DEPARTMENT OF MECHANICAL ENGINEERING TECHNOLOGY

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Design of a Seed Sowing Robot

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Subject: PJMMIA3

Date: 21 April 2024

DECLARATION

I (We) swear that this is the original work of the author(s). All information obtained directly or indirectly from other sources has been fully acknowledged. Furthermore, it represents my (our) own opinions and not necessarily those of the University of Johannesburg.

RAPATSA K	**16 March 2024**
Signed	**Date**

ABSTRACT

The seed sowing project aims to design an automated machine that can reduce the laborious work which small farms face in using the traditional farming methods, especially in rural regions where these practices are popular. These methods are labour-intensive as they require the use of hand tools which lead to poor and uneven distribution of seeds of which both affects the crop performance and puts the workers at risk for stooped-work and exertion of more physical strength for long hours. This project seeks to find solutions to these problems in the form of a reasonably priced automated machine which gives accurate depths and spacing of the seeds in a manner that it does not inhibit the growth conditions necessary for enhanced agricultural outcome.

The machine incorporates both mechanical and electronic such as the seed metering system, adjustable depth settings and a furrow closer. These aspects have been designed and integrated in a manner that the machine minimizes human effort, eliminate planting errors and achieve higher efficiency. The design is focused on simplicity, affordability, and environmental sustainability, making it accessible to farmers with limited resources. Throughout the project, extensive research and analysis were conducted to ensure the machine is capable of operating on uneven terrains and handling various seed types, thereby increasing its adaptability to different farming environments. The overall goal is to offer an affordable, scalable solution that can significantly reduce labor while improving yields and supporting sustainable farming practices.

ACKNOWLEDGEMENTS

I would like to thank my supervisor, Dr C. Anghel, who devoted so much of her service onto the project. Given the determination to succeed in the project I would also like to extend my gratitude to the University of Johannesburg for their unending support, assistance and encouragement for completing this project.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS, ABBREVIATIONS

1. SABA – South African Bureau of Standards

1. INTRODUCTION AND BACKGROUND

Domestic farming is one of the important practices in South Africa for various reasons including household consumption, economic contribution, and environmental sustainability. Thus, it is imperative to optimize the yield and quality of the crops produced. Most of the challenges faced in domestic farming is that farmers must plough and sow seeds by hand tools, and this affects the quality and yield of the crops. The quality of the crops planted in farming depends mostly on the type of planting method, because different seeds need different conditions for optimal growth. For example, each type of seed has its own depth for which it must be planted and different spacing with other seeds to reduce competition for resources such as water, light, and carbon dioxide. To address all these problems, it is evident that a seed sowing machine that is more precise and accurate needs to be designed to ensure that every seed is consistently sowed to the right depth and distribute seeds evenly.

In early history, seed sowing was done manually by humans using basic tools, for example hoes and hand-pulled seed drills. This was very tedious work because before sowing the seeds, the soil had to be ploughed. Ploughing loosens the soil, removes weeds and creates an environment that promotes seed germination. After ploughing the seeds were scattered by hand and again had to be covered by the soil. The whole process was very time-consuming to complete, requires a lot of energy and exerts a significant amount of physical strain on the workers. Unfortunately, even in modern times people still use these basic tools to plough and sow seeds. They are mostly used in rural areas or small-scale farmers because they are unable to afford modern seed sowing machines. Research looking at low back disorders in agriculture and the role of stooped work, (Fathallah, et al., 2008) has concluded that long term effects working in stooped positions can lead to the workers developing lower back disorders. It further indicates that the prevalence of lower back syndromes is a major occupational health concern affecting both developing and developed countries and is higher in non-developed countries.

Figure 1: Domestic Farmer ploughing using a hoe. Adapted from (Anon., 2016).

BACKGROUND ON SEED SOWING MACHINES

There are many seed sowing machines in the industry, each designed with the purpose of streamlining the process of seed sowing and reduce its labor-intensive demand to farm workers. Depending on the design or application, a typical seed sowing machine consists of a seed hoper, metering system, seed dispensing mechanism, wheels (motion), and furrow opener.

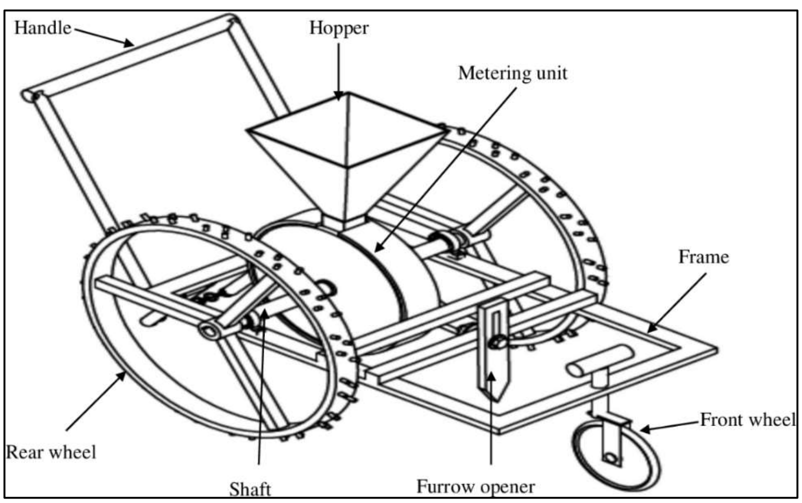

Figure 2: A simplified Seed sowing machine. Adapted From (Soyoye, et al., 2016).

The hopper is a large container for storing the seeds to be planted. Its big size allows a substantial number of seeds to be stored before operation thus, reducing the need for frequent refilling. The metering system is responsible for releasing the seeds to be planted uniformly by releasing the seeds at a constat flow rate. This allows the seeds to be planted at constant spacing between each other. The spacing distance can be varied by changing the flow rate at which the seeds are released, with a higher flow rate resulting in short spacing and lower flow rate resulting in long spacing. A common metering system is shown in figure 3 below. From figure 3 it is evident that the shaft causes the model-hole wheel to rotate anticlockwise and each seed from the seeding-filling area gets carried by the wheel to the seed-guide-tube to be planted.

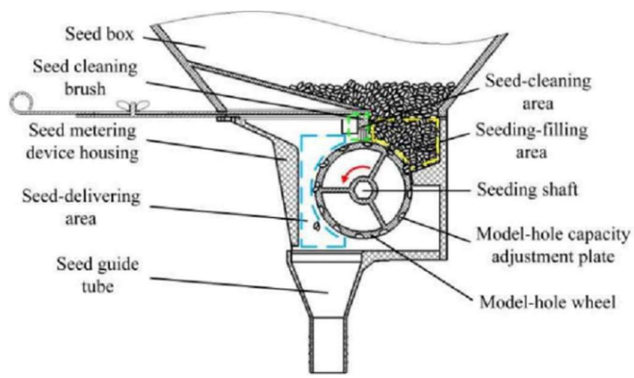

Figure 3: A general metering system. Adapted from (Zhaodong, et al., 2022).

As the machine moves forward, seeds from the seed-guide-tube are dropped in the furrow with uniform distance between them. The furrow is created by the furrow opener as the machine is moving forward. The seed sowing machine can generate motion in three ways: by connecting it to a tractor, requiring manual pulling or pushing from a human, or operating autonomously. Some seed sowing machines require to be connected to a tractor that will pull it so it can operate, some consist of a handle that it can be pulled or pushed by a person. The last one is by utilizing a software program that autonomously automates the entire process. Depending on the design requirements these ways of providing motion to the machine will make the process of sowing efficient and accurate.

EXISTING SEED SOWING MACHINES

Seed sowing machines are divided into two types, manual and automatic. Manual seed sowing machines require human assistance for operation, this involves pushing or pulling and guiding the machine across the field. The first innovation in seed sowing machines was the seed drill, designed by Jethro Tull in the 17th century (Hidden, 1989). This served as the benchmark for many years and ultimately his designed evolved with time until present days. The following are manual seed sowing machines available in this era.

Hand Operated Seed Sowing Machine

The hand operated seed sowing machines are manual devises used in small scale farming or gardens to assist the operator with the sowing process. It consists of the following key components: handle, wheels, furrow opener, hopper, metering meter and a furrow closer. To operate the machine, the operator must first place the machine in the field, adjust the metering meter, fill the burrow with the desired seeds then pull the machine with the handle. This machine is labor intensive because it requires an extensive amount of energy to pull it around the field and if used for long periods of time without rest, it could lead to injury. The intensive labor requirement and simple design of the machine allows it to be cost effective and affordable to small-scale farmers. An evaluation study on this type of seed sowing machines has revealed that these machines produce uniform germination of crops (Ali, et al., 2020) thus proving that the precision of seed placement is high and consistent

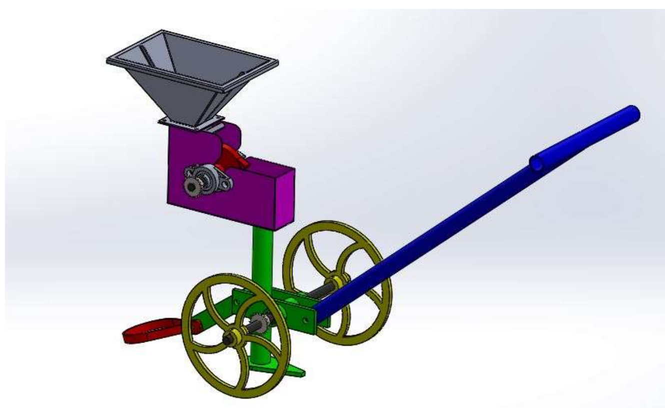

Figure 4: Manual seed sowing machine. Adapted From (Balusamy, 2020).

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Seed Drill

A seed drill is a seed sowing machine that is mounted and dragged by a tractor to operate. It is a manual seed sowing machine used in both small- and large-scale farming for sowing seeds, positioning them at the right depth and burying them. To operate the seed drill, the operator must first adjust the machine's setting according to the requirements of the crops being planted, spacing between seeds, seed depth and the soil conditions. Then the following steps are followed, mounting the machine to the rear of a tractor, fill the hopper with the desired seeds, align the seed drills to plant the seeds in a straight line. Seed drills are not very labor intensive as compared to other machines because they are also used in soil preparation and removing weeds around the fields before the sowing process. The machine has high efficiency and precision in planting crops at the right depth and consistent spacing. A study at the University of Ruse has revied at the challenges facing contemporary seed drill and some of these challenges were found that seed drills require a lot of energy to operate and are expensive to purchase and maintain (Bratoev, et al., 2018). The seed drills require powerful tractors for operation due to its large mass and resistance offered by the soil. The complex mechanisms integrated into the machine make it more expensive to perchance and maintain thus making it inaccessible to other people. Figure 5 shows an example of the seed drill equipment.

Figure 5: Seed Drill. Adapted from (Elmalı, 2022).

Automatic or autonomous seed sowing machines are robots that capable of automating the seed sowing process accurately without requiring any human assistance throughout the operation. The purpose of these robots is to reduce stooped work and reduce human effort in both small- and large-scale farming. These types of machines utilize mechanical mechanisms from the manual seed sowing machines and solve their limitations by incorporating both electronics and software. The following is an existing design of an automatic seed sowing machine.

Automatic Seed Sowing Machine

Figure 6 shows an automatic seed sowing robot from SRM Institute of Science and Technology (Saravanan, et al., 2018). This robot consists of the following key components: motor, burrow opener, seed hopper, burrow closer, battery and a microcontroller. It functions the same as the manual seed sowing machines but powered by a battery and instead of a human operating it, it is operated by code installed in the microcontroller. The robot can take commands via an input from the user about the seed spacing and depth to plant the seeds and through the code in the microcontroller, the robot will carry on the operation without any assistance and navigate through the field using GPS.

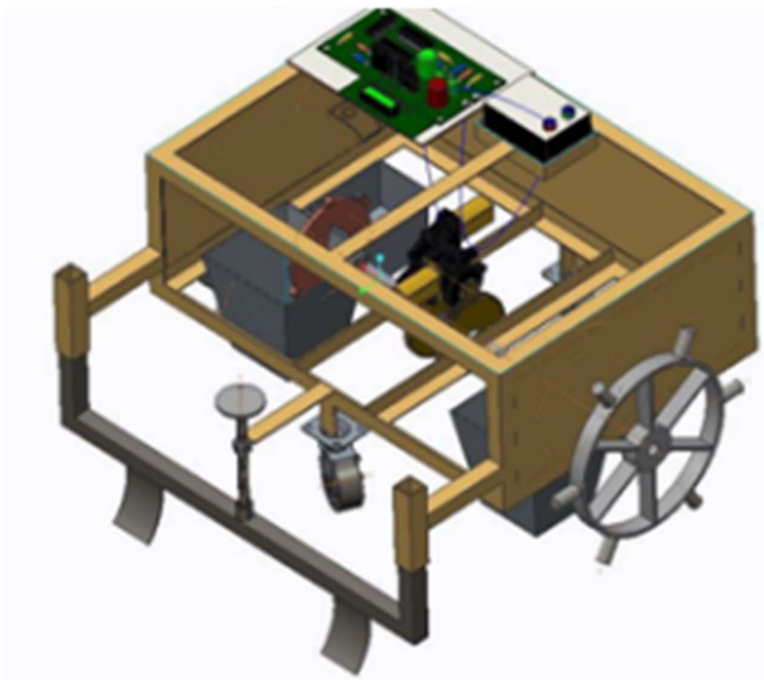
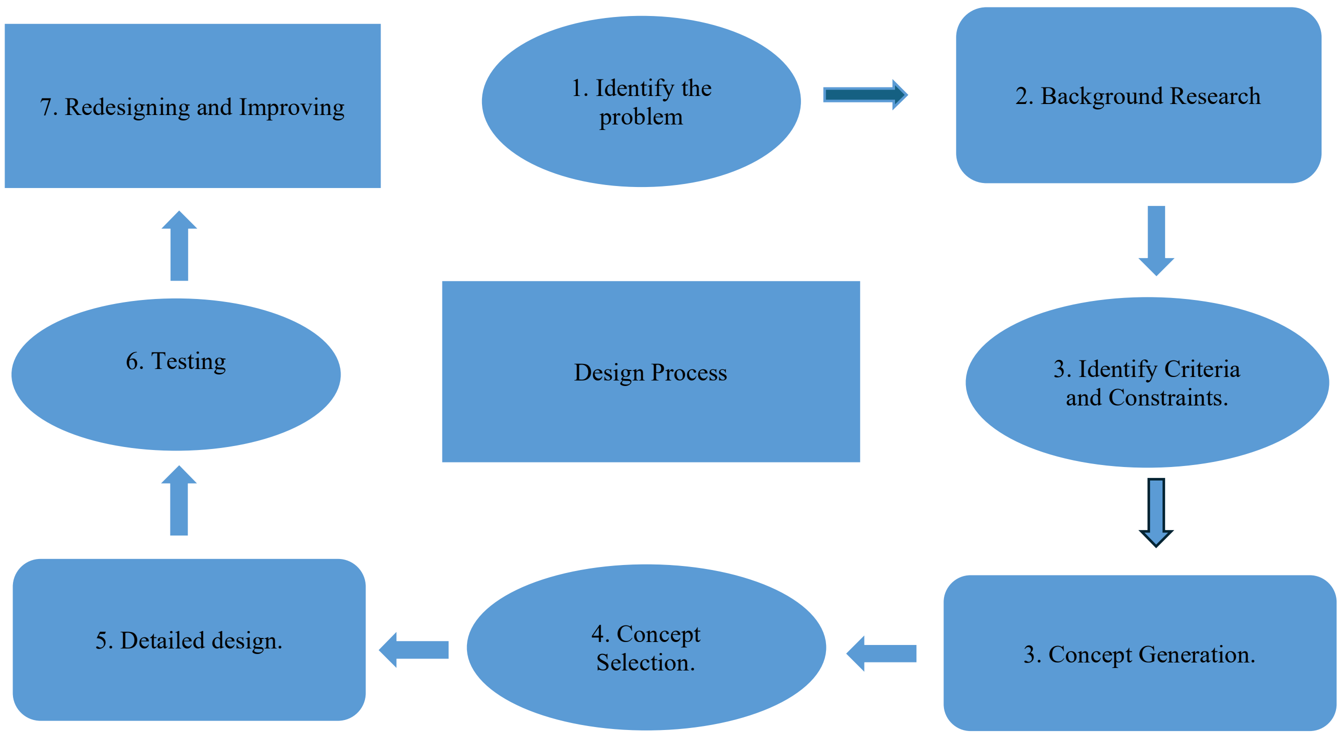


Figure 6: Automatic seed sowing machine. Adapted from (Saravanan, et al., 2018).

2. DESIGN STRATEGY

This section outlines the of design process and steps that will be utilised in the design of the automatic seed sowing machine.



- The first step of the design process is identifying the problem and developing an understanding of its nature. This step will also help in identifying the target market. The second step will be conducting research about the target market and existing solutions, evaluating why these solutions are not appropriate to the given problem.
- The following step is identifying the design criteria and constrains. This step is where the design goals and requirements are set also identifying the constraints early in the process. This step will provide structure and direction to the project. The third step is concept generation. In this step possible solutions to the problem are generated by using the S.C.A.M.P.E.R technique. Which stands for Substitute, Combine, put to another use, Eliminate and Reverse.
- The fourth step is the selection of the best generated concept in the third step. This is done by comparing the concepts by the previously set criteria. The concept that scores best is selected and is the chosen as the solution to the problem. The following step is providing the detailed design in terms of drawings or CAD files.
- The sixth step is testing the model if it works though software or calculations. This step is important because it allows us to save money on building a prototype.

3. DEFINITION OF PROBLEM

3.1.Problem statement

On domestic farms, farmers continue to face challenges when it comes to optimizing their crop yield because of the use of traditional methods of seed sowing. This is due to not being able to afford expensive equipment and the demanding physical labor. A journal looking at low back disorders in agriculture and the role of stooped work (Fathallah, et al., 2008), has shown that long term stooped work can lead to a person developing lower back disorders and another journal by Davis & Kotowski indicated that 37-41% of farmers experience this lower back pains due to stooped work (Davis & Kotowski, 2007). All these challenges lead to the workers compromising the crop yield by not following the strict rules of seed sowing, such as equal spacing and coverage of the seeds by the soil to obtain maximum yield.

Figure 7: Domestic Farmer ploughing using a hoe. Adapted from (Yekani, 2024)

The aim of this project is to design a seed sowing robot for small-scale farms that will automate the process of seed sowing. The robot will be able plant the seeds at the correct depth in the soil and equal spacing between the seeds and should help to eliminate the human effort needed for seed sowing and to increase the crop yield. Before operation, the robot will be set the depth to plough and the spacing between seeds and will carry out the operation efficiently through uneven terrain in a series of straight lines around a farm.

The project aims to reduce the number of injuries caused by stopped work in farming and the human effort needed. It also aims to inspire people of South Africa to use small-scale farming to fight poverty, start building businesses and come up with innovative ideas to make farming easier and productive.

3.2. Requirements

- The robot must be automatic and function without human assistance.
- The robot must be simple to use and maintain.
- It must be able to plant the seeds in straight rows even on uneven terrain.
- The robot should be able to plant different types of seeds.
- The design must allow different types of ploughing depths and seed spacing for basic.
- The design must be affordable.

3.3. Constraints

- The robot must be able to plough half an acre farm in series of straight rows.
- The robot must operate on rows of 40 centimeters wide.
- The robot must be able drive over obstacles or terrain of maximum height of 10 cm.
- The total mass of the robot must not exceed 50 kg.
- The robot must be able plough at depths of 5, 10, and 15 cm.
- The robot must be to plant seeds at spacing of 15, 30 and 45 cm consistent spacing.
- The final product must not exceed R22 000.

3.4. Criteria

- Price – The cost of the robot must be affordable.
- Maintenance – The product must be easy to maintain and clean or replace any part if damaged.
- Accuracy – The robot must plant the seeds at the correct depth and spacing with accuracy.
- Environmentally friendly – The product must not emit any greenhouse gases or cause damage to the farm.
- Operation – The product must be autonomous and plant seeds.

- Safety – The product must be safe to operate, consist of safety measures for example an emergency stop button.

4. FUNCTIONAL ANALYSIS

The system engineering process was broken down into subunits, each having an integral function to the entire process. These subunits are depicted in the diagram below.

Table 1: Functional Analysis

Subunit	Function
Control unit	A microcontroller is used as the control unit which operates the entire machine by giving a set of instructions to the components and ensures that every part operates as one system.
Battery	A battery will supply power to every electrical component of the machine (Motor, Microcontroller etc.).
Motor	A combination of motors and wheels is responsible for propulsion of the robot.
Sensors	Used to detect obstacles or people around the robot and prevent accidents.
Seed Hopper	A compartment that temporarily stores the seeds during operation.
Supporting Frame	A frame responsible for providing support to the entire machine and hold components in place.
Seed Dispensing Mechanism	A mechanism responsible for delivering seeds from the seed hopper to the soil.
Timing mechanism	The mechanism responsible for timing the release of seed to the soil at a controlled rate.

5. DESIGN DEVELOPMENT

5.1. Concept generation

In this subsection three concepts were developed using the S.C.A.M.P.E.R technique (Substitution, Combine, Adapt, Modify, put to another use, Eliminate, Reverse). First, research was conducted on existing designs in the market and recent scientific developments, then original concepts were developed with the given requirements and criteria of this project.

Concept 1

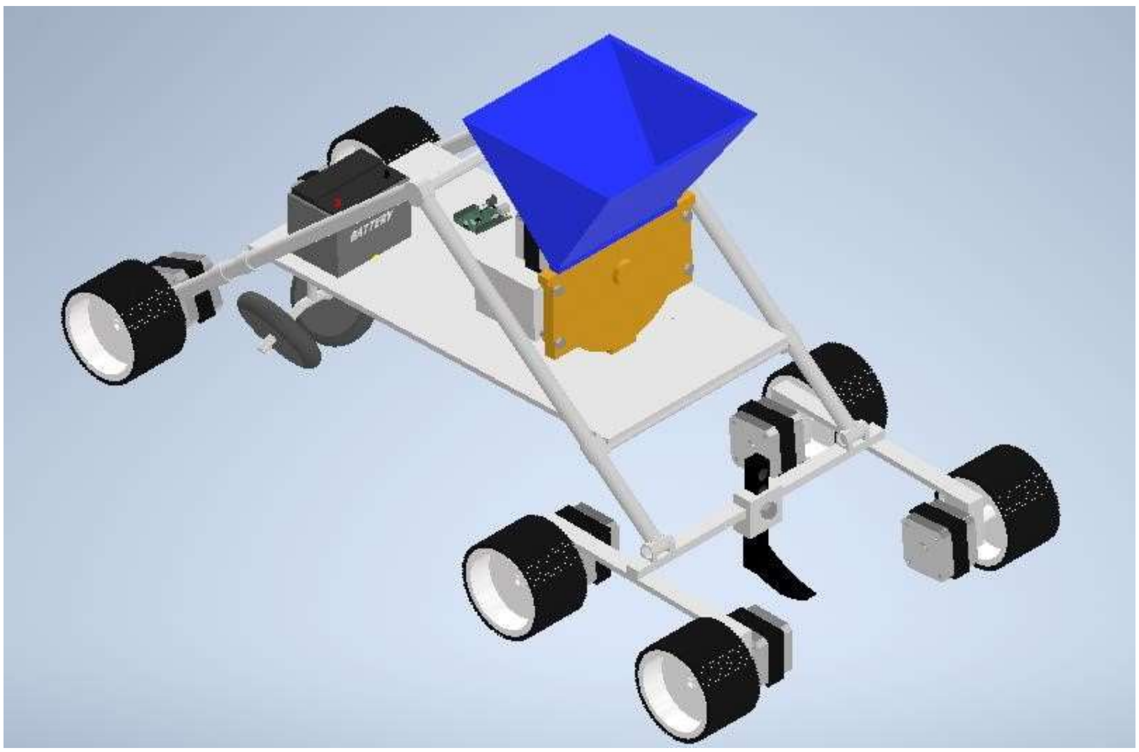


Figure 8: Concept 1 of an Automatic seed sowing machine from AutoCAD inventor 2025.

The figure above depicts the first concept to be considered, which is an automatic seed sowing machine consisting of a modified Rocker-bogie suspension. The Rocker-bogie suspension was first designed by NASA in 1988 to use in their first rover to Mars named Sojourner. It was incorporated in the Concept because of its stability on uneven surfaces, ability to overcome obstacles, ability to maintain traction and reduced chance of tipping over. The design consists of seven motors, six of which are connected to the wheels and are used for motion, and one is used to rotate the cup disk in the seed metering mechanism to disperse the seeds. The design uses the cup feed type metering system which has individual cups or chambers that are grouped in a revolving wheel hold the seeds, then each cup takes a set number of seeds from the seed hopper and releases them into a seed tube for planting as the wheel turns. The furrow opener is placed at the front to make sure the furrow is open before the seeds are dispersed. It is also adjustable to different depths and can be held at the desired depth by a bolt and a nut. It also consists of a seed hopper to temporarily store the seeds as they are transferred to the seed metering system, then the fluted roller collects each seed individually and is dispersed into the soil. Finally, the design has two press wheels configured in a V-shaped to cover and press down over the newly sown seeds with soil.

Concept 2

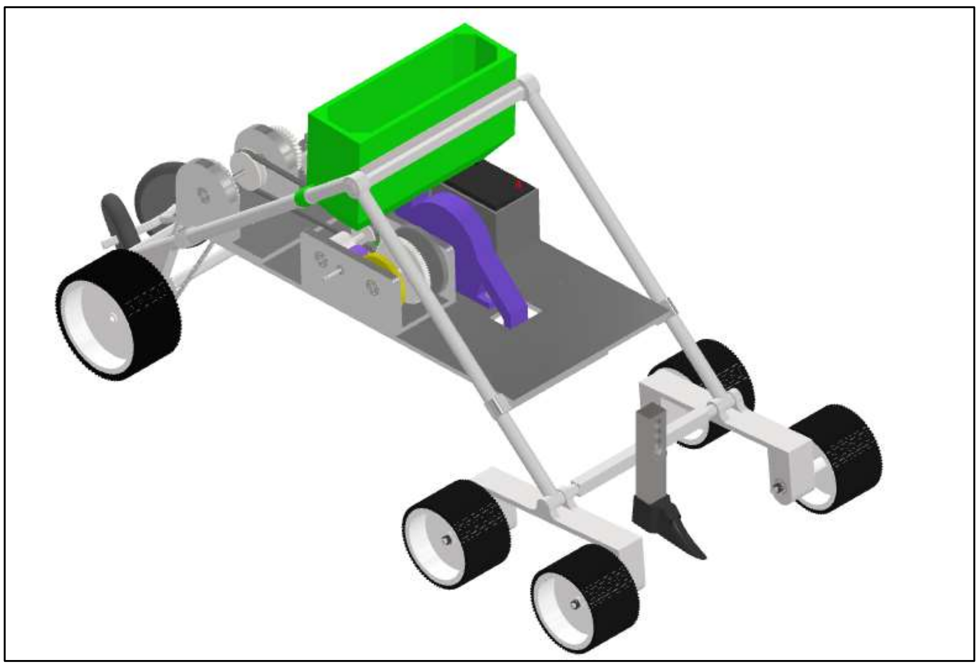


Figure 9: Concept 2 of the design of an Automatic seed sowing machine from AutoCAD inventor 2025

The second concept also consists of the rocker bogie suspension with a single motor drive. This is more cost-effective as it requires only one motor for propulsion but reduces wheel traction. The motor is connected to a main shaft that powers the rear wheels and the metering system. A chain drive is used to transfer torque from the main shaft to the rear wheel shaft because chain drives can transfer torque over long distances and does not slip. It also consists of a metering system that is adjustable for different seed spacing. The metering system is made of a set of gears that change the rotational speed of the dispersing mechanism.

Concept 3

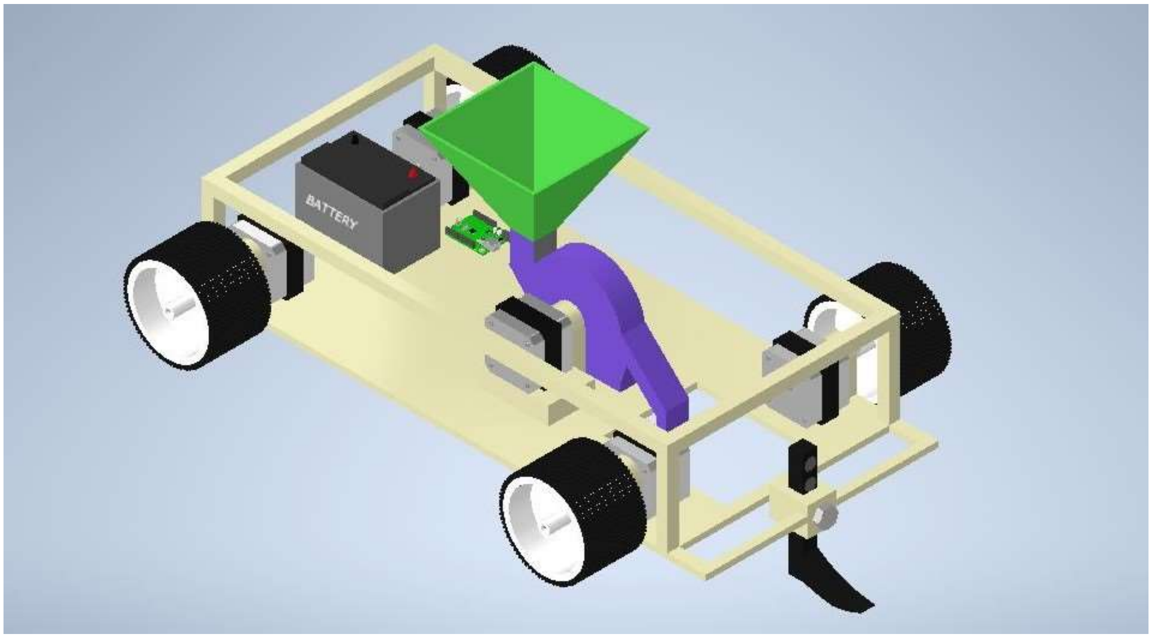


Figure 10: Concept 2 of an automatic seed sowing machine AutoCAD inventor 2024.

The figure above shows the second concept, which is a seed sowing machine consisting of a four-wheel drive mechanism. This concept consists of five motors, four are located at the wheels and are used for propulsion and one is used to rotate the fluted roller to disperse the seeds. The wheels are big to increase its stability and traction during operation on uneven terrain. It also has a seed hopper to store the seeds and a fluted seed metering mechanism to disperse the seeds. The fluted seed metering mechanism consists of a revolving motor shaft having helical grooves and the seeds are dumped into a seed tube for planting after being driven along the grooves by the rotating shaft. The battery and the seed hopper were placed towards the back of the robot to balance the robot from tipping over when ploughing due to the moment caused by the force exerted by the ground to the plougher. It also consists of a microcontroller to control the rate at which the seeds are dispersed and the motion of the robot. The wheels are connected to the supporting frame by bearings to reduce friction as the shafts of the motors rotates. The furrow closer in this concept the drag chain furrow closer, which is just a chain connected on both ends at the rear side of the robot and is dragged along as the robot moves forward.

5.2. Concept evaluation

The concepts that were generated all satisfy the specifications of this project and are all possible solutions. As such, in this section the concepts will be evaluated using the design evaluation matrix. Which contrasts the three concepts by the same specifications and two with the highest score are selected and are used to generate the final design.

Table 2: Design Evaluation Matrix

	Concept 1	**Concept 2**	**Concept 3**
Specifications	**Score**	**Score**	**Score**
Performance	2	3	2
Maintainability	3	2	2
Reliability	2	3	1
Stability	2	3	2
Affordability	3	1	3
Accuracy	1	2	0
Safety	1	3	2
TOTAL	14	17	12

From the table above the best two concepts that scored the highest points are concept 1 and 2 and will be evaluated further in the following section to develop the final design. The concepts were evaluated using the following specifications: performance, maintainability, reliability, affordability, stability, accuracy, and safety. Each specification can be awarded points between 0 to 3. With 3 indicating the specification was highly achieved, 2 indicating moderately achieved, 1 indicating partly achieved and 0 not achieved.

6. DESCRIPTION OF FINAL DESIGN

6.1. Overall design

In this section, the final design and justification of the design in fulfilling the requirements mentioned in the beginning of the project are presented. Figure 11 depicts the final design and figure 12 shows different views of the design with dimensions. The final design was selected using decision matrix in the previous section and is concept 2 in the decision matrix table. It is divided into subsections which will be discussed in this section.

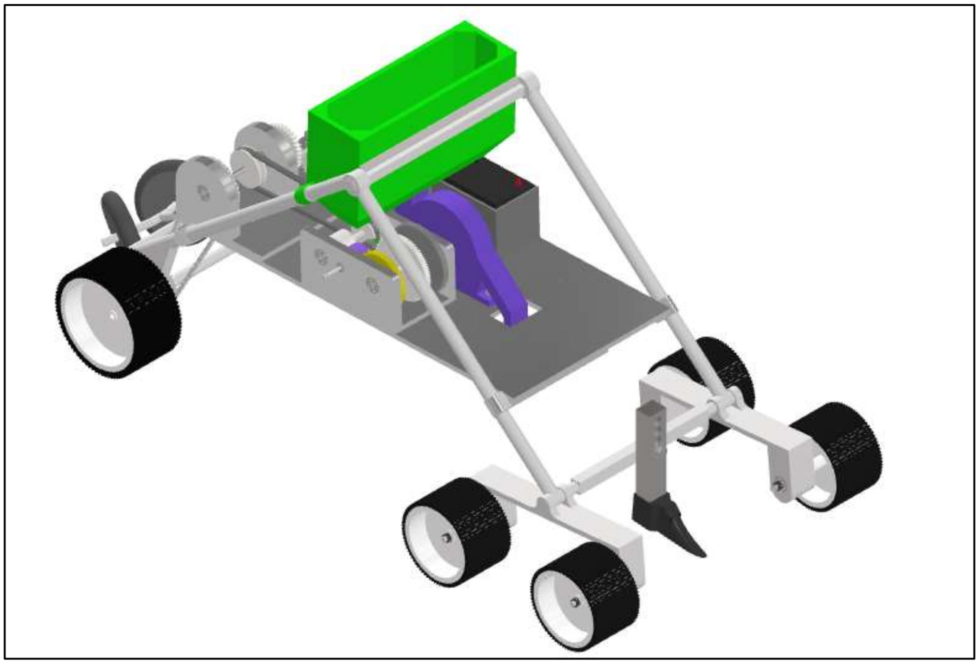


Figure 11: The Final Design.

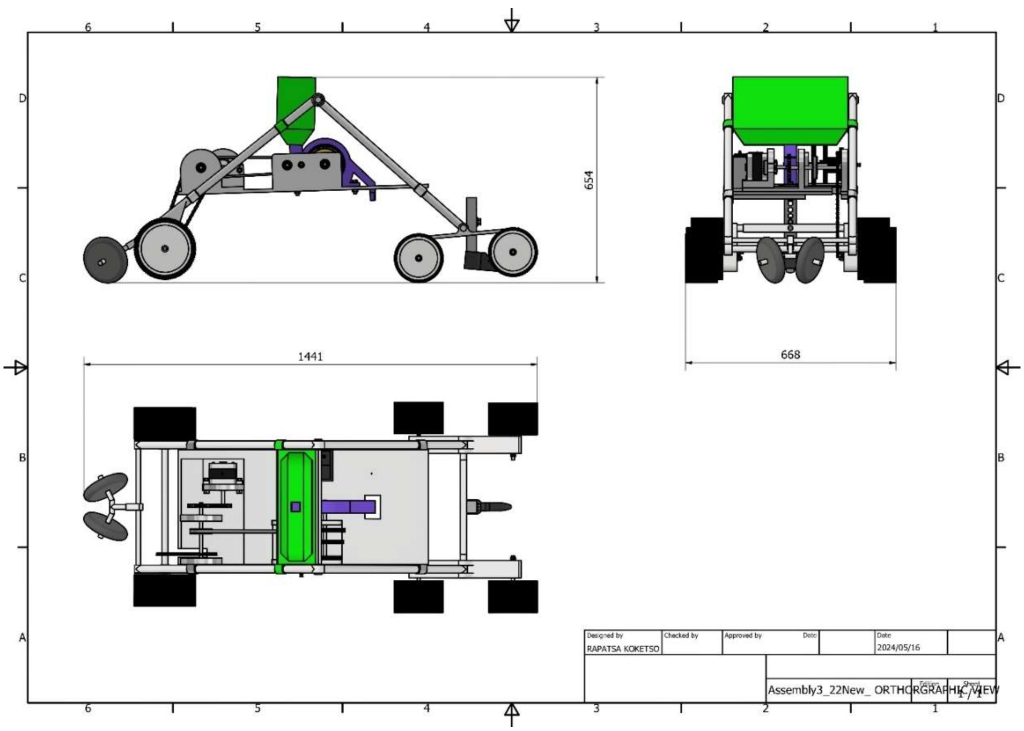


Figure 12: Orthographic projection of the Final Design with dimensions.

6.2. Detailed design description

The figure below depicts the parts and part list of the automatic seed sowing robot and is followed by the description of the important parts, description of the electronics, and the code used to operate the robot.

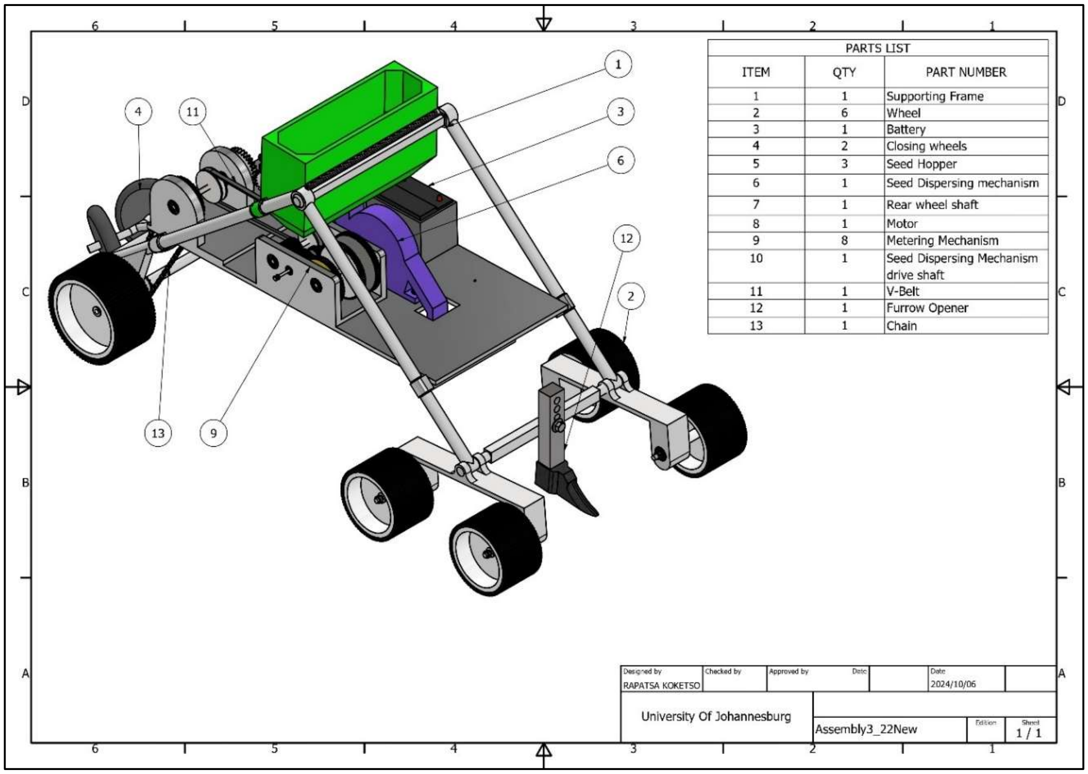


Figure 13: Part list of the seed sowing robot (1).

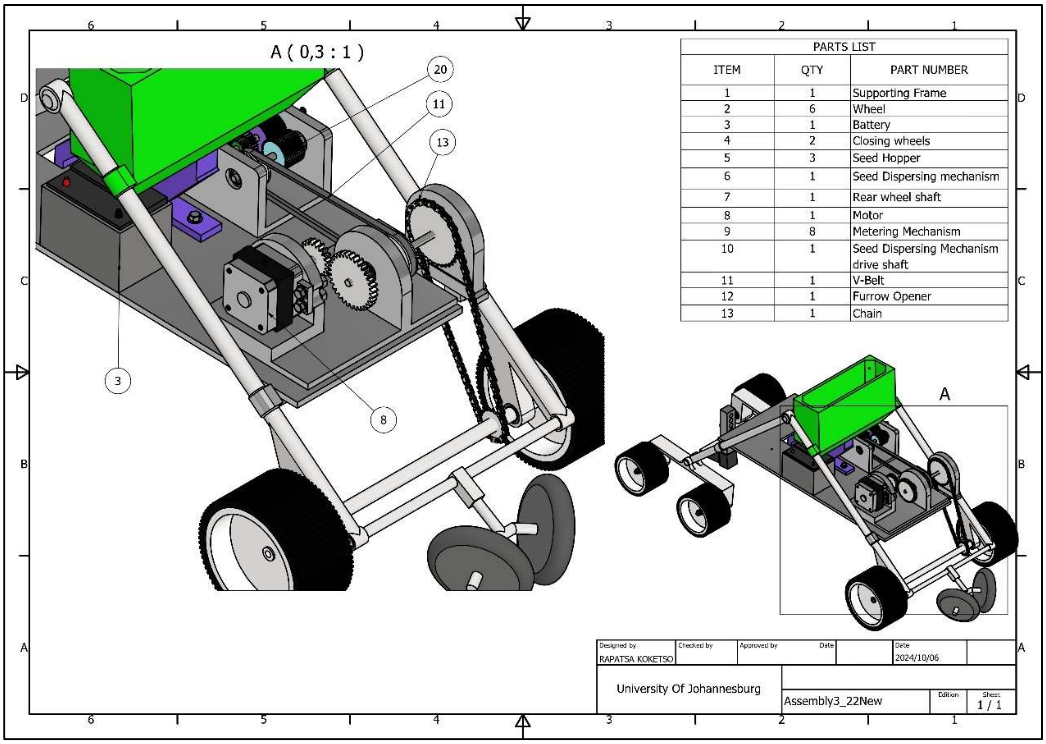


Figure 14: Part list of the seed sowing robot (2).

Description of each part

<u>Metering Mechanism</u>

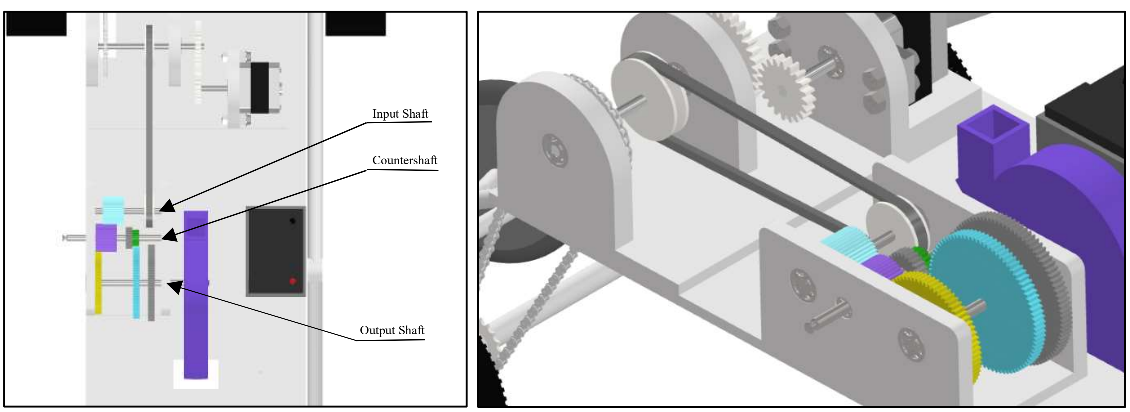


Figure 15: Metering Mechanism

The metering mechanism is an integral part of the robot as it is responsible for the release of seeds at the required spacing. The mechanism is a combination of gears, set to the right gear ratio to provide the correct rotational speed to the roller. It is designed to have three options of seed spacing and one can be selected before operation. As shown in figure 15 above, it consists of three shafts namely are the input shaft, countershaft, and the output shaft. The countershaft can be manually adjusted by sliding sideways to change the transmission gear ratio, which changes the speed of the rotating roller in the seed dispersing mechanism. Sliding the countershaft to the right disengages the current set gear and engages the next gear. The gears are set such that the seed dispersing mechanism plants the seeds into the soil at 15, 30, or 45 cm apart from each other by calculating the required gear ratios, then the dimensions of the gears.

Seed Dispersing Mechanism

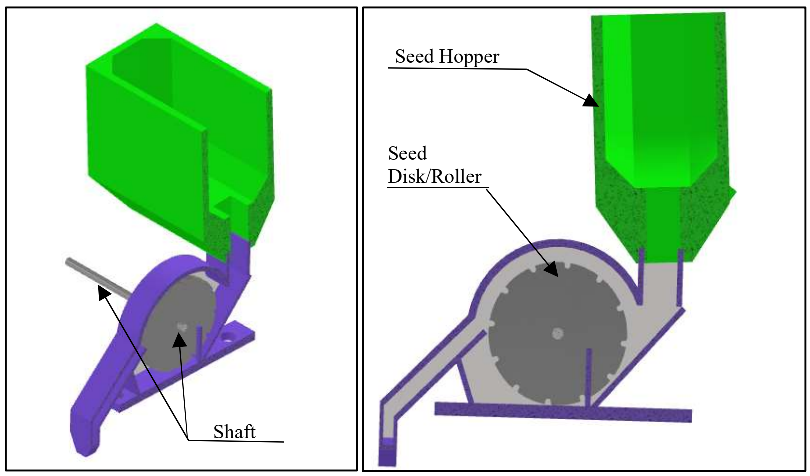


Figure 16: Seed Dispersing Mechanism

The seed dispersing mechanism is a crucial component of the seed sowing robot, which is responsible in ensuring that seeds are dispensed from the hopper to the soil at a controlled and consistent rate and maintaining proper spacing between the planted seeds for optimal growth. The seeds contained in the seed hopper enter at the top of the dispersing mechanism through a small opening. Then the seeds get collected from the seed--filling area by the rotating fluted roller, through its small grooves and are delivered to the tube leading to the ground to be planted. The fluted roller is driven by the output shaft from the metering mechanism

Supporting Frame

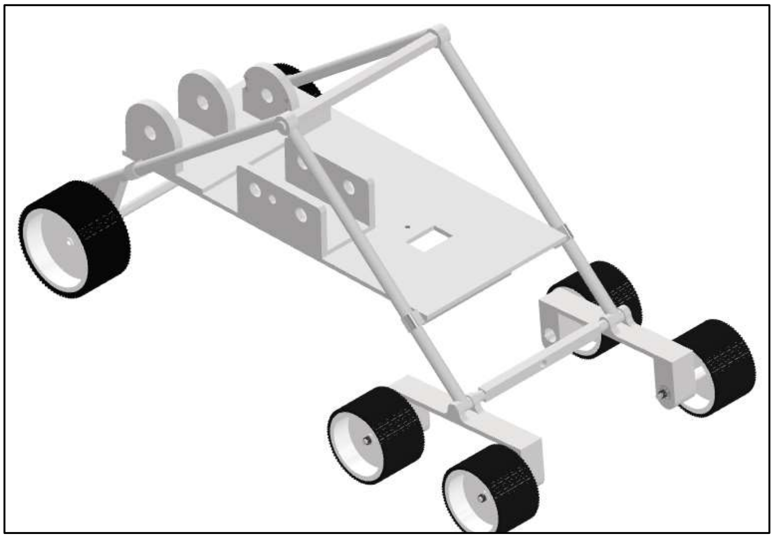


Figure 17: Rocker-Bogie Suspension Mechanism.

The Supporting frame has six wheels, with a symmetrical structure on both sides. Each side has three wheels linked together by two connectors. The main connector, called the rocker, has two joints: one joint connects to the front wheel, and the other connects to another part called the bogie, which functions like the suspension in train cars. The Rocker-Bogie design does not use springs but has short axles for each wheel, allowing it to move with ease on uneven terrain and climb over rocks that are up to twice the size of its wheels while keeping all six wheels on the ground. This system is meant to be used at slow speeds to reduce shocks and prevent damage when going over large obstacles. An example of the suspension mechanism in operation is shown in the figure below.

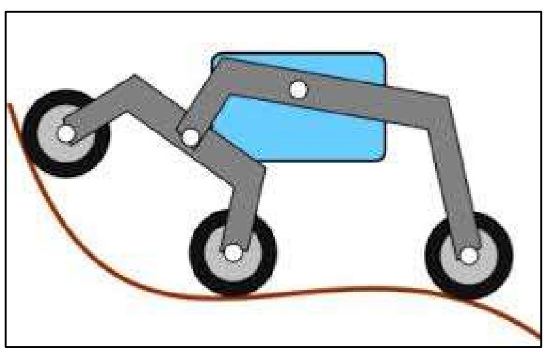


Figure 18: A rocker-bogie Suspension robot on uneven terrain. Adapted From (Cucu, 2014).

<u>Furrow closer</u>

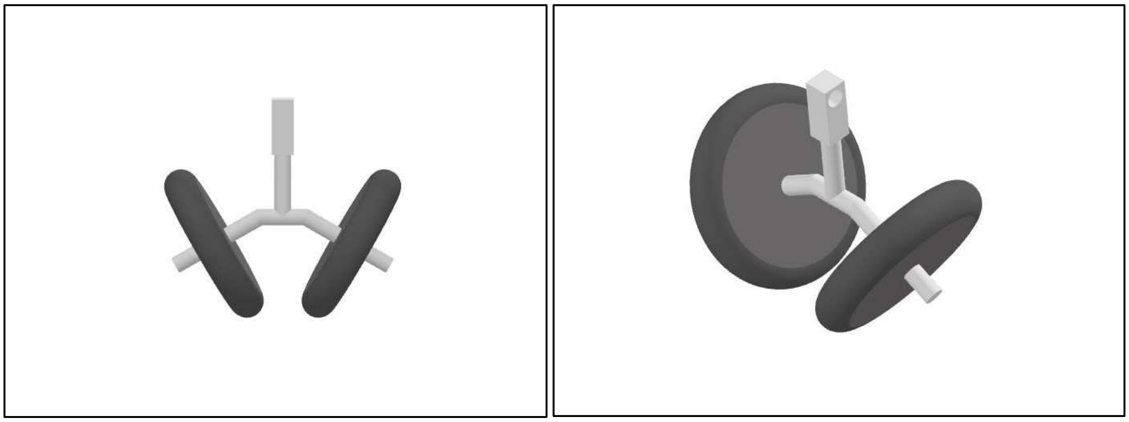


Figure 19: Furrow closer of the seed sowing robot.

The furrow closer consists of two press wheels configured in a V shape at 45 degrees from each other and are connected to the body of the robot. Their purpose is to close the furrow opened by the furrow opener after the metering mechanism has dispersed seeds into the furrow. The soil on the sides of the furrow displaced by the furrow opener is moved into the furrow and pressed down gently by the press wheels to close the furrow.

Description of the electronics

Figure 19 below depicts the circuit schematic drawn using Fritzing of the seed sowing robot and shows how the electronic components will be connected. The robot will consist of the following electronic components: Arduino, proximity sensor, motors, relays, inferred receiver, inferred remote, battery and DC to DC converter.

<u>The significance of each electronic component</u>.

- Arduino – This is the microcontroller, responsible for interpreting the inputs from the sensors, process the information then decides on the decision based on the code that run it. It also ensures that every component works at their intended time and in synchronization with each other as one system.
- The proximity sensor – This sensor continuously scans for any obstacle in front of the robot and sends the information to the microcontroller for processing. If the obstacle is more than 30 cm in height the microcontroller will deactivates the motors to stop the robot. It is also a safety feature because not run over workers in the farm.

- Relays – The relays are used to form an H-bridge to control the motors. An H-bridge is a simple electronic circuit used to control the DC motors to move the robot forward or backwards. It consists of four relays configured as in figure 18 below and has four states of operation open, forward, backward and braking. The motors/robot is stationary when the relays/switches are open (open state). The robot will move forward if diagonally opposite relays allow current to flow. The robot will move backwards if the opposite relays are flipped.

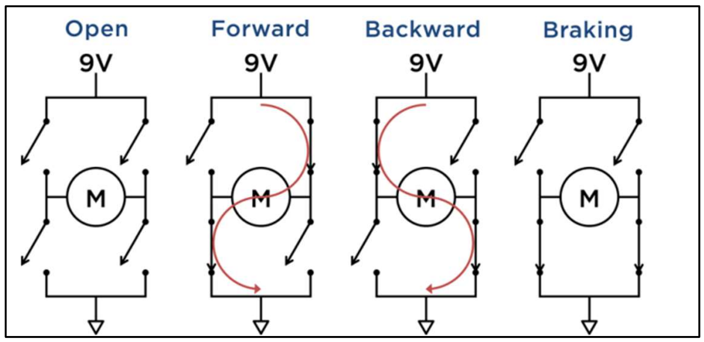


Figure 20: H-bridge in operation. Adapted From (Blum, 2013)

- Inferred remote – This is the interface between the robot and the operator. The operator can enter the required seed spacing distance, and the microcontroller will calculate the required speed to rotate the seed dispersing mechanism. The operator can stop the robot in case of emergency or malfunction.

- DC to DC converter – This component is responsible for reducing the power from the battery to the operating voltage of the smaller components. For example, the operating voltage of the Arduino is approximately 5V and that of the motors is 12V while the battery voltage is higher, thus, to operate these components the voltage from the battery must be reduced.

- Inferred receiver – This is the sensor that detects the commands sent from the Inferred remote and transfers them to the microcontroller for processing.

7. MATERIAL SELECTION

The material selection for the components of the seed sowing machine is a crucial step in the design process because materials can affect the weight, strength, durability and cost of the design. This section provides an analysis and evaluation of materials for each component. This is done by defining the material properties essential for each component to perform well in application. A range of materials are selected and contrasted with each other based on a set criteria for that component. The material properties include mechanical properties (e.g. stiffness, density, durability, strength, etc.), environmental resistance (e.g. corrosion resistance, rust, UV resistance, etc.), manufacturability (e.g. Machinability, formability and weldability), cost and sustainability.

Seed hopper

The seed hopper is responsible for storing seeds before they are dispensed into the soil for planting. Because of this important function it must be manufactured with a material that is corrosive resistant, to protect it from chemically reacting with the insecticides and fungicides used to coat seeds before they are planted. The material also needs to be lightweight, durable, cost-effective and weldable. A lightweight material will reduce the machine's overall weight and improve its maneuverability and efficiency. The weldable property of the material will ensure it can be easily assembled to the supporting frame and can support the mass of the seeds. Choosing a durable material will allow the seed hopper to withstand impacts and resist wear, ensuring it remains functional over time. The following are the materials meeting the requirements mentioned above:

1. Stainless Steel 304 – This material is such that it is suitable for outdoor usage where exposure to water and respective fertilizer may come into play, owing to its high corrosion resistance ability (MatWeb, 2015). It is also tough and easy to weld which is what will create a strong and solid structure for the hopper.
2. Mild Steel – Mild steel is cheap, has good weldability, and has fair of strength. When galvanized or powder coated, it can have fair corrosion resistance and be used outdoors. However, even when coated, mild steel can still be prone to rust corrosion and did not get level of rust corrosion resistance like stainless steel or aluminum. With time, the protective coating may erode, resulting in exposure of the steel to corrosion.

3. Carbon Steel with coating – This steel is strong, affordable, and weldable, and it can withstand impacts well (Tariq Islam, 2019). Adding a protective coating such as polyurethane to improve the material's corrosion resistance will make it suitable for the seed hopper applications (Nguyen Thuy Duong, 2019).

Table 3; Decision Matrix for seed hopper material

Material	Corrosion Resistance (25%)	Weight (Density) (20%)	Weldability (20%)	Durability (25%)	Cost (15%)	Total Score
1. Stainless Steel 304	10 ($10 \times 0.25 = 2.25$)	5 (1.0)	9 (1.8)	7 (1.75)	5 (0.9)	7.65
2. Mild Steel	7 (2.5)	6 (1.2)	10 (2.0)	8 (1.6)	9 (1.35)	7.9
3. Carbon Steel	8 (2.0)	6 (1.2)	9 (1.8)	9 (1.8)	8 (1.2)	8.0

Carbon steel was rated the highest in the decision matrix above. This is because it has a good balance of durability, weldability, and resistance to impact, which is necessary for a seed hopper exposed to field conditions. Furthermore, with a protective coating, it has satisfactory corrosion resistance for agricultural applications, making it cost-effective and reliable.

Seed Metering Casing and Fluted Roller

The seed metering mechanism, which consists of a casing and the fluted roller is responsible for discharging seed to the soil from the hopper, requires a material that is wear resistant, has high dimensional stability, lightweight, and corrosion resistant. The wear resistant property will guarantee that these components maintain their function and accuracy over time. Otherwise, precision of the roller (or its casing) will be compromised, which may lead to unbalanced spacing between seeds or mistakes in seed metering. The material dimensional stability will guarantee that the shape and accuracy of the components does not change while being put under different loads, temperatures and humidity levels. Accurate shape of casing and fluted roller is very important for control of seed's position and its flow rate. Such as the seed hopper, the seed metering casing and fluted roller will also be subjected to corrosion because of the chemicals in the farm. The material needs to be corrosive-resistant to lengthen its lifespan. The selected materials are explained below and are compared with each other in a decision matrix table.

1. Aluminum Alloy 6061 – this aluminum alloy has high strength-to-mass ratio, wear resistance, corrosive resistance and has easy machinability. The lightweight property of the material helps reduce some load for the motor, which makes it easier for the metering system to operate with less resistance. The corrosion resistance of the material further enhances the life of the casing and the roller against moisture and fertilizers while used in field conditions. The alloy is also relatively easy to machine, allowing for precise dimensions, which are critical for maintaining seed spacing accuracy.
2. Stainless Steel (304) – The use of 304 Stainless Steel will guarantee that the components is strong, and will not rust, oxidize or get corroded by some fertilizers, which makes it suitable for the seed sowing process. The material's high durability and superior wear resistance allow it to contact seeds and fertilizers without rusting, which in turn cuts down on maintenance.
3. High-Density Polyethylene (HDPE) – HDPE is a lightweight, flexible, and highly impact-resistant thermoplastic that offers excellent chemical and moisture resistance, making it a cost-effective option for seed metering components. Its corrosion resistance allows it to withstand contact with fertilizers and damp soil without degrading, while its affordability further enhances its appeal. Additionally, HDPE is easy to mold and machine, making it suitable for producing the precise shapes required for the metering system.

Table 4: Decision Matrix for Seed Metering Casing and Fluted Roller material.

Material	Wear Resistance (30%)	Corrosion Resistance (25%)	Weight (25%)	Cost (20%)	Total Score
Aluminum Alloy 6061	7 (2.1)	9 (1.8)	8 (2.0)	8 (2.0)	7.9
Stainless Steel (304)	9 (2.7)	5 (1.0)	9 (2.25)	6 (1.5)	7.45

High-Density Polyethylene (HDPE)	5 (1.5)	10(2)	6 (1.5)	9(2.25)	7.25

Drive Wheels

The drive wheel of the robot must provide excellent traction and durability, as they are responsible for moving the machine across different types of terrain. A combination of rubber for the tread and steel for the core will be used. The rubber tread will provide grip and traction, ensuring that the machine can move steadily over different soil conditions and minimizing slipping. Additionally, rubber has shock absorption properties that will help reduce the stress on the machine's components, expanding its lifespan. The steel core of the wheels will provide the necessary strength to support the weight of the machine and resist deformation.

Frame

The machine's structure, made of rods and beams, must support the weight of all the weight of the seed hopper, metering mechanism, drive wheels, and other components, it must be strong enough to bear the stresses caused by operation, and be strong enough to assure the machine's overall stability. The material must be weldable, to allow the rods and beams to be assembled and form rigid connections. It must also be cost-effective because it is one of the biggest components, its material and cost of manufacture will directly determine a great deal the cost of the machine. The selected materials are explained below and are compared with each other in a decision matrix table.

1. Aluminum 6061 – Due to its high strength-to weight ratio, corrosion resistance and good manufacturability (MatWeb, n.d.), it is a light alloy that is will be able to hold heavy parts and still allow the mobility of the machine. Its corrosion resistance is reliable, especially where moisture and fertilizers may corrode other

materials. Weldability and machinability of Aluminum 6061 is also very good which make it economical for mass production (Anderson, et al., 2019).

2. Mild Steel –Mild Steel will provide good strength, durability and is cheaper than other metals. But it is also heavier than aluminum, which can add to the weight of the machine and thus reducing the efficiency (Edwards, 1952). Mild steel is susceptible to rust but it can be applied with a protective layer coating which can help to prevent this.
3. Stainless Steel 304 – This material has high corrosion resistance as well as high impact strength, making it highly suited for environments where the frame will be exposed to moisture or corrosive substances like fertilizers (MatWeb, n.d.). Due to its increasing strength, stainless steel also provides greater reliability under heavy loading conditions.

Table 5: Decision Matrix for Frame material.

Material	Strength-to-weight ratio (30%)	Corrosion resistance (25%)	Durability (20%)	Cost (25%)	Total Score
Aluminum 6061	8 (2.4)	7 (1.75)	6 (1.2)	8 (2)	7.35
Mild Steel	6 (1.8)	5 (1.25)	9 (1.8)	9 (2.25)	7.1
Stainless Steel 304	9 (2.7)	10 (0.25)	10 (2.0)	5 (0.125)	8.45

Furrow opener

The Furrow opener is responsible for ploughing and ensuring that seeds are planted at the correct depth. It will require a material that has a very high resistance to wear because its going to be in direct contact with abrasive soil and rocks that can cause wear over time. The material also needs to have a high impact resistance, because it might encounter rocks or compacted soil that can subject it to impacts or shocks. The furrow opener needs to penetrate soil easily and consistently to create clean, uniform furrows, thus the material also needs high hardness.

1. High Carbon Steel – A high carbon steel of carbon content that ranges from 0.6% to 1.0% will make the steel hard and more wear resistant. This hardness means a sharp edge is retained for longer which is necessary when clean edges are needed to plough in fields. Since high carbon steel has high durability and impact resistance, it can be used in high abrasion areas making it suitable for a perfect tool (Singh, 2020). When compared to advanced alloys, high carbon steel is economical as well.
2. Titanium Alloy – titanium alloy possesses high strength to weight ratio, high corrosion-resistance, and moderate hardness which makes them suitable as material furrow opener. It also has natural oxide layer which has anti-corrosion properties (Aswathy Jayakumar, 2023).

Table 6: Decision Matrix for Furrow Opener material

Material	Wear Resistance (35%)	Impact Strength (30%)	Corrosion Resistance (20%)	Cost (15%)	Total Score
High Carbon Steel	8(2.8)	7(2.1)	5(1)	9(1.35)	7.25
Titanium Alloy	6(2.1)	6(1.8)	9(1.8)	4(0.6)	6.3

Closing Wheels

The closing wheels are responsible for covering the seeds with soil after they have been deposited. These wheels must be made from a material that is both heavy enough to press soil effectively and durable enough to withstand constant contact with the ground. They must maintain good traction with the soil and must be wear resistance. The following is the selected material.

1. Cast Iron with Rubber Coating – Steel is strong, durable, and capable of supporting high loads, while rubber provides flexibility, traction, and shock absorption. The steel core gives the wheel the weight needed to press soil effectively, ensuring firm contact with the ground and minimizing soil compaction. Rubber treads enhance traction and

reduce slippage, which is particularly useful in loose or moist soils. Rubber also absorbs shocks, protecting the machine from jolts when navigating uneven or rocky terrain.

2. Steel with Rubber Coating – Cast iron is dense and durable, providing significant weight, while rubber adds traction and helps prevent soil sticking. The extra weight of cast iron ensures effective soil pressing, even in hard or compacted soils. Rubber coating on cast iron helps prevent soil buildup and provides better traction. The rubber coating also adds some shock absorption, which minimizes impact stress on the machine.

Table 7: Decision Matrix for Closing Wheels material

Material	Weight (35%)	Durability (25%)	Wear Resistance (25%)	Cost (15%)	Total Score
Cast Iron with Rubber Coating	9 (2.25)	9 (2.7)	8 (2.0)	7 (1.4)	8.35
Steel with Rubber Coating	7 (1.75)	8 (2.4)	7 (1.75)	8 (1.6)	7.5

Table 8: Table of selected materials of components.

Components	**Material**
Seed Hopper	Carbon Steel
Seed Metering Casing and Fluted Roller	Aluminum Alloy 6061
Drive Wheels	Steel coated with rubber
Frame	Stainless Steel 304
Furrow Opener	High-Carbon Steel

Closing Wheels	Cast Iron with Rubber Coating

8. ASSEMBLY, OPERATING, AND MAINTENANCE SPECIFICATIONS

1. Assembly Specifications

The automatic seed sowing robot consists of multiple components, including the seed metering mechanism, furrow opener, suspension system, and electronic control system. The assembly process should follow the following steps:

- Assembling the supporting frame – The supporting frame is assembled using rods by welding to form connections. The figure below shows how the supporting frame is welded, along with the size of the welds. Welding will provide a permanent strong bond between the metal components and is more durable than its counterpart temporary connections, which tend to loosen with time due to operational vibrations.

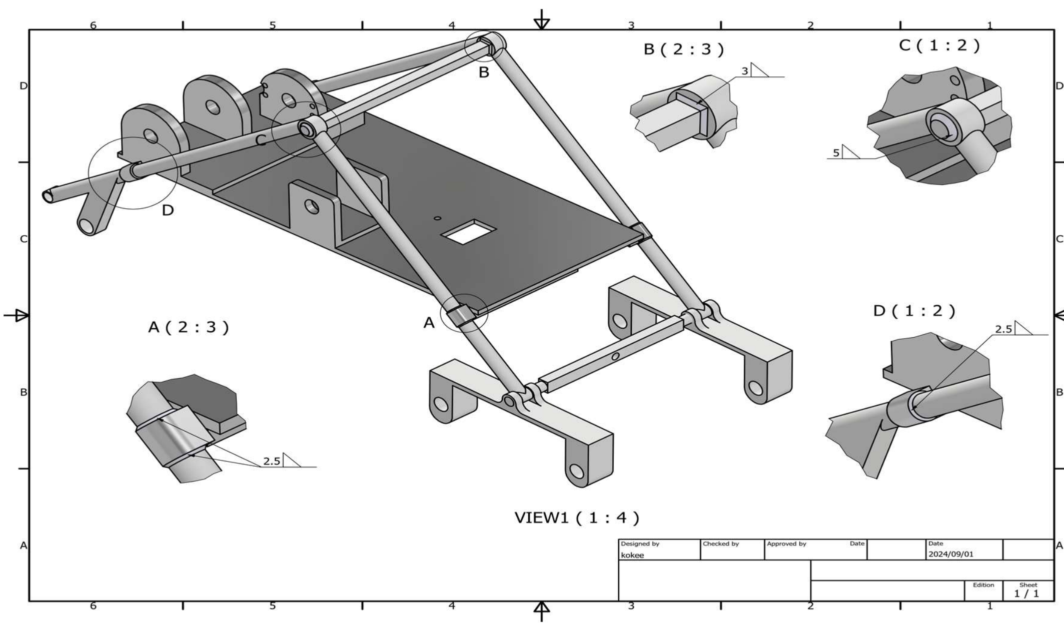


Figure 21: Support frame assembly.

- Assembly of wheels onto the supporting frame – In order to attach the wheels to the supporting frame, several additional components are required, including a shaft, bearing, and a locking collar. Firstly, the bearing is inserted into the bearing housing by applying constant pressure unto the bearing into its seat, using a bearing press tool. A shaft is then fitted through the bearing, and the wheel is slid onto it. A locking collar is put on both sides of the shaft, to secure the wheel. They are then slid to firmly secure the wheel, allowing a clearance of $\pm 2\ mm$. Finally, the set screws on the locking collars are tightened ensuring the collars hold the wheel and shaft securely. The two rear wheels are assembled in the same manner but are secured to the shaft by a key to avoid slip between the shaft and the wheels. This is done because the shaft drives the wheels and if not secured the will be a relative velocity between them.

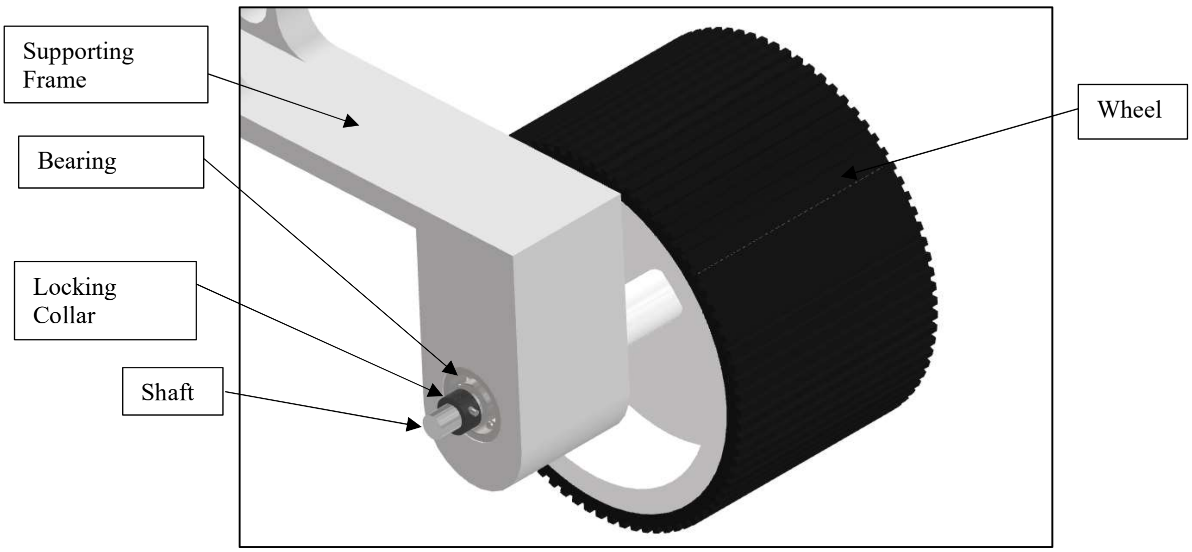


Figure 22: Assembly of wheels onto Supporting frame.

- Assembling the seed metering mechanism – the seed dispensing mechanism is secured by two M20 bolts with nuts to the supporting frame ensuring that it handles the large weight of the seeds. The mechanism consists of a roller, bearing and a shaft. The roller is secured to the shaft by a key and is placed inside the seed dispersing casing. The shaft transfers power from the motor to the roller in a form of torque to do work on the seeds.
- Securing the seed hopper on the frame above the metering mechanism – The seed hopper is assembled to the robot by welding it to the supporting frame at the locations shown in figure 22. Welding the seed hopper to the supporting frame will increase its stability and ensure that the robot can support the weight of seeds without the seed hopper detaching.

- Furrow opener assembly – The furrow opener is placed at the front of the robot and assembled to the frame by a bolt and nut shown in figure 22. The furrow opener has holes that allow the control of ploughing depth, and the user can change the depth by assembling it with a hole that gives the right depth.
- Assembly of motor, gears, belt and chain – The motor is screwed to the supporting frame by M18 screws and is connected to a gear by a shaft. The gear on the shaft of the motor is meshed to another gear to avoid damage to the motor because of deflection caused by the shaft mountings during operation. The belt is assembled by slipping the belt over the pulleys and adjusting the tension until the belt is tight enough, then the pulley was secured in place.

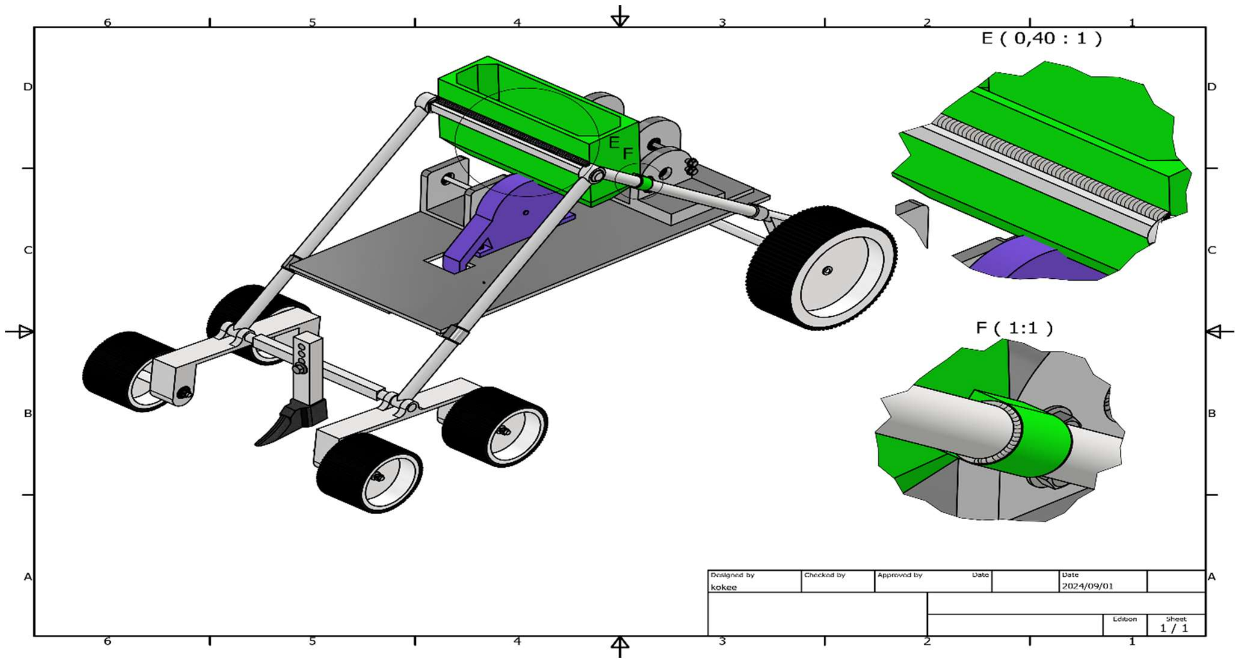


Figure 23: Assembly of the Seed Hopper.

Tools and Equipment Required

- Wrenches/Spanners – required to tighten bolts and nuts used in the design. Specifically, M10 and M14 sizes will be required, or size varying wrenches/spanners may also be used.

- Torque wrench – required to ensure the fasteners are tightened to specific torque specifications, to avoid under tightening or overtightening.
- Welding Equipment (Welding machine, Electrodes, etc) – the welding equipment is required to assemble the supporting frame and other parts that require permanent fastening.
- Alignment jig - will be required for aligning critical parts, such as the motor shaft and the seed dispensing mechanism, ensuring accurate seed spacing and metering.

2. Operation Specifications

Operation Conditions:

- The robot will operate between temperatures ranging from 0 to 45 degrees Celsius. At temperatures of greater than 45 ℃ the chemical reactions taking place in the battery will occur at faster rates and shorten the lifespan of the battery causing damage (Oosten, n.d.). At lower temperatures (less than 0 ℃), the chemical processes slow down increasing its internal resistance alternately decreasing performance of the robot.
- The robot will operate in environments of humidity of less than 90%. High humidity can corrosion of metallic materials and electrical malfunctions of the electronic components.
- The robot can handle uneven terrain and inclines of up to 20 degrees. The frame of the robot allows it to climb over obstacle, operate on uneven terrain and inclines.

Performance Requirements:

- Speed of Operation – The speed of operation consists of two speeds: the sowing speed and ground speed. The sowing speed for a small farm should range from 20-60 seed per minute, depending on the desired seed spacing. The ground speed is the translational speed of the robot and for this design will depend on the sowing speed since they are run by the motor and calibrated using ratio but should range from 0.5-1 km/h.
- Seed Hopper Capacity – The seed hopper is responsible for holding the seeds before they are planted into the ground and should have the capacity of 3-5 kg

of seed to avoid refilling while in operation. The robot will handle the mass of the hopper without any reduction of mechanical efficiency.

- Varying Sowing Speed – The speed of sowing or seed spacing may be varied by changing the roller. For small seed spacing a roller with more holes may be used, and for big seed spacing a roller with less holes may be used. Changing the roller is a simple and uncomplicated process which involves the user to select the correct roller based on seed spacing, unscrewing the cover off the metering system, inserting and screwing on the correct roller and screwing back the cover on the metering system.
- Efficiency – The robot is designed to minimize electrical power by utilizing energy-efficient electrical components that contribute to longer operation time and reduced operational costs. The target power consumption being less than 1kWh per hectare.

Control System:

The robot operates autonomously with the help of a microcontroller to help streamline the tedious process of manual labour and improve the yield and quality of crops. To operate the robot, the user must set the furrow-opener to the desired depth and insert the correct roller in the metering system all according to the requirements of the type of crops being planted. The robot can then be brought to site and making sure it is perfectly aligned with the furrow. The seed hopper can then be filled with the seeds. The following step is checking for potential obstacles in front of the machine that can cause harm to it. To start the robot, the user can use a remote while standing behind or not in front of the machine by pressing the start button, and then it will operate automatically until the stop button is pressed on the remote.

Safety Considerations:

To comply with the Occupational Health and Safety Act, No. 85 of 1993 which governs safety in the workplace, the design of the automatic seed sowing robot has been incorporated with safety features to ensure safety of the user and surrounding people. The robot consists of an emergency stop button both on the remote and on the robot itself. Which will aid in situations of emergencies and malfunctioning and the robot must be stopped immediately. It also has an ultrasonic sensor in the front to detect big obstacles on its path. After the detection of an obstacle, the sensor will send a signal to the microcontroller to stop the robot from operating further.

3. Maintenance Specifications

Maintenance is an important practice that determines the longevity and performance of any machine. It is important because it ensures that equipment runs efficiently, reduces the chances of breakdowns and increases the lifespan of the machine. Regular maintenance check allows early detection of any problem before escalating into a major problem. This minimises repair costs in the long run and improves safety by preventing accidents. Maintenance for the automatic seed sowing machine can be conducted in the following ways:

1. Conducting routine maintenance procedures, which include:
    - After every use the machine's seed hopper and seed dispersing system should be cleaned thoroughly to remove dirt, seed residue and durst, to prevent build-up which alternately leads to bigger problems.
    - Regularly lubricating the chain, motor, gears, shafts and bearings with oil to minimize tear and wear
    - Conducting inspection on all components for wear, loosened connections and misalignment. This step can prevent further damage to the robot and help prevent accidents.
2. Conducting Scheduled Maintenance:
    - Spare parts replacement – Parts that are prone to wear are chain, belt, rollers, bearing and fasteners. These parts will eventually wear out and fail and require replacement. It is recommended that these parts be replaced at the time intervals set by the manufacturer.

    - Recalibrating the seed metering system – The seed metering system needs to be recalibrated before use to ensure accuracy in seed distribution and prevent uneven sowing.

9. COMPLETE CALCULATIONS, ANALYSIS, AND DATA INTERPRETATION

This section aims to optimize the performance of the machine, ensuring it meets the required specifications for efficient seed sowing. This is done by calculating the power requirements, speed, forces and sizes of various components and performing an analysis based on the results of the calculations. Firstly, the sizes of the components that need to be sized are calculated, then the specification of the sub-assemblies such as the battery and motor are calculated.

1. Calculating the mass of the machine.

To calculate the mass of the machine, the volume of every component was calculated in AUTODESK INVENTOR, because of the complexity of the geometry of some components. The volume of each component is listed in table 4. The mass of the pulley, belt and battery were assumed. The mass is then calculated using the following equations.

Mass of component

$$m_i = p \times V$$

Where: $m_i = mass\ of\ component.$

$p = Density\ of\ the\ material.$

$V = Volume\ of\ the\ component.$

Total mass of the machine

$$m = \sum_{i=1}^{n} m_i$$

Where: $m = Total\ mass.$

Table 9: Calculating the mass of the machine.

Component	**Volume, V (m^3)**	**Material**	**Density, p (kg/m^3)**	**Mass, m_i (kg) ($p \times V$)**
1. Supporting Frame	7.77693	Aluminum alloy	2.710	21.075

2. Closing Wheels	0.88549 (80% rubber and 20% steel)	steel coated in rubber	0.93 rubber 7.85 steel	2.049
3. Wheels	3.91306 (70% rubber and 30% steel)	steel coated in rubber	0.93 rubber 7.85 steel	12.059
4. Pulleys and belt				1.483
5. Chain and Sprockets	0.04203	steel	7.930	0.333
6. Shafts	0.28532	Aluminum	2.710	0.7732
7. Furrow opener	0.36719	high-carbon steel	7.850	2.8824
8. Seed hopper	0.4773	Stainless steel (304)	7.930	3.7851
9. Seed dispersing cover and roller	0.379379	Aluminum	2.710	1.0281
10. Battery				5.00
11. Gears	0.351547	Steel	7.850	2.76
Total Mass				**53.23**

12. Design of the rear wheels shaft

To determine the diameter of the rear wheel's shaft, firstly the maximum bending moment and maximum torque must be calculated, then using the Von Mises theory the diameter will be determined. The formulas used and assumptions are indicated below. The machine will operate at constant speed; therefore, the applied force will be equal to the total of the resistance forces and the torque of the shaft can be calculated using the total of these resistance forces. The torque experienced by the shaft is calculated by considering the frictional force experienced by the wheels and the tillage resistance.

<u>Rolling frictional force formula</u>

$$\boldsymbol{F_f = \mu N}$$

Where: $F_f = Rolling\ frictional\ force.$

$\mu = Rolling\ coefficient.$

$N = Norma\ force.$

<u>Tillage resistance force formula</u>

$$\boldsymbol{F_t = kA}$$

Where: $F_t =$ Tillage resistance force.

$k = Specific\ tillage\ resistance\ of\ the\ soil.$

$A = Area\ of\ the\ furrow\ being\ opened\ .$

<u>Torque formula</u>

$$\boldsymbol{T = F \times \frac{d}{2}}$$

Where: $T = Torque.$

$F = Total\ force$

$d = diameter$

<u>Bending stress formula</u>

$$\boldsymbol{\sigma_B = \frac{My}{I}}$$

Where: $\sigma_B = Bending\ stress.$

$M = Bending\ moment.$

$y = distance\ from\ neutral\ axis.$

$I = moment\ of\ Inertia.$

<u>Shear stress formula</u>

$$\boldsymbol{\tau = \frac{Tr}{J}}$$

Where: $\tau = Shear\ stress.$

$T = Toque$

$J = Polar\ moment\ of\ Inertia$

<u>Von Mises Stress Equation formula</u>

$$\boldsymbol{\sigma_v = \sqrt{\sigma_B^2 + 3\tau^2}}$$

Where: $\sigma_v = Von\ Mises\ stress.$

Assumptions

- The material of the shaft is aluminium alloy, with yield strength of 90 MPa.
- The factor of safety is 3.
- The tillage resistance coefficient is 0.12 MPa
- The gravitational acceleration is 9.81 m/s^2.

<u>Step 1: Calculating frictional force.</u>

$F_f = \mu N$

But $N = mg$

$\therefore\ F_f\ =\ \mu mg$

$= 0.2 \times 53.23 \times 9.81$

$= 104.44\ N$

Step 2: Calculating tillage resistance force.

$F_t = kA$

$= (0.12 \times 10^6)(14.4 \times 10^{-2})$

$=$ 17280 N

Step 3: Calculating Torque

$Total\ resistance\ force,\ F = F_f + F_t$

$F = 104.44 + 17280$

$= 17384.44\ N$

Torque, $T = F \times \frac{d}{2}$

$= 408.28 \times \frac{190\times10^{-3}}{2}$

$=$ 1651.52 Nm

Step 4: Calculating Maximum bending moment

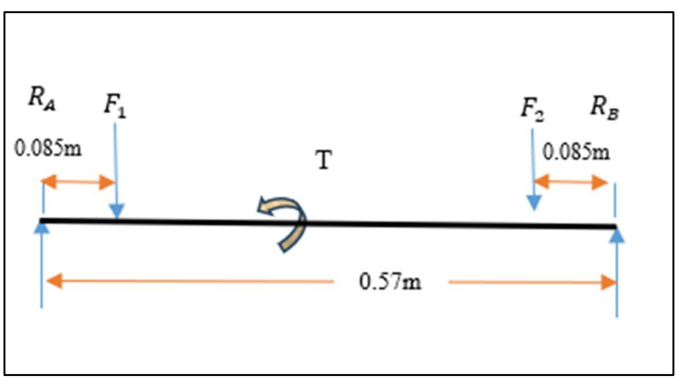


Figure 24: Shaft free body diagram

$F_1 = F_2 = \frac{mg}{2}$

$$= \frac{9.81 * 53.23}{2}$$

$$= 261.09\ N$$

The sum of moments about point A,

$$F_1 \times 0.085 + F_2 \times (0.57 - 0.085) - R_B \times 0.57 = 0$$

$$R_B = \frac{261.09 * 0.085 + 261.09(0.485)}{0.57}$$

$$= 261.09\ N$$

Sum of all forces.

$$-R_B + F_2 + F_1 - R_A = 0$$

$$R_A = -261.09 + (261.09 + 261.09)$$

$$= 261.09\ N$$

The Maximum bending moment will act at 0.085m to 0.485m of the shaft is shown in the Bending moment diagram below,

$$M_{max} = F_1 \times 0.085$$

$$= 261.09 \times 0.085$$

$$= 22.19\ N\ m$$

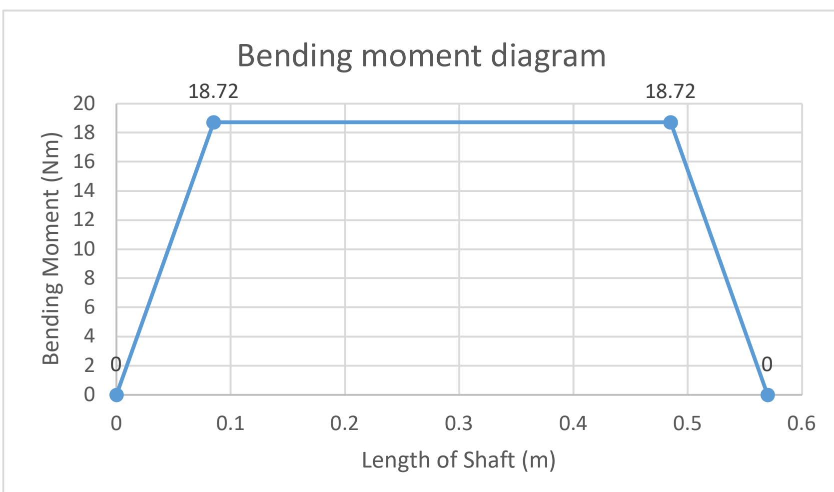


Figure 25: Bending moment diagram.

Calculating Bending stress

$$\sigma = \frac{M_{max}y}{I}$$

But $I = \frac{\pi D^4}{64}$

$$\therefore \sigma = \frac{22.19 * \frac{D}{2}}{\frac{\pi D^4}{64}}$$

$$= \frac{710.08}{\pi D^3} \text{ Nm}$$

<u>Calculating Shear stress</u>

$$\tau = \frac{Tr}{J}$$

But $J = \frac{\pi D^4}{32}$

$$\therefore \tau = \frac{1651.52 \times \frac{D}{2}}{\frac{\pi D^4}{32}}$$

$$= \frac{26424.32}{\pi D^3}$$

Using Von Mises Stress formula

$$\frac{\sigma_y}{n} = \sqrt{\sigma^2 + 3\tau^2}$$

$$\frac{90}{3} = \sqrt{\left(\frac{710.08}{\pi D^3}\right)^2 + 3\left(\frac{26424.32}{\pi D^3}\right)^2}$$

D = 0.079 m

$\therefore D = 8\ cm$

13. <u>Determining the specification of the motor</u>

To select the correct motor for the design, parameters such as torque, power and speed of the motor must first be calculated. A diagram of the assembly and formulas used is shown below.

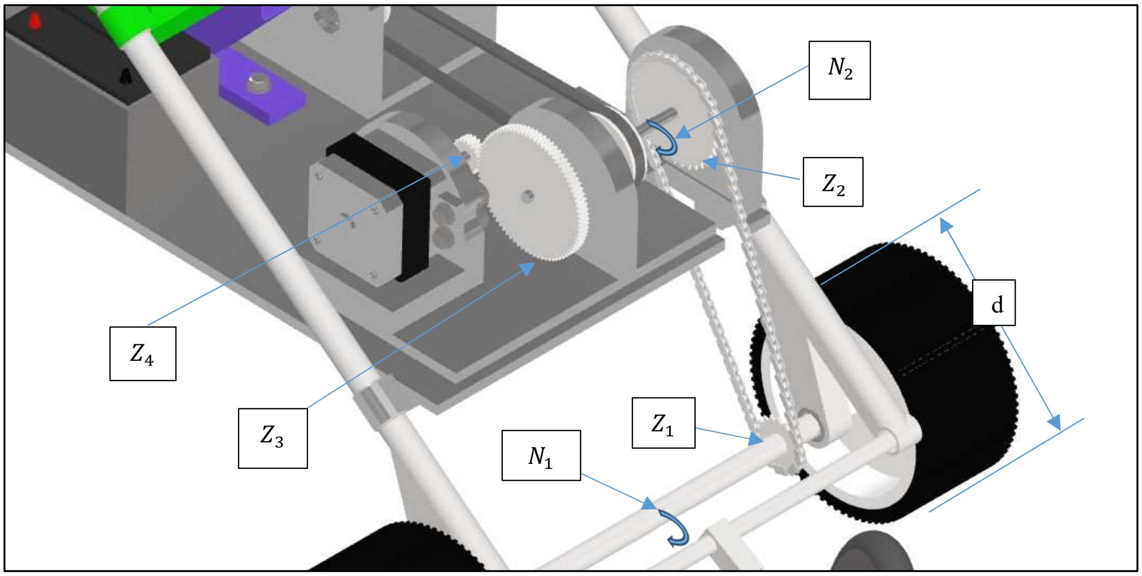


Figure 26: Assembly Setup

From the diagram above it can be deduced that:

- N_1 , represents the rotational speed of the rear wheel shaft.
- N_2 , represents the rotational speed of the main shaft.
- d , represents the diameter of the wheel. $(d = 0.18\ m)$
- Z_1 and Z_2, represent the number of teeth of the sprockets. $(Z_1 = 18\ and\ Z_2 = 37)$
- Z_3 and Z_4, represent the number of teeth of the gears. $(Z_3 = 80\ and\ Z_4 = 20)$

<u>Step 1: Calculating the speed of the motor</u>

Assumption: The operating speed (v) of the machine is 0.45 m/s

Wheels rotational speed,

$$N_1 = \frac{60v}{\pi d}$$

$$= \frac{(60)(0.45)}{\pi(0.18)}$$

$$= 47.75\ rpm$$

Main shaft rotational speed,

$\frac{N_2}{N_1} = \frac{Z_1}{Z_2}$

$N_2 = \frac{18}{37} \times 47.75$

$= 23.23\ rpm$

∴Motor speed, $\frac{N_m}{N_2} = \frac{N_{oth\_2}}{N_{oth\_m}}$

$N_m = \frac{80}{20} \times 23.23$

$= 93.93\ rpm$

<u>Step 2: Calculating the Power of the motor</u>

Assumption: The torque required to drive the metering system is 10 Nm.

Power used to drive the machine,

$P_{drive} = F_T \times v$

$= 272.92 \times 0.5$

$= 136.46\ W$

Power used in the metering system,

$P_{metering} = T\omega$

$= (10)\left(\frac{2\pi \times 23.23}{60}\right)$

$= 24.33\ W$

$\therefore Total\ power = P_{drive} + P_{metering}$

$= 136.46\ W + 24.33\ W$

$= 160.79\ W$

<u>Step 3: Calculating the Torque of the motor</u>

Torque, $T = \frac{P}{\omega}$

$= \frac{60P}{2\pi N_m}$

$= \frac{60\times160.79}{2\pi\times93.93}$

$= 16.34\ Nm$

14. <u>Determining the battery ratings</u>

To determine the capacity of the battery, a battery voltage of 24 V was assumed in order to calculate the supply current and a run time of 8 hours to calculate the capacity of the battery. A detailed explanation of the formulas used below followed by the calculations.

<u>Power formula</u>

$$\boldsymbol{P = VI}$$

Where: $P = power\ consumption\ (W)$

$V = Voltage\ (V)$

$I = Current\ (A)$

<u>Battery capacity formula</u>

$$\boldsymbol{Battery\ Capacity\ = I \times t}$$

Where: $I = supply\ current\ (A)$

$t = operating\ time\ (hours)$

<u>Step 1: Calculating the supply current.</u>

$P = VI$

$I = \frac{P}{V}$

$= \frac{160.79}{24}$

$= 6.7\ A$

Step 2: Calculating Battery Capacity.

$$Battery\ Capacity\ = I \times t$$

$$= 6.7 \times 8$$

$$= 54\ Ah$$

The seed sowing machine calculations focused on three main areas, which are mass, motor requirements and battery requirements. The weight of the machine was calculated to be 53.23kg, which is light enough to reduce soil compaction but heavy enough to guarantee stability and reduce chances of tipping-over. Motor requirements such as the torque (1651.52 Nm), motor speed(94 rpm) and power(161W) were calculated by first considering the tillage and frictional resistances, ensuring the machine will be capable of traversing different terrains and depositing seeds at uniform intervals consistently. The last criterion is the battery capacity, which was calculated at about 20.8 Ah to support an 8-hour operational time, balancing power needs with efficient energy use. Together, these calculations ensure that the machine is optimized for efficient, with precise seed placement and minimal interruption, making it ideal for small-scale agricultural settings.

Cost Analysis

Table 10: Bill of Materials.

Part Number	Component	Supplier	Price per Unit	Quantity	Total Price
1	Supporting Frame	Aluminium Alloys (Pty) Ltd	R 3,462.56	1	R 3,462.56
2	Closing Wheels	eBay	R 894.00	2	R 1,788.00
3	Wheels	EMD Online	R 379.00	6	R 2,220.00

4	Pulleys	RS online	R 348.40	2	R 696.80
5	Belt	RS online	R 56.30	1	R 56.30
6	Chain	BMG world	R 135.99	1	R 135.99
7	Sprockets	BMG world	R 172.20	2	R 344.40
7	Shafts	RS online	R908.58	2	R 1,817.16
8	Furrow opener	Zees Knife supplies	R 400.00	1	R 400.00
9	Seed hopper	Zees Knife Supplies	R 230.00	2	R 460.00
10	Battery	Battery Power Zone	R 7,975.25	1	R 7,975.25
11	Motor	Stepper online	R 2,111.45	1	R 2,111.45
12	Gears	RS online	R 288.29	5	R 1,441.45
TOTAL					22909.36

The table above shows the price of each component and the names of the suppliers who sell them. Components such as the supporting frame, furrow opener and seed hopper will have to be fabricated because due to their unique geometry suppliers do not sell them. The prices of these components listed in the table above is the price for materials in a form of metal sheets. Other costs that to be adhered to in the fabrication of the design to a product are indicated below:

- **Manufacturing costs** – The manufacturing costs will include labour costs, material costs and tooling and equipment costs. One robot will approximately take 2 hours and 30 minutes to assemble, so all labour related costs are calculated for this time period.

- **Transportation costs** – Majority of the suppliers mentioned in the table below offered free delivery, except for few which the price amounted to R845.65

Table 11: Comprehensive Cost Analysis

Cost Analysis	Prices
Equipment used	R 600.60
Electricity and welding	R 700
Material costs	R 22909.36
Labor cost	R400
Transportation cost	R 845.65
Total	**R 25,455.61**

10. SUSTAINABILITY, THE IMPACT OF ENGINEERING ACTIVITIES, AND PROFESSIONAL ETHICS

This section outlines on how the developed design upholds the principles of sustainability and the social, economic, and technological impacts caused by engineering activities. It also shows how the design adheres to professional engineering ethics.

Sustainability:

- The design uses recyclable or eco-friendly materials which minimize harmful effects to the environment during production and at disposing off the machine. Further, the machine also streamlines the sowing process and therefore reduces over-seeding by using proper farming practices that enhance the use of resources like seed, water, and fertilizers.
- The robot has electrical components that are energy efficient, and the robot may add alternative electric energy sources such as solar energy so that its carbon emission becomes minimal or even have a solar charger for the battery.
- Reducing Seed Waste: The machine makes precise seed placement by meeting the requirements for depth and spacing resulting in increased yields. Additionally, the

components have been manufactured from robust parts which lead to less wastage from use of the machine since it will not require frequent replacements.

Environmental Impact:

- Battery Disposal and Maintenance – When implementing the battery-powered seed sowing machine, the environmental impact of the battery's disposal at the end of its service life should be considered. This is because if the batteries are not disposed of properly, the chemicals can leach into nearby soil and rivers and cause soil and water pollution which may threaten the local ecosystems. To protect the ecosystem from this destruction, it is important to emphasize safe disposal techniques for all machine wastes, including the battery and any spent parts, to keep the machine as green as it can be during its entire life cycle.
- Minimal environmental impact – The machine's efficient design results in a small environmental footprint, its compact size and minimal use of materials during production reduces the environmental impact in comparison to traditional agricultural machinery. Precision planting facilitated by the machine helps to decrease the overuse of fertilizers and water, providing additional environmental benefits.
- Reduction in carbon emission – The machine reduces the requirement for multiple passes across a field with heavy machinery by automating the sowing process, which also decreases fuel consumption. Designing the machine to work with an electric battery guarantees that it operates in an eco-friendly manner, reducing its dependence on fossil fuels.

Economic Impact:

- Reduction in Manual Labor – This machine would dramatically lower the amount of labor that goes into planting seeds. Planting seeds by hand using conventional methods, is a laborious process that requires time and effort. For example, it could approximately take one person to sow seeds manually half an acre farm approximately 120 hours, but it would take a sowing machine just a few hours, saving costs on wages.
- Increased Crop Yield – Because of the precision of the machine, the seeds can be positioned accurately in terms of depth and spacing making sure that the conditions for their growth are optimal. This will result in a better rate of germination of the seeds,

higher crop density and healthy plants which guarantees an increased yield and hence more income for the farmers.

- Return on Investment – Over time the combination of reduced labor costs and enhanced resource efficiency results in significant cost savings, while simultaneously increasing crop yields. These factors collectively will contribute to a positive return on the initial investment.

Social Impact:

- Reduction in Labor-Intensive Work – The conventional methods of the seed sowing process require a significant amount of physical labor, resulting in health problems like lower back pain and musculoskeletal disorders. Through the automation of the sowing process, this robot decreases the requirement for manual labor, reducing the physical stress on farmers and workers. This enhances the overall productivity of the farm as farmers can dedicate their attention to other crucial tasks without the burden of tiring manual planting.
- Designing the machine to meet the requirements of small-scale farms will have a substantial economic influence on the rural areas. Increased crop production can result in greater profits for farmers, thereby stimulating local economies. Additionally, the robot will encourage the development of local manufacturing and service sectors, generating employment opportunities and fostering innovation in rural areas.
- Increase Innovation in Agriculture - The seed sowing machine will serve as a catalyst to further technological developments. Inspiring other companies or individuals to develop their own version, which ultimately will bring about more innovation and this will benefit the farmers.

Professional Ethics:

- Safety – To consider safety, the machine is equipped with an emergency stop button, as well as sensors that prevent the occurrence of accidents during operations in the field. Principles of safety during the design process were adhered to such as the Occupational Health and Safety Act (OHSA) in South Africa. Hence the requirement of emergency stop button during machine operations was designed to prevent the risk of injuries

- Environmental Responsibility – To be consistent with ethical engineering practices, the design uses eco-friendly materials and energy saving devices. Therefore, reducing the negative effects on the environment. This ensures that it is in line with the requirements of ASME and ECSA. This means that environmental aspects associated with each stage of production of the product and its disposal have been carefully considered.
- Professional Integrity – The engineering process included transparency in reporting and truthful assessments of the machine's performance. Thorough testing must be carried out to guarantee that the machine fulfills its design objectives while maintaining safety and quality. This demonstrates the dedication to ethical accountability in providing a dependable and eco-friendly product.

Compliance with Standards and Regulations

- **Safety standards and regulations (OHSA & SANS 12100)** – The Occupational Health and Safety Act (OHSA) No. 85 of 1993 provides a framework for safe work practices in South Africa and makes it clear that any machinery employed must not be dangerous to the user or other people. Among the other major provisions of OHSA are the requirements for risk assessments, operational hazard identification and the establishment of measures such as the installation of emergency stop buttons and protective guards over moving parts of the machines. Signs and labels are also required to be present and provide important information to the operators of the machines on how the machines should be used and serviced. Furthermore, guidelines for the safe design, risk assessment and reduction of machinery hazards are given in the South African National Standard (SANS) 12100 which is based on the ISO 12100. This standard specifies safety design measures which include the inclusion of large controls and a remote shut-off system to enhance safety of use (The South African Bureau of Standards, 2013).
- **Compliance with SANS 62619** – The SANS 62619 (SABS, 2022) standard was developed based on IEC 62619 and sets standards for the safe use, storage, and disposal of lithium batteries in industrial equipment. It includes provisions for thermal stability, protection against overcharging, and safety features to prevent potential hazards from battery failure. The used in the seed sowing machine is a lithium-ion battery system intended to be SANS 62619 compliant. Safety measures are incorporated in place

to prevent batteries from over-charging, which can damage the battery and lead to unsafe operating conditions. In the operational specification it is indicated that the operational temperature should not exceed the range of 0 to 45 degrees Celsius to enhance battery performance and safety.

11. Conclusion

The primary aim of the design of an automatic seed sowing machine was to design and develop a machine that will increase crop yield, efficiency and address the challenges faced in agriculture, particularly in small-scale farms. The challenges faced in small scale farming stem from manual seed sowing procedures, which can cause uneven seed spacing, inconsistent seed depth and medical problems to the workers from prolonged stooped work. The effects of these challenges can cause low yield and in the long run affect the health of the farmers themselves. To address these challenges, adequate background research was conducted to evaluate other projects that have been done or solutions that were brought forward. Information was collected from many sources to assist in the new development by highlighting the weak areas of the current developments. This groundwork was very important in clarifying the goals of the project.

Three design concepts were then developed and thoroughly assessed through a decision matrix, guaranteeing that the final design would address the requirements of farmers. The chosen design concept integrates a robust seed metering system that can place seed in three spacing options (15, 30, and 45 cm) by simply adjusting the metering system, adjustable sowing depth, and an automated furrow-closing mechanism, all of which contribute to precise seed placement. This precision is important for optimizing growth conditions and improving productivity in agricultural.

The machine was designed to be user-friendly and affordable, making it suitable for small-scale farmers who may have limited financial resources. Safety features had also been included in the design. The machine will be equipped with an emergency stop button that could bring the machine to a halt in the case of malfunction. It also has sensors for sensing obstacle in its path, which will automatically cause the robot to stop if detected. The design process also considered the availability of parts, with components chosen for their affordability and ease of manufacture. This strategy ensures that the machine can be manufactured and maintained without exerting a significant financial strain on its users.

In conclusion, the automatic seed sowing machine provides a practical and sustainable solution to improve productivity and labour conditions for small-scale farmer. Thus, this project has a potential for changing traditional sowing methods by adding innovation and contributing to the advancement of modern agriculture. The knowledge obtained from this project could be the starting point for new research and development work on agricultural mechanization for the betterment of food security in rural areas.

For future projects, I recommend enhancing energy efficiency, looking at other energy-efficient power sources could make the machine more sustainable rather than depending on fossil fuels to charge the battery. Options like using solar energy to charge the battery of the machine. Also consider scaling for larger farms. Exploring options for larger operations could broaden the machine's appeal. Designing scalable models that can handle bigger plots and higher volumes of seeds would help improve agricultural efficiency on a larger scale.

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APPENDIX A: Technical Drawings

Components of the finial design

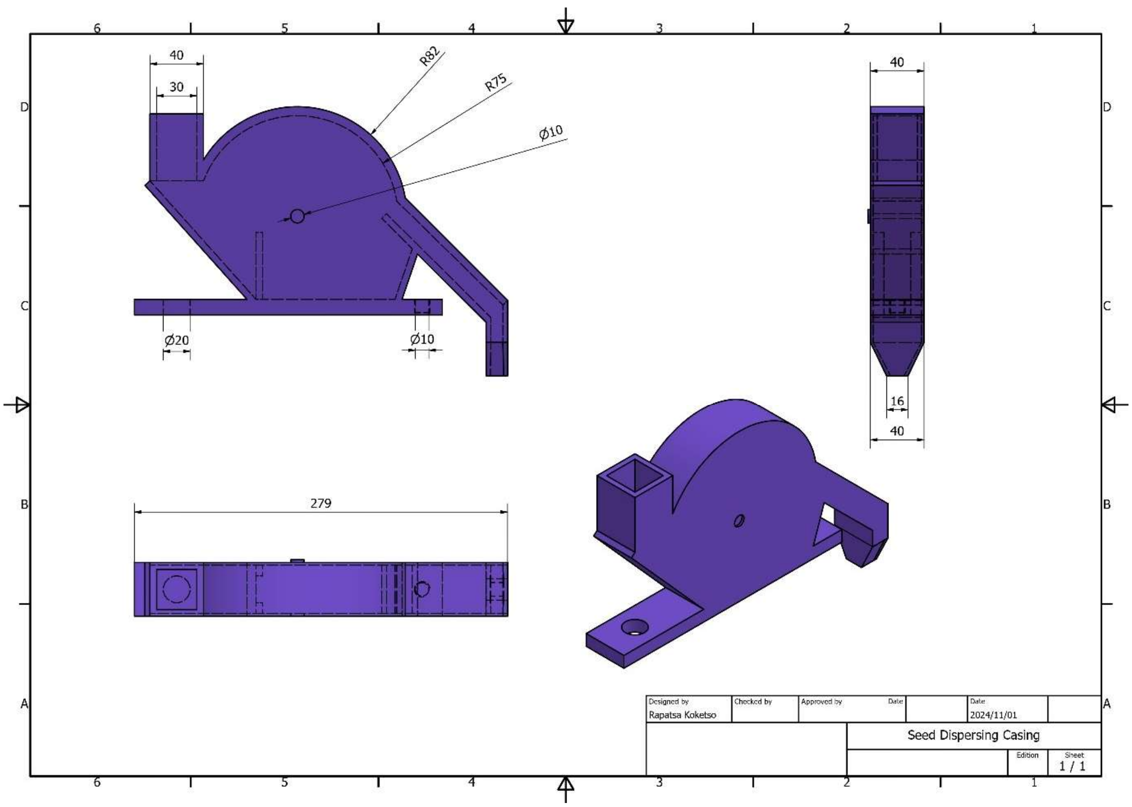

Fig. C-1: Seed dispersing casing

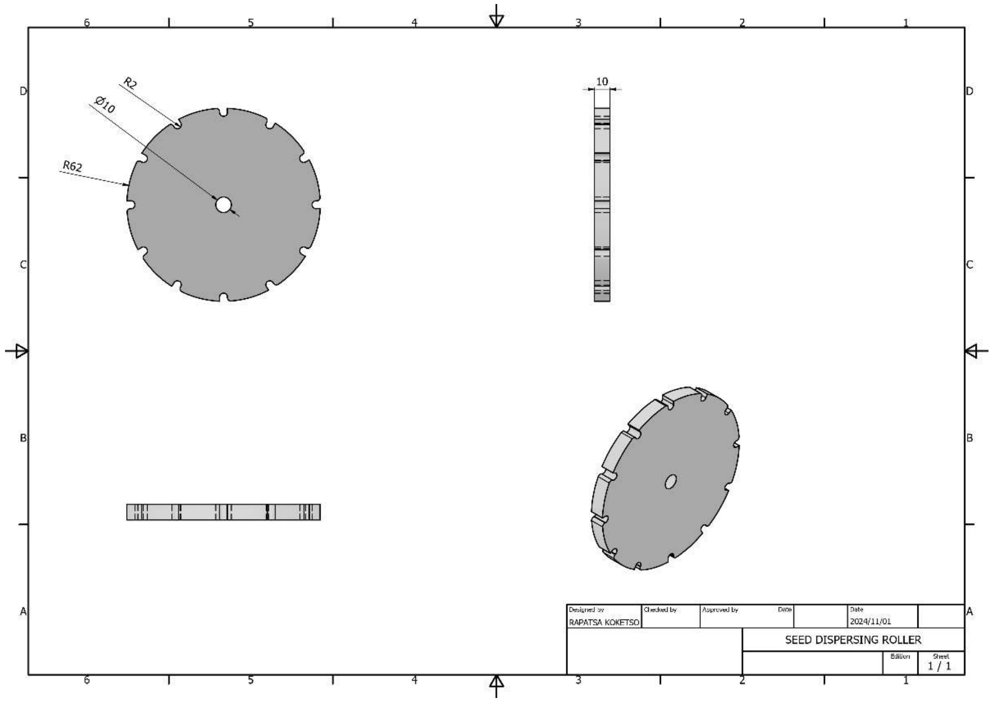

Fig C-2: Seed dispersing roller

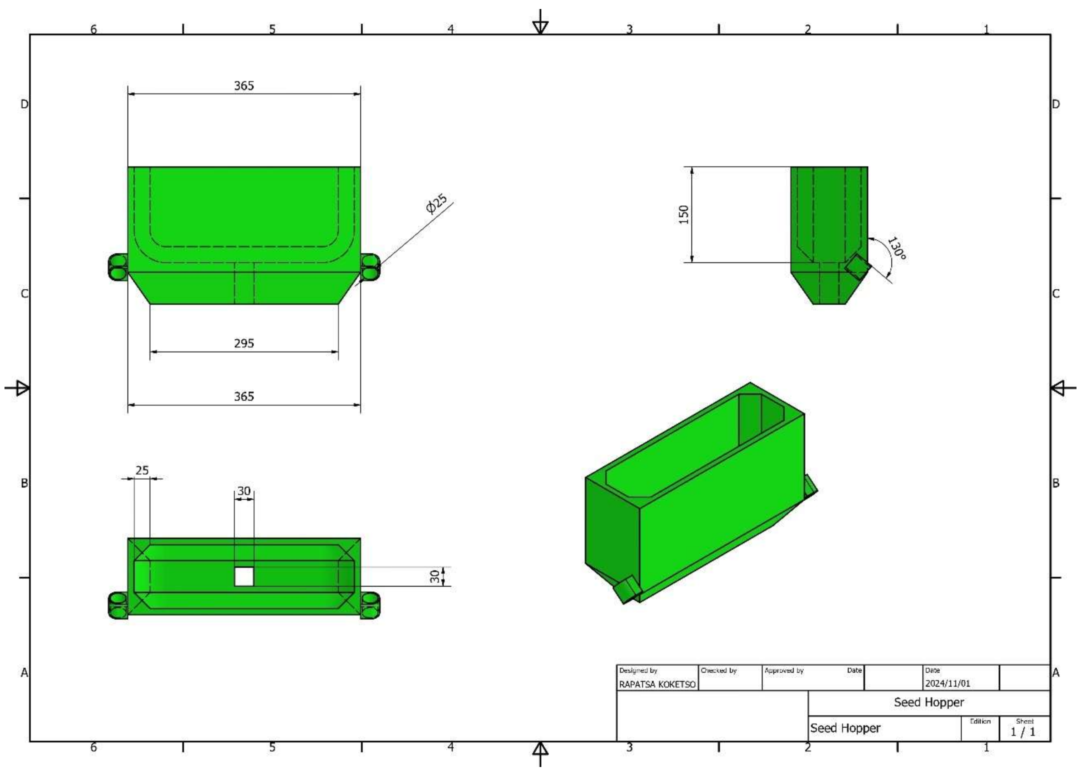

Fig C-3: Seed hopper

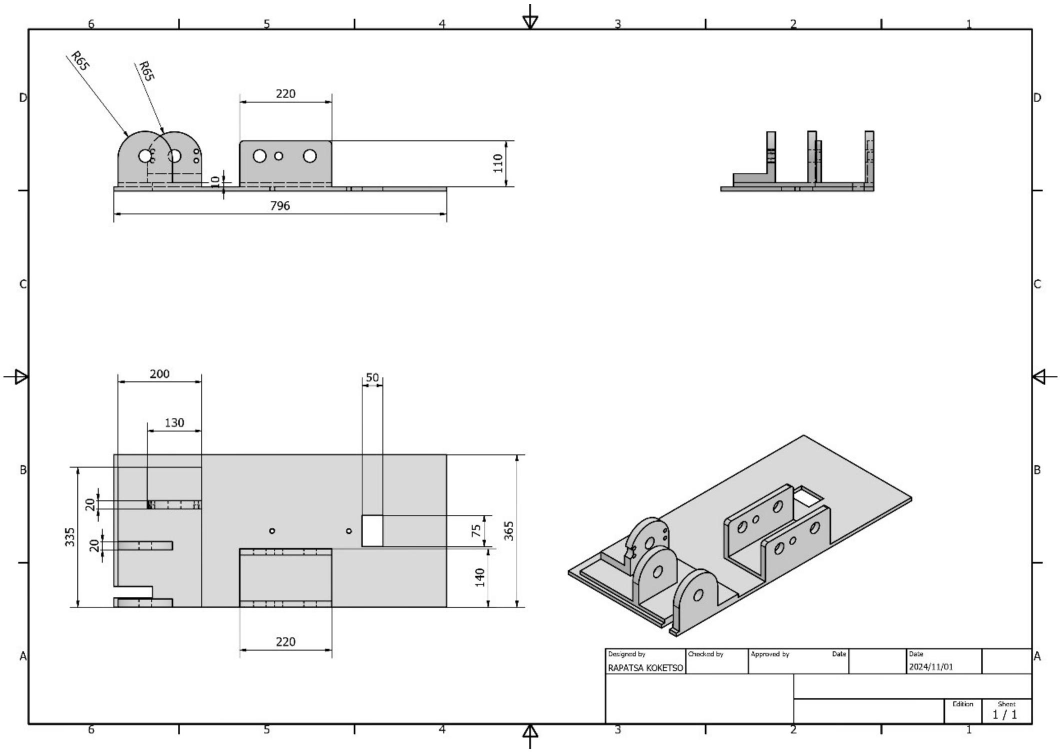

Fig C-4: Body

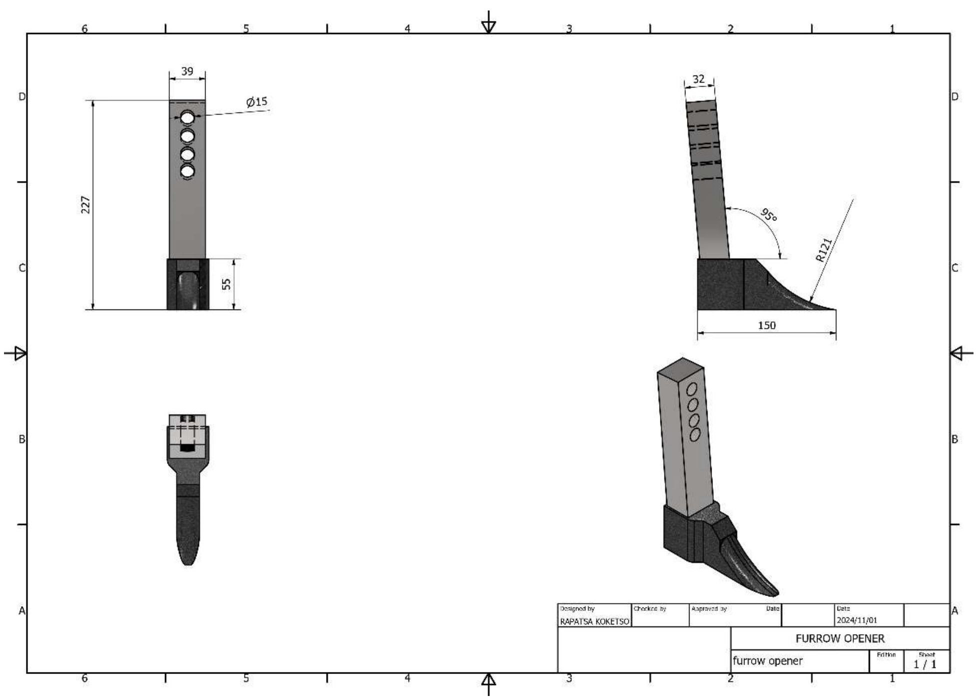

Fig C-4: Furrow Opener

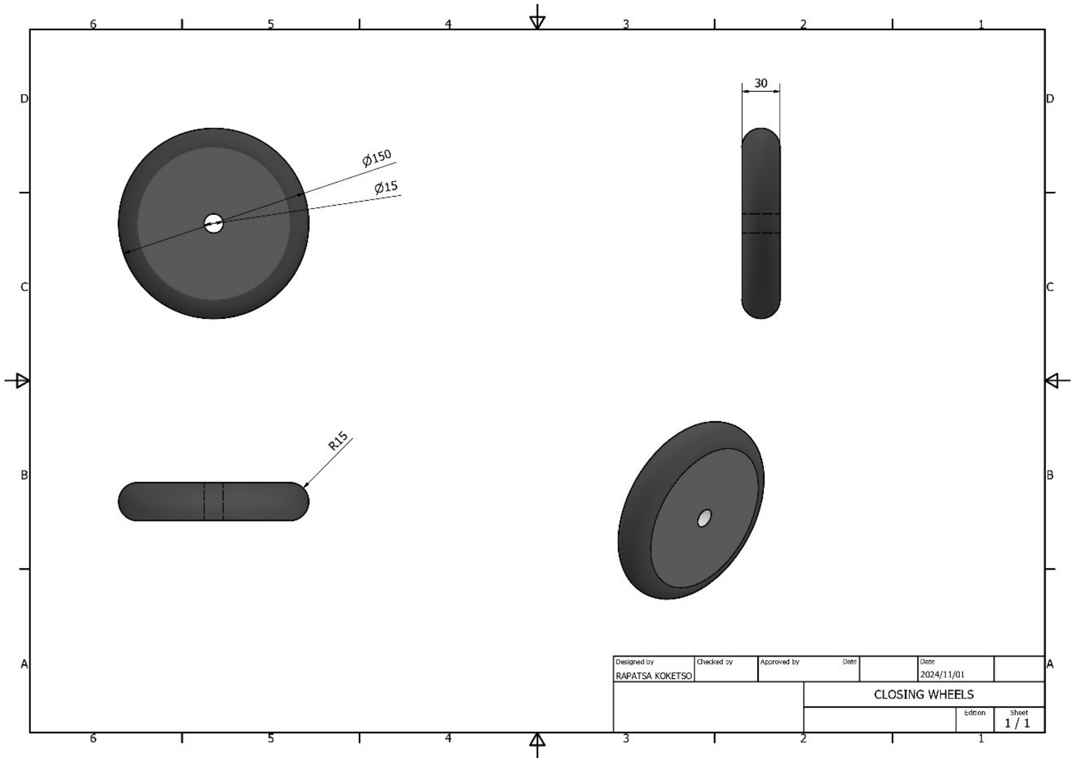

Fig C-4: Furrow Opener

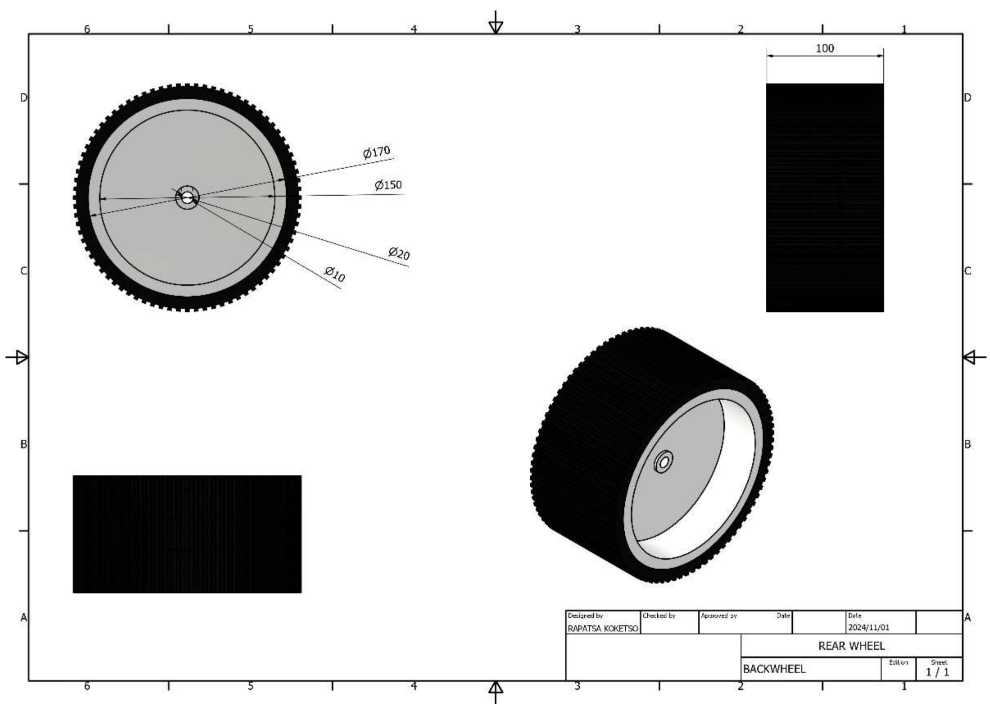

Fig C-4: Wheel