

# Design and Fabrication of a Mechanical Sweeper

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**ABSTRACT:** Encouraging clean and hygienic public areas is made more difficult by urbanization and growing population density. Current cleaning techniques can sometimes be ineffective, not environmentally friendly, unsustainable to handle different variety of debris and mostly expensive as they are imported into the country. This study presents the design and construction of an innovative mechanical sweeper from locally sourced materials to handle street and walkway cleaning challenges. By utilizing simple technique and employing locally available materials, the sweeper collects debris and eliminates negative effects of gasoline powered sweeper on the environment. Sturdy features include a mop function for thorough particle removal, an adjustable lever mechanism for agility, and a flexible brush configuration for cleaning various variety of surfaces. Testing the sweeper in different conditions on different types of trash, confirms the sweeper's ability to clean adequately as the designed sweeper with a single 24v battery and 0.5 hp electric motor gave a cleaning efficiency above 58%. The simulation and analysis of the sweeper frame using SOLIDWORKS 2018 gave a maximum displacement of  $1.621 \times 10^{-1}$  mm, maximum strain of  $2.415 \times 10^{-5}$ , maximum stress of  $9.167 \times 10^6$  N/m<sup>2</sup> and factor of safety of 3. The results of the analysis suggest that the sweeper has been well-designed and can withstand the loading conditions it has been designed for. The application of the sweeper can ensure notable gains in environmental sustainability, operational effectiveness, and cleanliness.

**KEYWORDS:** Sweeper brush, Suction blower, Electric motors, Adjustable lever mechanism, Debris collector

[Received Sep. 1, 2024; Revised Nov 27, 2024; Accepted Dec 2, 2024]

Print ISSN: 0189-9546 | Online ISSN: 2437-2110

## I. INTRODUCTION

Keeping public areas clean and hygienic is critical for both human and environmental health. While sweeping has historically been done by hand, the growing issues of urbanization and population density need more effective and efficient ecological means of cleaning. The history of mechanical sweepers can be traced back to the 19th century, with the first mechanical street sweeper invented in 1843 by C.S. Bishop of the United States. This early mechanical sweeper used a system of brushes and conveyor belts to sweep and collect dirt and debris from the streets (SCA, 2024). However, these early sweepers were large and heavy, requiring teams of horses to pull them.

In the early 20th century, advancements in technology and engineering led to the development of more efficient and effective mechanical sweepers. The first motorized sweeper was introduced in 1914, with an internal combustion engine replacing the horse-drawn system. These early motorized sweepers were also large and heavy. However, significant improvement was recorded in terms of efficiency and speed of the motorized sweepers (Adedeji & Adebisin, 2020; D'Andrea *et al.*, 2022).

As time passed, newer technologies led to improvement in the development of mechanical sweepers with the introduction of hydraulics, water systems, and suction capabilities. By the 1960s, mechanical sweepers had become more compact and efficient. New machines are designed to be more environmentally friendly, with reduced emissions and noise levels. Some machines are now equipped with Global Positioning System (GPS) technology and sensors, allowing for more precise and efficient cleaning in large or hard-to-reach areas (Javaid *et al.*, 2021). Moreover, robotic and autonomous sweepers have been developed, eliminating the need for human operators and allowing for more efficient cleaning (Floorbotics, 2024). The quest to keep the environment cleaner and healthier has led to the introduction of various types of sweepers such as mechanical broom sweepers, regenerative air sweepers, vacuum sweepers and combination sweepers. The introduction of different types of mechanical sweepers has been more effective than the manual mode of sweeping (Amato *et al.*, 2010; Walker & Wong, 1999). Figure 1 shows the image of a typical sweeper used in cleaning the streets and open spaces.

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doi: <http://dx.doi.org/10.4314/njtd.v21i4.2781>



Figure 1: A typical sweeper (Hako Machines Ltd, 2024)

Despite the advances, there are still some challenges as manual cleaning may be required in difficult-to-reach locations, and periodic maintenance is essential for maximum sweeper operation. Moreover, high-tech and more sophisticated cleaning equipment can be very expensive to import and maintained thereby incurring lots of foreign exchange. This work is on design and development of an efficient and cost-effective locally fabricated sweeper as huge sums of money are expended in importing machine sweepers (ICIR, 2020).

## II. METHODOLOGY

The procedures used in this study are as follows: Design conceptualization, calculation of component parts, material selection, cost assessment, fabrication and testing. The design considerations for the mechanical sweeper include simplicity of manufacturing, operator's safety, material availability, cost of construction, quality of working life, and functional needs.

### A. Material Selection

The selection of material has been carefully chosen based on some specific criteria such as weight, surface finish, stiffness, resistance to chemical assaults from the environment, service life and dependability, local material availability, mechanical strength, durability, availability and cost. The sweeper frame and body were constructed mainly with steel, most especially mild steel with inherent advantage of being easy to weld and containing low carbon content (Meng *et al.*, 2021). The machine is made up of the following components: a front axle, a rear axle, a roller brush made of polypropylene, a lead-acid battery, a wheel shaft, DC electric motors (0.5HP), a frame, a lever, a battery (24v), steering, a blower which is dependent on the desired suction capacity and type of debris, a pipe, a waste bag (Low-density polyethylene), and a seat.

### B. Methods

The description of the methods used in the development of the mechanical sweeper are presented as thus. Largely involving the design calculation, modelling of the mechanical sweeper using computer aided design software (SOLIDWORKS 2018), carrying out finite element analysis simulation, fabrication, instrumentation and testing.

#### i. Design calculations of the Sweeper

Design considerations and calculations of major parts (hopper, dustpan, hood, frame, DC motor) of the Sweeper are presented in this section.

#### 1. Weight of the Hopper

The rectangular prism shaped hopper has been designed based on selected design specifications of required size and material specifications with respect to strength, durability and availability. Steel plate of 1 mm thickness with a density of  $7850 \text{ kg/m}^3$  and having external and internal dimensions of  $701 \times 151 \times 251 \text{ mm}$  and  $700 \times 150 \times 250 \text{ mm}$  respectively have been selected for this project.

The volume of the hopper tank (V) = external volume - internal volume

$$= (0.701 \times 0.151 \times 0.251) - (0.7 \times 0.15 \times 0.25)$$

$$= 0.02656 - 0.02625 = 0.0003186 \text{ m}^3$$

$$\text{Mass of tank (m)} = 7850 \times 0.0003186 = 2.501 \text{ kg}$$

$$\text{Weight of the hopper tank (W}_c) = mg = 2.501 \times 9.81 = 24.53 \text{ N} \quad [g = \text{acceleration due to gravity} = 9.81 \text{ m/s}^2]$$

However, in calculating the weight of the hopper at full capacity ( $W_f$ ) basis assumption was made as the sweeper takes care of debris such as stone grits, leaves, paper crumbs, etc. as such, the additional mass of 100 kg of debris together with the mass of hopper will give a total weight of hopper at full capacity to be 102.501 kg.

$$\text{Therefore, the weight of the hopper at full capacity (W}_f) = 102.501 \times 9.81 = 1005.53 \text{ N}$$

#### 2. Hood design

The hood is designed to effectively gather the debris encountered during the cleaning process. The hood is a receptacle located beneath the sweeping system that collects the dust and waste swept by the roller brush. Its primary function is to ensure proper containment of the debris, preventing it from scattering and maintaining a clean environment. The effective collection area of the rectangular shape hood is determined by its dimensions ( $0.7 \times 0.15 \times 0.25 \text{ m}$ ).

$$\text{Effective collection area} = \text{Length} \times \text{Width} = 0.7 \times 0.15 = 0.105 \text{ m}^2$$

Therefore, the effective collection area of the rectangular-shaped hood is  $0.105 \text{ m}^2$ .

#### 3. Hood entry loss

The hood converts static pressure to velocity pressure (Kairouz & Price, 2013) and incurs hood entrance losses when dust is caught and drawn into it from a dust source. The following equation determines the hood entry loss:

$$He = k \times Vp$$

Where  $He$  = hood entry loss,  $K$  = hood entry loss coefficient;  $Vp$  = velocity pressure in the duct (w.g). Selecting a rectangular shaped hood which has a divergence of 60 degrees, the hood entry loss is given as 0.17 (Kairouz & Price, 2013). Therefore, the velocity pressure in the duct can be calculated using the equation:  $Vp = He/K$  Therefore, the velocity pressure in the duct ( $Vp$ ) =  $0.17/0.93 = 0.18 \text{ wg}$

#### 4. Determination of Torque to drive the Mop D.C. Motor

To determine the torque required to drive the mop D.C. motor, using a DC motor of 50 rpm, estimated rag and rag

holder weight of 5 kg and rag holder diameter of 200 mm and a factor of safety of 1.5 were used to calculate the maximum torque.

The force exerted by the rag and rag holder is given as:  
 Force = 5 × 9.81 = 49.05N  
 Torque = Force × Distance = 49.05 × 200 = 9810 N-mm = 9.81 N-m  
 Therefore, Maximum Torque = 9.81 × 1.5 = 14.72 N-m

The power requirement of the electric motor is given as:

$$Power = \frac{2\pi NT}{60}$$

where N is number of rotations in rpm and T is torque in N-m

$$= (2\pi \times 50 \times 14.72) / 60 = 77.1 \text{ Watts}$$

Therefore, a motor of 80W is selected for the sweep/mob components of the sweeper.

5. *Determination of Air velocity of the suction blower*

To determine the air velocity for the blower suction unit, the relationship of air velocity is equated to airflow rate divided by the cross-sectional area of the suction unit. That is,

Air Velocity = Airflow Rate / Cross-sectional Area  
 Using an average airflow rate of 100 m<sup>3</sup>/h and the inlet diameter of 0.05m of the cylindrical suction unit, then, calculating the cross-sectional area becomes:  
 Cross-sectional Area = π x (Inlet Diameter/2)<sup>2</sup> = π x (0.05/2)<sup>2</sup> = 0.0019635 m<sup>2</sup>

Therefore, the air velocity is given as:  
 Air Velocity = 0.0278(m<sup>3</sup>/s) / 0.0019635 (m<sup>2</sup>) = 14.147 m/s

6. *Determination of power required to drive the roller brush*

To determine the power required to drive the roller brush, a sweeping force of 78.5N as stated by (Walker & Wong, 1999) and roller brush radius of 0.055 m are used.  
 Torque = force × radius = 78.5 x 0.055 = 4.3175 N-m

Taken Factor of Safety as 1.5,

$$\text{Maximum torque} = 4.3175 \times 1.5 = 6.476 \text{ N-m}$$

Therefore, to calculate the power required,

$$Power = \frac{2\pi NT}{60}$$

$$Power = \frac{2\pi \times 1000 \times 6.476}{60} = 678.165W = 0.91hp$$

7. *Determination of the speed of the roller brush*

To calculate the linear velocity, the radius of the roller brush must be known. With a roller brush radius of 0.055 m, the authors determine the linear velocity of the roller surface based on its rotational speed as thus.

Speed of the motor (N) = 1000 rpm,

Roller brush radius = 0.055 m

Linear velocity, v =

$$\frac{2\pi \times \text{roller radius} \times \text{rotational speed (in rpm)}}{60}$$

$$V = \frac{2\pi \times 0.055 \times 1000}{60}$$

= 5.76 m/s

ii. *Design of the chassis frame*

The frame is what supports both the machine body and other attached components. The mechanical components were attached by bolts to the machine body and chassis and other features welded to the chassis were applicable. Thus, the chassis should be sufficiently robust to endure vibration, shock, twisting and other forces. Rigidity, Strength, torsional stiffness and bending are crucial factors to take into account when designing chassis for better handling (Hazimi et al., 2018). Angle bar (25x25x3mm) of total length of 11.18 m was used for the chassis frame with an estimated load carrying capacity of 150 kg acting on it. The design of the sweeping machine employed theoretical and finite element analytic techniques using SOLIDWORKS 2018 software. The orthographic view of the mechanical sweeper is shown in Figure 2, while Figures 3 and 4 show the exploded diagram and isometric view of the designed mechanical sweeper respectively.

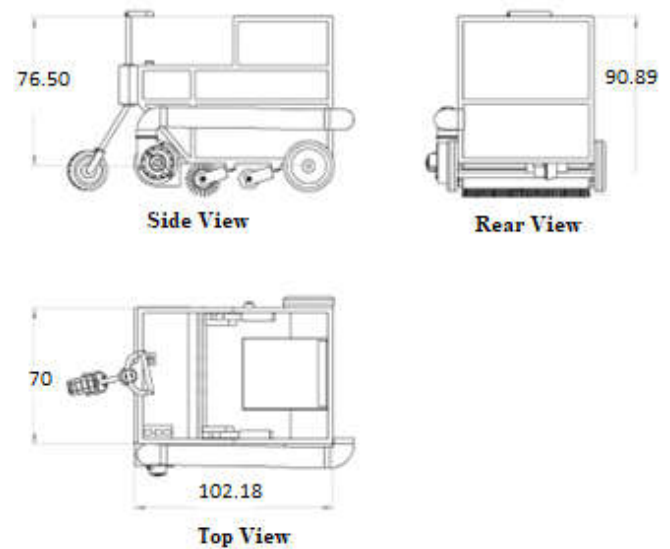


Figure 2: Orthographic view of the mechanical sweeper

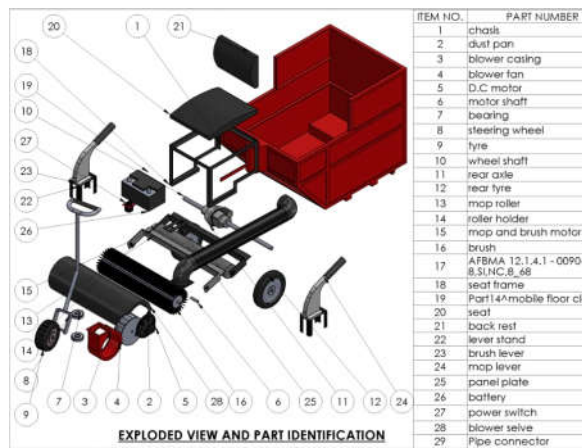


Figure 3: Exploded view showing the parts of the mechanical sweeper



Figure 4: Isometric view of the mechanical sweeper

iii. *Simulation of applied load on the chassis frame*

The total load on the chassis acting along the span of the entire beam (top of chassis frame) was considered as uniformly distributed load. Taking a ratio of the total length (3400 mm) of the chassis frame to a total load the chassis was subjected to (1500 N), the force ( $w_1$  as shown in Figure 5) of 441.17 N was applied to one of the longer lengths (1000 mm) of the chassis.

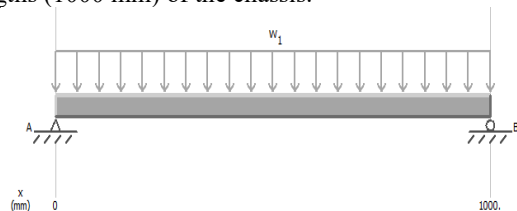


Figure 5: Load diagram of chassis frame

1. *Determination of stress and strain on the frame*

Static stress analysis is often sought after for structural analysis using the finite element method (FEA). FEA was

used in the analysis of the designed chassis because of its known effectiveness in proffering excellent solutions to structural problems in solid mechanics (Bi, 2018) and has also been suggested as a diagnosis tool in identifying design defects in failure of components (Bi & Mueller, 2016). Stress, strain and deformation of a component or assembly are investigated under range of load conditions to be sure appropriate design conditions are met to prevent unwarranted failure. The chassis is analyzed using SOLIDWORKS 2018 software. The Table 1 shows the properties of the material selected in the analysis of the chassis frame. Figure 6 shows applied load (in purple colour) and the fixed points (in green) to which the frame has been subjected. With the aid of MDSolids 4.0 software, the bending moment, slope and deflection of the chassis frame longest length were obtained as shown Figure 8 to figure 10.

Table 1: Stress and Strain Properties of the frame

NAME	ALLOY STEEL
Model type:	Linear Elastic Isotropic
Default failure criterion:	Max von Mises Stress
Yield strength:	$6.20422e^{+08}$ N/m <sup>2</sup>
Tensile strength:	$7.23826e^{+08}$ N/m <sup>2</sup>
Elastic modulus:	$2.1e^{+11}$ N/m <sup>2</sup>
Poisson's ratio:	0.28
Mass density:	7700 kg/m <sup>3</sup>
Shear modulus:	$7.9e^{+10}$ N/m <sup>2</sup>
Thermal expansion coefficient:	$1.3e^{-05}$ /Kelvin

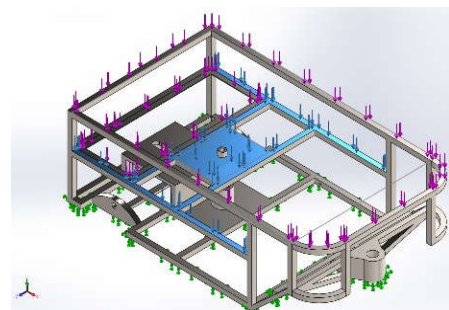


Figure 6: Mechanical sweeper frame under load condition

iv. *Fabrication and assembling*

The fabrication was carried out at the University of Ilorin Mechanical Engineering Workshop. The fabrication process involves marking out of required lengths, cutting of individual parts of the chassis frame, joining each member through welding and assembly of other components. The image of the assembled sweeper is shown in Figure 7.





Figure 7: Fabricated mechanical sweeper

v. Mode of operation

To operate the mechanical sweeper, the electric motor that drives the sweeper is engaged via the start button. The handle or control mechanism is used to maneuver the sweeper to and around the desired location to be cleared. Then, the button controlling the rotating brush is engaged. As the operator maneuvers the sweeper, the rotating brush sweeps the debris from the ground and the debris is sucked into the collector. The debris in the hood is emptied after the cleaning process is stopped by the operator.

III. RESULTS AND DISCUSSION

A. Bending moment, Slope and Deflection

The estimated bending moment of  $55.15 \times 10^6$  (as shown in Figure 8) acquired with deformable body mechanics software (MDSolids 4.0) constitutes a significant structural parameter in the evaluation of the steel-fabricated mechanical sweeper's top frame. This moment value represents the frame's ability to resist bending under applied stresses, which is a critical element impacting its mechanical dependability and integrity throughout operation. The large bending moment indicates the frame's capacity to endure large stresses and moments without structural collapse or excessive deformation.



Figure 8: Bending Moment diagram of chassis frame

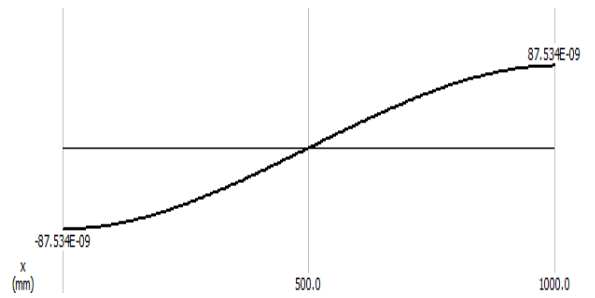


Figure 9: Slope diagram of chassis frame

The deflection slope of  $-87.534 \times 10^{-9}$  to  $87.534 \times 10^{-9}$  in Figure 9, indicates a negligible deformation within the frame, reflecting its flexibility and elasticity under the specified loading circumstances. This research gives important information on the frame's capacity to bend and return to its original position within acceptable limits, providing operational capability while preserving structural integrity. Likewise, the deflection diagram (Figure 10) with maximum deflection value of  $-1.077 \times 10^{-6}$  shows that the frame is able to carry the applied load without any significant deformation.

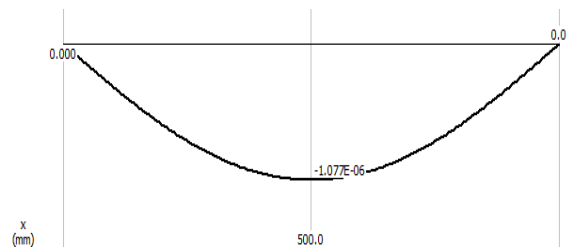


Figure 10: Deflection diagram of chassis frame

B. Analysis of Force acting on the chassis

The results (stress, strain, displacement and factor of safety) of the FEA conducted on the chassis has been presented in Figure 11 to Figure 14. Figure 11 shows the stress distribution on the chassis with a minimum of  $1.877 \times 10^{-6} \text{ Nm}^2$  to a maximum of  $9.167 \times 10^6 \text{ N/m}^2$  on the minute areas depicted with red coloration. Figure 12 shows the strain condition of the chassis with a minimum strain of  $3.991 \times 10^{-18}$  to a maximum of  $2.415 \times 10^{-5}$  mostly witnessed on the areas depicted in green coloration. Figure 13 revealed the minimum ( $1 \times 10^{-30} \text{ mm}$ ) to maximum ( $1.621 \times 10^{-1} \text{ mm}$ ) displacements values obtained in the chassis analysis, while a factor of safety of 3 (as shown in Figure 14) was achieved in the chassis design.

The minimal values obtained in the strain and displacement and the considerable factor of safety recorded, clearly indicated that chassis can withstand the applied load. This indicates that the chassis is not disposed to any significant deformation provided the load is within the designed specification as also noted by Yahaya & Abdulrahman (2018).

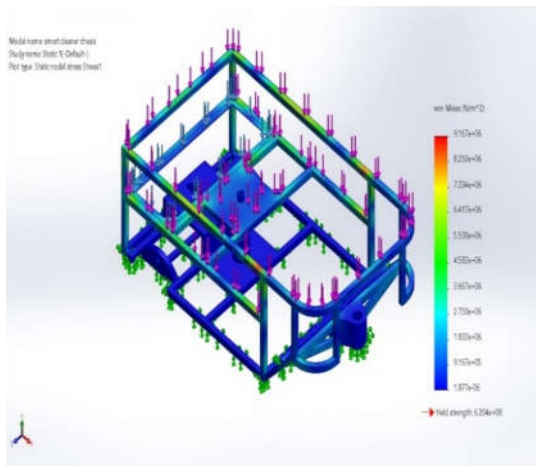


Figure 11: Chassis under stress condition

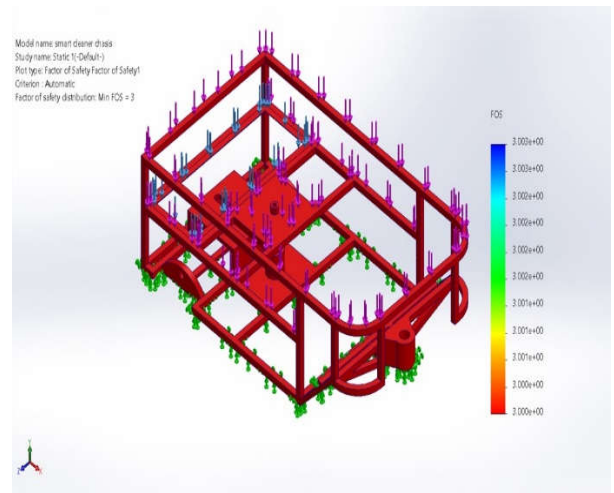


Figure 14: Chassis factor of safety

C. Performance Evaluation

The mechanical sweeper demonstrated impressive cleaning efficiency during testing, exceeding 58% removal of various debris types, including fine dust, pet hair, and small particles. This performance is attributed to the optimized brush design and powerful suction system, ensuring thorough cleaning across diverse surfaces. The battery life proved sufficient for practical use, with a single charge enabling a runtime of 20 minutes. This duration minimizes operational interruptions and ensures convenient cleaning sessions without frequent recharging. The sweeper operates at a pleasantly low noise level, measured at 55 decibels, significantly quieter than common household appliances like vacuum cleaners.

Durability was another key strength, with the sweeper demonstrating resilience to regular use and minor impacts. The rugged design and construction were done to ensure long-lasting performance and make it a reliable cleaning alternative. Simple setup process, intuitive controls, hassle-free maintenance, easy accessibility and user friendliness makes the sweeper suitable for a user with minimal or no technical expertise.

i. Analysis of debris removal by the sweeper

From the experiments or testing and/or graphical result obtained, the mechanical sweeper gives an efficiency above 58%. The power of the motor or suction system, combined with the design of the brushes, ensures optimal cleaning results. Table 2 gives the breakdown of particle removal efficiency of the mechanical sweeper. The results obtained revealed that the density of material is directly proportional to the cleaning efficiency of the machine. That is, the lower the density of material to be removed, the higher the efficiency of cleaning.

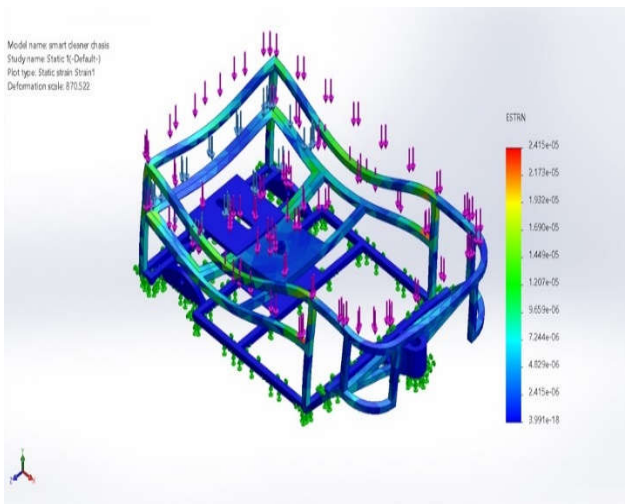


Figure 12: Chassis under strain condition

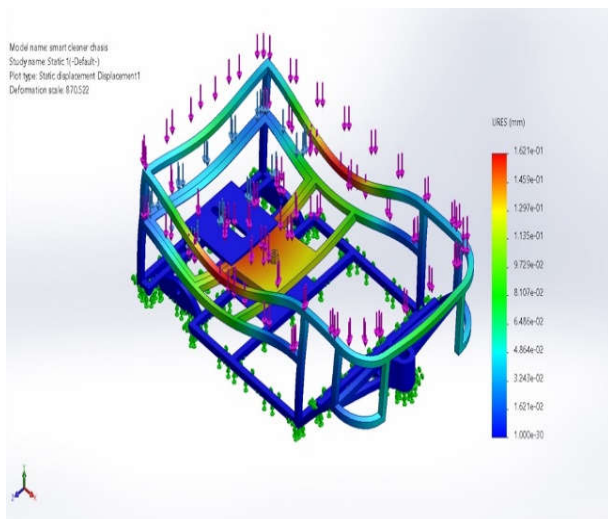


Figure 13: Chassis under displacement condition

Table 2: Effect of particle types and sizes on the efficiency of particle collection.

Particle material	Particle size range, d (mm)	Particle removal efficiency, $\eta$ (%)
Stone-sand	<5	58
Leaves	10-25	80
Paper	15	82
PVC	3	74
Wood	8-20	71
Glasses	3-5	67

ii. Experimental Result of the mechanical sweeper versus handheld broom

The experiments carried to out to determine the time taken in sweeping a specified area using manual method of hand-held broom and the designed mechanical sweeper revealed the results in Table 3 and the corresponding graph (shown in Figure 15). The results indicate considerably reduction in time using the mechanical sweeper as against the handheld broom method of sweeping. An average commercial 1 HP mechanical sweeper such as KARCHER KM 70/20 C (Glotelho, 2022), which cost about \$1,275.31 (as at 27<sup>th</sup> of February, 2024), has a maximum area yield of 3680 (m<sup>2</sup>/h) or 1.02 m<sup>2</sup>/s as against the developed mechanical sweeper with an average area yield of 0.2 m<sup>2</sup>/s. Also, a product of Sweep care C-20 mechanical sweeper has the performance of 2600 m<sup>2</sup>/h or 0.72 m<sup>2</sup>/s (Charnock, 2024) as against the developed sweeper. However, the result of the mechanical sweeper indicates that the performance could be improved if the motor power is increased.

Table 3. Values of swept area and time taken of a hand-held broom

Average swept area (m <sup>2</sup> )	Time taken using handheld broom (s)	Time taken using mechanical sweeper (s)
0.6	4.0	3.0
1.2	8.5	6.0
1.8	12.5	9.0
2.4	17.0	12.0
3.0	21.0	16.0
3.6	25.0	19.0
4.2	29.0	21.0
4.8	34.0	24.0
5.4	38.0	28.0
6.0	42.0	31.0
6.6	46.5	33.0
7.2	50.0	35.0
7.8	54.5	37.5

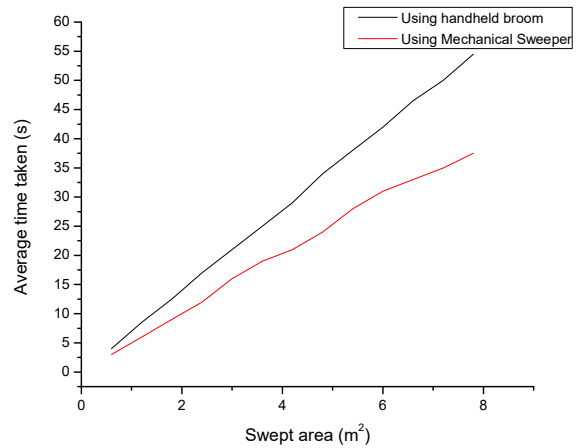


Figure 15: Graph of average time taken (s) against swept area (m<sup>2</sup>) using handheld broom and mechanical sweeper

The relationship between the swept area and time taken for both methods used are linear, that is, the larger the swept area, the more the time taken to complete sweeping. The mechanical sweeper as compared to the handheld broom method of sweeping covered the specified areas in lesser times. The advent of a motorized sweeper designed specifically for low-resource situations is a significant achievement in urban sanitation engineering. In the face of increasing urbanization and population density, traditional cleaning methods frequently fail, creating difficulties of inefficiency, environmental degradation, and economic pressure, especially in countries depending on imported equipment (Abubakkar *et al.*, 2021).

The study's innovative design highlights a paradigm change, combining locally accessible materials and cutting-edge technologies to address these difficulties (Raihan *et al.*, 2024). The use of indigenous materials not only promotes cost-effectiveness, but also maintains sustainability which is an important factor in resource-constrained environments. The sweeper serves as a catalyst for raising cleaning standards in public spaces by maximizing debris collecting efficiency while minimizing environmental effect.

Rigorous testing under varying conditions confirms the sweeper's robustness and performance. The dependency of such developed sweeper is important in locations where maintenance resources are scarce, assuring prolonged operational functionality (Prassler, 2000).

D. Limitations

While this study solves a very important problem in low resource area at a comparatively cheap price of production cost of N300,000 (\$203) as against imported ones with an average cost of \$1200, certain limitations worthy of consideration is acknowledged. This work focuses on the technical design and fabrication of a mechanical sweeper for developing countries, no biomechanical analysis has been done to know if there is an adverse effect on user. This study concentrates on the technical aspect with performance evaluation done in controlled

environment. Further investigation will be needed to know the challenges users may face in adopting this technology. Further evaluation would also be needed to answer questions on the reliability of this solution, though this work demonstrates no apparent safety concerns, and it shows functionality with good efficiency. Our efforts were largely concentrated on getting the device to perform cleaning function, the device would certainly benefit from additional features like autonomous driving, which presents opportunities for future research.

### III. CONCLUSION

This work demonstrates the potential of locally constructed mechanical sweeper to revolutionize urban cleaning and reduce if not eliminate the importation of similar sweepers. By effectively removing diverse debris types from various surfaces, the developed sweeper offers a practical solution to sweeping and more appealing urban environment. Its good efficiency (with respect to areas covered at minimal cleaning time), user friendliness (with simple controls that make it easy for use by the operator), and low maintenance (as the mechanical design employed minimizes the need for frequent maintenance). The results obtained on the chassis design with minimum stress distribution of  $1.877 \times 10^{-6} \text{ Nm}^2$  to a maximum of  $9.167 \times 10^6 \text{ N/m}^2$ , minimum strain of  $3.991 \times 10^{-18}$  to a maximum of  $2.415 \times 10^{-5}$ , minimum displacement of  $1 \times 10^{-30} \text{ mm}$  to maximum displacement of  $1.621 \times 10^{-1} \text{ mm}$  and a factor of safety of 3, all indicated that the chassis have been well designed against failure for the designed load specification. The design and local production of this type of mechanical sweeper is expected to provide a significant step towards sustainable urban sanitation, paving the way for a cleaner and healthier future for our cities.

### IV. AUTHOR CONTRIBUTIONS

**K. O. Abdulrahman, S. P. Oghenetega, and O. J. Shopeyin:** Conceptualization, Software Simulation and Validation, and Writing – original draft. **S. P. Oghenetega, O. J. Shopeyin, A. O. Sayodun and K. O. Abdulrahman:** Conceptualization, Methodology and Supervision. **K. O. Abdulrahman, F. O. Ogunwoye and S. A. Yahaya:** Writing – review & editing.

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