

The 3D Modelling of Cat Litter Box in Solidworks and Design Improvement

Abstract

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Title of the thesis The 3D Modelling of Cat Litter box in Solidworks and Design Improvement		
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Abstract <p>This study simulates the 3D design and modelling of the cat litter box on the software called Solidworks. The 3D design, 3D modelling, and 2D drawing demonstrated this design plan and concept in all aspects. Further study is required to investigate background and demands to determine the usefulness of the litter box and find the design direction. Then find a design improvement method according to the advantages and disadvantages of the existing Litter-Robot.</p> <p>At the beginning of modelling, Litter-Robot guided the design idea to achieve the demands of a full manual cat litter box. The heavyweight of the cat litter box and contained litter cause the cleaning process became tiring. To develop a force-saving model, the improved edition design added two force-saving devices- gear system and lever device.</p> <p>Comparing with the precision components or other mechanical experiments, this research seems to lack academic knowledge. However, it is indispensable to consider the material selection, the strength of the material, the yield strength, and etcetera that all belong to the mechanical field. The purpose of our research is to show people how to deal with problems in reality in mechanical way.</p>		
Keywords Cat litter box, Solidworks, 3D Modelling		

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1 Introduction and Design Objectives

1.1 Research Background

The number of pet cats in Finland has steadily increased since 2014 and reached 950 thousand in 2019. (Niinimäki, 2020) As an essential good for the numerous of cat owners in the world, the cat litter box has more choices in terms of shape, dimension and price. Meanwhile, depends on the preferences and requirements of the cats, the owners may have to purchase new litter box occasionally till the cats find the favorite litter boxes for themselves.

Cats, for instinct, love burying and covering their feces and urine, the owners have to provide a private place because they are vulnerable during toileting. The litter box offers a quiet place for cats as they can dig randomly without digging litter outside of the box. (CatProtect) However, cat owners need to scoop solid wastes out of the box every day to prevent bad odor transmission, especially in closed and airless indoor environments. And the inappropriate litter box design did not consider the burying behavior will cause cat litter everywhere. There may have some cat litter from the cats' paws when they jumped out on the floor.

The traditional cat litter box only has two parts: a box for saving cat litters and a colander for scooping solid wastes. In a word, the cleaning process is repeatedly scooping in the cat litter, and it causes the odor to spread rapidly in the air with the uncovered litter box. With the development of the economy, cat owners are willing to spend money on the varieties of cat litter boxes to improve the living level for both owners and cats. In 1999, Brad Designed the initial concept for the litter robot with a year of trial and error in a lot of prototypes, this highest-rated self-cleaning cat litter robot has been invented to rescue pet parents from a lifetime of dirty tasks. (LitterRobot, about us) As their introduction, quote

“The Litter-Robot’s patented sifting system uses an elegant combination of time, rotation, and gravity to automatically separate your cat’s waste from the clean litter—so you don’t have to.”
(LitterRobot, how is works)

1.2 Research Objectives

Litter-robot has an intelligent design on the self-cleaning system in an oval sphere, it provides the design and improvement inspiration for our research. The design principle is converting the automatic design to full-manual design in order to reduce the manufacturing process and cost. Secondly, utilizing the mechanical knowledge in the cleaning process in order to save manpower maximize. Thirdly, improving the design of own litter box by looking for the deficiencies of the existing litter box to achieve a more perfect design at a reasonable price. Through the illustrations in the following paragraph, we can find the 3D figures and 2D mechanical drawings about our design components separately.

Based on these backgrounds, the research aims to model a 3D cat litter box by the parametric design modular called Solidworks, it comprises the functions of 3d modeling, 2d drawing, and force analysis. The 3D model demonstrates our design plan and concept in all aspects, it assists the design ideas to become understandable and visible. And the built-in applications, such as analytical tools and design automation, helps to simulate physical behavior instead of inaccurate manual calculations. (Cadtek, 2020)

After completing the model design, our research requires analyzing reports of the strength of materials on several hypotheses. The final analyzing report used motion analysis of the Solidworks to simulate the stress or deformation analysis with setting loads on. For instance, calculating the impact force on the shell when the cats jump from a high place or side place, and stability of the bottom when the cat turns inside. Safety, rigidity, and cost based on different needs of the components are all needed to be considered during our material selection process.

The purpose of choosing this topic is to make people understand that learning can be interesting and professional at the same time. Like the background of Litter-Robot Company, when you ask an engineer to scoop the litter, he will invent a robot to take over his job. Innovative products of mechanical engineering represent a lifestyle, more than an appliance.

2 Initial 3D Design Introduction and Part View

The automatic Litter-Robot used a detective sensor to control the rotation of the oval sphere after cats leaving, then drives the sifting process for removing the bar to the waste drawer and preserve clean litter in the oval sphere. High efficiency and timely operation also reduce the spread of unpleasant odors. However, the foremost problem is the fact that the price exceeds most cat owners' budgets, for example, the Litter-Robot 3 costs over 600 euro, which is much expensive than a usual litter box. (LitterRobot3) The principle of our design work is to cut down the price so that most people can afford it.

In order to achieve the research target, the first step removes all the electric intelligent system. The initial design idea wanted to rotate the inner container directly by moving the frame so that the cylindrical bar in the litter can be sifted and removed to the waste drawer by gravity. Basically, the cleaning process is the same as the Litter-Robot, they both do not need to scoop the litter by hands. The overall 3D drawing as shown in figure 1.

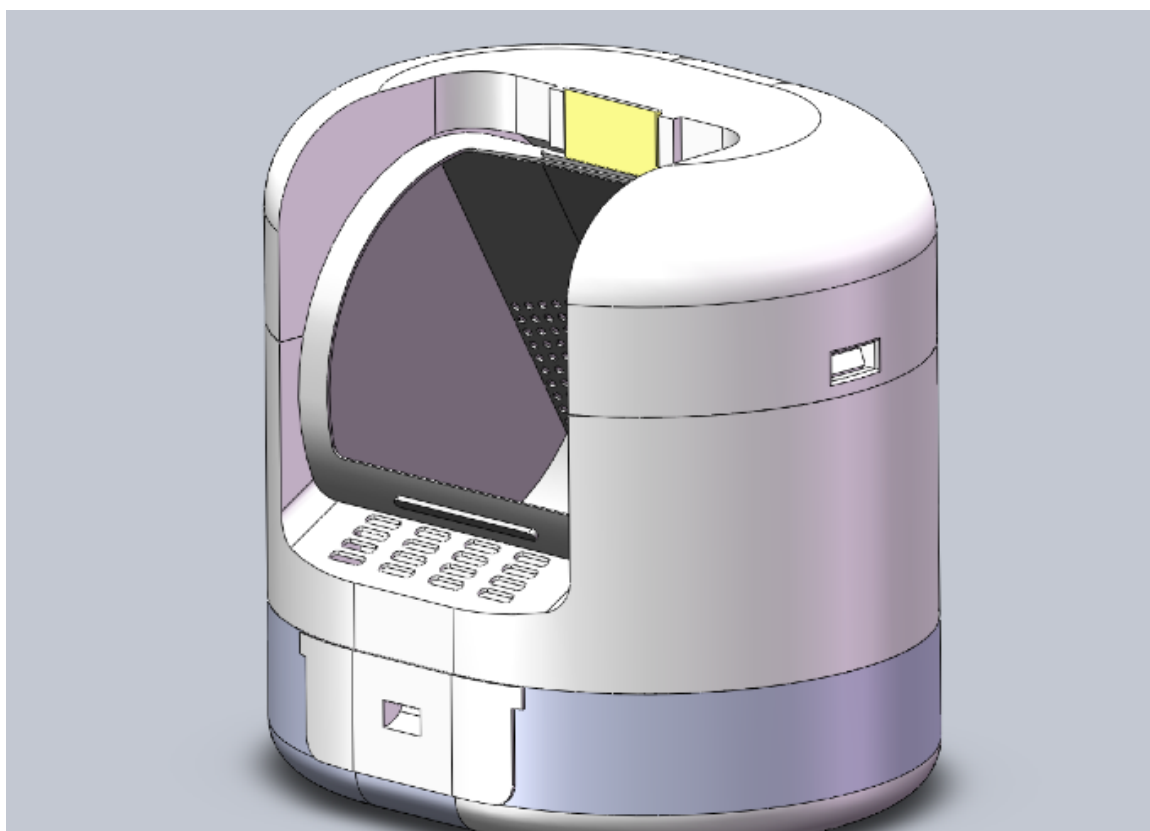


Figure 1: The overall of 3D representation of the initial design

2.1 The Main Body of Litter Box

As the loading-bearing part, the middle part provides a platform for the cat when they jump in and out. It also supports the inner container when the cat occupying or the owner rotates for cleaning. According to research requirement, the middle part does not need a complex structure but a shell with thickness. On the other side, digging some holes in the platform to filter the litter sticks for cats' feet after they buried their waste as shown in figure 2 below.

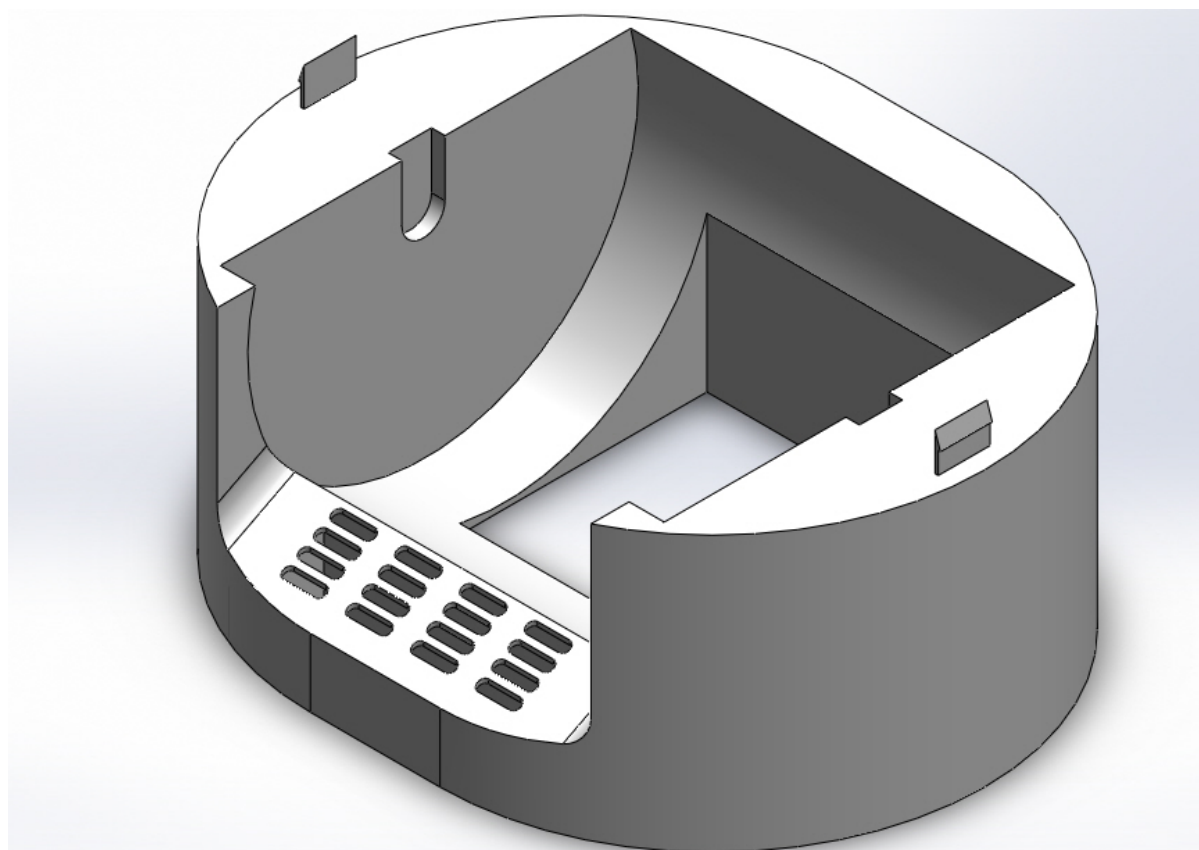


Figure 2: The 3D modeling of the middle part

2.2 Inner Rotating Container

The inner container is the core part of our design, it laid the foundation of our design principle and improvement. Returning to the objectives posed in the middle of the introduction, the solution of reducing the cost of litter is changing the automatic to full manpower. Meanwhile, the difference between design and the basic litter box is this study still need to consider the importance of saving manpower and simplify the

cleaning process.

The modeling built a folded plate in the middle can ensure the solid waste rotates into the center of the waste box instead of the outside of the waste box. When the inner containers turning to a certain angle, the cylindrical bar run to the garbage drawer, and the rest clean litter is kept in a saving cell inside the inner container. Then the clean litter back to the container after turning the inner container to the original angle as the figure 3 and figure 4 shows.

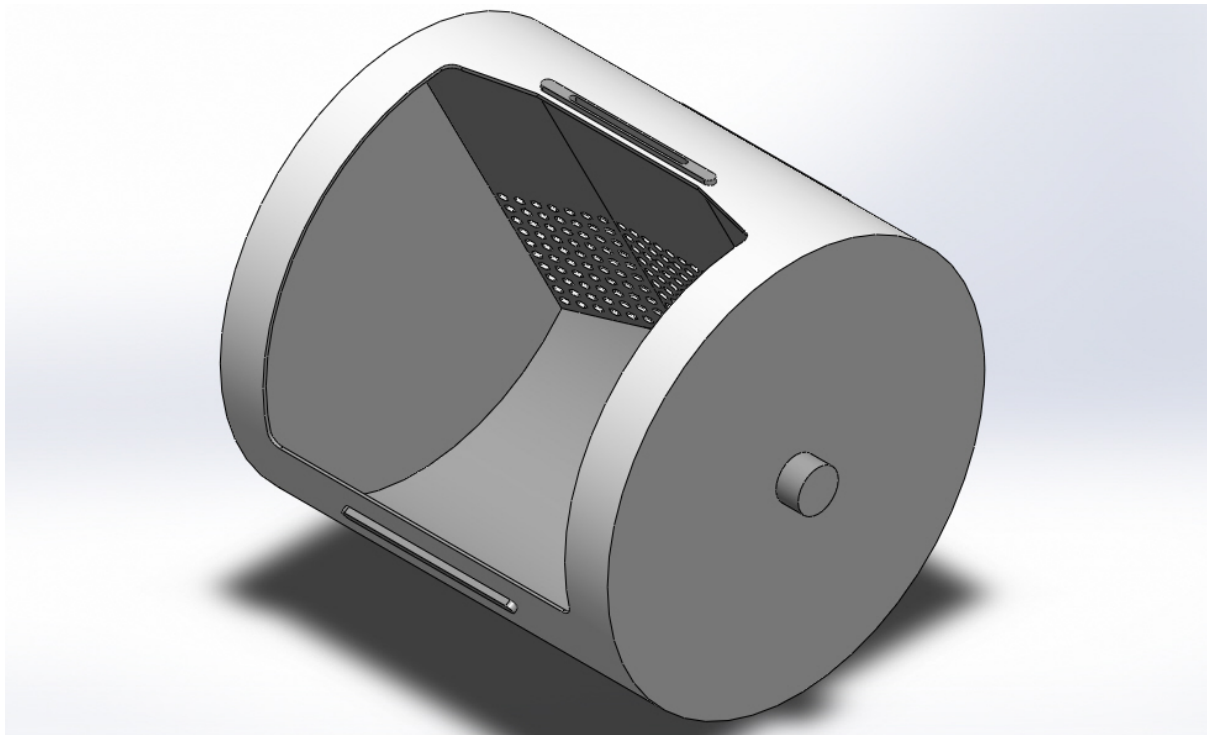


Figure 3: The 3D modeling of the inner container

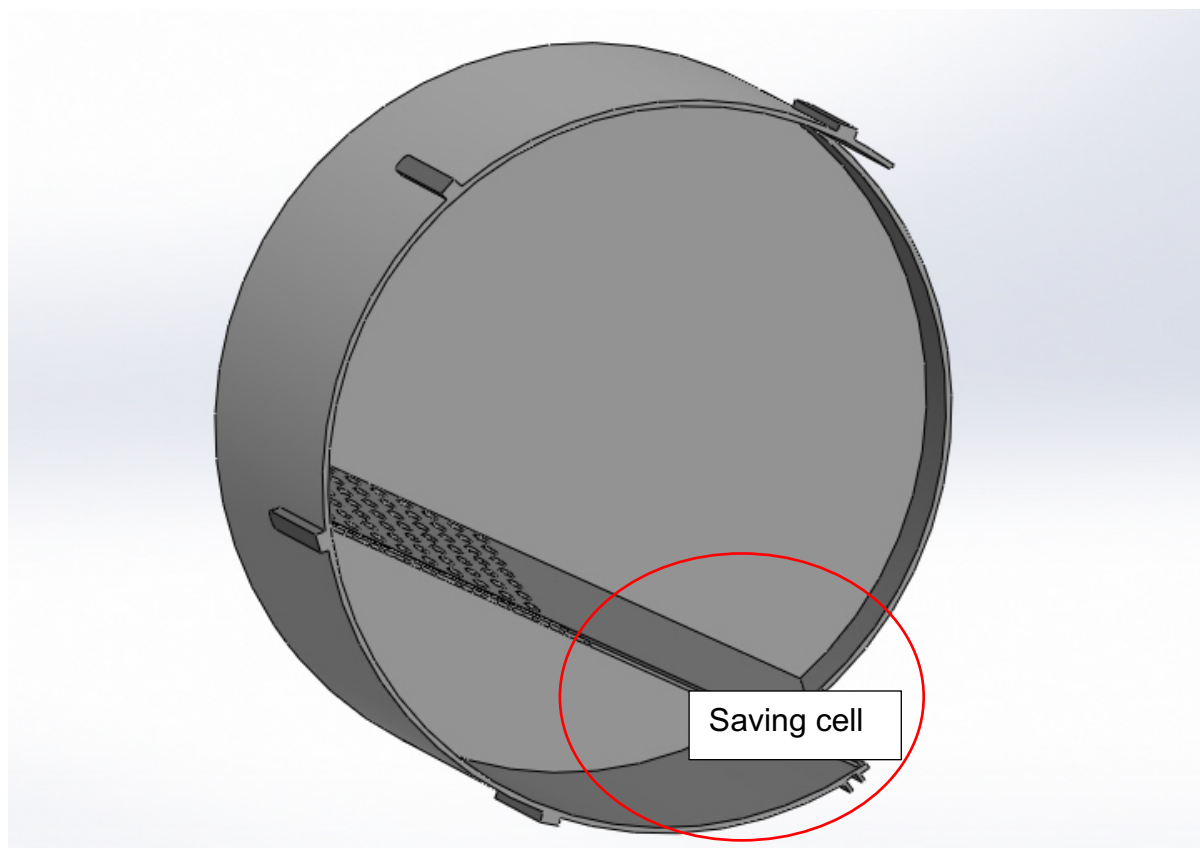


Figure 4: The section view of the inner container

2.3 The Top Shell Introduction

The shell and the main body connected with two buckles that make it easy to take the shell off and take the inner container out. The inner container needs to clean occasionally to ensure the living environment of cats, the detachable shell head shows in figure 5.

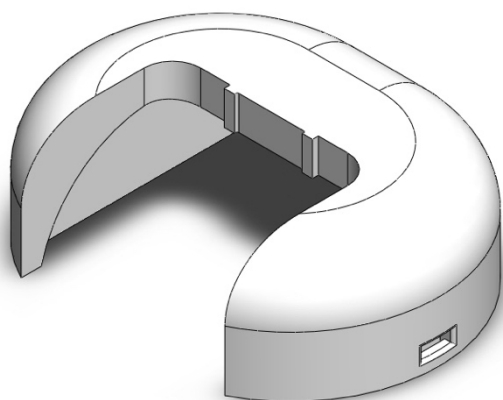


Figure 5: The 3d modeling of top shell

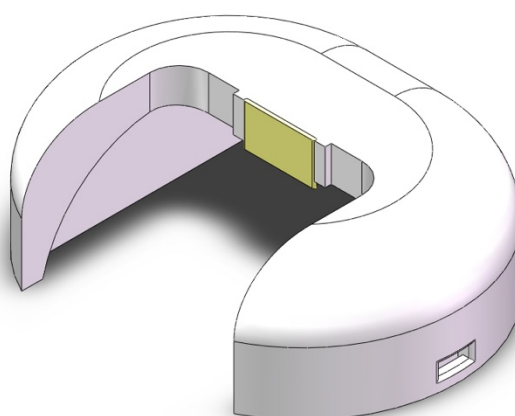


Figure 6: The 3d modeling of top shell with a fixed piece

Illustration 6 presents the 3d modeling of the top shell with a fixed piece that used stable the inner container without rotating. The fixed piece needs to be fixed on the top shell and inserted into the internal groove of the inner container at the same time. The existence of the top shell is mainly to fix the inner container and make our design look more linear.

2.4 The Bottom Base Introduction

The bottle base contains a bottle shell and inside drawer with a small container for collecting waste. It provides small storage space for placing activated carbon or plastic bags in the spare space of the drawer as the illustration 7 shows below.

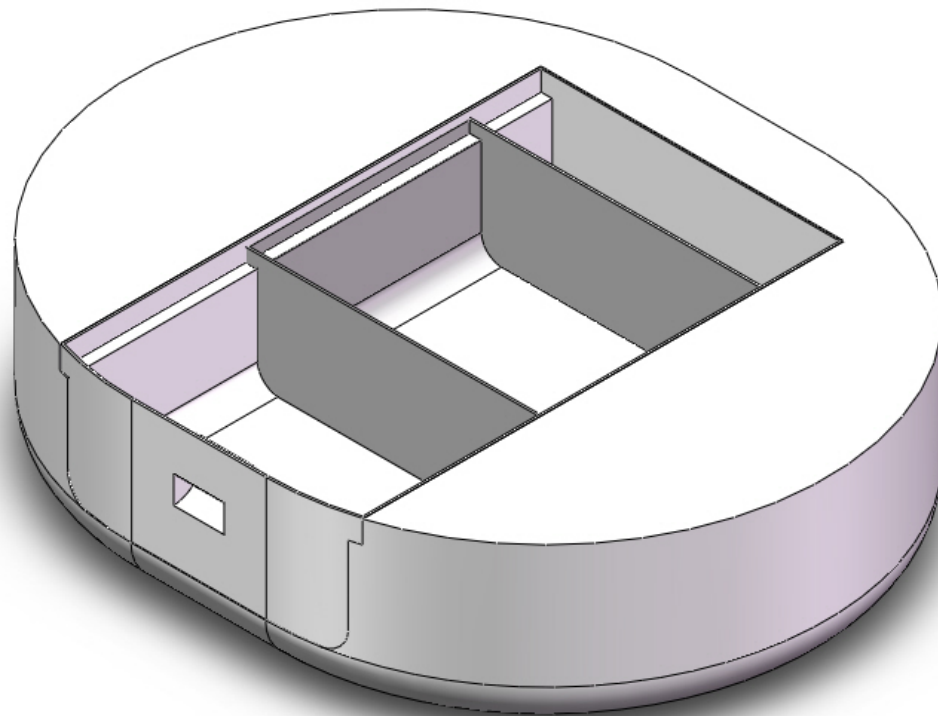


Figure 5: The 3d modeling of the bottom base with drawer assembly

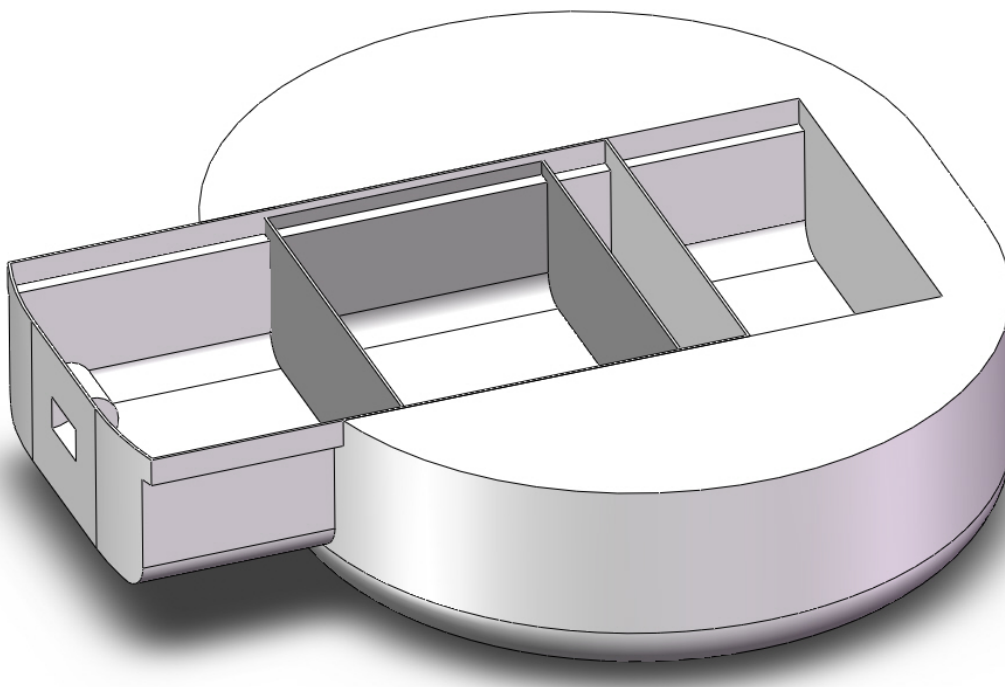


Figure 6: The 3d modeling of opened drawer

This design did not add a complicated sliding device on the drawers because that used in one common way as the garbage storage. It is a garbage bin for cats' waste when the owners are cleaning and the bin for collecting the falling litter from above. Based on research requirement, the drawer can be easily pulled in and out if the selected material has low surface roughness.

2.5 Anti-Slip Bar Design and Selection

The balance of our bottom base increased to ensure it does not tilt even under the impact force from cats. The bottom base is designed with an oval cutting with a groove to glue the anti-skid bar. The cut surface of the anti-skid bar is round and the radius is the same as the groove illustrates in figure 9.

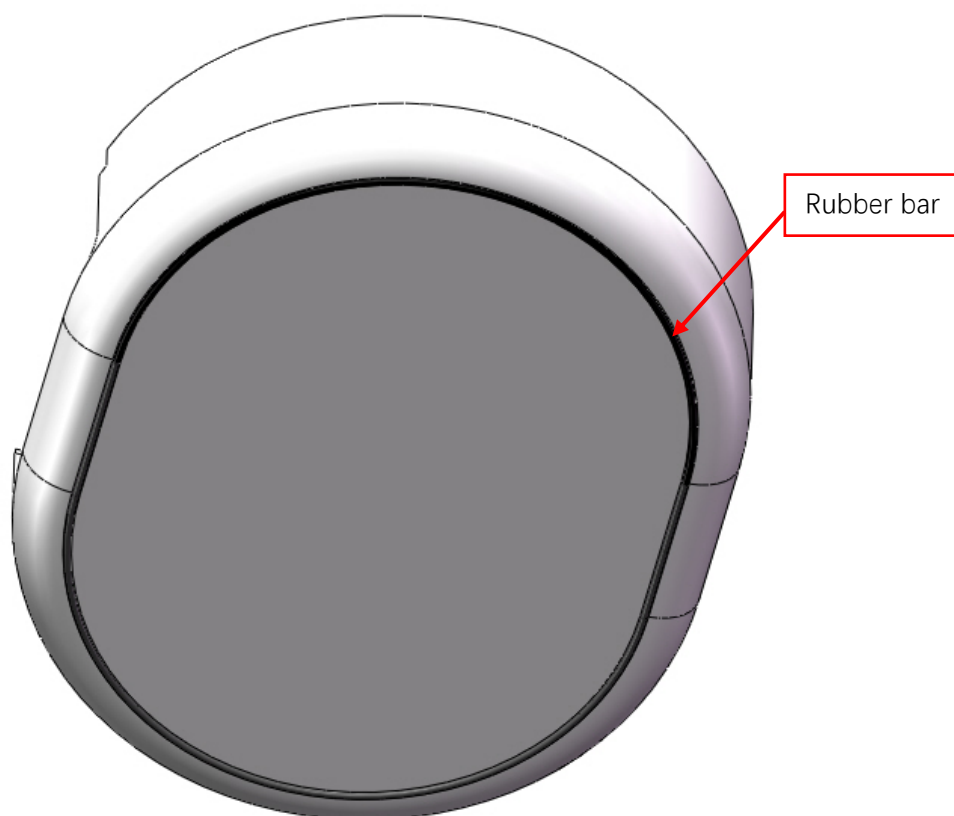


Figure 7: The 3d modeling of bottom base with rubber bar

The friction force increased by increasing the static frictional coefficient about the same normal force. From the material friction coefficients, we can find that rubber has great static friction coefficients in non-metallic materials in table 1.

Table 1: Coefficients of friction (Tammertekniikka, September 2013)

Materials	Static μ_s	Kinetic μ_k
Wood – wood (dry)	0,7	0,4
(lubricated)	0,11	0,075
Steel – steel (lubricated)	0,12	0,1
Friction bearing (lubricated)	0,14	0,02 ... 0,08
Leather – Metal (dry)	0,6	0,5

(lubricated)	0,15	0,12
Rubber – Asphalt (dry)	0,9	0,8
(lubricated)	0,4	0,2

2.6 Operation Diagram and Exploded View

The design has few parts and the cleaning steps are simple as the above paragraph described. Here are a few step diagrams to help understand.

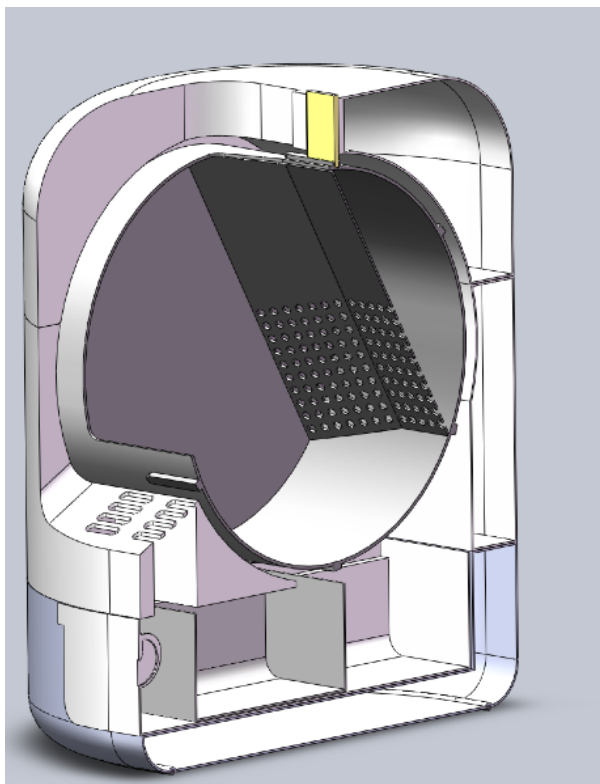


Figure 9: The overall section view with fixed piece

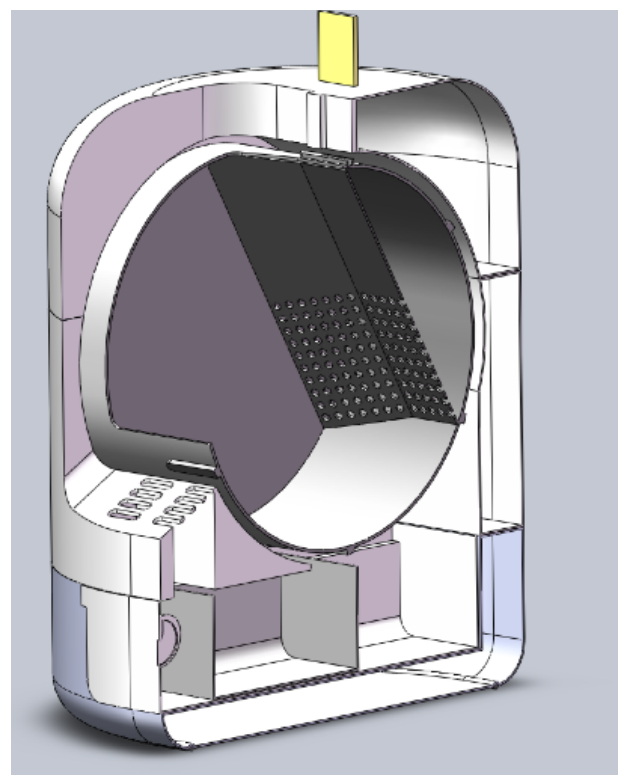


Figure 8: The overall section view without fixed piece

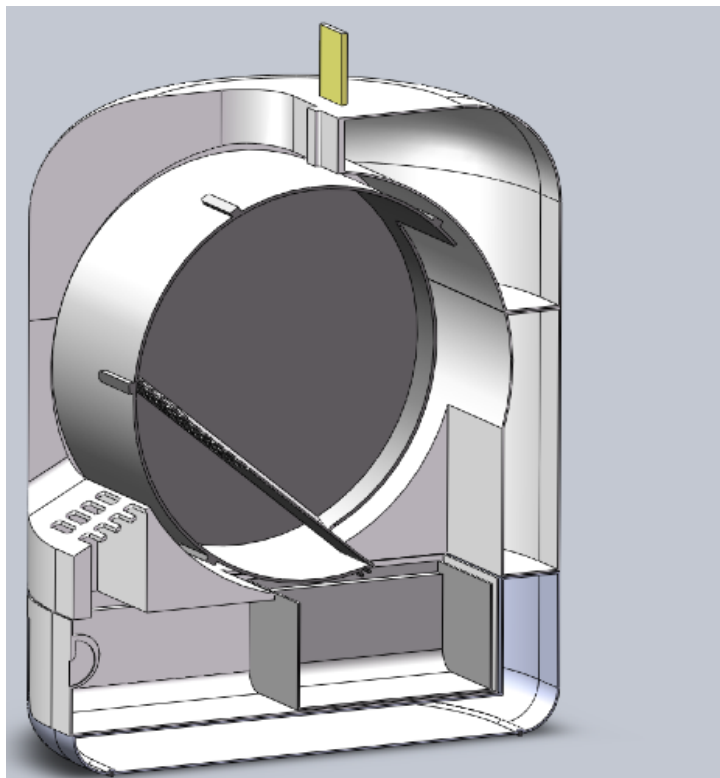


Figure 10: The section view on cleaning process

The illustrations describe the cleaning process as firstly take off the fixed piece on the top shell, then rotating the inner container by moving the outwards cylindrical bars. After cleaning the fixed piece have to put in the original place to stable the inner container. The exploded view like below figure 13 highlights the assembly instruction and the list of components.

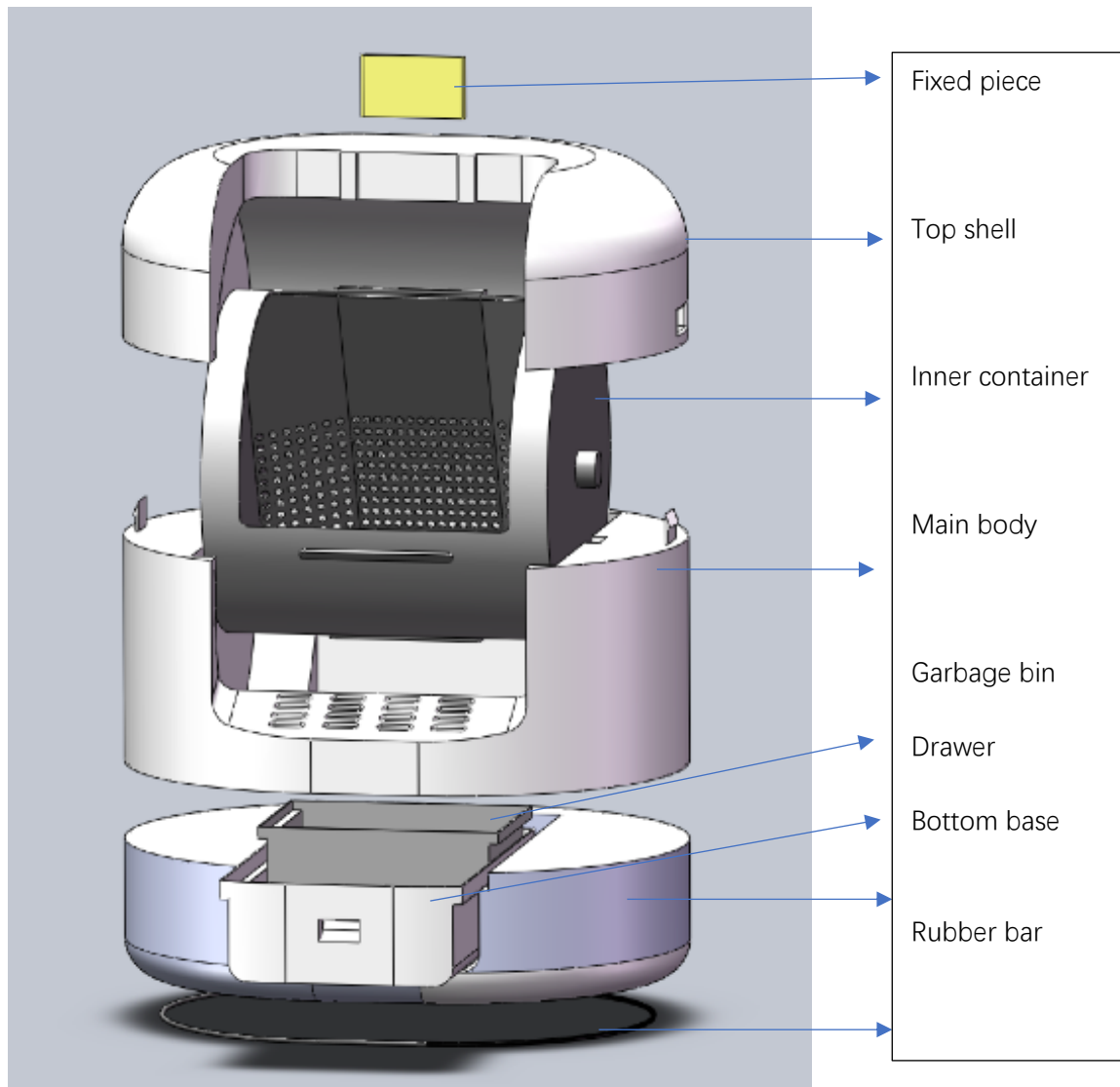


Figure 11: The exploded view of the initial design

2.7 Material Selection of Main Parts

This study has to select materials depends on different requirements, here are three material selection demands for our major parts of design:

- The cat litter box is an indoor product without consideration of UV exposure and weathering.
- The litter box needs to be corrosion resistant to resist the corrosion caused by cat feces and urine.
- The cat litter box is not a consumables product, high resistance of physical

impacts can let cat owners use it for a long time without break

As a result of material demands, this research selected Acrylonitrile Butadiene Styrene (aka ABS) as the main material of our design components. It has high toughness and strength properties to satisfy the demand of physical impact and highly resistant to chemical corrosion. Because of this point, our design did not choose Polypropylene (aka PP) but ABS, Polypropylene does not have good resistance to chemical corrosion. Base on its low melting point, ABS is easily enabled for injection molding to create a desired design effect. (AdrecoPlastics, 2018)

Table 2: Young's Modulus for non-metal materials (Toolbox, 2003)

Material	Tensile Modulus (Young's Modulus, Modulus of Elasticity) (Gpa)	Ultimate Tensile Strength (Mpa)
ABS plastic	1,4 – 3,1	40
Acrylic	3.2	70
Nylon-6	2 - 4	45 – 90
Nylon-66		60 - 80
Polypropylene,PP	1,5 - 2	28 - 36
Polyethylene HDPE (high density)	0,8	15

3 The Improvement of Separate Parts

There is another chapter for showing the improvements between the original design and the ultimate one. The main parts are dominated in our design idea and the way that can lower the cost is to simplify the manufacturing process by reducing

replaceable components.

The previous inner container did not do any force-saving operation, and the container plus the placed cat litter requires a pushing force of several kilograms. The improved design added a gear device on the side of the inner container to save manpower when rotating it. The illustration displays that a highlight of the improved design is the addition of a handle to rotate the inner container in figure 12.

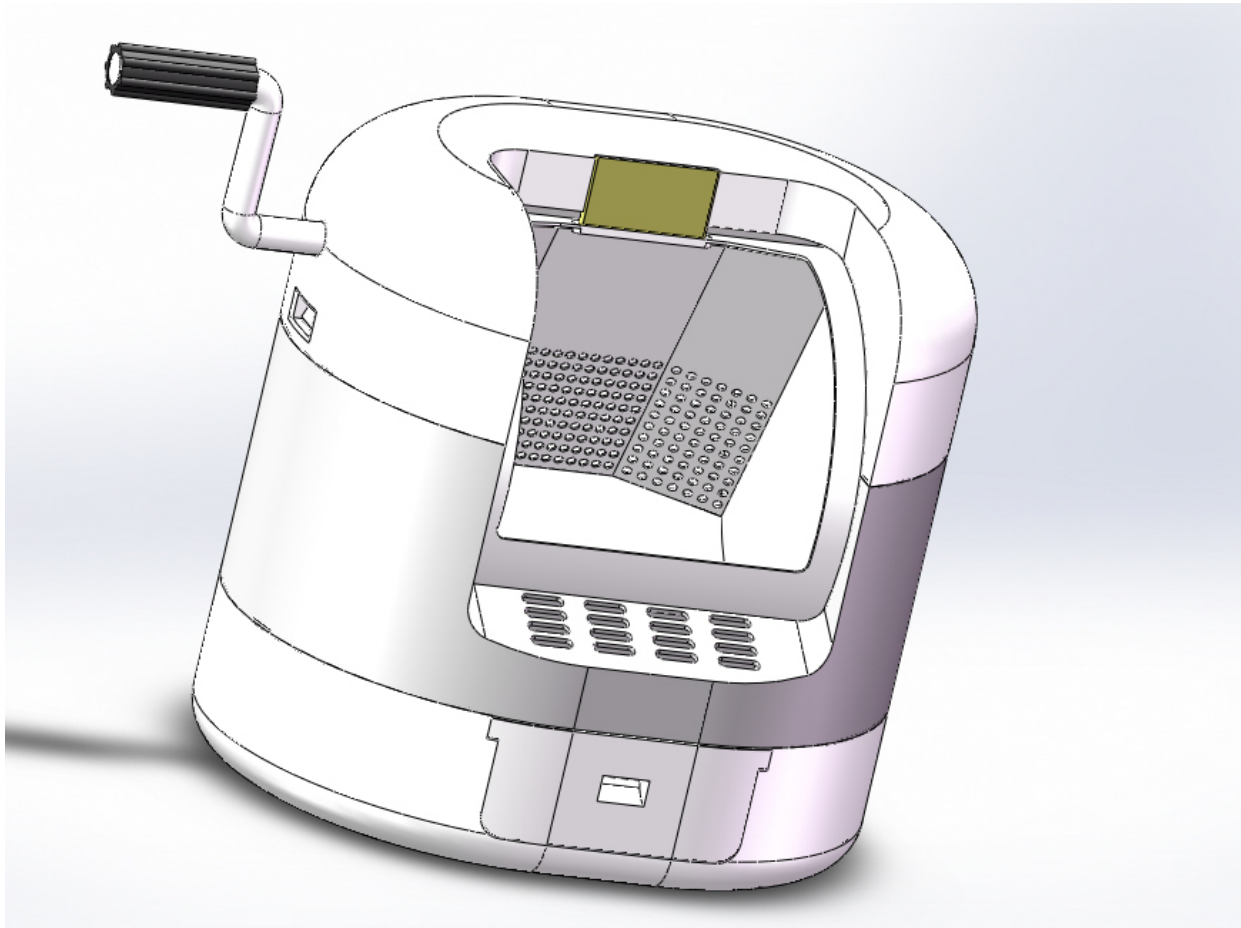


Figure 12: The 3d modeling of improved design

3.1 The Spur Gear System

The research requires a cleaning system that can rotate and save manpower together, after studying the gear system became the first candidate. As the result of design demands, selecting a power transmitting system called Spur Gears Device to increase our rotating force, the force calculates process and formulas shown in the backward

section. The principle of manpower cleaning utilizes the handle to rotate the smaller gear and driving rotation of the inner container by the bigger gear at the same time. (Woodford, 2020)

On the other hand, the gear system assembly method shown in the figure 13 as the exploded view. The rubber plug glues it on the handle and there is a cube groove at the end of the handle to match the cube convex groove in front of the smaller gear.

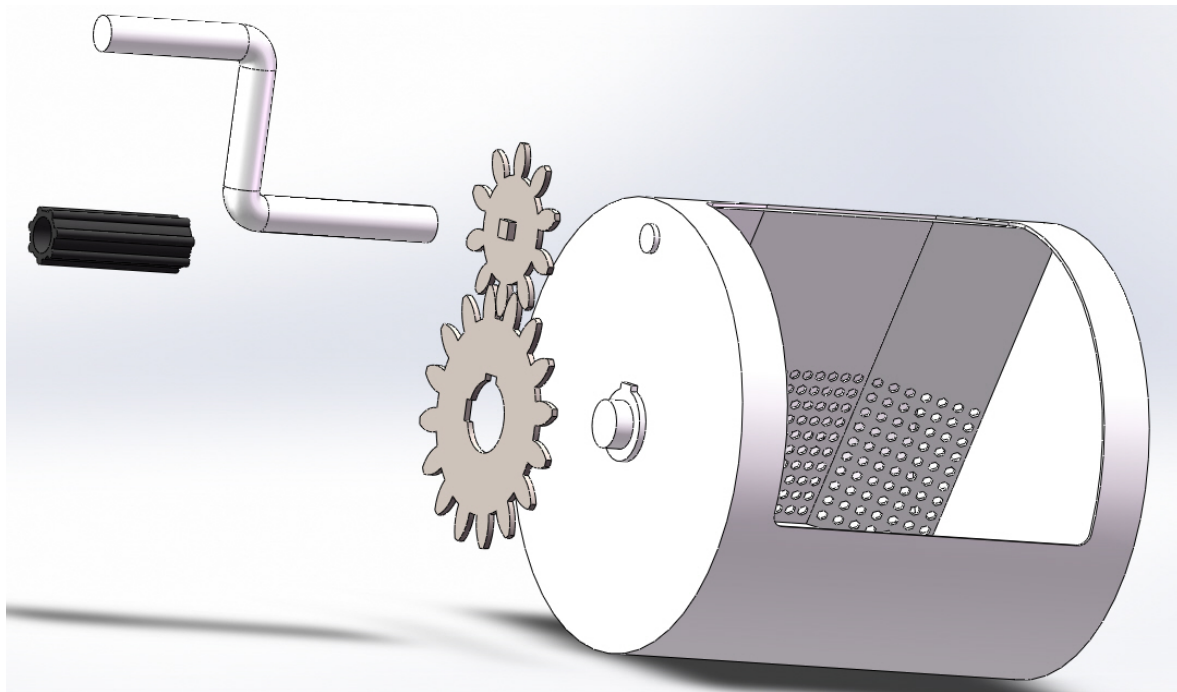


Figure 13: The 3d modeling of inner container with gear system

From the exploded view, the handle, small gear, and the inner container are all spliced like Lego. Turning the small gear by the handle alone does not drive the inner container because the three of them are not fixed together. Only when the pitches of the small gear and the large gear are overlapped, turning the handle can turn the inner container as well.

The inner container rotated by turning the small gear to drive the large gear, in that case, the big gear has to be fixed on the inner container. The big gear has two cutting keyways to match the inner container and the smaller one has one cylindrical groove in the back to support it hangs on the inner container as illustration 14 below.

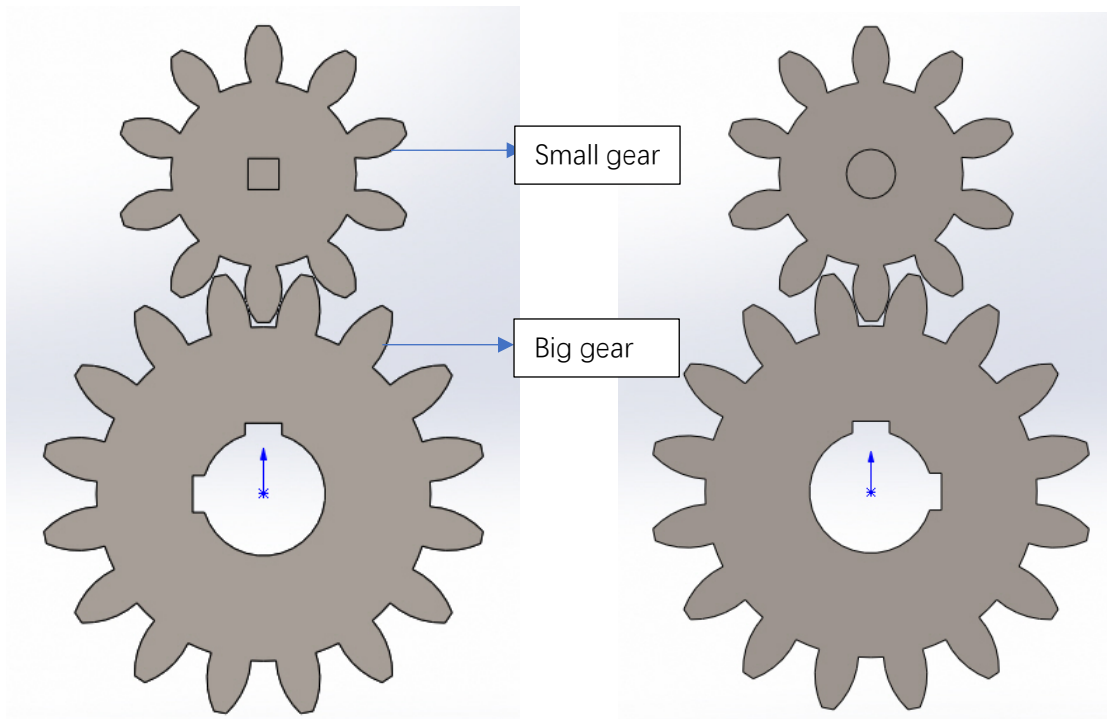


Figure 16: The front and back view of gear system

3.2 The Material Selection of The Spur Gear

The material of the gear system used Nylon in our research, the key benefits of nylon are low self-weight, and the ability to absorb shock and vibration. The elastic modulus and tensile strength of Nylon 6/10 is much higher than Nylon 101 according to the information provided in Solidworks as figure 16 and figure 17 shows below. These two mechanical properties can help the gear system resist tension with the high tensile

strength as it working. (Dengel, 2017)

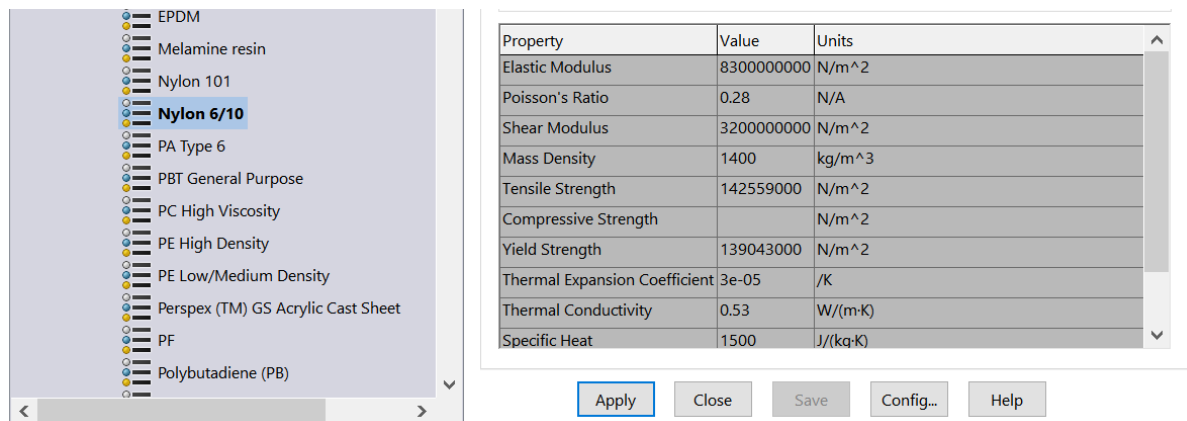


Figure 14: The mechanical property of Nylon 6/10 in Solidworks

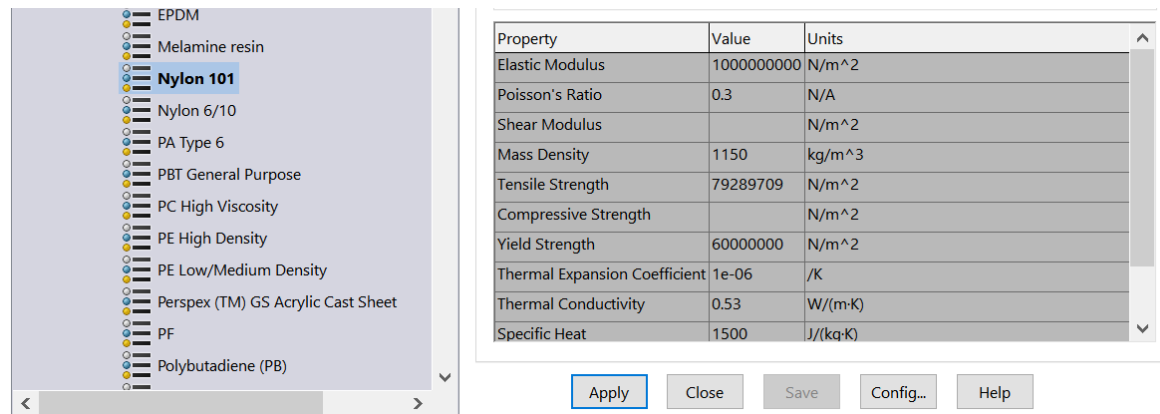


Figure 15: The mechanical property of Nylon 101 in Solidworks

3.3 The Handle Introduction

Most of the design parts use plastic material but the small components such as handle and sleeve are metal and rubber separately. Handle Sleeve is designed with the convex and concave rubber surface to increase surface roughness when rotating handle and the manpower system is learned from the lever principle of the bicycle pedal. (ToolBox, 2008)

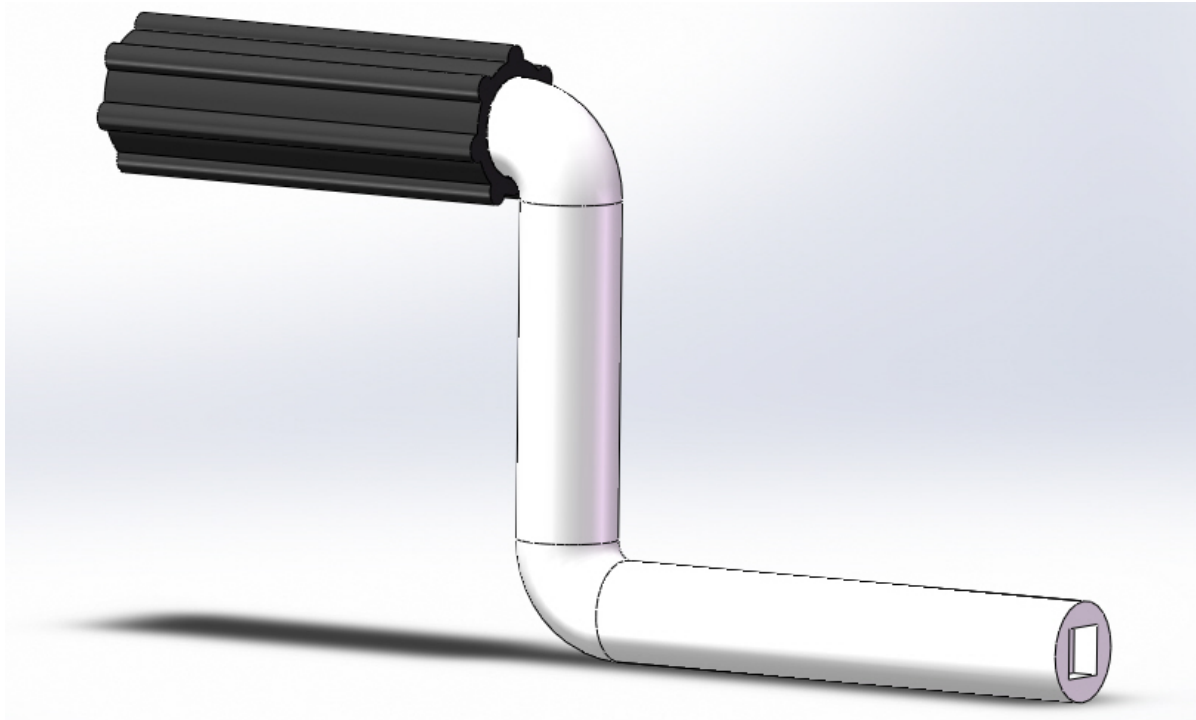


Figure 16: The 3d view of handle and rubber sleeve

3.4 The Fixed Piece

The automatic litter box has an automatic calibration function after self-cleaning, for that purpose, this design adds a fixed piece to stabilize the inner container when the cat uses it. Figure 12 indicates the purpose of the fixed piece, it perfectly matched the gap between the top shell, and the inner container and the fixed piece through extremely low tolerance to achieve a fixed effect.

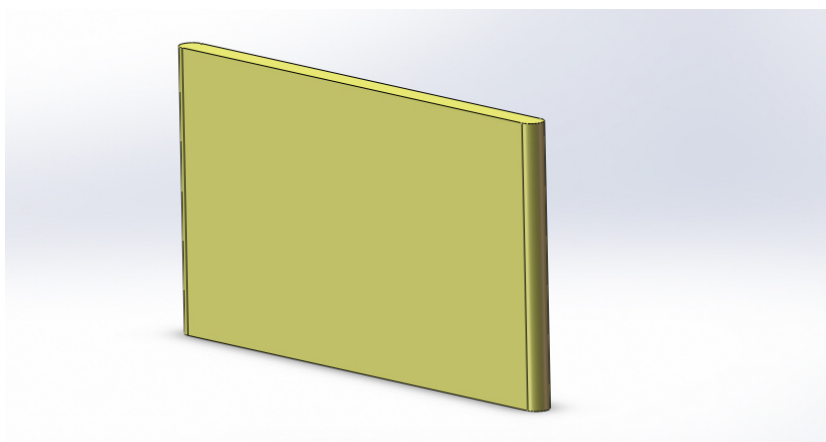


Figure 17: The 3d modeling of a fixed piece

3.5 The Exploded View of Improved Design

In general, the improved design focuses on saving the force of rotating the inner container so that other parts are unchanged except for the inner container, and a hole is only added to the top to allow the handle to pass through as illustration 19 shows.

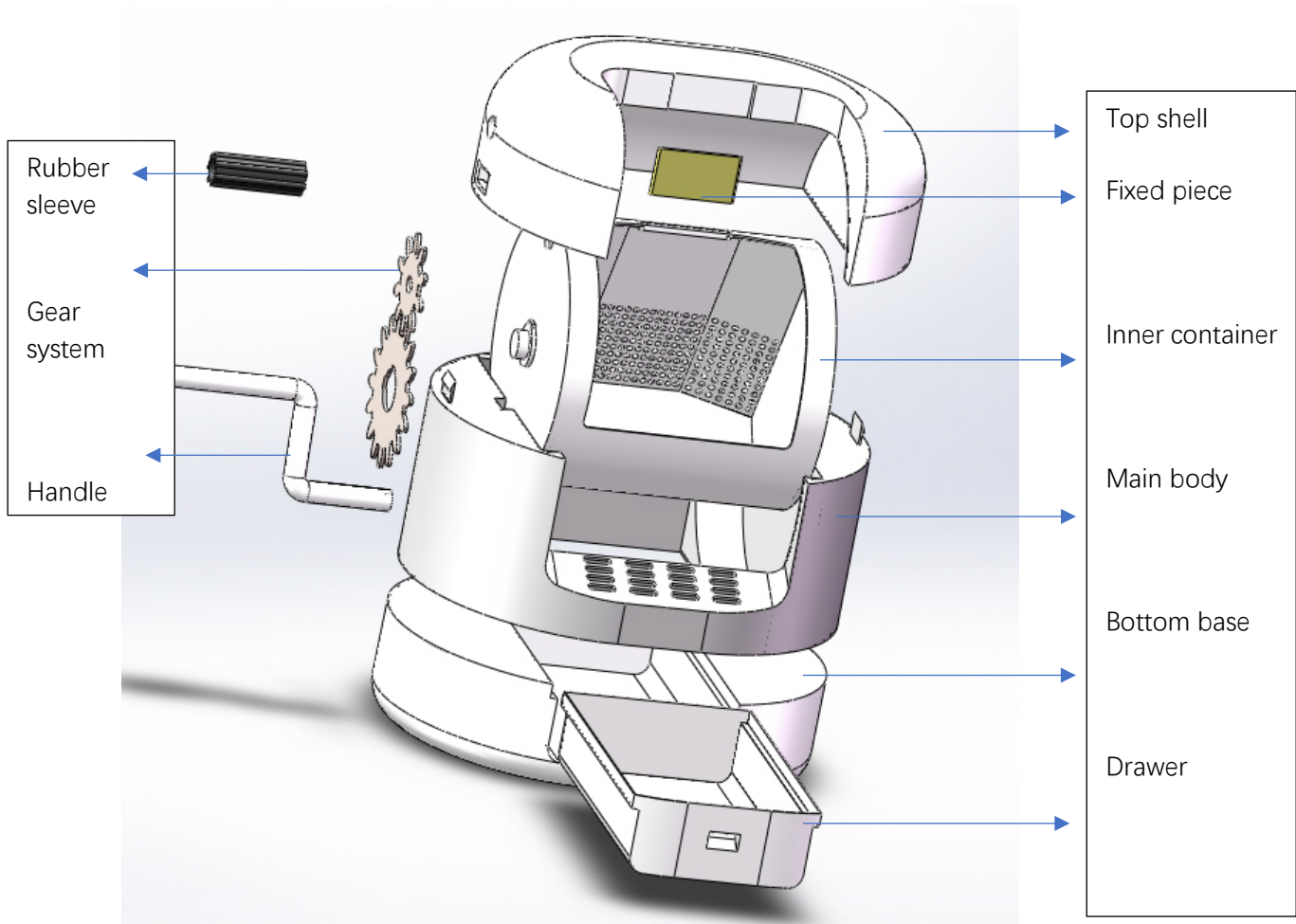


Figure 18: The exploded view of the improved design

The previous paragraph may make the installed process of the gears system unimaginable, but with the section view 20 below it became visible. First, the red is the small gear, the green is the large gear, and the yellow is the cylindrical support on the side of the inner container. The width of the gap on the top shell is smaller than the combined width of the large and small gears. Even if there is no cylindrical support on the side, the small gear can stand stably on the large gear.

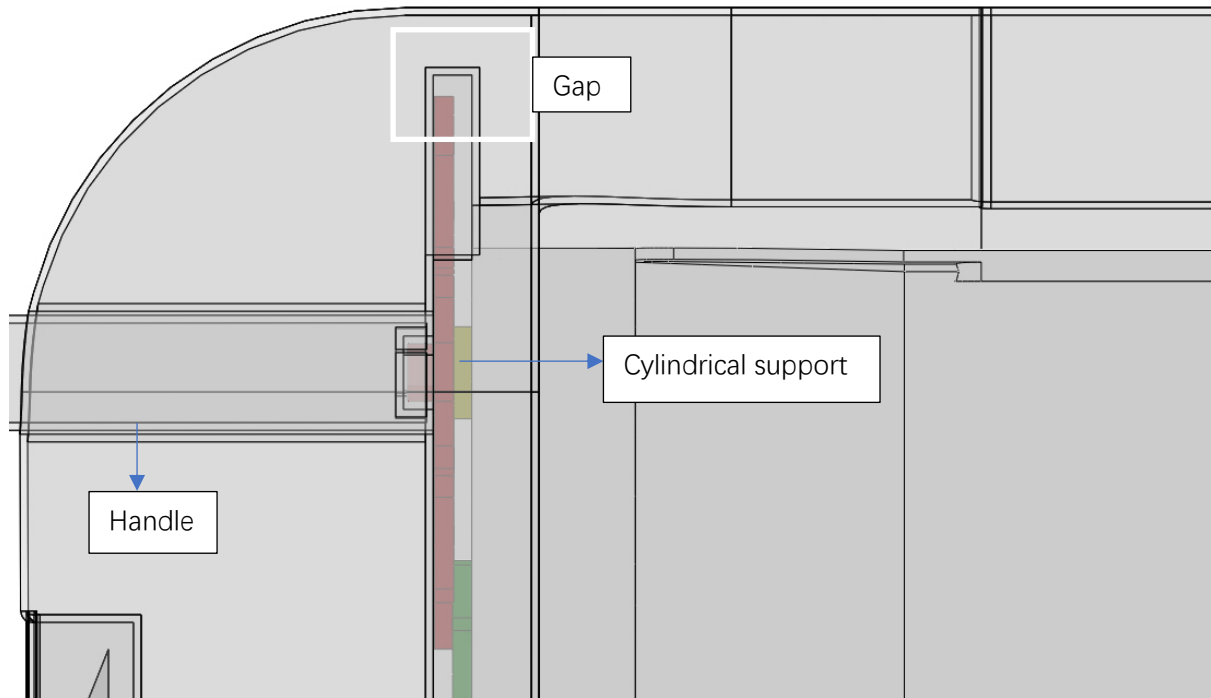


Figure 19: The section view of the gear system assembly

4. The 2D Drawing and Force Calculation

The dimensions of the litter box are also one of the decisive topics in our research. According to research, domestic cats have a certain preference for the size of the litter box. The second point is that a litter box that is too small will make it difficult for cats to move, and if it is too large, it will take up too much space. The results of this study show that a larger litter box (86 x 39 cm) will be more attractive for cats than a regular one (56 x 38 cm). Therefore, this design refers to the size of a larger litter box and decided an external 62 x 50 cm design. (Guy, N. C., Hopson, M., Vanderstichel, R, 2014)

4.1 Inner Container Volume Calculation

The more precise calculation must contain the cat litter in the inner container, for that purpose the result of maximum cat litter capacity is essential in our research. Although there is a variety of cat litter with different materials and sizes, our study selects one to calculate the approximate weight of cat litter.

Through the research, the density of cat litter cannot be referred to directly with precise official data. Base on this situation, we use the product standard from the Draynecs BVBA to measure the about weight that the inner container can be accommodated. According to the information provided on Draynecs website, the bulk density of litter is about 850 gr/ltr +/- 6%. (BVBA)

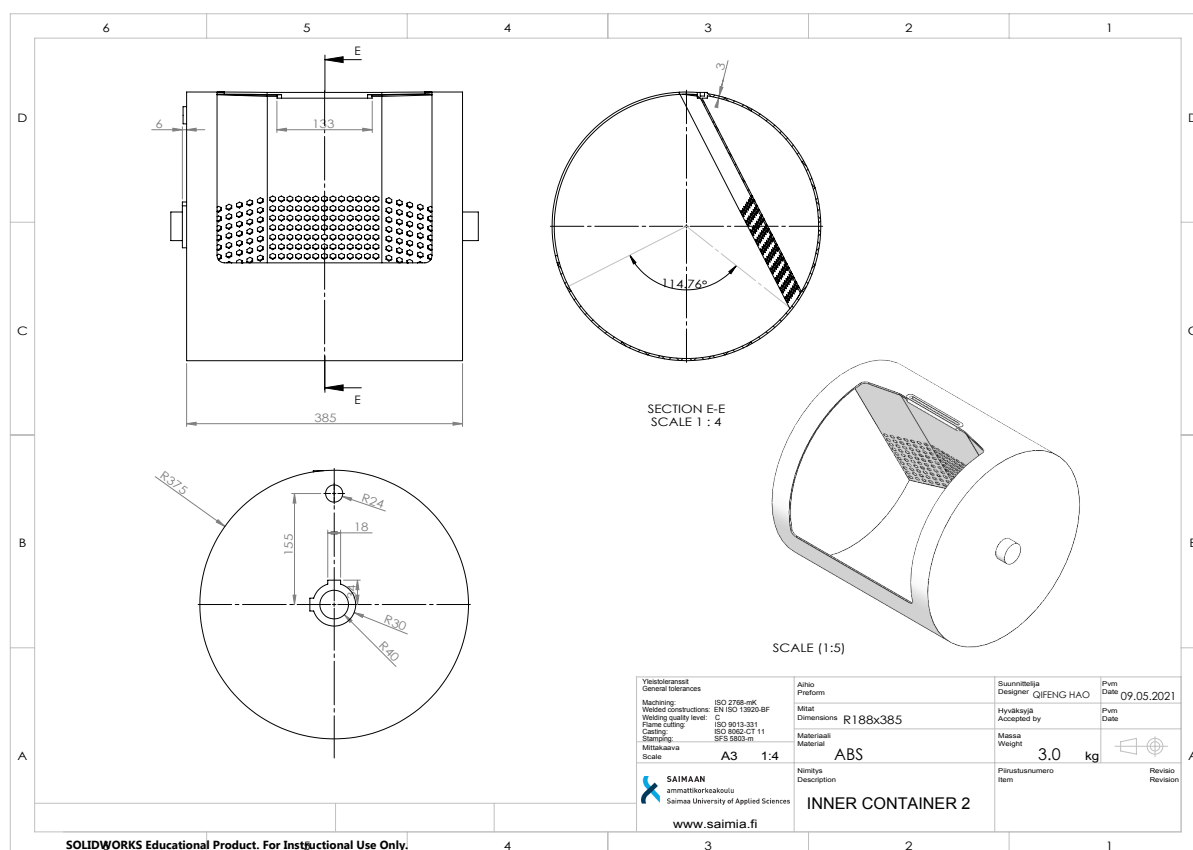


Figure 20: The 2d drawing of the inner container 2

As the figure 21 of the 2d drawing of the inner container 2 shown, the volume can be

calculated as the Area multiply Length. The area of a segment of a circle can be expressed as:

$$Area = \frac{r^2}{2} \left(\frac{\pi \times \theta}{180^\circ} - \sin\theta \right) \quad (1)$$

Radius=182.50 mm ;

Angle $\theta=114.76^\circ$

$$A = \frac{182.5^2}{2} \left(\frac{\pi \times 114.76}{180^\circ} - \sin(114.76) \right) = 18233mm^2$$

Length= 370 mm

$$Volume = Area \times Length \quad (2)$$

$$= 18233 \times 370$$

$$= 6746211.1mm^2$$

Then converting cubic millimeter to liter is about 6.75 liter.

According to calculation, the volume of the inner container shows in the last equation result and the next step is calculating the mass by the Density Equation as:

$$\rho = \frac{m}{v} \quad (3)$$

$$Mass = 850 \text{ gr/ltr} \times 6.75\text{ltr} = 5737.5 \text{ gram} \approx 5.74 \text{ kg}$$

As a result of the above calculation shows, the inner container can hold 5.74 kg cat litter at least.

4.2 The Calculation of Gear System

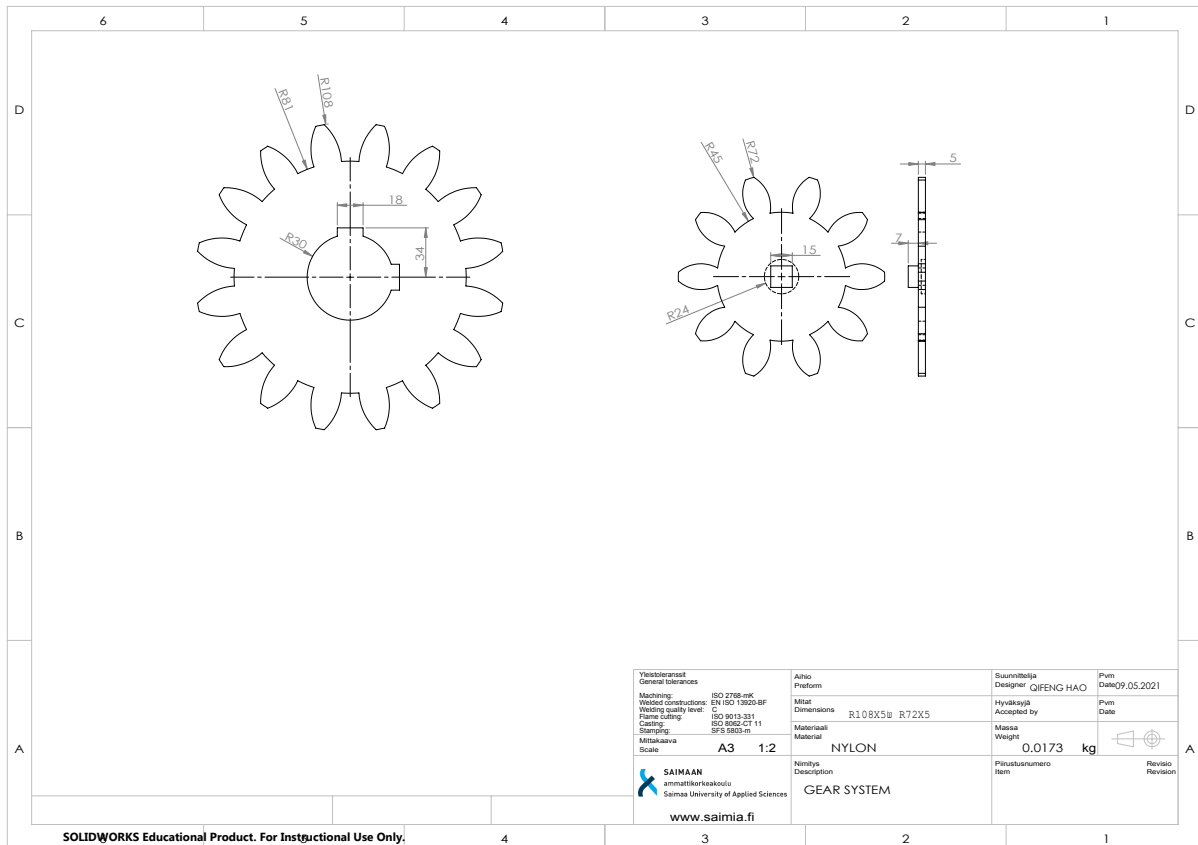


Figure 21: The 2d drawing of gear system

The dimensions we need for calculation shown in section view figure 22. The effort force of the gear system expressed as below, all the gravity in our study $g=9.81 \text{ m/s}^2$.

And where:

$$F = \frac{W \times (r1 \times r2 \times \dots r_n)}{R1 \times R2 \times \dots R_n} \quad (4)$$

W = load force (N) = Sum of cat litter (inner container and maximum litter);

r = gear wheel inside diameter (m);

R = gear wheel outside diameter (m);

As the result, the force required to turn the inner container with maximum litter inside after using the gear system is:

$$F1 = \frac{(5.74 + 3.0) \times 9.8 \times (0.03 \times 0.024)}{0.045 \times 0.081} = 16.92N$$

4.3 The Calculation of Lever Device

The effort force of the handle expressed as lever equal below (ToolBox, 2008)

$$F_e \times d_e = F_l \times d_l \quad (5)$$

Where:

F_e = effort force (N) ; F_l = load force (N) ;

d_l = distance from load force to fulcrum (m) ;

d_e = distance from effort force to fulcrum (m) ;

The load force through the gear system is 16.92 N as the calculation above

$$F_e = 16.92 \times 0.12 \div 0.18 = 11.28 \text{ N}$$

As the result, the force required to rotate the inner container (with the maximum litter inside) after the gear system and lever device is

$$11.28 \text{ N} \div 9.81 \text{ m/s}^2 \approx 1.15 \text{ kg}$$

5. 2D Drawing and the Basic dimension of Components

This chapter contains the 2d drawing and basic dimensions of different component parts to simulate the manufacturing process in our study. The 2d drawing has more details rather than 3d drawing, such as weight, scale, material for our components.

5.1 2D Drawing of Top Shell

The previous illustrations indicate that there is no change in the main body and the bottom base of the design in the first and second editions. The top shell added two cutting holes on the side to enter the handle and a place for small gear separately, and the inner container is the most significant change during our design process. The 2d drawings below indicate the differences mechanically and the components in the

same dimension are not repeated show in our study.

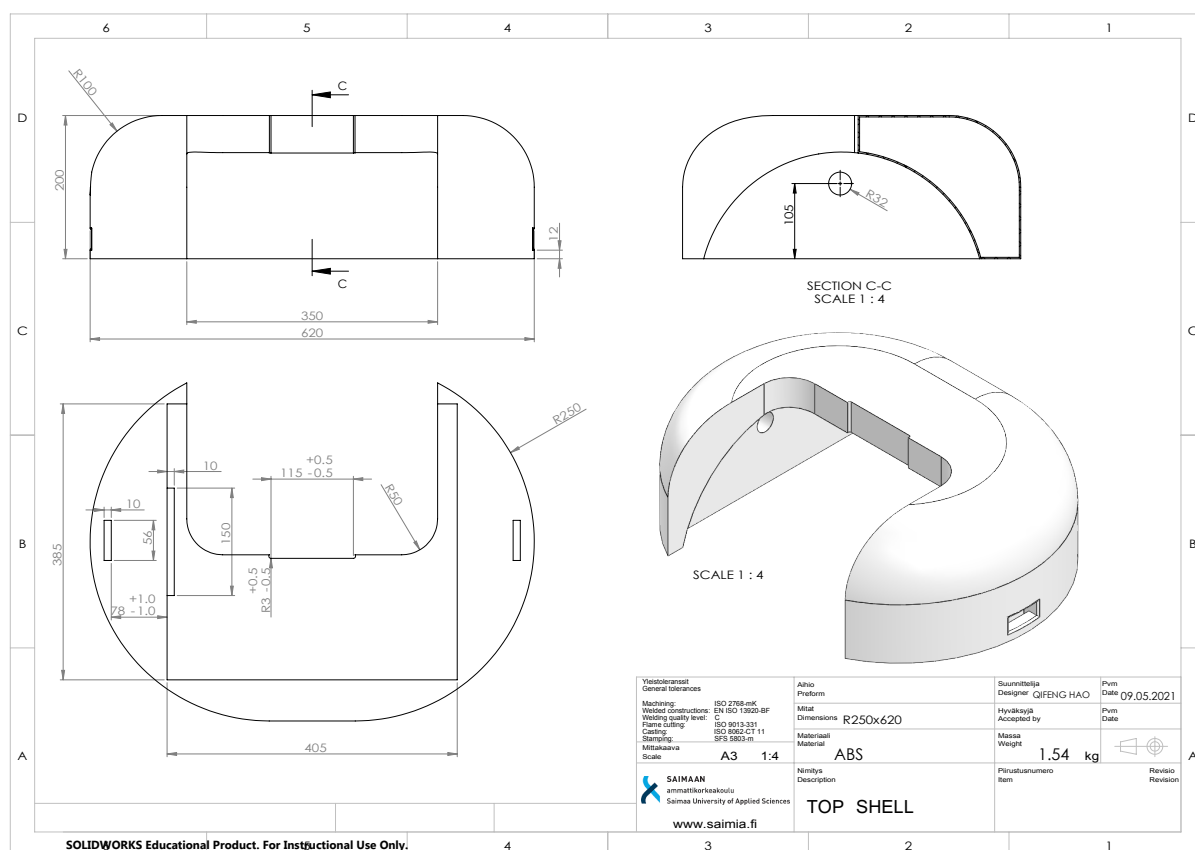
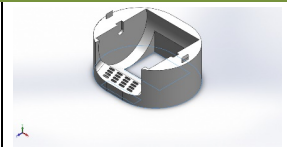


Figure 22: The 2d drawing of top shell

The top shell is a symmetrical object in the initial design, after the improvement, two holes have been added to become an asymmetrical object, but the other dimensions are the same. Since the top shell did not bear too much force, this study did not run the force simulation for it.

5.2 2D Drawing and Simulation Report of the Main Body

Loads and Fixtures

Fixture name	Fixture Image	Fixture Details		
Fixed-1		Entities: 1 face(s) Type: Fixed Geometry		
Resultant Forces				
Components	X	Y	Z	Resultant
Reaction force(N)	-0.015071	240.794	0.00495791	240.794
Reaction Moment(N.m)	0	0	0	0

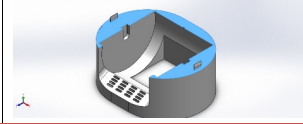
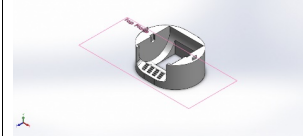
Load name	Load Image	Load Details
Force-1		Entities: 1 face(s) Type: Apply normal force Value: 200 N
Gravity-1		Reference: Top Plane Values: 0 0 -9.81 Units: m/s^2

Figure 24: Loads and Fixtures report of the main body

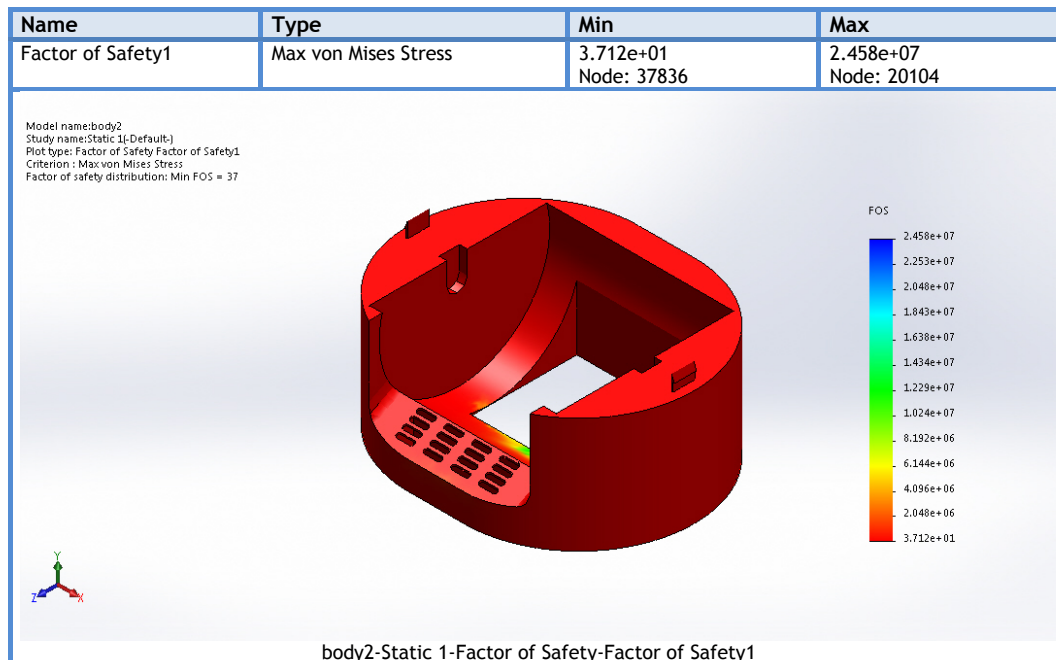


Figure 25: Factor of safety of the main body

5.3 2D Drawing and Simulation Report of the Bottom Base

As the bottom of the base, it carries all the components and litter and the cats, its FOS must be high enough to avoid fracture. In order to avoid deformation caused by high temperature, it is prefer to use glue to connect the bottom and body parts.

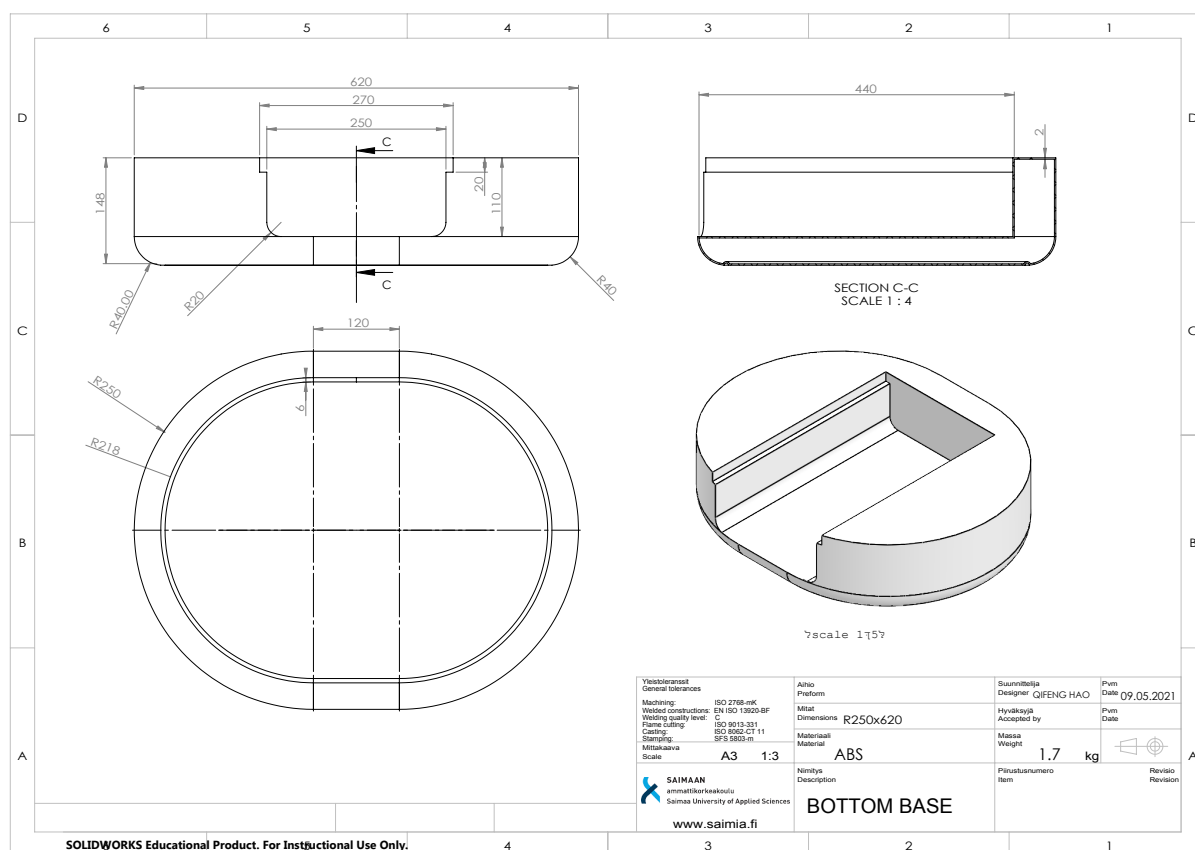


Figure 26: The 2d drawing of the bottom base

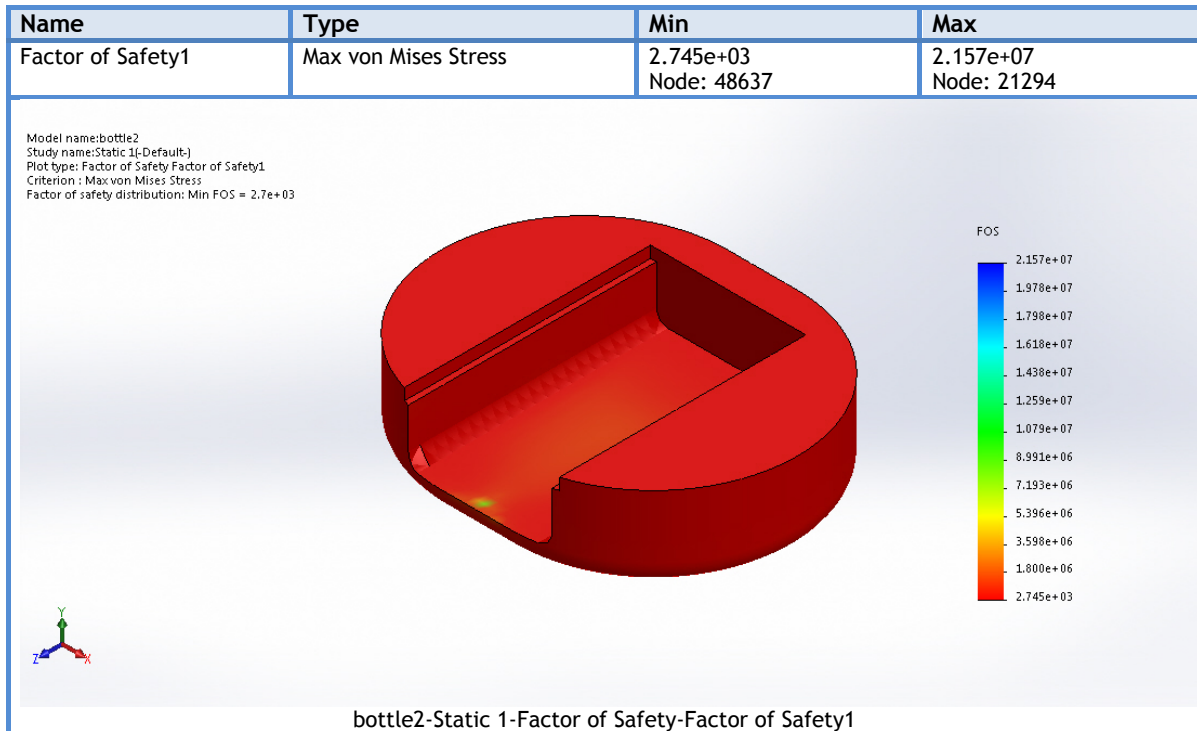


Figure 27: The factor of safety report of the bottom base

From the result of FOS of the bottom base in figure 30, our design component has an excellent quality to load the force far more than 200N.

5.4 2D Drawing of inner container 1

The improved inner container has been exhibited above, and here is the initial 2d drawing for reference and comparison as figure 31.

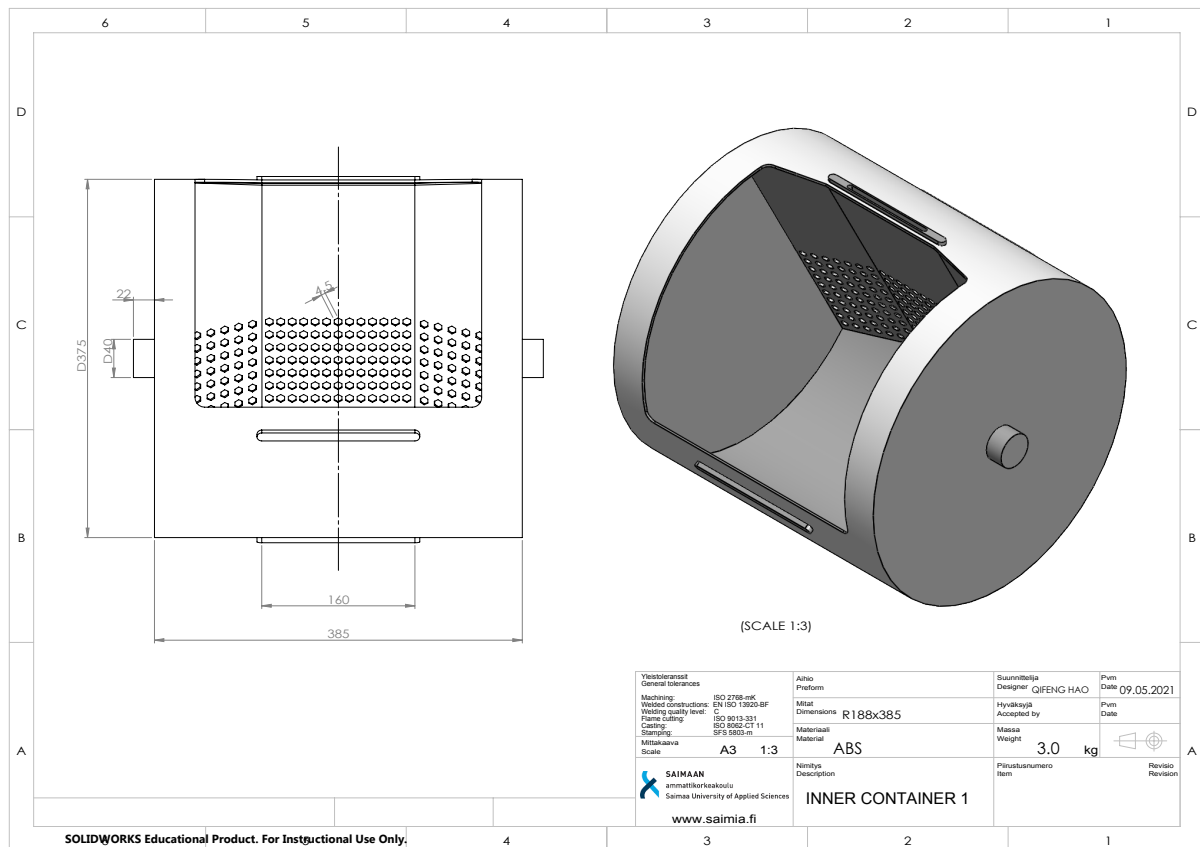


Figure 28: The 2d drawing of inner container 1

5.5 2D Drawing of rest components

The rest parts are displayed in one table, they have different scales as shown in the illustration 30 including the list of parts.

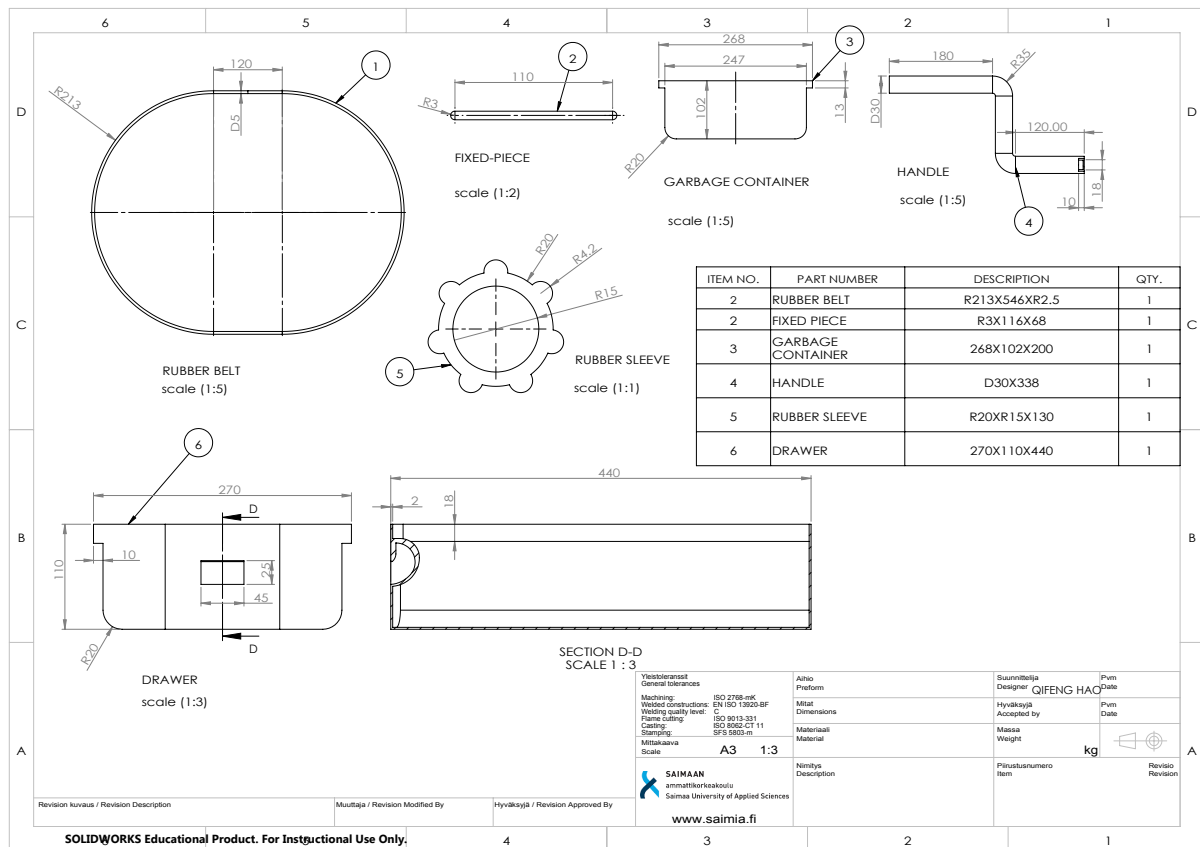


Figure 29: The 2d drawing of the rest components

6. Summary

This research did not include more precision instruments but focused on the design plan and design concept. Improve the design size through Solidworks, and then use the simulator to ensure the safety of the design.

The core part is the inner container, which needs to balance the design size and force saving device. That caused the first edition of the inner container needs to be improved in some way. As the result of that, the combination of gears system and levers device perfectly reduces the force that needs to be applied.

This research not only shows a design process but also a learning process for researchers. Another important research goal is to explain to people who don't understand mechanical manufacturing that this major is more interesting and closer to

life than they thought. The knowledge learned in machine manufacturing is not only used in laboratories or factories but is often applied in real life.

This research has undergone a series of improvements from the beginning of determining the direction to finding the target. Constantly exploring new directions from improvements is the purpose of our learning.

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