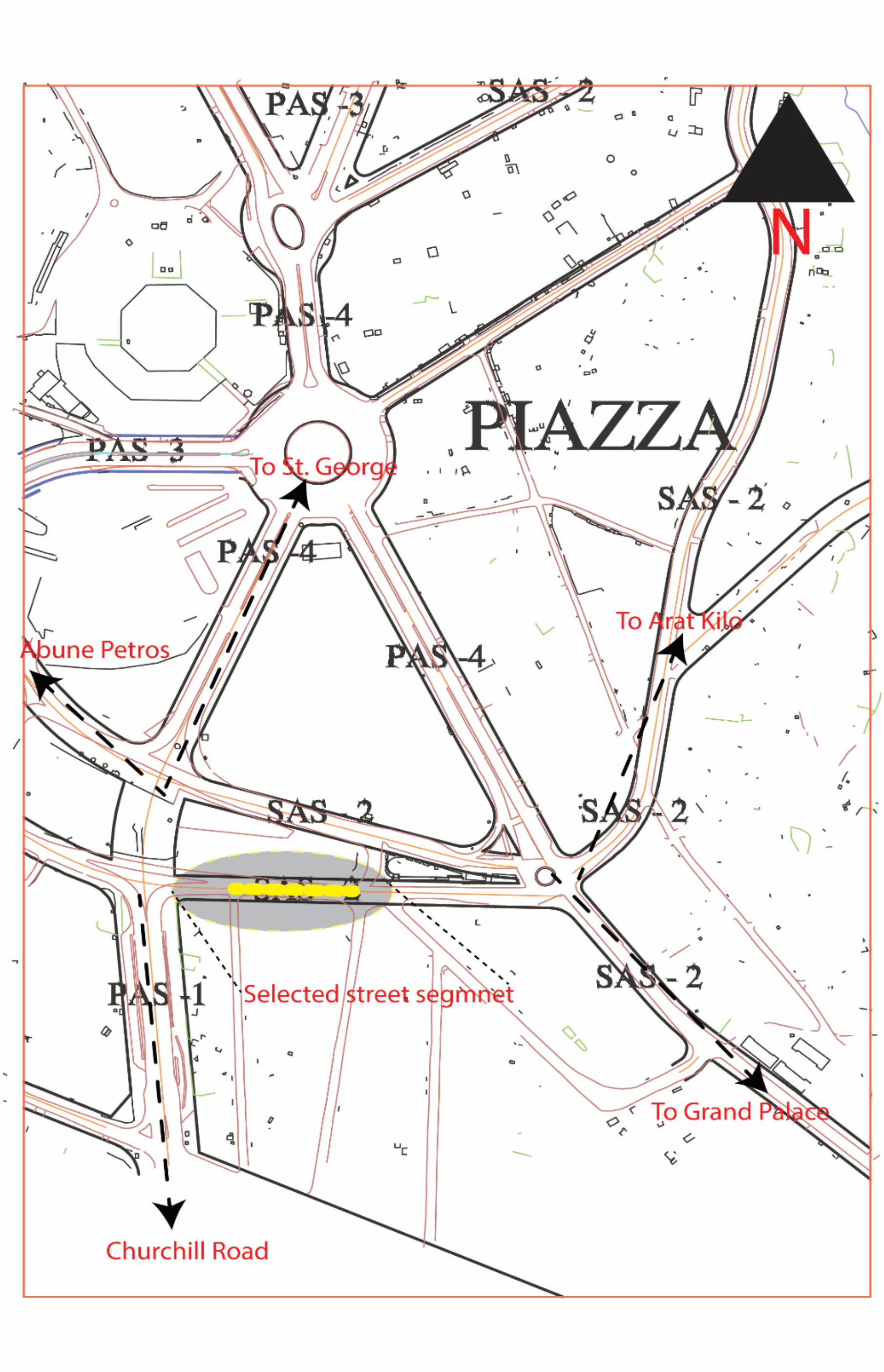


Figure 17: Piassa street segment.

The segment marked by yellow dashed line, along the former 'mahmud muzika bet' was selected for PLOS analysis

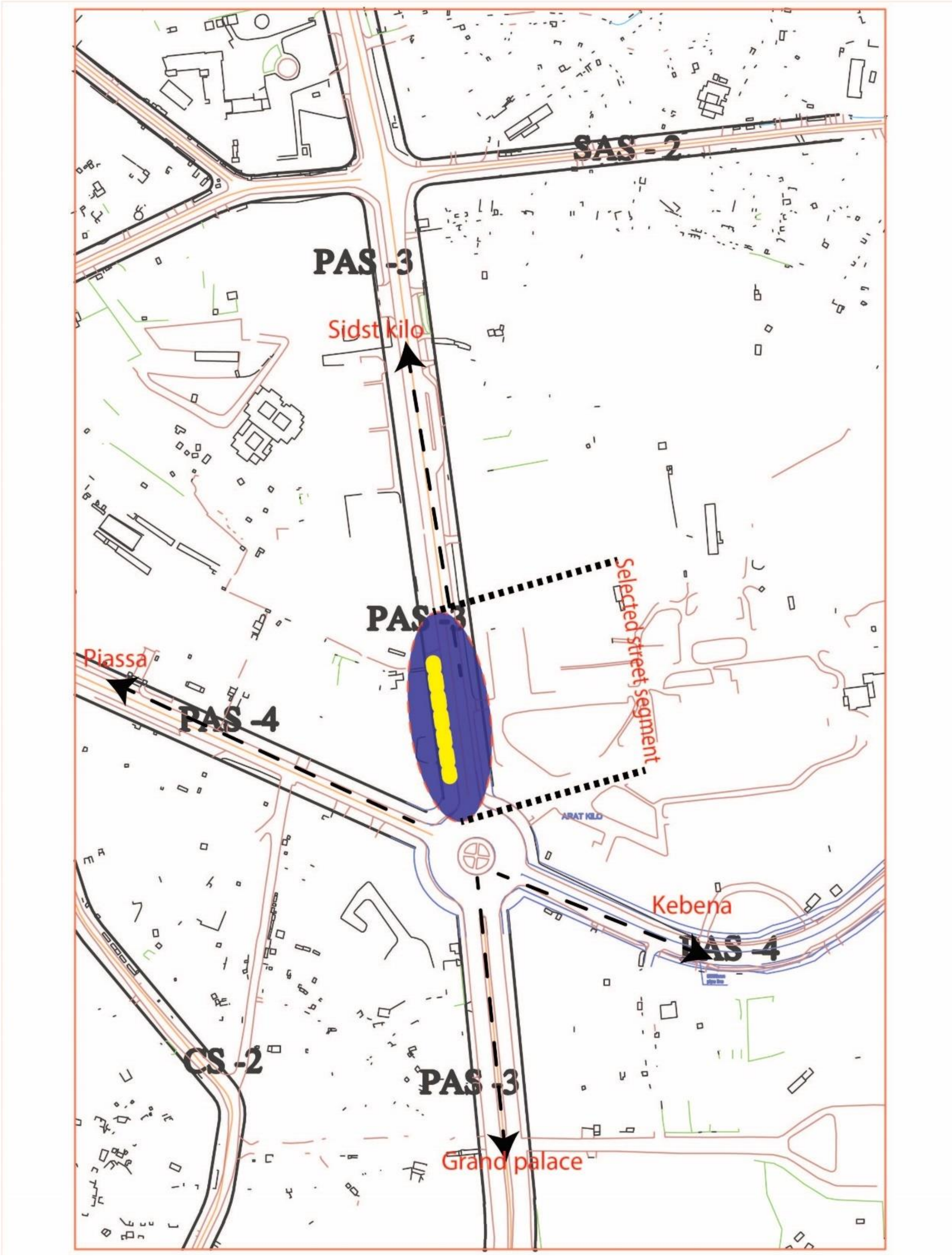


Figure 18: Aratkilo street segment

The segment marked by yellow dashed line, in front of Addis Ababa University was selected for PLOS analysis.

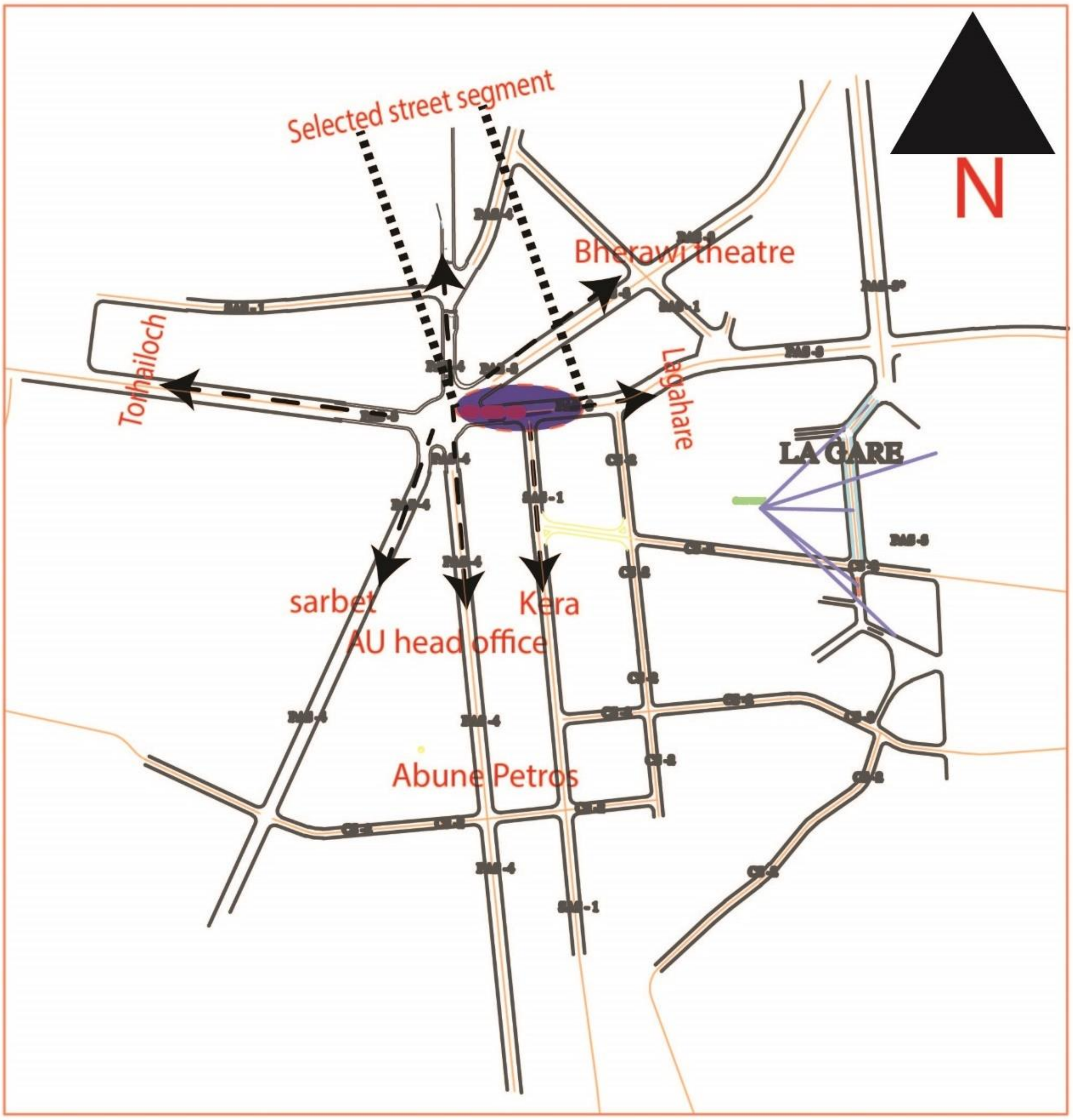
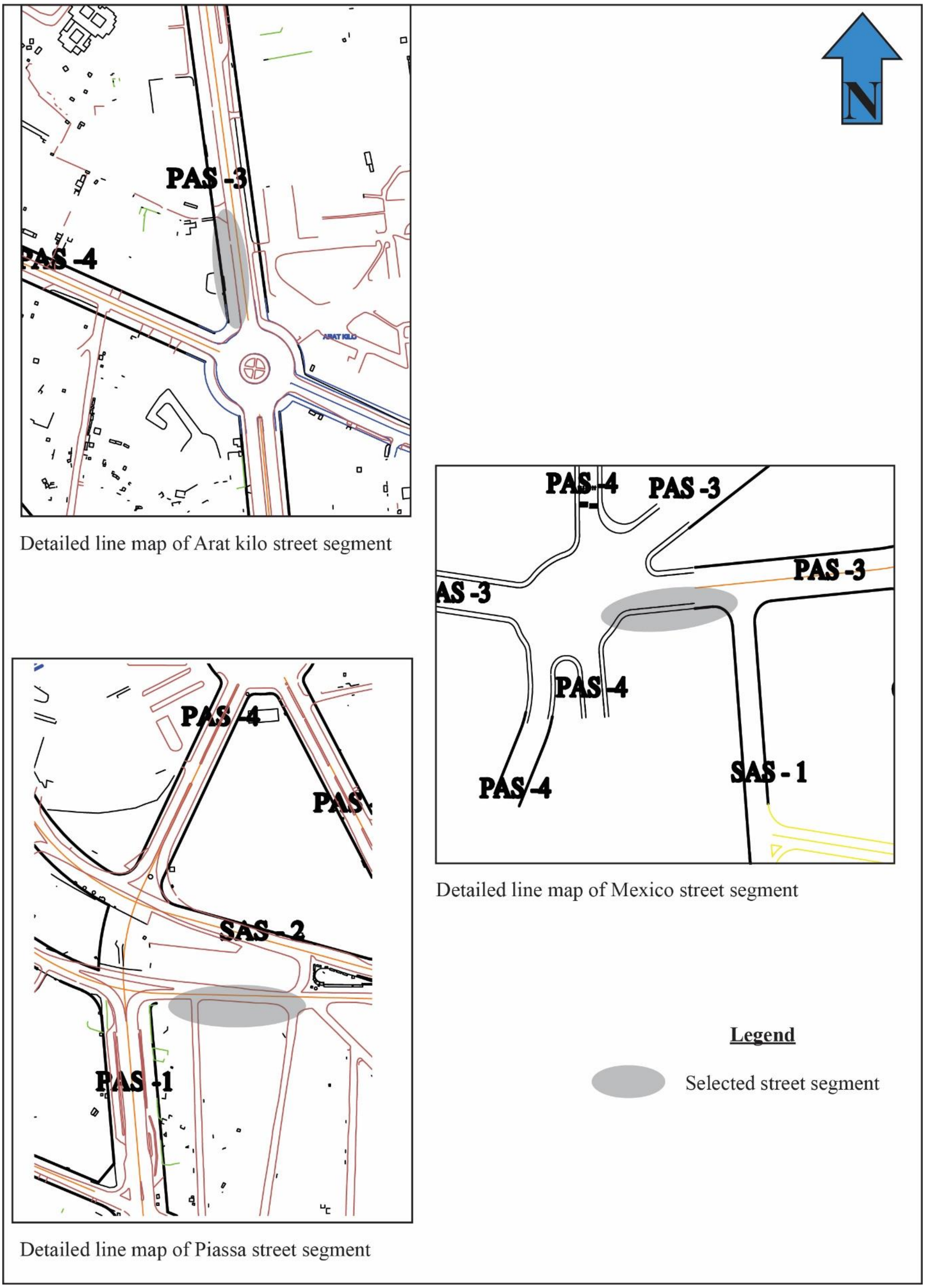


Figure 19: Mexico street segment

The segment marked by red dashed line, along EEPCO was selected for PLOS analysis.



Detailed line map of Arat kilo street segment

Detailed line map of Mexico street segment

Detailed line map of Piassa street segment

Figure 20: Detailed map of selected street segments.

D. Prototype Detail Drawing

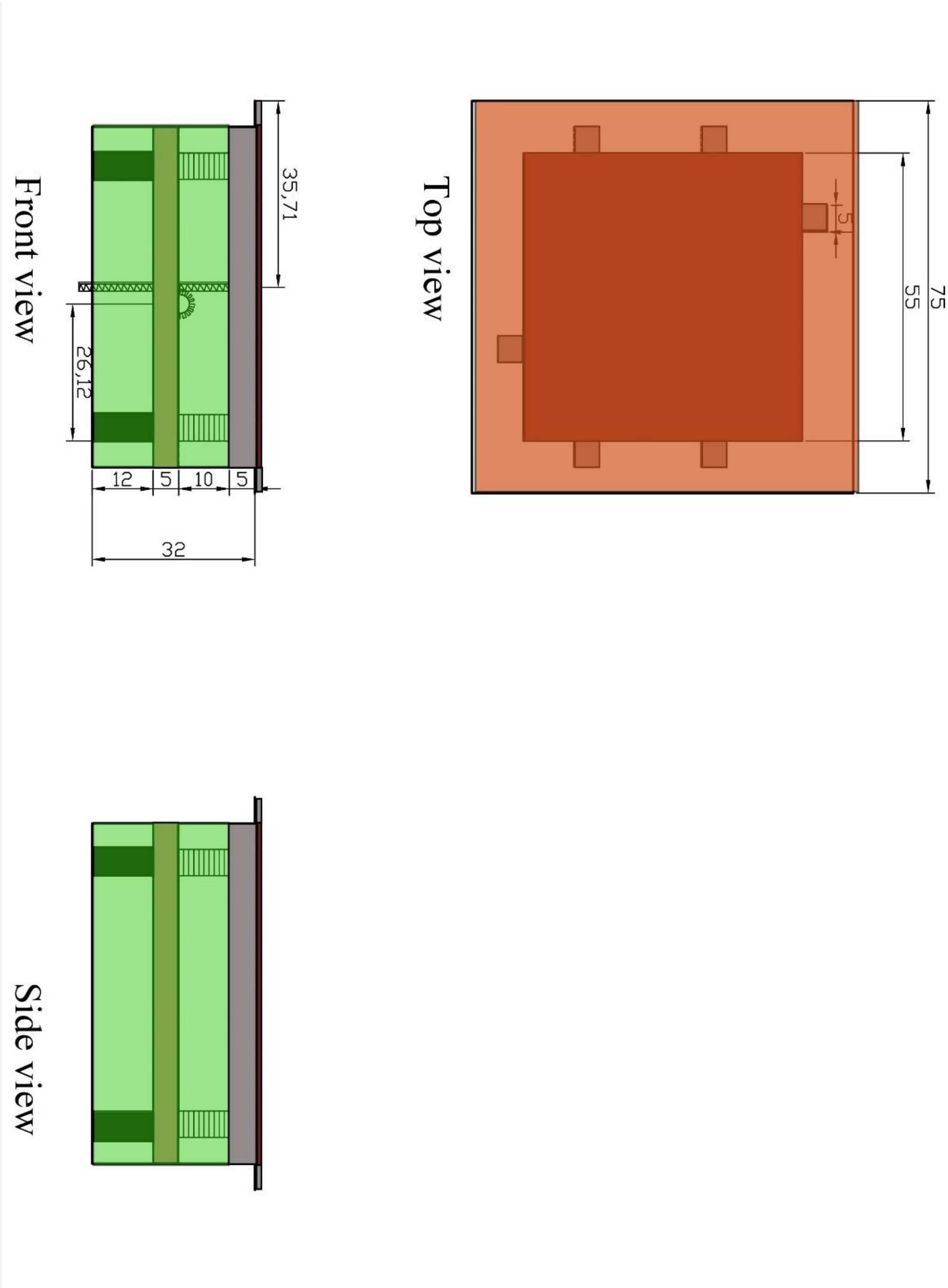


Figure 21: Detail drawing of the machine

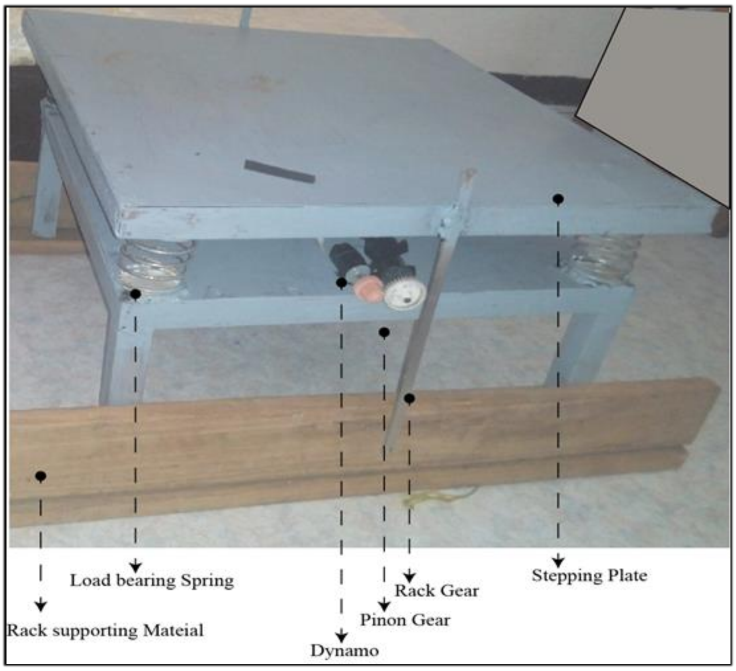


Figure 22*:* The pre - modified prototype illustrated

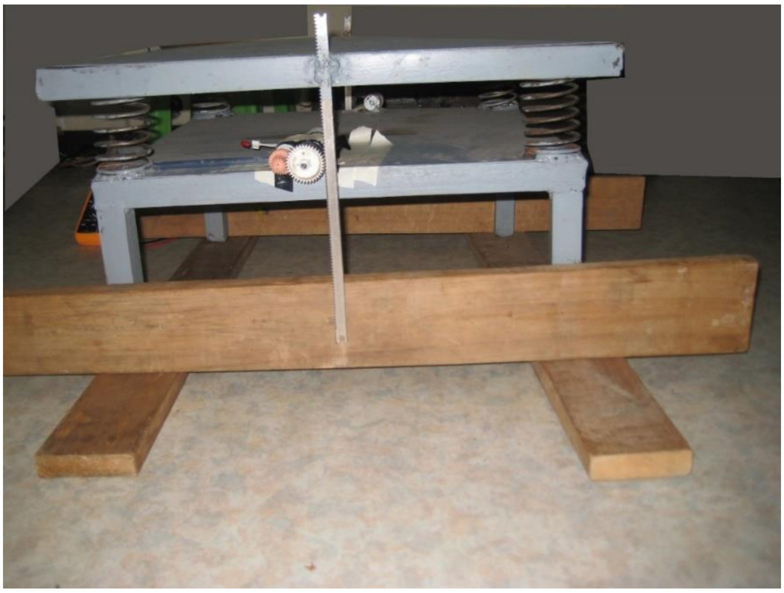


Figure 23*:* Photo of the machine before modifications.

***Figure 24**:* Photo of the modified machine and the metal box

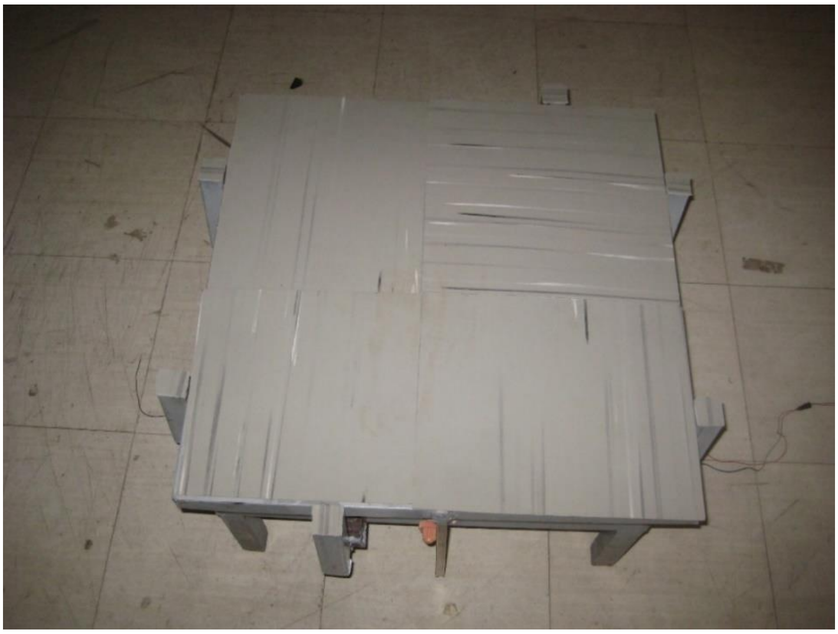


***Figure 25**:* Top view of the machine out of the metal box (container)

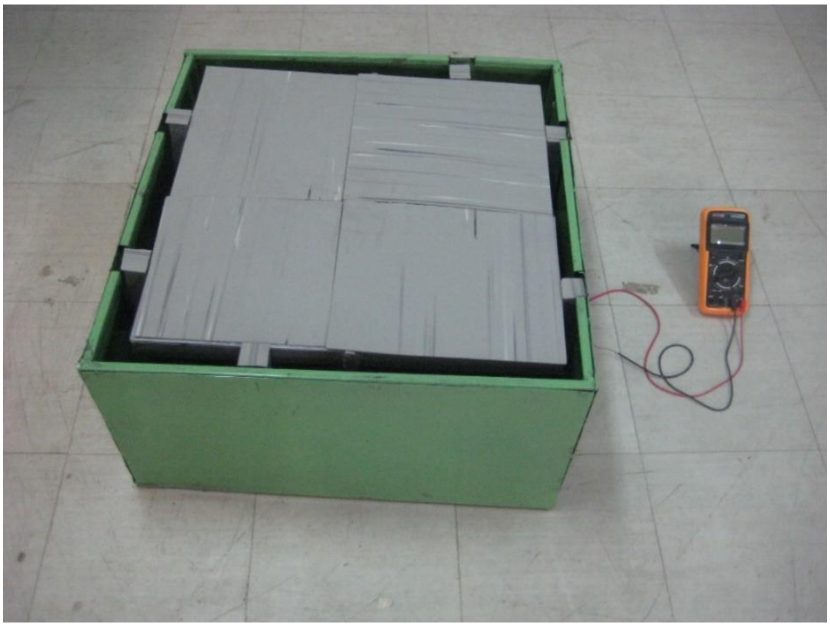


***Figure 26**:* Aerial view of the prototype(P3)

***Figure 27**:* The final modified prototype.

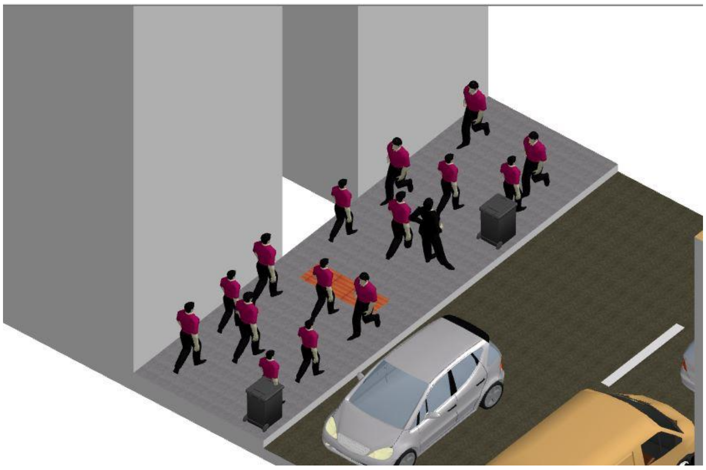


Figure 28: The prototype installed on street walkways

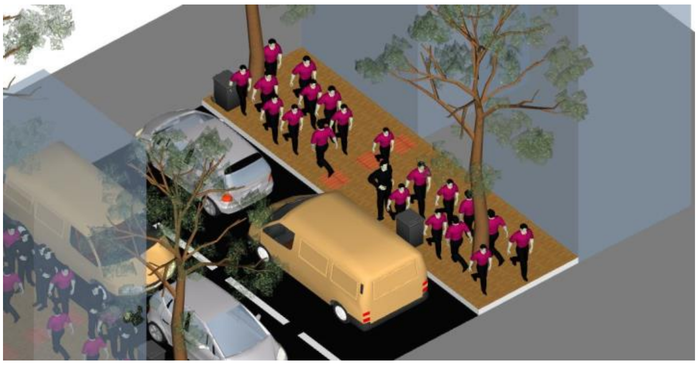


Figure 29: Prototype installed on the street walk way

E. Test Result for the Three tests on the prototype

Table 15: Output of the three tests

	Min. weight (kg)	Max. weight (kg)	Average output (volt)	Sample size(no.)
Test 1	48	90	0.09	51
Test2	46	91	0.64	51
Test3	49	79	0.37	51
Test 4	49	78	0.21	51
mean	48.00	84.50	0.33	
Average Weight	66.25			