Solar Powered Waste Compaction Bin

By

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Approval Sheet

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Abstract

Solid waste generation globally is on the rise parallel to the massive rise in world's population. 33% of the solid waste which is generated annually is not managed in an environmentally friendly manner. (Bank, 2021) With rapid population growth, the waste generation per capita is expected to increase by 70 percent from the current levels to 3.40 billion tons in 2050. Despite the solid waste generation rising by such whopping amounts, the unsustainable collection of waste remains the major challenge. Compared to residents of developed nations, the residents of poor developing nations are severely impacted by untimely and unsustainable waste management. Pakistan generates about 49.6 million tons of solid waste per year, which has been increasing at a rate of 2.4 percent annually. (Guide, 2022) However, like other developing nations, about 40 percent of waste in Pakistan goes uncollected in metropolitan cities like Karachi with the situation being even worse in the smaller cities. This uncollected waste remains dumped on the streets, parks, and empty plots leading to severe health and environmental impacts. To meet this alarming challenge, proper waste collection and handling mechanisms are required to reduce waste generation by 2030 which is the Target # 05 of the sustainable development goal 12-Responsible Consumption and Production. The objective of this project is to design a solar powered waste compaction bin which helps in proper collection and segregation of waste according to several types to reduce the health and environmental impacts of improper waste management. The project also aimed at making the people aware about the health and environmental impacts of improper waste management. The bin is designed using locally available, economical feasible, and environmentally viable materials to optimize the costs and achieve the desired results. The bin is designed smartly so that it detects the type of waste that was thrown in. The types of waste that can be detected have been set as metal, paper, plastic and general (food, glass, etc.). The bin comprises of 3 different compartments for holding the segregated waste with an overall capacity of 120 liters. When the fill level in the bin reaches 80 percent, the sonar sensor on each bin detects and activates the compaction mechanism. The compaction stops when the fill level in the bin has reached 30 percent. The bin was tested at two different locations namely IESE and Concordia-I at NUST main campus. Based on the results obtained and analysis of the data, it is analyzed that the bin reduces waste collection frequency from 7 days a week for a standard 120 liters bin to once a week. The bin also saves 2.08 tons of CO_2 emissions per year. Thus, the proposed system can be employed at mass level to reduce waste generation substantially and thereby reduce the health and environmental impacts of improper waste management.

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1. Introduction

This chapter discusses about the current situation of waste management worldwide. It also includes details about the problem that we are trying to address by creation of our model. Furthermore, it discusses the objectives that we intend to achieve and novelty of our idea.

1.1 Global Situation at a Glance

The waste generation rate is increasing at an alarming rate all over the world, 4 years ago, cities over the globe generated around two billion tons of solid waste, generating a carbon footprint of about 0.74 kilograms per person per day. With the population expansion at a rapid rate combined with the urban sprawl, the waste generation per year is estimated to increase by 70 percent by 2050.

The modern economy is posing a serious threat to the environment owing to the increasing volume of waste generated, the technological advancements increasing the complexity of waste are rendering waste management more difficult and creating ecosystem and health hazards. According to the data gathered by the UN, about 5 percent of the greenhouse gas emissions are generated by the decay of organic proportion of solid waste.

The problem of waste management in developing parts of the world is more alarming than that in the developed nations. The residents of developing countries, especially those which are economically challenged are the most affected by inadequate and unsustainable waste management practices. According to a survey by the World Bank, more than 90 percent of the waste is disposed of unregulated or is openly burned leading to environmental and health hazards. The unregulated dumps and open burning of the waste create serious environmental and health safety consequences. This untreated, poorly disposed, and managed waste serves as a breeding ground for disease causing organisms. This waste is also a source of methane generation which is a major contributor to the global climate change problem, moreover, it can also promote urban violence.

For the building of a cleaner, aesthetic, livable, and sustainable city, it is essential to have a proper waste management system. A proper waste management system is an expensive practice comprising a major portion of the municipal budget, hence is a challenge for many underdeveloped and economically challenged countries and cities. An efficient sustainable and integrated system is required to make this essential municipal service operational, another key factor to make this work is social support.

One of the biggest problems created by waste management practices is an increased carbon footprint, fuel, and energy requirements, and aesthetic issues. The current waste collection system requires repeated small collection cycles of solid wastes from malls, schools, cafes, and residential and commercial areas then taking them to the management facility, where the waste is segregated and compacted using energy hence increasing the carbon footprint. So, there is a need for a waste management system that can separate different waste types, compact them increase the waste holding capacity, and all that without using the conventional energy resources.

The "Solar Powered Waste Compaction Bin" provides the solution to all these problems. The bin serves its purpose by using solar power to run its machinery and hence does not require any additional energy source. The bin uses image processing and sensors to segregate the waste and then the compactor to compact the waste increasing the waste storage and in turn reducing the collection cycle. There are still some questions about whether it is applicable at every level or is it an economically viable option, but further refining of the processing and sensor availability and design research can be a golden milestone in the history of humankind.

1.2 An Insight into the Sustainable Development Goals

SDGs abbreviated for Sustainable Development Goals are the set of goals developed by the United Nations in 2015 to achieve a sustainable and better future. 17 goals are interlinked, to ensure a sustainable future these goals need to be achieved. The goals address the challenges faced by the world for a better future. The mission of these goals as stated by UNSDG is:

"A blueprint to achieve a better more sustainable future for all by 2030." (UNSDG)

Our project is aligned with SDG-12 which is "to ensure sustainable consumption and production patterns." (UNSDG) and target 12.5 which is "sustainably reducing waste generation" (UNSDG). The interlinked SDGs with our project are SDG1 "no poverty", SDG-3 "good health and well-being", and SDG-11 "sustainable cities and communities". SDG 7 highlights the sustainable waste generation and waste reduction techniques, SDG-1 deals with the reduction of poverty by the quote of waste is gold, and SDG-11 highlights actions and practices to have sustainable and cleaner cities and communities for all.

The Solar-powered waste compaction bin known as SO-WAB, meets SDG 12 by providing an energy-efficient and automated waste collection, separation, and compaction techniques, it caters to SDG 1 by providing a separated waste that can be used as a resource to help the economy, the project covers SDG 3 by providing a solid waste management practice that resolves health issues faced by the unsustainable dumping of solid waste which leads to different disease vectors.

SDG 12 is covered by resolving aesthetic, and environmental issues faced by the unsustainable dumping of solid waste leading to sustainable communities.

1.3 Facts and Figures

The data that helped us in the research and development of our projects are as followed:

The data shows the waste quantity generated, collected, transported, treated, and disposed of in different large, medium, and small cities and rural areas of Pakistan. The data is collected from waste management companies at Faisalabad, Rawalpindi, Multan, Peshawar, and cities of D.I.Khan, Okara and Hafizabad. The data has been collected from 2015 to 2022. The data has been taken from:

Table 1 Quantity of Waste Generated for Different Cities of Pakistan

Settlement Area	**Waste Quantity**					
	Generated Waste		**Collected Waste**	**Transported Waste**	**Treated Waste**	**Disposed of Waste**
	Daily Quantity (kg per capita per day)			**Yearly (million metric tons per year)**		**(% of waste generated)**
Large cities (11)	0.55	9.44	80	80	20	**80–100a**
Medium-sized and small cities	0.42	4.44	50–70	50–70	10	**90–100**
Rural communities	0.33	13.72	20	20	20	**80–100**
Total		**27.58**				

(Batool, 2008-2017)

The rate of waste generation and collection of solid waste in a few major cities of Pakistan are shown in a graph taken from (Mahar, 2019).

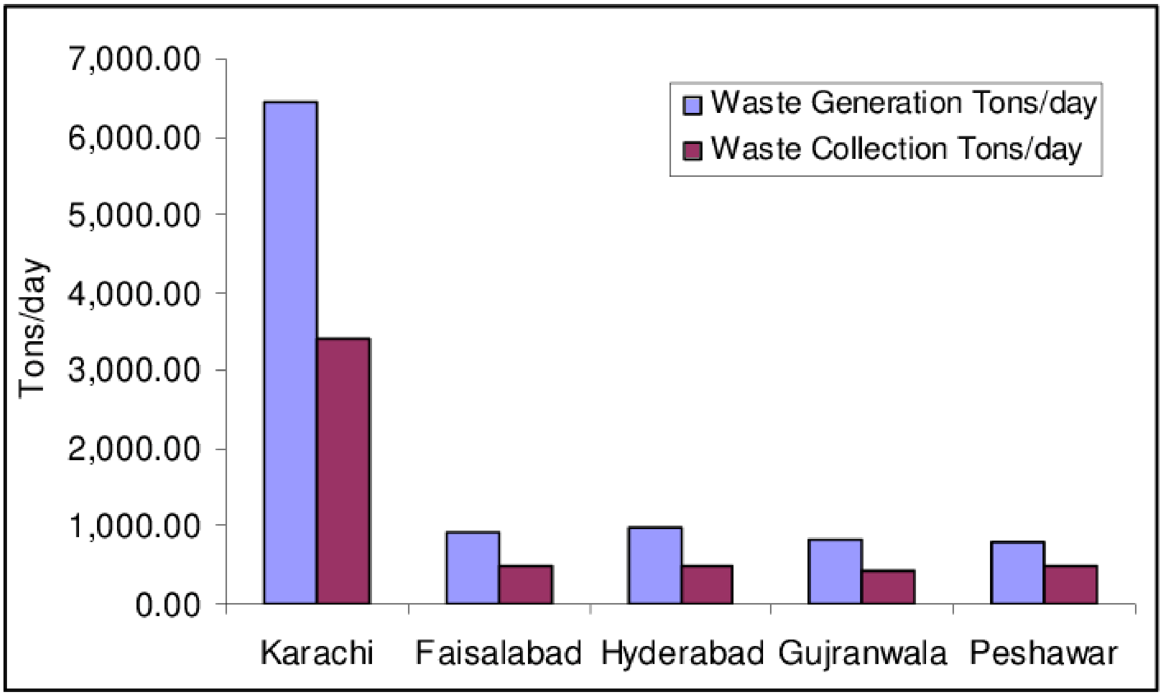

Figure 1 Comparison of Waste Generation & Waste Collection

1.4 Problem Statement

Pakistan comes in the list of developing countries, the solid waste management is a major problem in Pakistan, the solid waste is a source of deadly diseases, according to data, more than 5 million people die in Pakistan due to waste borne diseases. (Lew, 2021). In Pakistan there is the absence of proper solid waste management and collection system, this inadequate system leads to waste being dumped by the population in open, there are a few numbers of bins available that also overflow once they get filled which leads to an aesthetic problem in a community. The waste collection in Pakistan is a challenging situation because the administration lacks on-time for waste collection and taking steps to cater to the solid waste problems. The existing practices of solid waste management are very inefficient and expensive.

The existing servicing trash bins require manual labor to collect and swap the bins, and the heavy machinery and energy required for collection, separation, and compaction incur substantial operational costs. A shift to a smart collection system is the need for the hours

The solar-powered waste compaction bin provides the advantage of reduced waste collection frequency, cleaner public areas, data collection of waste, reduction in GHG emissions, and saving operational costs. However, apart from its advantages, the solar-powered waste compaction bin has its limitations, like high investment costs, and waste detection mechanisms that can be improved.

1.5 Research Objectives

The objectives of our project can be broken down into 3 parts:

a) **Awareness Generation**

To generate awareness among people using posters and social media about the effects of improper waste disposal

b) **Designing a smart waste management system**

Designing a socially acceptable, economically feasible and environmentally viable waste management system

c) **Comparison**

Comparing the system with traditional waste management practices.

1.6 Novelty/Innovation

Our project is the first project to combine the separation and compaction process in a single device, it is the first of its kind to use sensors and IOT to identify waste types and separate them based on their type, record data notify the authorities for the collection of waste, it uses a mechanical compactor to compact the waste segregated. The bin is completely automated and uses solar power as its electricity generation source.

1.7 Scope of the project

The scope of our project is to use easily available materials in the Pakistani market, do an economic analysis of the system for selecting the materials and development, analyze in detail the environmental impacts, and in turn development of an effective waste collection system.

1.8 Applications

The idea of developing an automated smart waste management system is to improve the waste collection at public sites, the initial application sites for our project are the airports, shopping centers different institutions, tourist attraction spots, and nonhazardous waste at hospitals and cafes, and restaurants. Not only it will create an aesthetic effect due to the design and hiding the waste, and promote a healthy and sustainable environment, the collected waste can be used to generate the revenue.

This chapter ends here and leads us onto the next chapter which is about literature review.

2. Literature Review

Tremendous research has been done globally on the issue of waste management. This chapter includes the details of the literature review that we did right from the stage of selection of the idea till the final defense. Literature review was done at stages of synopsis, first semester progress, second semester progress, final defense, poster competition and finally for the thesis itself.

2.1 Solid Waste Management Issues

In his research titled as “Solid Waste Management in Pakistan,” Engr. Muhammad Humayun Khan discusses that Pakistan has been generating about 50 million tons of solid waste anually and almost half of which goes uncollected. Even the waste that is collected is not collected based on several types of waste. This leads to a loss of revenues as waste is considered the new gold. Proper solid waste management (SWM) can lead to increased revenues for the municipality and the standard of sanitation can be tremendously improved leading to a reduction in health expenditures. (Khan, 2016)

Many projects and papers related to solid waste management have been written around the world. In the paper titled as “What a Waste – A Global Review of Solid Waste Management” the World Bank reports that currently the world’s cities generate about 1.3 billion tons of solid waste a year and it is expected that this generation will increase to 2.2 billion tons by 2025. (Bank, 2017) Moreover, the global impacts of solid waste are increasing as it is a huge source of methane, which is a powerful greenhouse gas. In the same piece of literature, the World Bank reports that the uncollected solid waste in developing countries leads to flooding, air pollution and spread of diseases such as diarrhea, fever, and many respiratory diseases. Apart from this, in lower income countries, solid waste management is one of the major budgetary items of a city. Thus, improving solid waste management should be of utmost priority as it benefits the society on sustainable grounds.

2.2 Model Design & Development

In the work titled as “Solar-Powered Compaction Garbage Bins in Public Areas: A Preliminary Economic and Environmental Evaluation” Poppy Jane Coleman and Long Duc Nghiem designed an excel-based model to assess the economic and environmental feasibility of placing solar-powered compaction garbage bins at public places in Australia. Input data were collected from Brisbane and Wollongong City councils, and Sydney Olympic Park. The results were very encouraging as the environmental and economic benefits of using these bins outweighed the use of normal bins. However, a reduction in monthly rental cost would be required for installation of the solar compaction bins to be sustainable. Moreover, these bins were feasible at locations where smaller number of bins is required. (Coleman, 2010)

In the research entitled “Design of a Waste Compactor,” (Vroom, 2016) Charles Bentum Vroom et al. present an idea to develop a manual waste compactor. This idea was put forward to resolve the solid waste disposal issues in Ghana, where the solid waste generation and collection rates differ significantly. A model was proposed to eliminate the problem by using the 3Rs (Reduce, Reuse, Recycle) strategy or compacting the waste to reduce its volume thereby helping in improved and easier waste management as it solves the issue of infrequent waste collection visits.

In her paper titled as “Waste Management using Internet of Things (IoT),” Saha along with her team proposed an idea of smart disposal of waste through the design of a system that works on solar energy and sensors to detect the quantity of waste within the enclosed bin. The bin can compact the waste to achieve volume reduction even by ten times as compared to a normal bin. The fill level of the bin is communicated via the wireless system to a cloud server and from there the information is communicated to waste collectors who can then decide based on the current level of waste in the bin. This system helps achieve benefits such as reduction of fuel consumption, cutting down on CO_2 emissions, maximize pick up time, and reduce collection costs by about 80%.

In the research titled as “The Design and Implementation of Smart Trash Bin,” Fady E. F. Samann proposed a cost-effective model of a smart waste bin for use over smaller scales. The system he designed is based on Arduino Nano board and an ultrasonic sensor to monitor the fullness level of the container and give SMS alerts using a GSM module. The system is powered by lithium battery power bank supported by solar cell panel. The system provides an option of charging external portable devices using the power bank. Moreover, the system will store usage events, recorded by PIR sensor, and fullness events on a memory card, which is also used to play audio message using a speaker, when the bin is being used. By implementation of his model, he determined that the cost of one unit was $168. Another conclusion made by testing was that many bins can be placed at a small-scale location as there is no need of internet to track the activity of the bins. (Samann, 2017)

In the research conducted by Mazhar Iqbal along with his team in 2018, titled as “Sustainability Analysis for Smart Waste Management System in Pakistan using IOT” it was determined that improper waste management systems in Pakistan lead to spread of diseases such as Diarrhea, Dengue, Typhoid among many others. Through the surveys conducted, it was identified that there is lack of smart approach to waste management. Therefore, it is a novel idea.

Claude-Noel Tamakloe in his work titled as “Smart Systems and the Internet of Things (IOT) For Waste Management” discusses the IOT approach to waste management. He, along with his team, designed a smart bin system for waste management. After software and hardware implementation and testing, he concluded that the web-based system proved efficient in terms of requiring fewer resources, time, and distance for waste management. The second test performed determined the compaction mechanism. Upon completion of the tests, it was determined that after each compaction cycle the space created was 5cm which represented 25% of free space which in total amounted to the bin capacity with compaction being twice the bin capacity without compaction. Their research proved a key step towards their country’s policy to move towards a cleaner communities and proper sanitation. (Tamakloe, 2020)

In their work “Automated Trash Compactor Bin with Auto-Seal Mechanism – Review,” Rafa Shaikh and Ketan Patni examined different models of waste management mechanisms currently in place in India and proposed an auto-seal mechanism for waste. The best of the models incorporated hydraulically and electrically actuated mechanism for compaction of waste. The mechanisms used was scissor mechanism and it was found that compaction increases the volume of the bin by about 6-8 times. (Patni, 2021)

This chapter has discussed the literature that was studied and leads onto the methodology of the proposed model.

3. Methodology

This chapter discusses the methodology that was incorporated to achieve the intended objectives of our final year project. The methodology has been divided into the following sections:

- Awareness Generation
- Model Design & Development
- Comparison with traditional waste management practices

3.1 Awareness Generation

Solid waste management (SWM) is one of the key issues with significant impacts on the environment and public health. SWM has become a major challenge to developing countries as they are in their stage of urbanization. The population in developing countries is increasing rapidly and that has put a pressure on the waste management systems. The waste generation has increased to an extent that it has overburdened the existing waste management facilities and there is a requirement for an improved, efficient, and technologically sustainable SWM mechanism to be put in place. However, the major challenge at hand is the generation of awareness among the masses about proper disposal of waste. Therefore, we as a group incorporated awareness generation as one of the major objectives of our final year project.

Two different means of awareness generation were incorporated.

3.1.1 Awareness Generation Through Posters

Posters are a great means of awareness generation as they help make an immediate and effective impact on the audience. The message that the posters give gets great responses when they are placed in high traffic areas. They are a means of reaching out to substantial number of people and influence them positively.

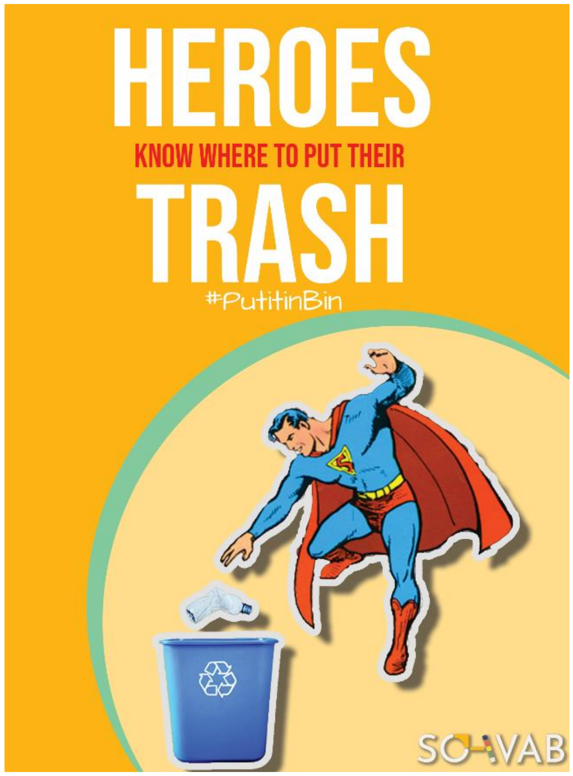

Figure 2 Poster for Awareness Generation

The poster above was designed to communicate a strong message. With the tagline "Heroes Know Where to Put Their Trash" the poster is communicating a message for its audience to put their waste in the bin instead of throwing it openly. This poster is in continuation to our aim of reducing waste generation and stopping open dumping of waste which is an eyesore and leads to several diseases.

3.1.2 Awareness Generation Through Google Forms & social media

Google forms are a means of acquiring opinion and information on an issue in a convenient, cost-effective, and quick way as they are circulated easily and do not require much time to fill as compared to printed forms which have to be filled by hand.

Considering the above advantages of googling forms, we also designed a form aimed at assessing the level of awareness among the public about waste types, waste management, and good waste practices. The table below shows the questions that were a part of the survey using google forms.

Table 2 Questions & Response for Google Survey

Question	Response				
I always throw garbage in a bin.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I have knowledge about sorting of waste according to diverse types.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
If there is no bin around, I store the waste and bin it later.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I am aware about the impacts of not throwing waste into a bin.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I have a role in protection of the environment.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

Social media platforms are a means of achieving social good. They are a means of creating awareness by building a community of social media users around an issue from various parts of the world. An Instagram handle was created for generating awareness about the impacts of improper waste disposal.

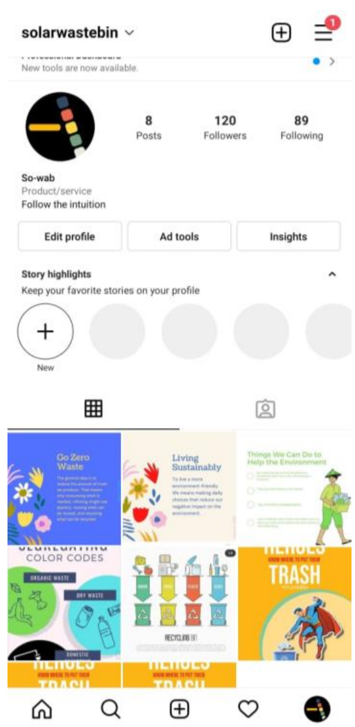

Figure 3 Screenshot of the Instagram Handle

3.2 Model Design and Development

Design and development of model for our final year project was our next objective. The methodology used for completion of this objective was divided into the following sections:

3.2.1 Model Design

The model design involved multiple stages. Each stage was given consideration and due time. It was ensured that our model remains cost-effective, suitable to local conditions, and sustainable in the longer run.

The stages involved in model design were selection of materials, procurement of selected materials, preparation of hardware, development of software, and integration of hardware and software.

3.2.2 Material Selection:

The materials were selected by keeping in mind the following factors:

- Availability in local market
- Cost-effectiveness
- Environmental Viability
- Suitability to the design

The table below contains the materials that were selected.

Table 3 List of Materials Selected for Model Design

Material
Iron pipe for iron frame
Sheet for outer covering
Solar Panel 30W
Raspberry Pi-4
Raspberry Pi-Camera
Rollers 2.5 inch
Conveyer Belt
Multiple Sensors (PIR, Metallic, Color, Infrared)
4AH 12V Battery
4 Pieces Gear Motor
Node MCU

Material Procurement:

The material procurement was done in two distinct phases based on their application. Firstly, the materials required for hardware development of our model were procured. Once the hardware procurement was done, then the software related components were procured.

The issue faced in the procurement process was the fluctuating prices of software-based components as they are imported, and the dollar rate was quite variable. However, we procured when the prices became reasonable and a few of the components were procured in used condition to keep our model cost-effective.

The table below contains the prices and quantities of the materials that were procured.

Table 4 Specifications and Prices of Materials Procured

Material	Specification or Quantity	Price per unit
Iron pipe for iron frame	Seven meters	800
Sheet for outer covering	7 meters	300
Solar Panel 30W	1	7500
Raspberry Pi-4	1	12500
Raspberry Pi-Camera	1	3000
HDMI Cable	2	400
Conveyer Belt	4 Ft length	12000
Multiple Sensors (PIR, Metallic, Color, Infrared)	1 each	3200
4AH 12V Battery	2	2500
Lead Screw for Compactor	1	4000

(a) (b) (c) (d)

Figure 4 (a) Sonar Sensor (b) Pi-Cam (c) Raspberry Pi (d) Arduino UNO

3.2.3 Preparation of Hardware:

The hardware preparation was carried out after the procurement of hardware components was completed. Firstly, the iron pipes were welded, and the frame was completed.

Figure 5 Iron Frame of the Model

The frame was 4 feet in length, 2 feet in width and 2.5 feet in height. The dimensions of the frame were sufficient to provide space for individual bins, the conveyer belt, the compactor, and the software components to be placed. The space for the solar panel was given on top of the frame so that it can gather the required sunlight efficiently for proper working of the model.

In the next phase of hardware development, bins for holding several types of waste were prepared.

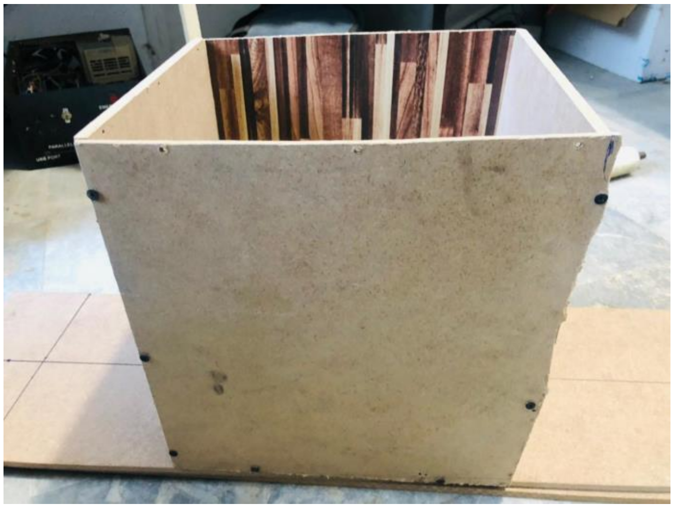

Figure 6 Bin for Holding Waste

Three bins of 1.5 feet length, 1 feet width, and 1 feet height were made. The total waste holding capacity of these three bins is 120 liters.

The next phase was the design of the compactor for effective compaction of the waste.

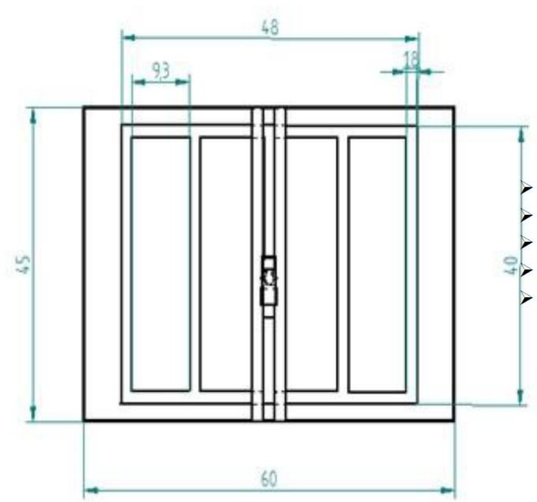

Figure 7 CAD Design of Compactor

Specification:

- Length of the piston = 48 inches
- Breadth of the piston = 40 inches
- Thickness of the piston = 1.8 inches
- Length of piston rod = 74 inches

Figure 8 Actual Representation of the Compactor Motor

3.2.4 Software Development:

The next phase was to develop the software code for running the different sensors, raspberry pi, compactor, and conveyer. All the software components were coded and made compatible with Arduino UNO. The percentage of compaction to be achieved was set and the LCD was connected to display the fill levels. The speed of conveyer belt was adjusted by employing a speed adjuster.

3.2.6 Integration of Software & Hardware:

The last stage was the integration of hardware and software together to complete the desired model. The software part was integrated and made compatible with the hardware of the designed model and was tested for working. The final product looks as shown in figures below.

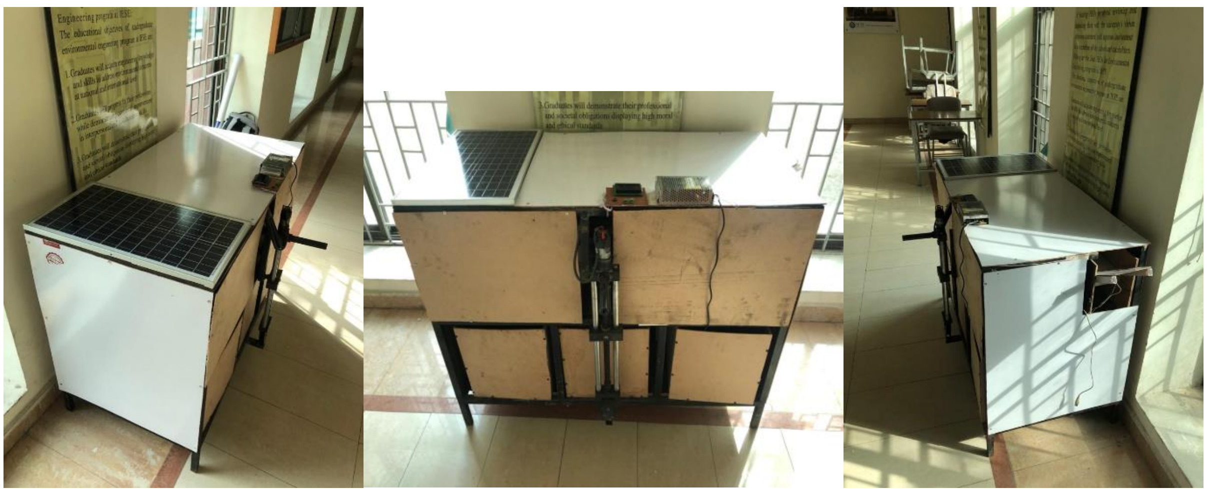

Figure 9 Final Shape of the Designed Model

3.3 Comparison with Traditional Waste Management Practices

The designed model was then tested to compare it with the traditional waste management practices. Two different locations were chosen at NUST main campus for the analysis. The parameters that were assessed included the following:

- Source Selection
- Physical Composition of Waste at the selected sources
- Waste Holding Capacity was determined
- Collection frequency comparison was done
- Cost savings were determined
- Emission savings were determined
- Break-even period was determined

3.3.1 Source Selection

- Two different waste sources were selected within NUST Main Campus to determine the waste characteristics for comparison with conventional waste practices.
- The selected sources were Institute of Environmental Sciences and Engineering (IESE) and Concordia-I.

Rationale for Selection of IESE

- It is the institute concerned with environmental practices and is the institute this final year project belongs to.
- The students of this department are aware of the consequences of improper solid waste management. Therefore, the objective was to assess the feasibility of the project amongst most aware people.

Rationale for Selection of Concordia-I

- C1 is one of the busiest areas of NUST where everyone including the Faculty Members, Students and Visitors come to eat. Thereby this activity generates a lot of solid waste in the vicinity.
- The objective was to assess the feasibility of our project to cater high quantities of waste.

Current Waste Management Practices at IESE

- The dustbins placed in IESE hold waste during the hours before they are emptied.
- During the daytime, the waste collection staff comes and empties the smaller dustbins into any the larger bin placed around at the back side of IESE
- A tractor trolley comes at the back side of IESE, and the larger bin is emptied into the trolley.
- All the collected waste is then sent to garbage transfer station (GTS) for segregation into recyclable and non-recyclable waste.
- The segregated recyclable waste is sold out to scrap shops from where it is sent to industries for reprocessing/recycling.

Current Waste Management Practices at Concordia-I

- The dustbins placed in C-1 hold waste during the hours before they are emptied.
- During break timing, 14:30 to 15:00, the waste collection staff comes and empties the smaller dustbins into any of the larger bins placed inside C1.

- A tractor trolley comes in front of C-1 and the larger bin is emptied into the trolley.
- All the collected waste is then sent to garbage transfer station (GTS) for segregation into recyclable and non-recyclable waste.
- The segregated recyclable waste is sold out to scrap shops from where it is sent to industries for reprocessing/recycling.

3.3.2 Analysis of Physical Composition of Waste

Methodology Employed by our Group for Analysis of Waste at Both Sources

- The average volume of the dustbin at both the sources was determined.
- The waste from the dustbins was emptied into a balance and its weight was determined.
- The waste was then segregated into several types.
- Physical composition of the waste was then determined.
- The data was then compared with the literature to evaluate the best handling practices.

Figure 10 Waste being weighed using a balance

Quantities of waste, segregated into different waste types, were determined for two different time periods. For C-1, the first time was 10 Am to 11 Am for 3 days to analyze the potential waste load and waste types. The second time was 1 Pm to 2 Pm which is the break time here at NUST main campus. This time was selected to analyze the performance of the bin during peak load time.

The table below shows the quantities of waste for different waste types at the two times mentioned above for Concordia-I.

Table 5 Quantities & Types of Waste for Concordia-I

Date: 13/04/2022 Time 10 AM to 11 AM				
Plastic Items (#)	Glass Bottles (#)	Paper Bags (#)	Food Waste (#)	Styrofoam Items (#)
38	09	56	22	65
Date: 13/04/2022 Time 1 PM to 2 PM				
Plastic Items (#)	Glass Bottles (#)	Paper Bags (#)	Food Waste (#)	Styrofoam Items (#)
88	22	137	57	156
Date: 14/04/2022 Time 10 AM to 11 AM				
Plastic Items (#)	Glass Bottles (#)	Paper Bags (#)	Food Waste (#)	Styrofoam Items (#)
19	13	62	29	61
Date: 14/04/2022 Time 1 PM to 2 PM				
Plastic Items (#)	Glass Bottles (#)	Paper Bags (#)	Food Waste (#)	Styrofoam Items (#)
98	31	125	61	133
Date: 15/04/2022 Time 10 AM to 11 AM				
Plastic Items (#)	Glass Bottles (#)	Paper Bags (#)	Food Waste (#)	Styrofoam Items (#)
25	16	46	18	72
Date: 15/04/2022 Time 1 PM to 2 PM				
Plastic Items (#)	Glass Bottles (#)	Paper Bags (#)	Food Waste (#)	Styrofoam Items (#)
68	17	69	77	165
Average Composition for the 3 days 10 AM to 11 AM				
Plastic Items (#)	Glass Bottles (#)	Paper Bags (#)	Food Waste (#)	Styrofoam Items (#)
27	13	55	23	69
Average Composition for the 3 days 1 PM to 2 PM				
Plastic Items (#)	Glass Bottles (#)	Paper Bags (#)	Food Waste (#)	Styrofoam Items (#)
85	23	110	71	151

For IESE, the first time was 12 PM to 1 PM for 3 days to analyze the potential waste load and waste types. The second time was 4 PM to 5 PM which is the time when most of the undergraduate classes' end, and postgrad classes start to commence. This time was selected to analyze the performance of the bin during peak load time.

The table below shows the quantities of waste for different waste types at the two times mentioned above for IESE.

Table 6 Quantities & Types of Waste for IESE

Date: 06/04/2022 Time 12 PM to 1 PM				
Plastic Items (#)	Glass Bottles (#)	Paper Bags (#)	Food Waste (#)	Styrofoam Items (#)
9	0	36	3	11
Date: 06/04/2022 Time 4 PM to 5 PM				
Plastic Items (#)	Glass Bottles (#)	Paper Bags (#)	Food Waste (#)	Styrofoam Items (#)
13	3	65	12	17
Date: 07/04/2022 Time 12 PM to 1 PM				
Plastic Items (#)	Glass Bottles (#)	Paper Bags (#)	Food Waste (#)	Styrofoam Items (#)
06	01	55	02	09
Date: 07/04/2022 Time 4 PM to 5 PM				
Plastic Items (#)	Glass Bottles (#)	Paper Bags (#)	Food Waste (#)	Styrofoam Items (#)
17	06	75	16	29
Date: 08/04/2022 Time 12 PM to 1 PM				
Plastic Items (#)	Glass Bottles (#)	Paper Bags (#)	Food Waste (#)	Styrofoam Items (#)
12	0	26	2	14
Date: 08/04/2022 Time 4 PM to 5 PM				
Plastic Items (#)	Glass Bottles (#)	Paper Bags (#)	Food Waste (#)	Styrofoam Items (#)
22	05	46	03	25
Average Composition for the 3 days 12 PM to 1 PM				
Plastic Items (#)	Glass Bottles (#)	Paper Bags (#)	Food Waste (#)	Styrofoam Items (#)
09	01	39	03	11
Average Composition for the 3 days 4 PM to 5 PM				
Plastic Items (#)	Glass Bottles (#)	Paper Bags (#)	Food Waste (#)	Styrofoam Items (#)
17	05	62	10	24

3.3.3 Waste Holding Capacity Calculations

The compaction mechanism in the bin starts when the waste compartment is 80% full and ends when the waste level has reached 30% of the bin capacity.

- Capacity of each bin = 40 Liters
- Capacity of the entire bin = 120 Liters

Using the data above, volume of waste after each compaction cycle was determined. The bin needs to be emptied when the capacity of the entire bin has reached, and it cannot hold more waste.

$$\textbf{Total Waste Holding Capacity} = Number\ of\ Compaction\ Cycles\ * \ Total\ Volume\ Compacted\ by\ each\ Compartment\ * \ Number\ of\ Compartments$$

Equation 1 Total Waste Holding Capacity

3.3.4 Collection Frequency

A standard 120 Liters wheelie bin is emptied once a day. (Business Waste 2021) So, it has a collection frequency of 7 days a week.

$$\textbf{Collection Frequency of our model} = \frac{Number\ of\ Collection\frac{Operations}{week}for\ a\ standard\ bin}{\frac{Total\ Waste\ Holding\ Capacity}{Volume\ of\ a\ standard\ bin}}$$

Equation 2 Collection Frequency

3.3.5 Cost Savings

a) Diesel costs of collection operations were determined for a standard 120 liters wheelie bin and our model. These costs were then compared to determine the diesel cost savings.

$$\textbf{Diesel Cost Savings} = Diesel\ cost\ for\ our\ model - \ Diesel\ cost\ for\ standard\ 120L\ wheelie\ bin$$

Equation 3 Diesel Cost Savings

b) Labor costs for the collection operations of both the bins were determined and compared to calculate the labor costs that our model is going to save.

$$\textbf{Labor Cost Savings} = Waste\ Collection\ Charges\ for\ SOWAB - \ Waste\ Collection\ charges\ for\ 120L\ bin$$

Equation 4 Labor Cost Savings

c) Capital costs for both SOWAB and standard 120 liters wheelie bin over a period of 15 years were calculated and compared. The key factors considered in calculating capital costs were the manufacturing cost, useful life, and number of bin equivalents.

$$\textbf{Capital Cost} = Manufacturing\ Cost\ *\ Number\ of\ Bin\ Equivalents$$

$$\textbf{Number of Bin Equivalents} = \frac{15\ years}{Useful\ Life(years)}$$

Equation 5 Capital Cost

d) Operation and maintenance (O&M) costs were calculated by keeping mind the average life of the components in SOWAB. The cost was then compared with the O&M cost of a 120-liter wheelie bin.

e) Finally, the net cost savings were determined by using all the costs mentioned above.

$$\textbf{Net Cost Savings} = Diesel\ Cost\ savings\ +\ Labor\ Cost\ savings - Capital\ Cost\ -\ O\&M\ Cost$$

Equation 6 Net Cost Savings

3.3.6 CO_2 Emission Savings

Another important parameter to be considered and determined was the CO_2 emissions that can be saved because of adopting SOWAB. The emission savings were calculated based on the number of collection operations required for a standard 120-liter wheelie bin and those required for SOWAB. CO_2 emissions from a gallon of diesel were taken from literature and the calculations were performed using that reference value.

$$\textbf{CO}_\textbf{2}\textbf{ Emissions} = Waste\ Pick-ups\ Per\ week\ *\ Distance\ to\ and\ from\ GTS\ * \\ Truck\ fuel\ Consumption\ *\ CO2\ Emissions\ from\ a\ gallon\ of\ diesel\ * \\ Gallons\ to\ Liter\ conversion\ Factor$$

Equation 7 CO2 Emissions by a bin

$$\textbf{CO}_\textbf{2}\textbf{ Emissions Savings} = CO2\ Emissions\ for\ A\ standard\ 120L\ bin\ -\ CO2\ Emissions\ for\ SOWAB$$

Equation 8 CO2 Emission Savings

Another important parameter that was considered in calculations was the mortality cost of carbon.

- R. Daniel Bressler, a Ph.D. candidate at Columbia University coined a term for the relationship between the increased emissions and excess heat deaths: the "**mortality cost of carbon**."

- 1 million metric tons of carbon dioxide emissions causes 904 deaths per century. (The New York Times, 2021)

- Mr. Bressler calculated that adding a million metric tons of carbon dioxide, to the atmosphere on top of 2020 levels for just one year will cause 226 deaths globally. (The New York Times, 2021)

Mortality Cost of Carbon = $Number\ of\ deaths\ from\ a\ ton\ of\ CO2\ emissions\ per\ year\ *\ CO2\ Emissions\ Savings\ from\ SOWAB\ per\ century\ *\ 100\ Years$

Equation 9 Mortality Cost of Carbon

3.3.7 Breakeven Determination

Breakeven period for the investment over one unit of SOWAB was determined. It was calculated using the equation as follows:

Breakeven Period (Months) = $\frac{Fixed\ Cost}{Contrbiution}$*12

Equation 10 Breakeven Period

Where,

Fixed Cost = Initial Investment

Contribution = Revenue – Variable Cost

Revenue = Net Savings per year

Variable Cost = O&M Costs per year

This chapter has discussed the methodology that was adopted to achieve the objectives of our final year project and leads onto the results for all the objectives.

4. Results

This chapter includes the results for the objectives of our final year project. It includes results for the following:

- Awareness generation through google forms
- Physical composition of Waste
- Waste holding capacity
- Collection frequency
- Cost savings
- CO_2 emission savings
- Breakeven determination

4.1 Awareness Generation Using Google Forms

The figures below show the results for the responses that were obtained from google forms.

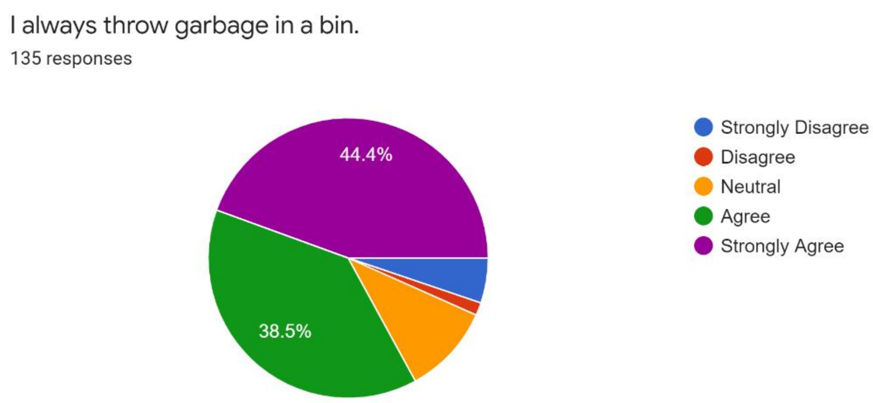

Figure 11 Responses for Question # 1 of Google Form

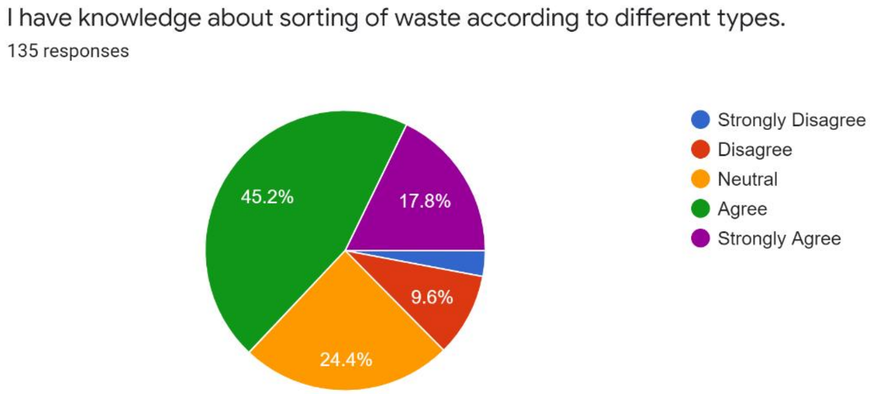

Figure 12 Responses for Question # 2 of Google Form

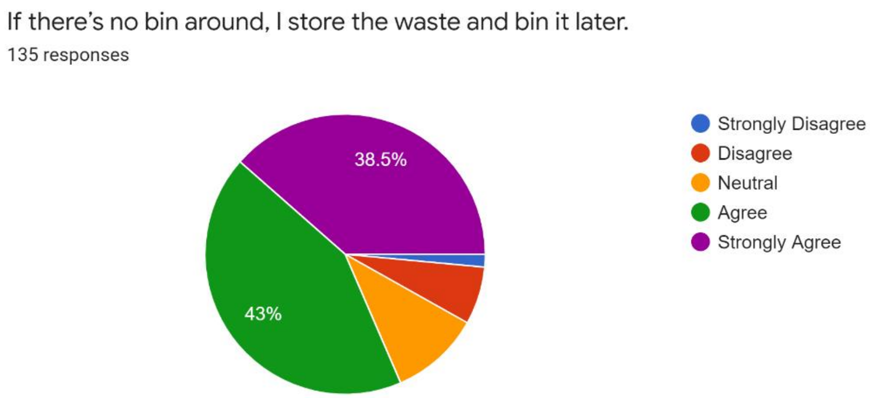

Figure 13 Responses for Question # 3 of Google Form

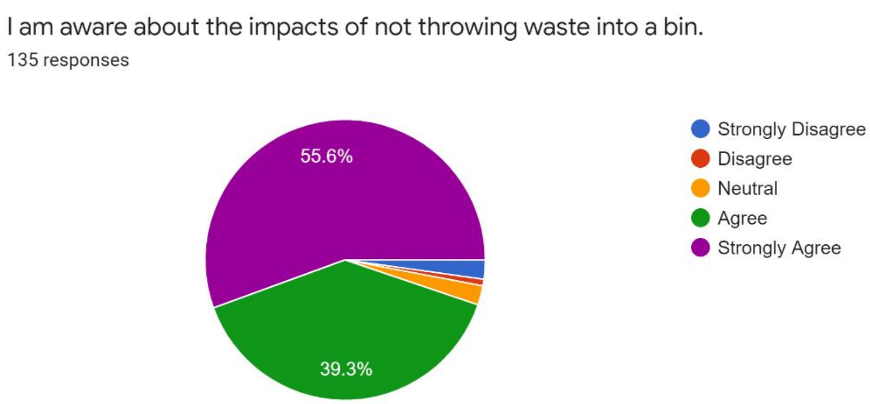

Figure 14 Responses for Question # 4 of Google Form

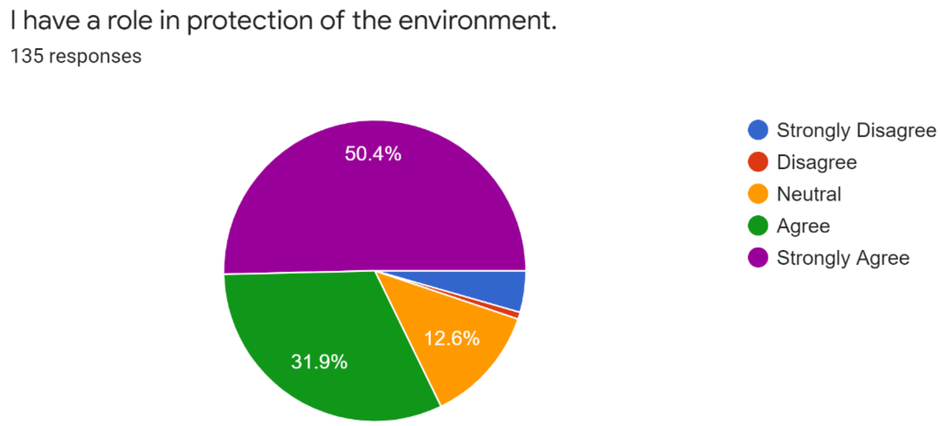

Figure 15 Responses for Question # 5 of Google Form

<u>Findings from the Survey:</u>

- 83% of the people throw garbage in the bin
- About 1/4th of the people is not aware about waste types and segregation
- About 82% of the people store waste if there is no bin around
- 95% of the people are aware about harmful impacts of improper waste disposal on the environment and public health
- 82% of the people believe they have a role in protection of the environment.

With the help of this survey and its findings, we were able to assess the feasibility of installation of SOWAB as it protects the environment and helps curtail the spread of diseases as there would not be any open dumping of waste. Moreover, many people are not aware about sorting of waste into several types so SOWAB can turn out to be a game changer towards our national efforts to improve solid waste management.

4.2 Physical Composition of Waste

The figures below are a pi-chart representation of the physical composition of waste.

<u>Concordia-I</u>

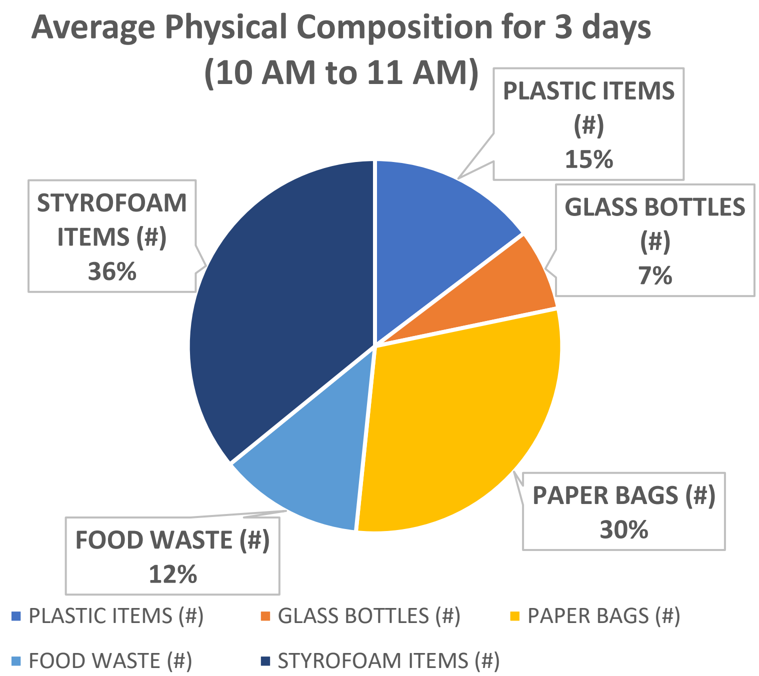

Figure 16 C-I Average Physical Composition of Waste 10-11 AM

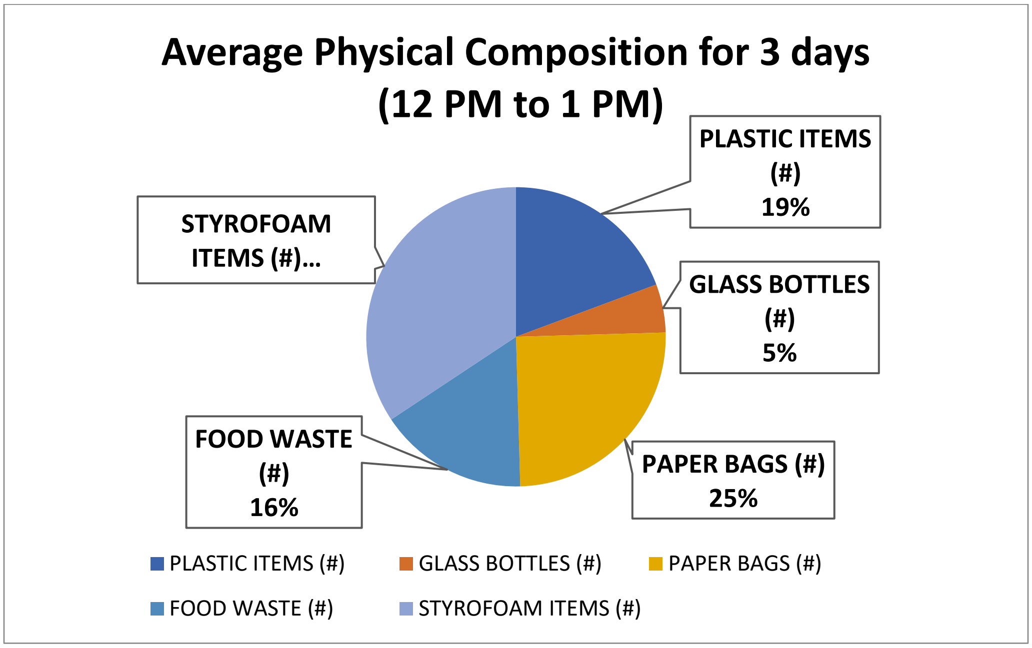

Figure 17 C-I Average Physical Composition of Waste 1-2 PM

Calculation of Waste Density:

- Average diameter of the standard size of bin at C-1 is Considered

Data:

Diameter of the bin = 65; radius = 32.5 cm

Height of the Bin, h = 75 cm

Mass of Waste, M =6.5 kg

Calculation:

Volume of the bin = $\pi * r^2 * h$

Volume of the bin = 248,905.3 cm^3

Volume of the bin (m^3) = 0.2489 m^3

Density of Waste = $\frac{Mass}{Volume}$

Density = 6.5/0.2489

Density = 26.11 kg/m^3

IESE

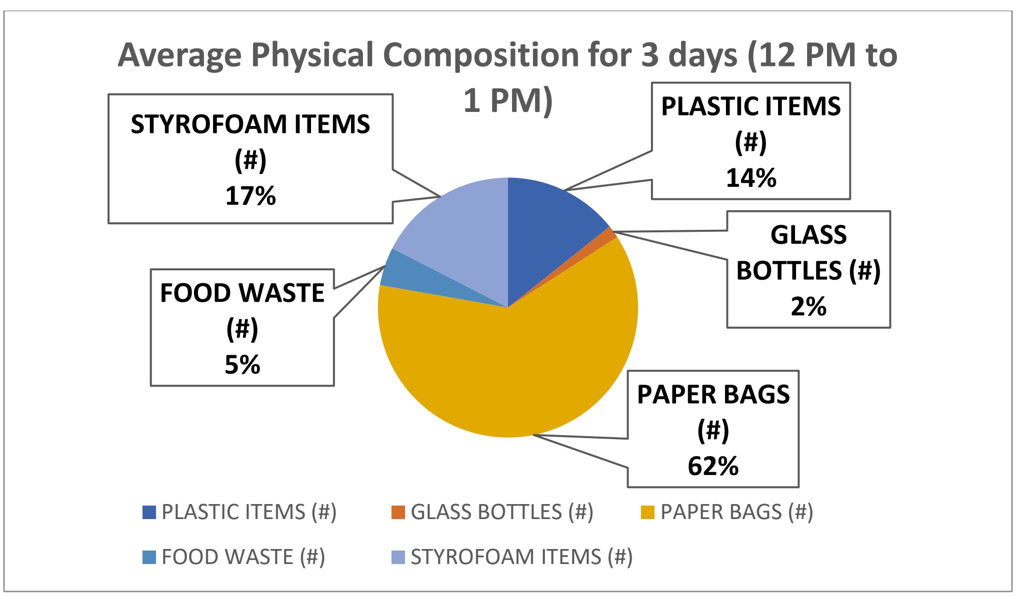

Figure 18 IESE Average Physical Composition of Waste 12-1 PM

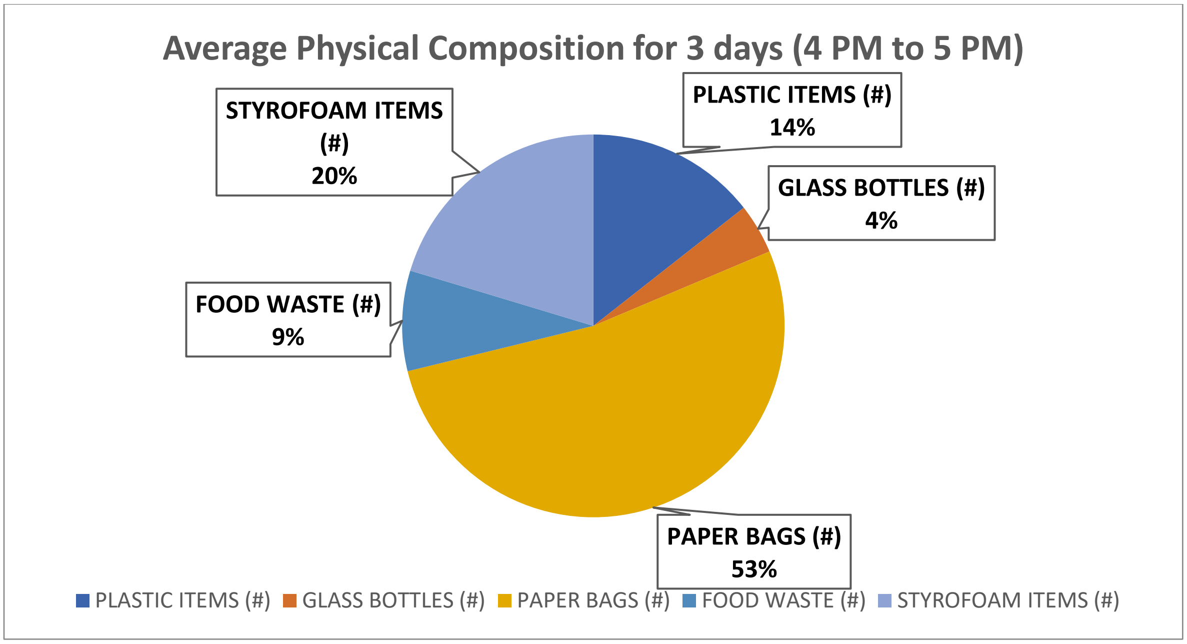

Figure 19 IESE Average Physical Composition of Waste 4-5 PM

Calculation of Waste Density:

- Average diameter of the standard size of bin at IESE is Considered

Data:

Length of the Bin, L = 45 cm

Height of the Bin, h = 65 cm

Width of the Bin, W = 50 cm

Mass of Waste, M =1.5 kg

Calculation:

Volume of the bin = $L * W * H$

Volume of the bin = 146250 cm^3

Volume of the bin (m^3) = 0.14625 m^3

Density of Waste = $\frac{Mass}{Volume}$

Density = 1.5/0.14625

Density = 10.26 kg/m^3

4.3 Waste Holding Capacity

Table 7 Waste Holding Capacity

Compaction	Fill Level (%)
Compaction Starts (a)	80
Compaction Stops (b)	30*a
Waste in Each bin After nth Compaction Cycle	**Volume (Liters)**
Waste in each bin After 1st Compaction Cycle	09
Waste in each bin After 2nd Compaction Cycle	15.9
Waste in each bin After 3rd Compaction Cycle	20.8
Waste in each bin After 4th Compaction Cycle	24.2
Waste in each bin After 5th Compaction Cycle	26.5
Waste in each bin After 6th Compaction Cycle	28.7
Waste in each bin After 7th Compaction Cycle	31.9
Bin needs to be emptied after the 7th Compaction Cycle	
Waste Holding Capacity of SOWAB After 7 Compaction Cycles	**669.9**

SOWAB's Waste Holding Capacity is **5.6 times** a standard 120 Liters wheelie bin.

4.4 Collection Frequency

$$\textbf{Collection Frequency of our model} = \frac{7}{\frac{669.9}{120}}$$

Collection Frequency of our model = 1.25/week

Thus, the collection frequency of our model is **once a week** as compared to 7 times a week for a standard 120-liter wheelie bin.

4.5 Cost Savings

The cost savings of our model are calculated below. The cost savings include the costs for:

- Diesel
- Labor
- Capital
- Operation & Maintenance (O&M)

4.5.1 Diesel Cost Savings

Table 8 Diesel Cost Savings

Parameter	Standard 120L Bin	SOWAB
Waste Pick-ups Per Week	07	01
Distance from GTS to Pick up Location and back, (km/day)	8.5	8.5
Distance from GTS to Pick up Location and back, (km/week)	59.5	8.5
Distance from GTS to Pick up Location and back, (km/year)	3094	442
Truck Fuel Consumption Rate (km/liter)	4.5	4.5
Diesel Fuel Cost (Rs/Liter)	144.5	144.5
Truck Fuel Consumption (Liters/Week)	13.2	1.89
Diesel Cost (Rs./Week)	1907	273
Diesel Cost (Rs./Year)	99164	14196

Diesel Cost Savings (Rs./Year) = 99164 – 14196

Diesel Cost Savings (Rs./Year) = 84968

4.5.2 Labor Cost Savings

Table 9 Labor Cost Savings

Parameter	Standard 120L Bin	SOWAB
Number of Collection Operations Per Week	07	01
Waste Collection Charges Per Occasion (Rs/Occasion)	500	500
Waste Collection Charges Per Week (Rs/Week)	3500	500
Number of Weeks Per Year	52	52
Waste Collection Charges Per Year (Rs/Year)	182000	26000

Labor Cost Savings (Rs/year) = 182000 – 26000

Labor Cost Savings (Rs/year) = 156000

4.5.3 Capital Cost Comparison

Table 10 Capital Cost Comparison

Parameter	Standard 120L Bin	SOWAB
Capital Cost (Rs)	10500	50000
Useful Life (years)	15	5
Number of Bin Equivalents	5	3
Capital Cost (15-year Period)	52500	150000

Capital Cost (Rs) = 52500 – 150000

Capital Cost (Rs) = -97500

4.5.4 Operation & Maintenance Costs Comparison

Table 11 O&M Costs for SOWAB

Parameter	SOWAB	Cost per Unit (Rs)	Units	Life Cycle Cost (Rs)	Cost (Rs/Year)
Average Battery Life (Years)	2.5	4500	2	9000	3600
Average Life of Compactor (Years)	05	4000	1	4000	1000
Average Life of Solar Panel Years)	25	7500	1	1500	300
Average Life of Conveyor Belt (Years)	05	12000	1	12000	2400
Cleaning of Solar Panel (per month)	1	300	1	18000	3600
Average Life of a Raspberry Pi (Years)	7	12500	1	8930	1786
Machine Oil for Lubrication of Compactor (per month)	One bottle lasts 3 uses	250	1	5000	1000
Miscellaneous Costs/year (Breakage, faulty connections, etc.)	-	5000	1	25000	5000

Total O&M Costs for SOWAB (Rs/Year) = 18686

Total O&M Costs for SOWAB (Rs/Year) = 0

Table 12 Net Cost Savings (Per Year)

Parameter	Cost (Rs)
Diesel Cost Savings (per year)	84968
Labor Cost Savings (per year)	156000
Capital Cost Comparison	-97500
Capital Cost Comparison (per year)	-19500
O&M Cost (per year)	-18686
NET COST SAVINGS (per year)	**202782**

4.6 CO_2 Emissions Savings

4.6.1 CO_2 Emission Savings

Table 13 CO2 Emissions Savings (Tons/Year)

Parameter	Standard 120L Bin	SOWAB
Waste Pick-ups Per Week	07	01
Distance from GTS to Pick up Location and back, (km/day)	8.5	8.5
Distance from GTS to Pick up Location and back, (km/week)	59.5	8.5
Distance from GTS to Pick up Location and back, (km/year)	3094	442
CO2 Emissions from a gallon of diesel (Grams/Gallon)	10180	10180
Gallons to Liter Conversion (Gallons/Liter)	0.2642	0.2642
CO2 Emissions (Grams/Liter)	2690	2690
CO2 Emissions (Grams/Week)	35508	5084
CO2 Emissions (kg/year)	2155.4	264.4
CO2 Emissions (tons/year)	2.37	0.29
CO_2 Emissions Savings (Tons/Year) = 2.37- 0.29 **CO_2 Emissions Savings (Tons/Year) = 2.08**		

4.6.2 Mortality Cost of Carbon

MORTALITY COST OF CARBON
1 Million Metric Tons of Carbon Dioxide Emissions causes **904 deaths** per century
1 Metric Ton = 1.1 Tons
1 Million Metric Ton = 1100000 Tons
Number of Deaths per ton of CO2 Emissions = 0.00082182
CO2 Savings from SOWAB = 2.08 Tons/year
CO2 Savings from SOWAB = 208 Tons/century
Lives Saved if one unit of SOWAB is installed = 0.1709 per century
100 Units of SOWAB can save 17 Lives per century

Figure 20 Mortality Cost of Carbon

4.7 Breakeven Period Determination

Table 14 Breakeven Determination

Parameter	Cost (Rs)
Revenue (Savings/Year)	202782
Variable Cost (O&M Per Year)	18686
Fixed Cost (Capital Cost)	50000
Contribution (Revenue - Variable)	184096
Break-even period years (Fixed/Contribution)	0.2716
Breakeven Period (Months)	**3.25**

This chapter has summarized all the results including cost analysis and now leads onto the conclusions that we have reached after the analysis of our results.

5. Conclusion & Future Work

This chapter discusses the conclusions that have been drawn after successfully achieving all the objects and completing this final year project. This chapter also discusses the feasibility of future studies on this project. This chapter is divided into the following sections:

- Conclusions drawn
- Scope of future work

5.1 Conclusions

The society model of the 21st century has been increasingly influenced by cities in their context. According to the United Nations data, by 2050, approximately 70% of the population will live in urban centers, and this rapid growth of people living in cities has been of great concern, since towns do not always grow in a sustainable way. In this regard, smart city design has been increasingly studied and discussed around the world to solve this problem. Following this approach, this project presented an innovative, effective, and viable smart waste management system for improving the health and well-being of the citizens, reducing waste generation, and benefiting the environment. The proposed system uses sensor and communication technologies where waste data is put into the bin where it is sorted and compacted to achieve the desired objectives.

Considering the results of this project, the following conclusions were made:

- Waste Holding Capacity = 669.9 Liters which is 5.6 times a standard 120L Bin
- Waste Collection Frequency reduces from 7 times a week for an average 120L bin to once a week for SOWAB
- Net cost savings of about PKR 202782 per year.
- 100 units of SOWAB can save 17 lives per century
- Outstanding breakeven period of 3.25 months.

5.2 Future Work

In future work, the following changes can be made and researched to make this a more sustainable waste management solution.

a) Development of a mobile- and web-based application for real-time monitoring of the fill level of the bin.

b) In future work, the application developed for this solution can be evolved by adding new facilities that can bring to the end user more significant interactions with the management system.
c) Object detection model can be developed for better detection of waste types and hence efficient sorting of waste.
d) In addition, the investment and operation costs of this solution will be an interesting study and can be performed as future work.

This chapter ends here and leads us onto the final part of thesis, which is recommendations.

6. Recommendations

This chapter discusses the issues faced during the phase of the project and provides recommendations.

After carrying out this project and doing extensive research, the issues faced are highlighted and their suitable recommendations are provided.

The issues at hand are:

- The capital cost of the bin is very high as compared to its competitor i.e., 120-liter wheelie bin.
- The compaction mechanism requires a higher output power, so AC current must be provided for it to compact the waste properly.
- Intermittent nature of solar energy is likely to hinder the operation of the bin.
- The waste holding capacity is 670-liters, which is limited if the waste loads are high.

Keeping in mind the issues above, following recommendations are made to make this product sustainable:

✓ Cost savings and environmental benefits are significantly high as compared to the capital cost. Moreover, instead of using Raspberry Pi, normal metallic and color sensors can be used to lower the capital cost.
✓ Battery and Solar Panel Capacity can be increased to get rid of AC Power.
✓ Real-Time Clock (RTC) based solar energy mechanism can be used and battery storage can be increased to power the bin during night hours.

- ✓ The bin is scalable, so its capacity can be increased by keeping in mind the budgetary limitations.

This chapter ends here and now leads us to the list of references that were used in writing of this thesis.

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