Modification of a smart trash bin segregator*

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Due to the damage that waste poses to the environment, the dynamic rise in waste production and the reprehensible disposal of waste have drawn attention. A smart trash bin segregator plays a crucial role in preventing this situation and making recycling easier. Only after segregation do the relevance and economic worth of waste become apparent. Since then, several improvements have been made to smart bin segregation. The objective of this project is to further modify the smart trash bin segregator by introducing a shredding mechanism to improve the process of segregating. The methods used were surveying for data, model development of the proposed design, performing analysis on the blade of the shredder and reviewing relevant literature to acquire some in-depth knowledge of the already existing designs. The machine design consists of some components such as a solar panel, polycarbonate shield shredder blade and motor, sensors, X-frame compactor, Arduino board, battery, etc. Segregation of waste into the required compartment was done with the aid of the sensors. A shredding mechanism with a power of 150.796 watts was designed for shredding bulk waste. The compactor required a force of magnitude (either exact or greater) to compress a full waste compartment, which weighs 1.7879 KN. The simulation results confirm the blade's design is robust and capable of withstanding a force of 600 N. The Von Mises stress, mechanical strain, and displacement are all within acceptable limits, ensuring the blade's structural integrity and performance. The factor of safety indicates that the blade can endure the applied load without failure, supporting the overall design's adequacy and safety. It was recommended that the machine should be fabricated to test its efficiency and an IOT-based waste collection system should be adopted to efficiently route and effectively schedule the collection of waste via text messages.

Keywords: Segregator, Polycarbonate shield shredder, Arduino board, X-frame Compactor

1 Introduction

Ghana's expanding population creates major threats to the availability of living space, the utilization of raw materials and natural resources, education, and employment due to the growing quantity of garbage created by each citizen every minute (Odonkor and Sallar, 2021). One such problem is solid waste management, which not only disturbs the environment's delicate equilibrium but also has a detrimental effect on society's health (Thimmappa, 2023). One of the biggest issues of the modern period is efficient waste management. Waste must be effectively managed in terms of segregation, management, transportation, and disposal to reduce environmental risk (Nawar *et al*., 2024).

To gather information on the rate of waste produced and the physical makeup of waste, specific houses in each region of the country were chosen. The findings show that Ghana produces 0.47 kg of waste per person per day or 12,710 tons of rubbish per day for a population of 27,043,093. Across the country, the amount of biodegradable garbage (organics and papers) per person per day was 0.318 kg, whereas the amount of non-biodegradable or recyclable waste (glass, metals, textiles, rubbers, and leather) was 0.096kg. Inert and auxiliary waste was 0.055 kg per person per day. Except for Tamale, the major cities all had high household garbage generation rates, averaging 0.72 kg per person per day. 61% of waste was organic, 14% was plastic, 6% was inert, 5% was miscellaneous, 5% was paper, 3% was metal, 3% was glass, 1% was leather and rubber, and 1% was textiles (Fiagbe, 2020). The composition of household garbage, particularly the amounts of organic waste and plastics, varies significantly around the world (Kodwo *et al*., 2015).

The population of Tarkwa Nsuaem municipal is growing by an average of 3% per year, used the house-to-house waste method estimates the mean daily generation rate per person to be 0.92 kg per day and the average daily generation rate per household to be 3.93 kg per household per day with an average size of 4.27 people. Organic waste accounted for 68.56% of the municipality's solid waste, which also included plastics or rubber, paper and cardboard, ash or sand, textiles, non-ferrous metals, glass or ceramics, ferrous metals, and possibly hazardous items at 16.02%, 1.65%, 0.92%, 0.31, and 0.29%, respectively (Benjamin, 2014).

The percentage of waste produced on the University of Mines and Technology campus, Tarkwa has increased due to the increase in the student populace. Results from a room-to-room survey conducted show that the dominant solid waste produced was plastics/rubbers, which constitute 43%, followed by organic waste at 29%, paper waste at 16%, non-ferrous metal waste at 11%, and glass waste at 1%. The greatest approach to realizing waste's economic worth is to recycle it entirely. The conventional method of physically sorting waste involves labour that is more labour-intensive, time-consuming, expensive, and rife with illness risks (Bravo, 2020). According to Jerie (2016), occupational dangers can

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be found at every level of the waste segregation process, from handling garbage for collection through final disposal. The main findings showed that manual solid waste segregation increased the incidence of obstructive and restrictive illnesses, diarrhoea, viral hepatitis, and musculoskeletal problems.

In literature, enormous research has been directed towards the devising of approaching the manufacturing of a smart trash bin segregator. In the view of Gupta *et al*. (2018), the process of segregating waste by sensors begins when the IR sensor detects whether or not the trashcan is full. The IR sensor detects when the bin is full and informs the PIC16F877A microprocessor. Then, after a delay of 5 seconds, a servomotor spins the trash bin at a 120° angle, allowing the waste to fall onto the subconveyor per the microcontroller's programmed instructions (Malathy *et al.,* 2022). Waste is being deposited into the bin for segregation, which has metallic, dry, and wet sensors installed. The segregation bin has a set location for the metallic inductive proximity sensor and a connection for the moisture sensor (Sanathkumar *et al.,* 2021). To detect trash arrival, an IR sensor is also attached at the end of the main conveyor; when waste is detected there, the software directs the segregation bin to spin at a 120° angle. The servo motor is attached to three different collection containers. It is possible to track the amount of each form of waste, such as metal waste, dry waste, and wet waste (Noor *et al.*, 2020). The garbage is monitored by an Internet of Things module, and the user's mobile phone will get the information. The smartphone app displays the amount of each sort of garbage being collected in the bins. Since the model's sensors and servo motor are driven by electricity, it is useless when the power is out. Once more, the proposed model of the segregation system as illustrated in Figure 1.1 is limited in its utilization since it is deemed suitable for use in the industry for commercial purposes.

Fig. 1 Existing Design of the Commercial Segregating System

Pereira *et al.* (2019), in their model of smart bin segregation and optimization module made use of an Atmega328PMicrocontroller, Infrared radiation sensor, copper Clads, Bluetooth module, Ultrasonic sensor, servo motor, stepper motor, motor drivers, and some other software requirements like Arduino IDE, R studio and Android studio. Since the door is attached to a servo motor, anything nearby will cause it to open thereby ensuring the smart bin's operation is entirely hands-free. Using spectroscopy, plastic may be separated from other materials and the IR sensor in spectroscopy can determine whether or not the waste is plastic (Kumar *et al.*, 2021). Through the use of a motor, clean water will be applied to the plates and collected in the waste chamber, the fourth chamber. A network is established when the app is linked to the cloud and the waste is optimized based on this network. Consequently, when the chamber of a given waste is full, the IR sensor sends a signal to the app, signalling the user that it is time to take out the trash. Additionally, the moist waste that can be composted will be detected, allowing us to prevent human mistakes and save a great deal of time. Nonetheless, it is incompatible with smartphones and internet connectivity in some rural areas where they are being used.

Building on the preceding discussion, this paper proposes a sensor-assisted smart trash bin segregator. The innovation lies in its ability to shred bulk waste using an integrated shredding mechanism and segregate the waste at the point of disposal. This addresses the current gap in waste management systems where segregation typically occurs post-collection, often leading to inefficiencies and contamination. By integrating shredding and segregation at the disposal level, the proposed solution aims to enhance the efficiency and effectiveness of waste processing.

2 Resources and Methods Used

2.1 Design Consideration

In designing the power needed to shred the polyethene material, the following parameters were considered.

i. The width of the blade (w) of 6 mm

ii. The radius of the blade from the centre to the tip of the blade (Ro) of 60 mm

iii. The radius of the hexagonal hole for fixing the drive shaft (Rh) of 10 mm

iv. The assumed thickness of the blade (t) of 5 mm

v. The yield strength of the polyethene material (τ_{AS}) of 20 MPa

vi. The radial blade distance (r) of 10mm

vii. The assumed rotational speed of the blade (N) of 1rev/sec

2.2 Detailed Design of the Trash Bin Segregator

2.2.1 Shredding Blade

Shredding of the selected material, that is polyethylene was done using a shredder blade with three cutting edges. The hexagonal through-hole at the centre of the blade was used for fixing the drive shaft. All dimensions are illustrated in Fig. 2.

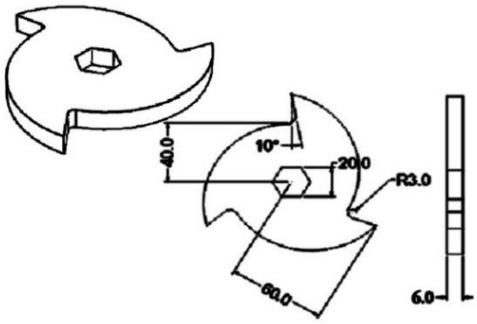

Fig. 2 Detailed Geometry of the Blade (Dimensions in mm)

2.2.2 Area of the Blade

$$A = w \times t \qquad (1)$$

Where;

A = Area of the blade

w = width of the blade

t = Assumed thickness of the blade.

$$A = 6mm \times 5mm$$

$$A = 30\ mm^2$$

Upon enormous research, the plastic material to be shredded is selected to be polythene bags (made from polyethene material). Table 1. illustrates the mechanical properties of the plastic material selected.

Table 1 Mechanical Properties of the Plastic Material

Mechanical Properties	Polyethylene
Phase at STP	Solid
Density	950 kg/m^3
Ultimate Tensile strength	30 MPa
Yield Strength	20 MPa
Young's Modulus of Elasticity	1 GPa
Brinell Hardness	40 BHN
Melting Point	317 ºC
Thermal Conductivity	0.5 W/Mk
Heat Capacity	1550 J/gK
Price	0.9$/kg

2.2.3 Force Exerted in Shredding

$$F = \sigma_{AS} \times A \qquad (2)$$

Where,

σ_{AS} = Yield strength of the polyethene material
A = Area of the Blade
F = Force exerted in shredding

$$F = 20\ \text{MPa} \times 30\ mm^2$$
$$F = 600\ \text{N}$$

2.2.4 Power Needed to Shred Polyethylene Material

$$T = F \times r \qquad (3)$$

where;

T = Torque
F = Force exerted in shredding
r = Radial blade distance

$$T = 600\ \text{N} \times 0.04\ \text{m}$$

$$T = 24\ \text{Nm}$$

From the equation,

$$T = P / 2\pi * N \qquad (4)$$

where,

T = Torque
N = Assumed Speed of the rotation of the blade
P = Power needed to shred the material

$$P = T \times 2 \times \pi \times N$$

$$P = 24 \times 2 \times \pi \times 1$$

$$P = 48\pi$$

$$P = 150.796\ \text{watts}$$

2.3 Force Needed for Compaction

2.3.1 Design Consideration

In calculating the force needed for compaction, the following parameters were considered.

i. The largest angle of the sector for the waste compartment ($\boldsymbol{\Theta_1}$) of 154.8 º

ii. The radius of the smart bin (r_s) of 0.3813 m

iii. The radius of the hollow compartment ((r_h) of 0.3 m

iv. The height of the smart bin (h_s) of 1.27 m

v. The height of the waste compartment (h_{wc}) of 0.9 m

vi. The acceleration due to gravity (g) of 9.81m/s

vii. The waste material with the highest density (ρ_1) of 2710 kg/m^3

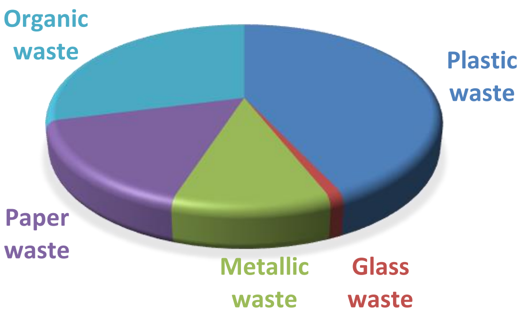

Fig. 3 Kinds of waste generated

2.3.2 Area of a Sector

$$A = \Theta_1/360 \times \pi \times ({r_s}^2 - {r_h}^2) \qquad (5)$$

where,

Θ_1 = **the** largest angle of the sector for the waste compartment

r_s = The radius of the smart bin

r_h = The radius of the hollow compartment

A = The area of the sector

$$A = 154.8^0/360 \times \pi \times (0.3813^2 - 0.3^2)$$
$$A = 0.0748\ m^2$$

2.3.3 Volume of a Full Compartment

$$V = A \times h_{wc} \qquad (6)$$

where,

V = Volume of a full waste compartment

h_{wc} = Height of the waste compartment

$$V = 0.0748 m^2 \times 0.9\ \text{m}$$

$$V = 0.06732\ \text{m}^3$$

2.3.4 Mass of a Full Compartment

$$\rho_1 = m / v \qquad (7)$$

where,

ρ_1 = The largest density of the waste material

m = mass of a full waste compartment

$$m = \rho_1 \times v$$

$$m = 2710\text{kg}/m^3 \times 0.06732\ m^3$$

$$m = 182.4372\ \text{kg}$$

2.3.5 Weight of a Full Compartment

$$w = m \times g \qquad (8)$$

where,

w = weight of a full compartment

g = Acceleration due to gravity

w = 182.4372kg × 9.81 m/s

w = 1.7897 KN

It is assumed that the compactor will require a force (F) of that magnitude or greater to compress a full waste compartment, which weighs 1.7897 kN.

2.4 Proposed Design

The smart bin segregator is an intelligent waste management system that uses analytics to translate the data gathered in the bin into actionable insights to help reduce waste reuse and recycle resources and products. (Acharya *et al.*, 2022). The basic design consists of a solar panel with a polycarbonate shield, indicator lights (sensors), bin compartments, an Arduino board, a shredder and shredder motor, an x-frame compactor, a vane for pushing waste, a cover and a coverlid, and the body of the bin as shown in Fig. 4.

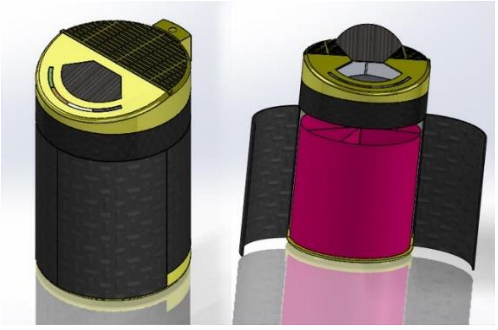

Fig. 4 Isometric View of the Proposed Design

2.5 Principle of Operation

The mechanism for the lid to open and close serves as a regulator to aid with the dumping of the waste. The garbage is pushed toward the shredder by the vane at the shredding chamber when it is judged that the waste's weight is more than usual. Bulk waste is fed into the shredder, which then shreds it at a speed of 60 revolutions per minute with the help of a direct current geared motor. The shredded waste passes from the shredding area to the holding compartment, which also has a vane and several sensors for waste detection. The offered sensors, such as inductive, proximity, and infrared sensors, are used to detect objects. The trash chamber rotates to accept the metal waste at the initial step if the sensor displays a positive command. If the sensor receives a no command, it tries to determine if the object is made of waste paper. If yes, the waste compartment moves one more to the paper waste compartment to accept the garbage. If not, the procedure continues to the end until the appropriate waste kind is identified and placed in the proper compartment and the process starts again. The waste is subsequently pushed into the designated compartment by the vane once the type of waste has been identified. As shown in Fig. 2., the X-frame mechanism is engaged when the various compartments are filled to push down the X-frame and compart the trash, which causes additional waste to be stored in the compartment. To make recycling of the waste simple, these mechanisms are repeated until the waste compartments are removed and emptied.

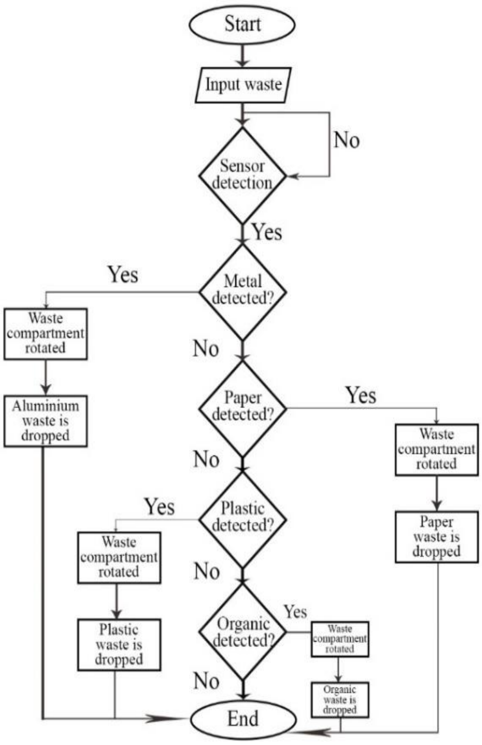

Fig. 5 Flow Chart of the Principle of Operation

2.6 Exploded View of the Assembly

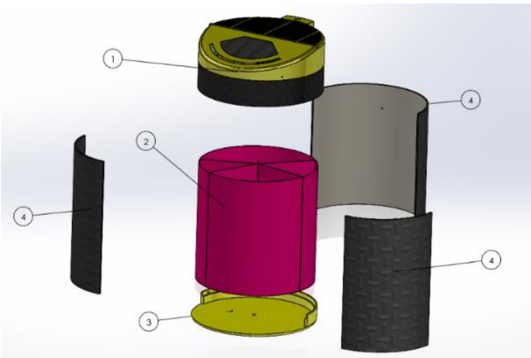

Fig. 6 Exploded view of the Waste Compartment

Table 2 Part List of the Waste Compartment

Part Number	Description	Qty	Material
1	Top cover	1	Stainless steel
2	Waste Compartment	1	High-Density Polyethylene
3	Base Cover	1	Stainless Steel
4	Access Covers	3	Stainless Steel

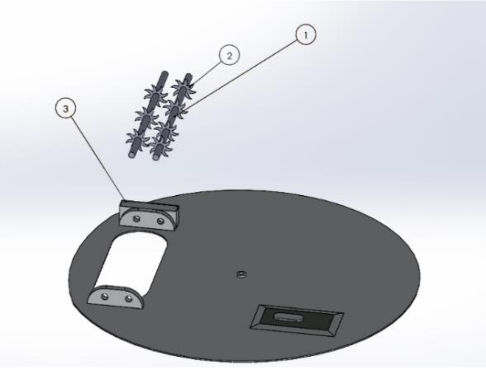

Fig 7 Exploded view of the Shredding Mechanism

Table 3 Part List of the Shredding Mechanism

Part Number	Description	Quantity	Material
1	Shredder Blades	7	Stainless Steel
2	Shredder Blade Shaft	2	Stainless Steel
3	Shredder Motor Case	1	Stainless Steel

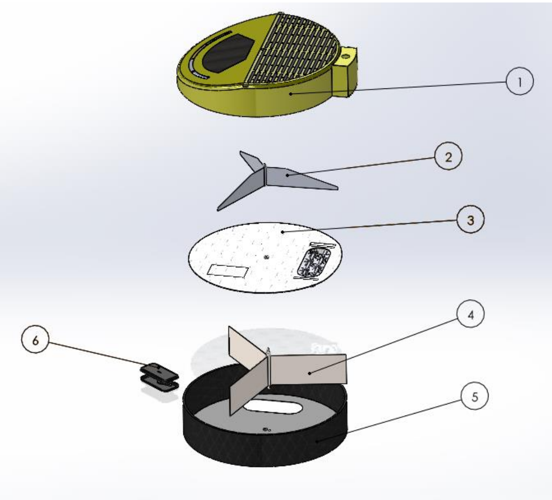

Fig. 8 Exploded View of the Top-Leveled Compartment

Table 4 Part List of the Top Leveled Compartment

Part Number	Description	Quantity	Material
1	Top Cover	1	Stainless Steel
2,4	Vane	2	Stainless Steel
3,5	Flat Plate	2	Stainless Steel
6	X-Frame Compactor	1	Mild Steel

2.7 Components Description of the Proposed Design

2.7.1 Polycarbonate Shield

Polycarbonate is a well-known material for its adaptable properties, eco-friendly production, and recyclable nature. Polycarbonate is a high-performance polycarbonate with the potential to provide safety and comfort in applications that call for great performance and dependability. The polymer is robust up to 140°C and down to -20°C and has a density of 1.2 – 1.22 g/cm^3 Making it indestructible. It is a crystal-clear plastic that transmits light at a rate of over 90 percent, equal to that of glass. The property also allows an increase in efficiency. Polycarbonates can be designed to block ultraviolet radiation and offer total protection against harmful ultraviolet rays. It offers good resistance to heat, thermally resistant up to a temperature of 135 °C.

2.7.2 Monocrystalline Solar Panel

The cylindrical silicon ingot used in the panel is made from highly pure single-crystal silicon, which gives it its name. The cell's single-crystal construction provides much mobility for the electrons to freely move, resulting in an optimal flow of electrons. Wafers are wire-cut into an octagonal form to optimize the use of the cells. When sunlight shines on the monocrystalline solar photovoltaic, the cells absorb the energy, and through a complex process form an electric field. Monocrystalline cells usually possess optimum efficiency ranging from 17% and 20% and the optimum power capacity.

2.7.3 Body

The body, which includes the base cover, access doors, cover, and coverlid, is made from stainless steel and has useful properties. As a result of its chromium content, it is highly resistant to corrosion. The at least 10.5% chromium content in stainless steel offers it a very high resistance (200 times) to corrosion than steels without chromium. Other favourable properties are its high strength and durability, high and low-temperature resistance, increased formability and easy fabrication, low maintenance, long-lasting, attractive appearance and it is environmentally friendly and recyclable.

2.7.4 Waste Compartment

The container that houses the waste is sectioned into four separate compartments. The sectioning is done based on the amount of waste produced on campus. With the dominant waste produced being 43% occupying the biggest compartment, 29% housing the next biggest compartment, 16% holding the third biggest, and 11% occupying the least sized compartment. The material suitable for the manufacturing of the waste compartment is polycarbonate plastic because of its good chemical and physical properties.

2.7.5 Arduino Board

Arduino, an open-source platform used in developing electronics projects. It is made up of a programmable circuit board (usually referred to as a microcontroller) and a software, or IDE (Integrated Development Environment) that runs on computers and is used for writing and uploading a computer program to the physical board. Some functions of an Arduino include increasing the readability of the code, conceiving and organizing the program, reducing the chances of errors, making the program compact and small, avoiding the repetition of the set of statements of codes, and allowing us to divide a complex code or program into a simpler one.

2.7.6 X-Frame Compactor

The X-frame compactor is powered by a photovoltaic cell array. The compaction feature allows the unit to be emptied less often than a typical trash container. The trash compactor includes a storage system to store power for compaction cycles.

2.7.7 Sensors

Inductive Proximity Sensor

This sensor identifies the object (usually metallic), which is brought close to their active side. It works under the principle of electrical inductance in which a fluctuating current induces an electromotive force in a desired object. These non-contact proximity sensors detect ferrous elements, typically mild steel greater than one millimetre in thickness.

Infrared Sensor

An infrared sensor is a basic electronic gadget, which emits and coordinates IR radiation to discover certain objects or impediments in its range. It uses infrared radiation of wavelength between 0.75 to 1000Âµm. The sensor works with a radar system and they both transmit and get infrared radiation. This radiation hits the objects adjacent and bounces back to the recipient of the gadget. Through this technology, the sensor cannot as it was identified motion in an environment but moreover how distant the said object is from the gadget. Infrared sensors can be utilized to decide the nearness of organic waste or food establishment.

Capacitive Proximity Sensor

Sensing devices called capacitive proximity sensors (CPS) are made to find both metallic and nonmetallic targets. They can pick up lightweight objects that mechanical limit switches are unable to take. Plastics and other nonmetallic substances of interest, liquid level management, and the sensing of powdered or granular material are all excellent applications for capacitive proximity sensors.

Filling Level Sensor

The fill level is measured using filling level sensors. They are particularly utilized for the continuous filling level assessment of liquids and bulk items. The filling level limit switch used to illustrate a given filling level and then begin a response, is also a filling level sensor. The filling level sensor generates an analogue or digital display of the measurement data in various absolute and relative sizes as well as measuring units during continuous filling level measurement. As an illustration, some sensors display the value as a percentage. A filling level limit switch, on the other hand, will output the value in this situation through a switch contact.

3 Results and Discussion

3.1 Simulation Process

3.1.1 Blade Design and Analysis

There are three cutting edges on the shredder’s blade. SolidWorks was used to generate the geometry of one blade, as illustrated in Fig. 9. The blade’s hexagonal hole enables it to be fastened to the drive shaft.

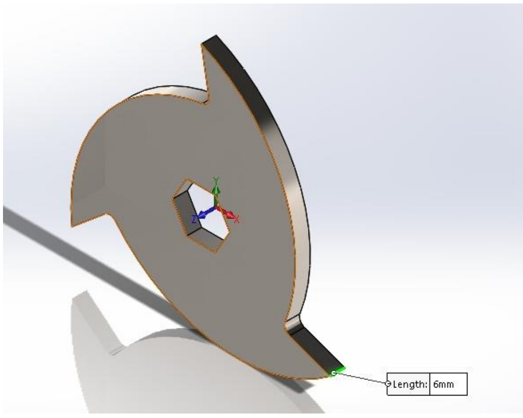

Fig. 9 The Three Cutting Edge of the Blade

The shredder blade's structural and deformational capabilities were verified using finite element analysis. The static structural analysis was carried out only considering static loads and strains, without considering vibration or dynamic analysis. Boundary conditions have been added to the model and the hexagonal hole in the center of the blade is fixed in all coordinate directions.

3.1.2 Finite Element Analysis (FEA) Setup

Material Properties

Poison's Ratio, Yield Strength, and Young's Modulus are among the properties taken into account when selecting the necessary material for the blade.

Boundary Conditions

Constraining the movement of the hexagonal hole in X, Y, and Z directions, the blade experiences static loads which include forces acting on the cutting edges.

3.1.3 Model Meshing

The preliminary mesh is generated using the meshing tool, with refinements applied to key regions, including the hexagonal hole and the cutting edges, to ensure precise results. The number of nodes and elements is documented post-meshing. The accuracy of the simulation is highly dependent on the mesh quality and density, similar to the approach adopted by Pereira *et al*., (2019); Gupta *et al*. (2018).

3.1.4 Static Structural Analysis

Calculated the stresses, strains, and deformations under the applied loads and boundary conditions, ensuring that the solver settings were properly configured for the model's complexity.

3.1.5 Post-Processing

The analysis of the results focused on maximum stress, strain, and deformation, with particular attention to areas around the hexagonal hole and cutting edges where stress concentrations are likely. The overall findings indicate that the blade is safe and reliable.

3.2 Analytical Findings

Analytical findings in Fig. 10 show that the maximum contour plot of Von Misses stress in the x-y-z plane is $5.755 \times 10^{-7}\text{N}/m^2$, Which is a safe value when contrasted against the yield stress of the material from which the blade was made under the application of a force of magnitude 600 N.

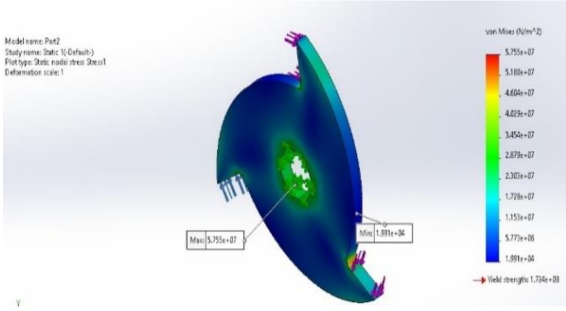

Fig. 10 Contour Plot of Von Mises Stresses

With the strain measuring the amount of deformation on the blade, the maximum mechanical train is 2.497×10^{-4} N/m m^2 which is very minimal. Maximum strain occurs when maximum forces are applied. If the deformation scale is a true scale, as shown in Fig. 11 then the strain is negligible which is good for the design of the blade.

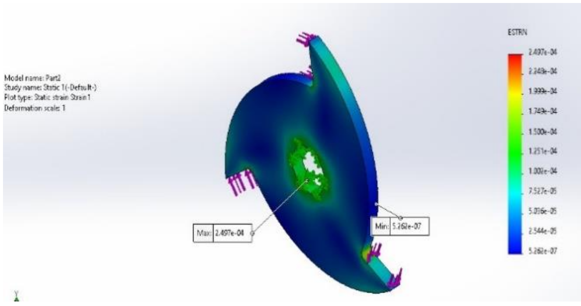

Fig. 11 Contour Plot of Equivalent Strain

With the scale of 1:1, representing the true scale, the maximum displacement on the edges of the three cutting blades as shown in Fig. 12 is 1.515×10^{-2} mm shows how much the edges of the blade are going to deflect. Arguably, if forces are applied on the edges of the blade, the deflection is very small and hence the blade is safe.

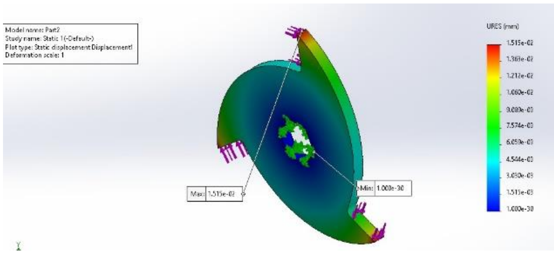

Fig. 12 Contour Plot of Static Displacement

The value of the factor of safety of the blade when subjected to a force of magnitude 600N using the true scale is 8.655×10^{-3}. The factor of safety expresses how much stronger the blade is than it needs to be for the intended load. With the value of the factor of safety expressed in Fig. 13, the material will be able to withstand the load without failure.

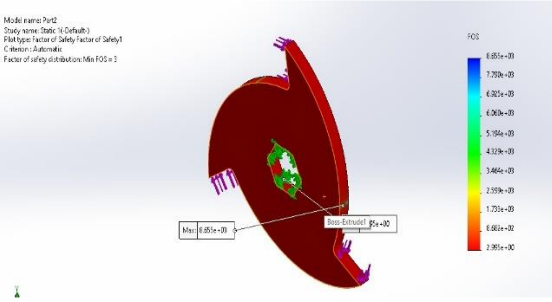

Fig. 13 Contour Plot of Factor of Safety

4 Conclusions and Recommendations

The modification of the smart trash bin segregator with the introduction of the shredding mechanism has been accomplished as formulated in this project. The materials used for each component are such that their properties satisfy the design requirements and at the same time cost effective and always available on the market. The shredder will require the power of 150.796 watts to shred the bulk waste deposited in the bin through the open and close mechanism of the lid. Weighting a full compartment to be 1.7897 kN, the compactor will require a force of that magnitude or greater to compactor the waste in the compartment giving rise to more volume for others to be accumulated in. The main advantage of this device is to segregate waste (be it bulk or not) into various compartments to aid in recycling. It is expected that the modification when manufactured and put to use will help minimize the risks of manually segregating wastes and maximize the rate of recycling waste into useful products.

It is recommended that an IOT-based waste collection system should be adopted to efficiently route and effectively schedule the collection of waste via text messages.

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