



**COMILLAS**

UNIVERSIDAD PONTIFICIA

ICAI

GRADO EN INGENIERÍA INDUSTRIAL

TRABAJO FIN DE GRADO

BAG ROLLER: SNACK AND SPIN

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Madrid

Julio de 2019

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SNACK & SPIN – a Mechanical Snack Dispenser

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MARÍA

Fdo.: Maria de Villanueva Nieto

Date: 21/06/2019

I authorize the submission of this project

PROJECT SUPERVISOR



Fdo.: Prof. Bruce Flachsbart

Date: 21/06/2019



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Director: Bruce Flachsbart

Madrid

Julio de 2019

# ENROLLADOR DE BOLSAS: SNACK AND SPIN

**Autora: Villanueva Nieto, María.**

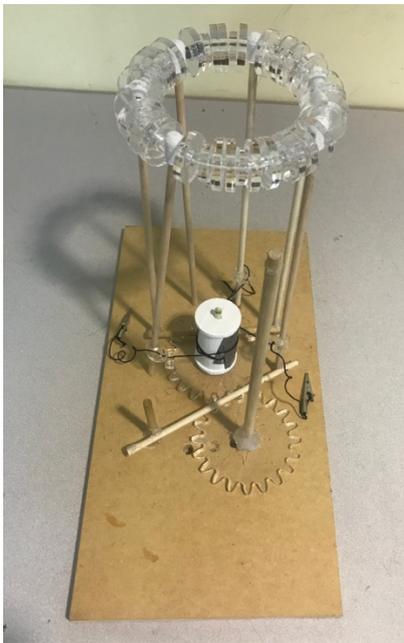
Director: Flachsbar, Bruce.

Entidad Colaboradora: ICAI – Universidad Pontificia Comillas.

## RESUMEN DEL PROYECTO

### Introducción

Snack and Spin es un dispensador mecánico de bolsas, una herramienta que permite a la gente enrollar las bolsas de manera eficiente y limpia para acceder a su interior en la parte más al fondo sin necesidad de tocar el interior de la bolsa.



*Figura 1. Enrollador de bolsa*

Hay muchos métodos para enrollar una bolsa, y después de hacer una investigación sobre los distintos métodos, la mejor manera de enrollarla es hacerlo desde arriba.



*Figura 2. Bolsa enrollada desde arriba*

Este mecanismo tiene como objetivo hacer que sea más cómodo coger algo de una bolsa sin tener que poner la mano en el fondo de esta. Además, sostiene la bolsa y la guarda bien para que no se rompa. También es beneficioso para el medio ambiente. La gente podría empezar a comprar bolsas grandes llenas de lo que quiera y llenar una pequeña bolsa de estas que durará mucho tiempo sin romperse y encaja dentro de este mecanismo. Y así no se desperdicia tanto plástico.

## **Metodología**

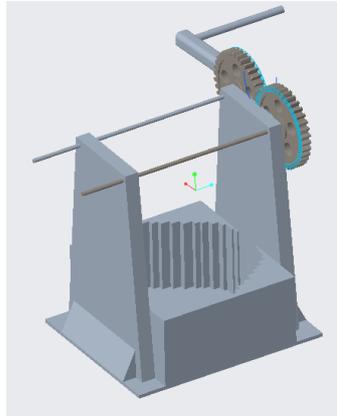
A lo largo de todo el proyecto se ha seguido una cierta trayectoria, que ha consistido en realizar una lluvia de ideas, diseñar el mecanismo y crearlo. Una vez construido, se analizaron las ventajas y inconvenientes, lo que funcionó y lo que no, y se realizó la lluvia de ideas para el siguiente prototipo.

Por un lado, se han utilizado diferentes técnicas para elaborar el mecanismo. Entre ellas se han utilizado la impresión en 3D (FDM) y la impresión en acrílico. Para ello fue necesario diseñar las piezas necesarias en CREO, un software de modelado en 3D.

Por otro lado, se han realizado algunos experimentos como el Diseño del Experimento y el Diseño para el Montaje para optimizar y analizar ciertos aspectos.

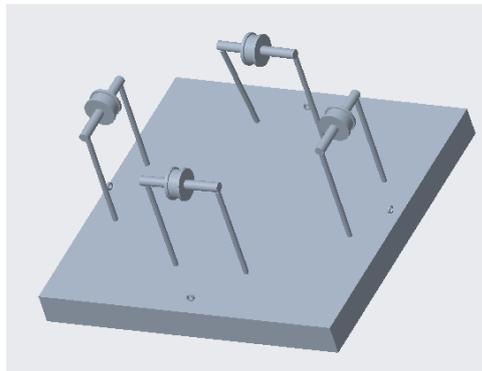
Por encima de todo, se han creado muchos prototipos a lo largo del proyecto para llegar al definitivo y que mejor funcione.

El primer prototipo fue creado con material muy barato y dos rodillos impresos en 3D. No funcionó porque era imposible hacerlo funcionar sin romper la bolsa por los lados.



*Figura 3. CAD del prototipo 1*

El segundo prototipo también se hizo con material muy barato que ya teníamos, y demostró que el método de enrollar era posible. Sin embargo, se necesitaban cuatro manos para que funcionara.



*Figura 4. CAD del prototipo 2*

El tercer prototipo era similar al anterior, pero tenía mejores ideas para tirar de la bolsa con las cuerdas. Tenía una barra en la base para hacerla rotar y tirar de la bolsa hacia abajo. Sin embargo, no tenía la fuerza suficiente y no funcionó.

El cuarto prototipo comenzó a enfocarse mejor hacia el objetivo final. Se fabricó con un aro superior y un mecanismo de engranajes con mayor fuerza en la base. Sin embargo, el material no permitía que la bolsa se deslizara y se necesitaban muchas cuerdas con pinzas para tirar de la bolsa hacia abajo.

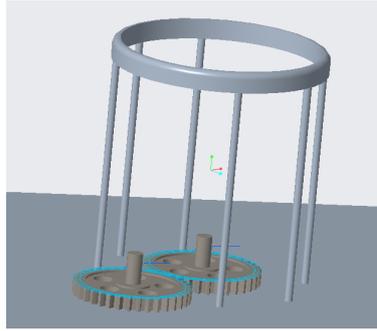


Figura 5. CAD del prototipo 4

Por último, el prototipo final tenía la misma estructura que el anterior, pero para resolver los problemas anteriores se añadieron muchos rodillos en el anillo superior y se necesitaron menos cuerdas para tirar de la bolsa.

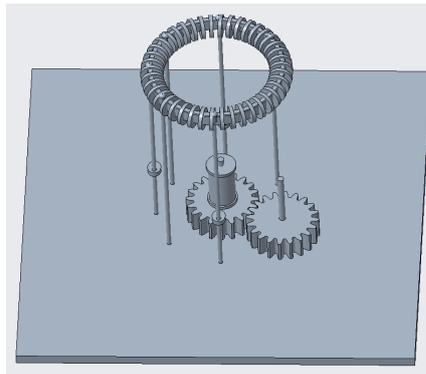


Figure 6. Final Prototype CAD

## Resultados

La trayectoria de todos los prototipos juntos de principio a fin:

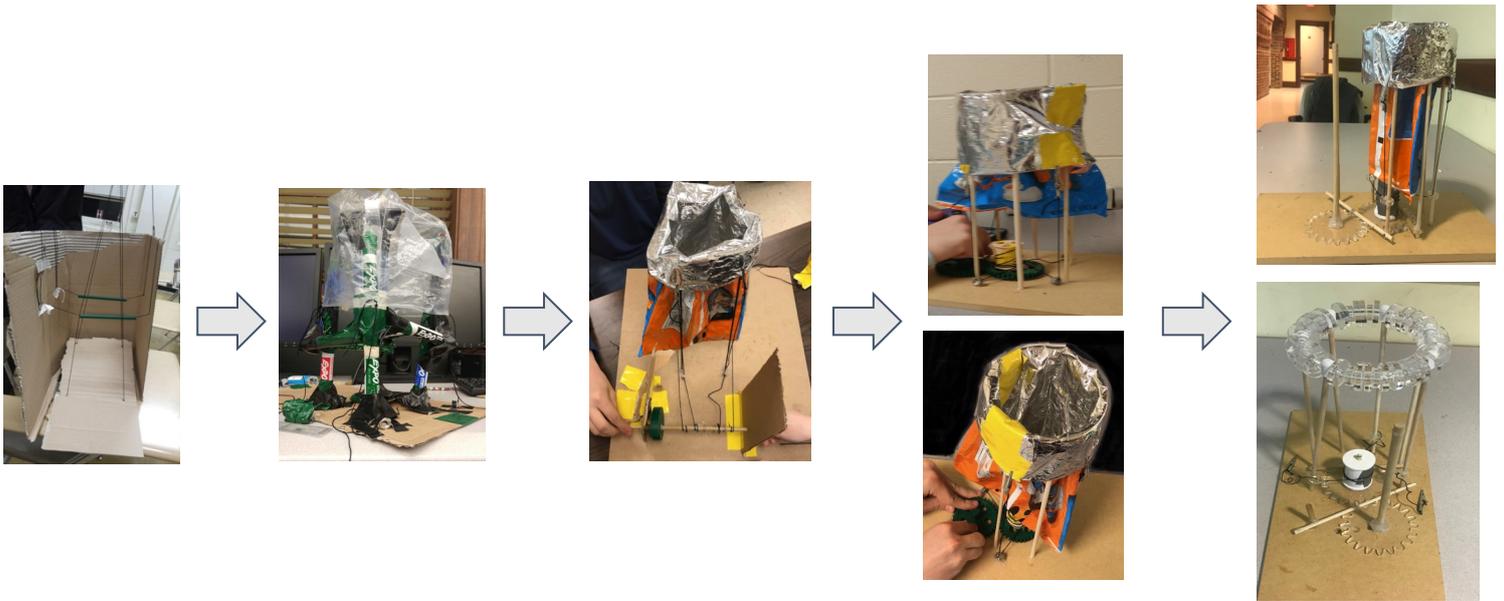


Figura 7. Trayectoria de los prototipos

Además, el Diseño del Experimento se ha realizado para optimizar tres variables: el tamaño del anillo superior, el número de rodillos y el ángulo de las barras de soporte.



Figura 8. Diseño del Experimento

Variables	high	low
1.Number of rollers	10	6
2.Diameter ring (mm)	135	117
3.Arm orientation	straight	angled

Tabla 1. Variables del experimento

Las variables se midieron encontrando la fuerza que se necesitaría para tirar de la bolsa hacia abajo en cada caso con una balanza de peso. Por lo tanto, hemos llegado al siguiente análisis usando estas fórmulas:

$$y = \text{max fuerza necesaria para tirar de la bolsa en kg} * 9,8$$

$$\text{Variance} = (\text{std dev})^2$$

$$E_1 = \frac{1}{4} * (\sum x_{ij} * E_j) \text{ (siendo i la variable y j el número del test)}$$

$$\text{Predicted} = y_{ave} + 0,5 * (x_1 E_1 + x_{13} E_{13}) \text{ (usando los valores significativos para } x * E)$$

$$\text{Residual} = y_{ave}(\text{actual}) - \text{predicted}$$

Test	x <sub>1</sub>	x <sub>2</sub>	x <sub>3</sub>	x <sub>1</sub> x <sub>2</sub>	x <sub>1</sub> x <sub>3</sub>	x <sub>2</sub> x <sub>3</sub>	x <sub>1</sub> x <sub>2</sub> x <sub>3</sub>	y <sub>1</sub>	y <sub>2</sub>	y <sub>ave(actual)</sub>
1	-1	-1	-1	1	1	1	-1	7,448	6,860	7,154
2	-1	-1	1	1	-1	-1	1	9,212	8,428	8,820
3	-1	1	-1	-1	1	-1	1	7,056	5,292	6,174
4	-1	1	1	-1	-1	1	-1	7,448	7,644	7,546
5	1	-1	-1	-1	-1	1	1	6,272	5,684	5,978
6	1	-1	1	-1	1	-1	-1	5,096	5,684	5,390
7	1	1	-1	1	-1	-1	-1	6,664	7,056	6,860
8	1	1	1	1	1	1	1	5,292	5,488	5,390
										<b>y<sub>ave</sub></b>
										6,664

Tabla 2. Análisis del experimento

<b>Main:</b>	<b>E<sub>1</sub></b>	<b>E<sub>2</sub></b>	<b>E<sub>3</sub></b>	<b>E<sub>12</sub></b>	<b>E<sub>13</sub></b>	<b>E<sub>23</sub></b>	<b>E<sub>123</sub></b>
	-1,519	-0,343	0,245	0,784	-1,274	-0,294	-0,147
<b>Noise:</b>	<b>E<sub>1</sub></b>	<b>E<sub>2</sub></b>	<b>E<sub>3</sub></b>	<b>E<sub>12</sub></b>	<b>E<sub>13</sub></b>	<b>E<sub>23</sub></b>	<b>E<sub>123</sub></b>
	-0,403	0,211	-0,365	-0,336	0,336	-0,432	0,403

Tabla 3. Efectos del experimento

Std Deviation	Variance	Predicted	Residual
0,416	0,173	6,787	0,368
0,554	0,307	8,061	0,759
1,247	1,556	6,787	-0,613
0,139	0,019	8,061	-0,515
0,416	0,173	6,542	-0,564
0,416	0,173	5,268	0,123
0,277	0,077	6,542	0,318
0,139	0,019	5,268	0,123
<b>Ave. Std Deviation</b>	<b>Ave. Variance</b>	<b>2 sigma threshold</b>	
0,559	0,312	1,117	

Tabla 4. Análisis del experimento

Para optimizar resultado, el sistema que menos peso requirió para bajar fue el de los tests 6 y 8 ( $y_{ave}=5,39$ ). Por lo tanto, la combinación de ángulo de 90 grados y 10 rodillos requiere la menor cantidad de fuerza hacia abajo para rodar y el tamaño del aro no parece

que afecte. Se anticipa que el diámetro del aro puede tener un mayor efecto en el resultado, pero no se sabe si los rodillos pudieron rodar libremente debido a los topes que se crearon para mantenerlos en el mismo lugar.

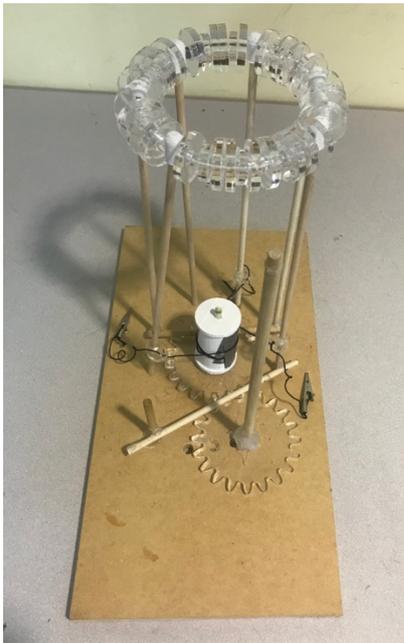
## **Conclusiones**

Finalmente, llegamos al mejor y último prototipo después de todos estos experimentos y análisis. Para conseguir la menor fuerza para bajar la bolsa, llegamos a la conclusión de que necesita muchos rodillos en el aro superior con barras de soporte a 90 grados de la base. Este mecanismo permite tirar hacia abajo de la bolsa mientras que lo que está dentro de la bolsa sube para alcanzarlo mejor.

# BAG ROLLER: SNACK AND SPIN

## Introduction

Snack and Spin is a mechanical snack dispenser, a tool that allows the user to efficiently and cleanly roll bags to access the chips at the bottom without the need to touch the inside of the bag.



*Figure 9. Bag Roller*

There are many methods of rolling a bag, and after doing some background research, the best way to roll it was doing it from the top.



*Figure 10. Bag rolled from the top*

This mechanism aims to make it more comfortable to take something from a bag without having to put your hand to the end of it. Also, holds the bag and keep them well saved so that they don't end up all broken. Furthermore, it is beneficial for the environment. People could start buying big bags filled with whatever they want and fill a small bag of these that will last a long time without breaking and fit inside this mechanism. Thus, not waste so much plastic.

## **Methodology**

Throughout the project a certain trajectory has been followed, which has been to brainstorm, devise the mechanism and create it. Once built, the advantages and disadvantages were analyzed, what worked and what did not, and the brainstorming for the next prototype was done.

On the one hand, different techniques have been used to elaborate the mechanism. Among them have been used 3D printing (FDM) and acrylic printing. For this it was necessary to design the required parts in CREO, a 3D modeling software.

On the other hand, some experiments such as Design of Experiment and Design for Assembly have been done to optimize and analyze certain aspects.

Above all, many prototypes have been created throughout the project to arrive at the definitive one that will work best.

The first prototype was created with very cheap material and two 3d printed rollers. It did not work because it was impossible to make it work without breaking the bag on the sides.

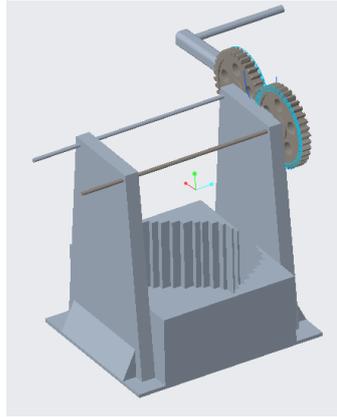


Figure 11. Prototype 1 CAD

The second prototype was also made with very cheap material that we already had, and it demonstrated that the method of rolling was possible. However, four hands were needed to make it work.

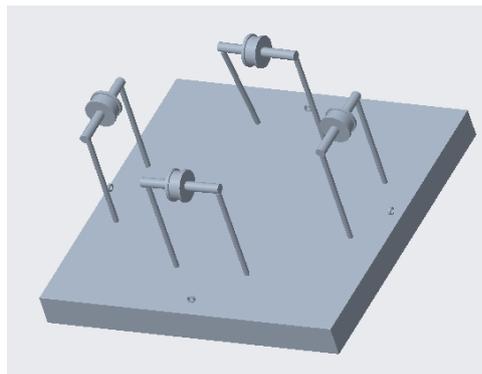


Figure 12. Prototype 2 CAD

The third prototype was similar to the previous one but had better ideas to pull the bag with the strings. It had a bar on the base to make it roll and pull the bag down. However, it did not have the enough force and it did not work.

The fourth prototype started to focus better towards the final goal. It was made with a top ring and a gear mechanism with greater force at the base. However, the material did not allow the bag to slide and many strings with clips were needed to pull the bag down.

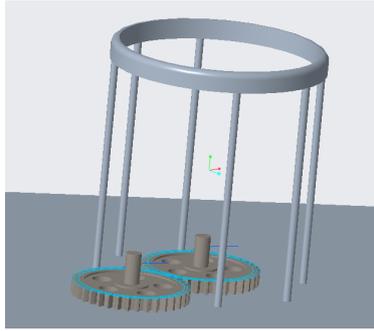


Figure 13. Prototype 4 CAD

Lastly, the final prototype had the same structure as the previous one but to solve the previous problems many rollers were added in the top ring and fewer string attachments were needed to pull the bag.

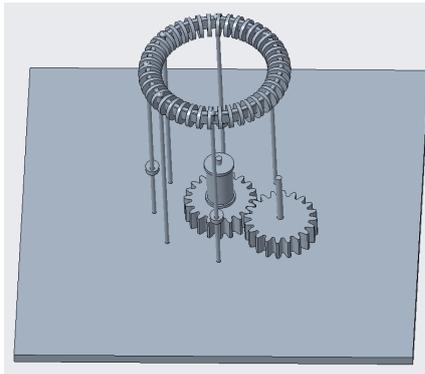


Figure 14. Final Prototype CAD

## Results

The trajectory of all prototypes together from beginning to end:

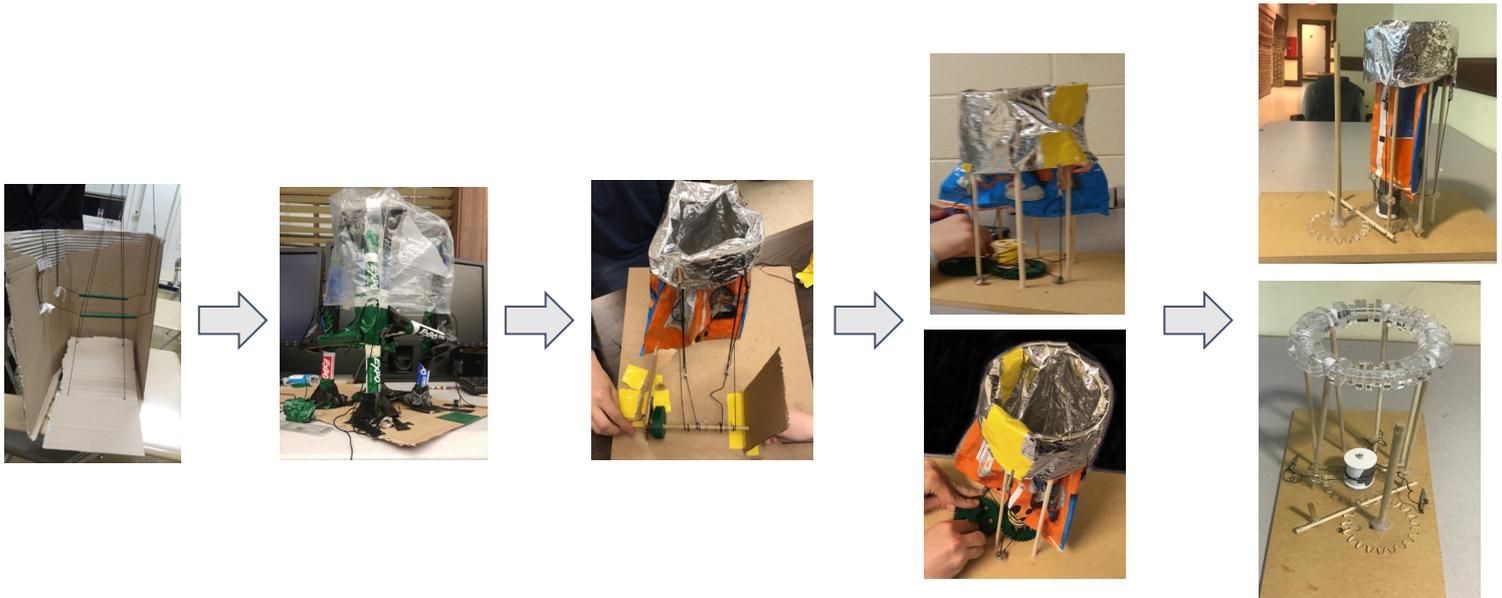


Figure 15. Prototypes trajectory

Moreover, the DOE experiment has been done to optimize three variables: the size of the top ring, the number of rollers and the angled of the support bars.



Figure 16. DOE experiment

Variables	high	low
1.Number of rollers	10	6
2.Diameter ring (mm)	135	117
3.Arm orientation	straight	angled

Table 5. DOE variables

The variables were measured by finding the force it would take to pull the bag down under each circumstance with a weight scale. So, we have come to the following analysis using these formulas:

$$y = \max \text{weight necessary to pull in kg} * 9,8$$

$$\text{Variance} = (\text{std dev})^2$$

$$E_1 = \frac{1}{4} * (\sum x_{ij} * E_j) \text{ (being i the variables and j the number of test)}$$

$$\text{Predicted} = y_{ave} + 0,5 * (x_1 E_1 + x_{13} E_{13}) \text{ (using just the significant values for } x * E)$$

$$\text{Residual} = y_{ave}(\text{actual}) - \text{predicted}$$

Test	x <sub>1</sub>	x <sub>2</sub>	x <sub>3</sub>	x <sub>1</sub> x <sub>2</sub>	x <sub>1</sub> x <sub>3</sub>	x <sub>2</sub> x <sub>3</sub>	x <sub>1</sub> x <sub>2</sub> x <sub>3</sub>	y <sub>1</sub>	y <sub>2</sub>	y <sub>ave(actual)</sub>
1	-1	-1	-1	1	1	1	-1	7,448	6,860	7,154
2	-1	-1	1	1	-1	-1	1	9,212	8,428	8,820
3	-1	1	-1	-1	1	-1	1	7,056	5,292	6,174
4	-1	1	1	-1	-1	1	-1	7,448	7,644	7,546
5	1	-1	-1	-1	-1	1	1	6,272	5,684	5,978
6	1	-1	1	-1	1	-1	-1	5,096	5,684	5,390
7	1	1	-1	1	-1	-1	-1	6,664	7,056	6,860
8	1	1	1	1	1	1	1	5,292	5,488	5,390
										<b>y<sub>ave</sub></b>
										6,664

Table 6. DOE analysis

Main:	E <sub>1</sub>	E <sub>2</sub>	E <sub>3</sub>	E <sub>12</sub>	E <sub>13</sub>	E <sub>23</sub>	E <sub>123</sub>
	-1,519	-0,343	0,245	0,784	-1,274	-0,294	-0,147
Noise:	E <sub>1</sub>	E <sub>2</sub>	E <sub>3</sub>	E <sub>12</sub>	E <sub>13</sub>	E <sub>23</sub>	E <sub>123</sub>
	-0,403	0,211	-0,365	-0,336	0,336	-0,432	0,403

Table 7. DOE effects

Std Deviation	Variance	Predicted	Residual
0,416	0,173	6,787	0,368
0,554	0,307	8,061	0,759
1,247	1,556	6,787	-0,613
0,139	0,019	8,061	-0,515
0,416	0,173	6,542	-0,564
0,416	0,173	5,268	0,123
0,277	0,077	6,542	0,318
0,139	0,019	5,268	0,123
Ave. Std Deviation	Ave. Variance	2 sigma threshold	
0,559	0,312	1,117	

Table 8. DOE Analysis

To optimize the output, the system that required the least weight to pull down were tests 6 and 8 (y<sub>ave</sub>=5,39). Therefore, the combination of 90-degree angle and 10 rollers required

the least amount of force downward to roll and the ring size does not appear to affect it. It is anticipated the ring's diameter may have a greater effect on the outcome, but it is uncertain if the rollers were able to roll free due to the bumpers that created to keep them in relatively the same place.

## **Conclusions**

All in all, we got to the best and final prototype after all this experiments and analysis. To achieve the less force to pull down the bag, we got to the conclusion that it needs many rollers on the top ring with 90-degree support bars. This mechanism allows to pull down the bag while what is inside the bag goes up to reach it better.

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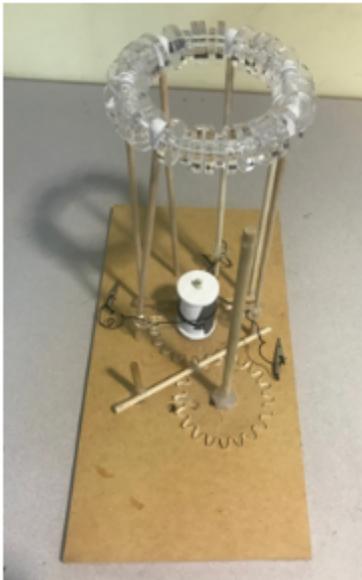
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## 1. Introduction

Snack and Spin is a mechanical snack dispenser, a tool that allows the user to efficiently and cleanly roll bags to access the chips at the bottom without the need to touch the inside of the bag. The bag will be attached to strings that would be activated at the bottom connected with two gears and a crank tool so that the bag will be pulled from the strings and it will roll over four small rollers. There has also been made sure that the bag can easily be attached to the strings so that the bag will neither rip nor get caught in the mechanism.



*Figure 1. Bag Roller prototype*

There are many methods of rolling a bag, such as:

- Elevating the chips in the bag by pushing the bag upward and inward from the bottom of the bag. Figure 2 and 3 shows this method:



Figure 2. Rolled bag



Figure 3. Bag being rolled from the bottom

- Rolling the bag from the top so that the chips won't be crushed. This method is shown in Figure 4:



Figure 4. Bag rolled from the top

However, people don't want to crush the chips. Therefore, there is going to be created a mechanism that will roll the bag from the top. It will have a structure base and vertical bars with rollers on the top around a top ring that will hold the bag of chips and will roll it as shown in Figure 4.

## 2. Background research

Analyzing this product and searching for background research we have found similar ideas for different products.

- Toothpaste roller: a roller that pushes the toothpaste to the top like in Figure 5.



*Figure 5. Toothpaste roller*

- Bag holders: used to hold open the bag like in Figure 6.



*Figure 6. Bag holders*

- Various types of hair curlers: this was our first idea to use as rollers. We wanted the bag to roll on the rollers in the same way that the hair rolls on hair curlers.



*Figure 7. Hair curlers*

We want a solution mixing these three ideas. Thus, our mechanism should hold the chips bag open while rolling it with string and rollers pushing the chips to the top.

### 3. Manufacturing techniques

There are many techniques that could be used to do this project. There have been tried many of them to see which one could be the best but not all of them have been used for the final roller bag.

The ones tried are 3D printing, acrylic board printing, machining and injection molding. The only ones used have been 3D printing and acrylic board printing.

#### 3.1. 3D printing

3D printing is a technique that creates a three-dimensional object adding material layer by layer. There are many different 3D printing techniques such as SLA, SLS, FDM, MJP, DMLS and EBM.

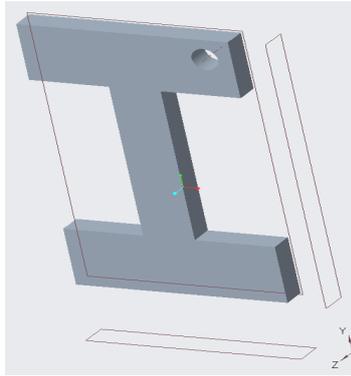
On the one hand, some advantages are that it can produce very elaborate shapes with just a file CAD and it doesn't use an expensive laser which make it more economic to purchase and use it. On the other hand, some disadvantages are that support structures are not water soluble and have to be removed tediously with a knife, and it is impossible to fill the build envelope with multiple layers of parts.

- SLA (Stereolithography Apparatus): It can make different parts at once during the same build and there are different sizes to use when purchasing a machine. However, there is really no easy way to remove the support scaffolding that is needed when creating parts, the resin cost is pretty steep, and the laser needed to create parts degrades over time and has to be replaced.
- SLS (Selective Laser Sintering): It uses a laser to melt together polymer powder into layer which increases the density and since the powder doesn't move, there is no need for scaffolding. But a problem could be that it only comes in one color, so you are unable to highlight key features in the prototype with color. It is fast

and require less work for the laser to melt while also having higher tolerances, yet it requires a dry environment, meaning no humidity can be present.

- FDM (Fused Deposition Modeling): A filament of polymer wax comes from a heated nozzle and traces CAD modeled parts. It has a wide variety of materials available that are not toxic, so they can be used anywhere. However, it is not possible to make ready assembled functional assemblies and it cannot operate with clear build material.
- MJP (Multi-Jet Printing): This process uses droplets of UV curable plastic in a manner that is similar to an inkjet printer and it can use different colors. This method also allows for smooth surfaces and thin layers. Some disadvantages include the brittle nature of the material leaving it susceptible to many cracks and breaks. It also requires support material that takes a long process to remove as well as increasing the cost due to the extra material required.
- DMLS (Direct Metal Laser Sintering): It uses metal powders and can achieve up to 80% density. It can use many metal alloys but is very expensive compared to the others and is less accurate with surface finish.
- EBM (Electron Beam Melting): It uses metal materials by melting them with a powerful electron beam. It can make fully dense metal parts and the accuracy is very good. It can even build parts with anything from steel to titanium. However, there needs to be a very high temperature to operate this machine and it is expensive.

The one thought to be the best one for this project had been Fused Deposition Modeling. A little example had been made to see how it worked out and how beneficial could be. In Figure 8 and Figure 9 are shown the CAD model and the real 3D printed figure.



*Figure 8. CAD model*



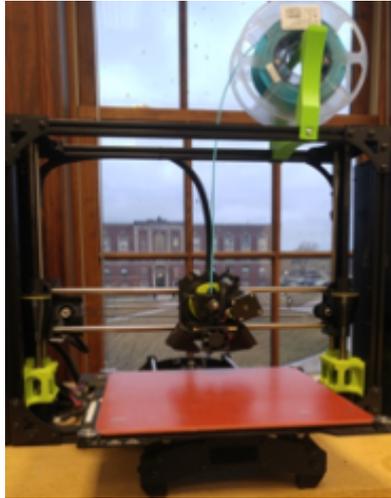
*Figure 9. Real model*

The CAD model is created in Creo program. The Creo design looked very similar to the 3D printing but it had some differences focusing on three different engineering parameters:

- **Device complexity:** The Creo model was smooth and the final printed version had different layers that can be appreciated in the picture.
- **Area of stationary object:** The Creo design didn't have a support material structure around the figure and the 3D printing had one (It is not appreciated in the picture because I took it away).
- **Measurement accuracy:** The final measures were very similar to the Creo ones, the little changes were just like 0.5 mm of differences.

Furthermore, the best orientation for this figure was the horizontal, laying it down with a flat surface. It is very thin to stand it up in a vertical way. Also, it is too large, and it would be more complicated for the 3D machine to print it. Orientating it in another way would have needed a very resistant structure and extra material for a basis so as to be printed well and not break. Moreover, if it had been used SLS it would be more accurate and would have been printed much smoother. Also, it wouldn't have needed support material and it would have had a better resolution. Moreover, using SLS would have printed it faster. However, SLS is more expensive and FDM is accurate enough for the project.

All in all, there are many 3D printing methods. The one used, FDM, is not the best and it is not the more accurate, but it is surprising that is quite useful for what is needed to be printed in this project. However, support material may alter the initial design, filling holes that shouldn't be filled.



*Figure 10. 3D printing machine*

### 3.2. Acrylic board printing

Acrylic is a material really smooth and transparent. It is a transparent thermoplastic homopolymer. It could be used in different colors and can be easy heated to form the Creo design shape. It is not toxic, but the problem is that it doesn't have a lot of resistance and strength.

With a printing machine from the UIUC (University of Illinois at Urbana Champaign) some figures for the project were printed. To 3D print them was also needed a CAD from Creo. Also, it was more expensive than the FDM method because the acrylic board needed for printing wasn't really big and cost 30\$. The acrylic figures for the bag roller were the top ring, the rollers and the two gears as shown in Figure 11.



*Figure 11. Acrylic gear*

### 3.3. Machining

Machining is a process where a raw material is cut to get a special shape by a material-removal process. This process is also called subtractive manufacturing. It can be used with metals, plastics, wood, ceramic and composites.

A 3D CAD aluminum block has been used to machine using a Tormach 3-axis CNC mill. The mill's instructions came in the form of a G-Code, which consists of a variety of commands that specify the geometric and kinematic properties of the machine and tool path in order to machine the desired part.

A Mickey Mouse design mold has been done injection mold to create miniature parts as shown in Figure 12 and Figure 13. Some design restraints included the fact that it has a limit in space, meaning that there was no possibility to go outside the given parameters of the block. Another design constraint was the knowledge that mills are unable to create sharp corners so it was necessary to create rounded edges and surfaces to allow for successful machining and later injection. The design also had to be rather simple with easy access to the channels which would be used to injection mold. Access to the channels dictated which would be the best orientations as well as the placement on the block.

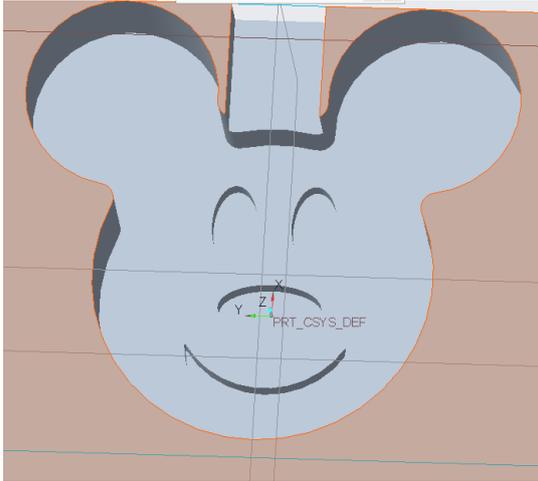


Figure 12. CAD design



Figure 13. Machining design

When looking at the CAD model as opposed to the physical piece, it can be seen that not all facets of the design are as prominent as anticipated. One of the main features that was not as defined when machined as it had been in the design was the mouth, which had two arcs that met up at a sharp corner. The reason the mouth was unsuccessful was because the mill's tip was too big to create the small indentation needed which in turn altered the shape of the mouth. The eyes and nose also did not have uniform depths like the Creo model contained. On the Creo part it can be easily create small features, but in terms of machining the part small features are difficult to execute if not impossible due to the mill's inability to render the miniscule features. The radius of the small head utilized on the mill must be equivalent or smaller than the features it will be used to create. Had the part been scaled up, it would have had clearer definition of the piece's features yet that would have increased the part's time of machining.

Moreover, to reduce the machining time for the design it could be increased cutting speed, but that would negatively impact the machine tool life span. The design size could also be scale down or potentially get rid of the nose, which would also decrease the time but would remove aspects of the design. Furthermore, the size of the cut feed could be increased but that would make the machining of the CAD design less accurate.

All in all, comparing the CREO to the final printed model, these parts are not exactly the same because of the mill's inability to render the miniscule features and the limit space of the block.



Figure 14. Machining machine

### 3.4. Injection molding

The injection molding process is done by an injection molding machine using raw plastic material and a mold. The plastic is melted in the machine and injected into the mold. Then it cools and solidifies into the final part.

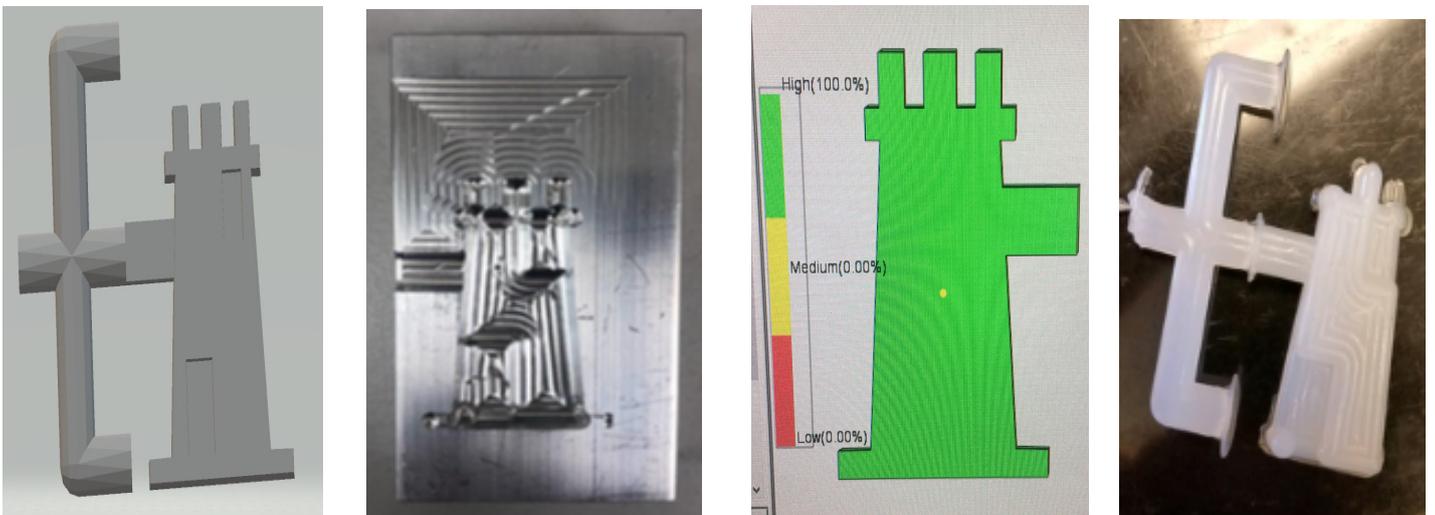


Figure 15. Injection molding designs

The part was a miniature castle mold that was then injection molded. The sharp corners on the part led to an issue in the beginning stages and would have potential led to an issue in removing the part yet it could be easily removed once it had been injected. The CAD model had 3-D extrusions at the top of the castle that showed varying geometries and how they can create complications in the injection molding process.

In MoldFlow (a plastic injection molding design software), the predicted confidence of fill was 100% for the high confidence green area, however our injection molded piece did not come out quite as expected. Maybe it wasn't used a high enough pressure or temperature when injection molding, but the fact that moldflow predicted this wrong is a bit concerning. When injection molding, the top left and top right rectangles stemming out from the piece did not replicate, but the rest of the mold came out solid. One possible reason this did not turn out how it was supposed to could be because moldflow does not account for the age or wear and tear of the machine we are using. To reduce this problem maybe the actual temperature and pressure could be increase on the machine from the predicted pressure and temperature used on moldflow.

Moreover, one defect that was encountered in the part was the fact that the top extrusions were too shallow which made it unable for the plastic to flow through. This resulted in the posts at the top of the castle to not be replicated in the plastic part. MoldFlow said that the outer edges would be the last part filled yet they neglected to state the possibility that they may not fill at all. Whether the mistake was made in the Creo model or the machining of the model, it nevertheless received an error when injecting. However, the most effective way to fix this would be to increase the depth on the posts to allow for easier flow when injecting.

- Using data from the actual spiral mold:

Pressure(KPa)	275	344	414
Temperature(K)			
436	0,26	0,34	0,44
450	0,29	0,38	0,44
466	0,32	0,44	0,40

*Table 1. Injection molding variables*

- Flow distance(m) vs. temperature(K)

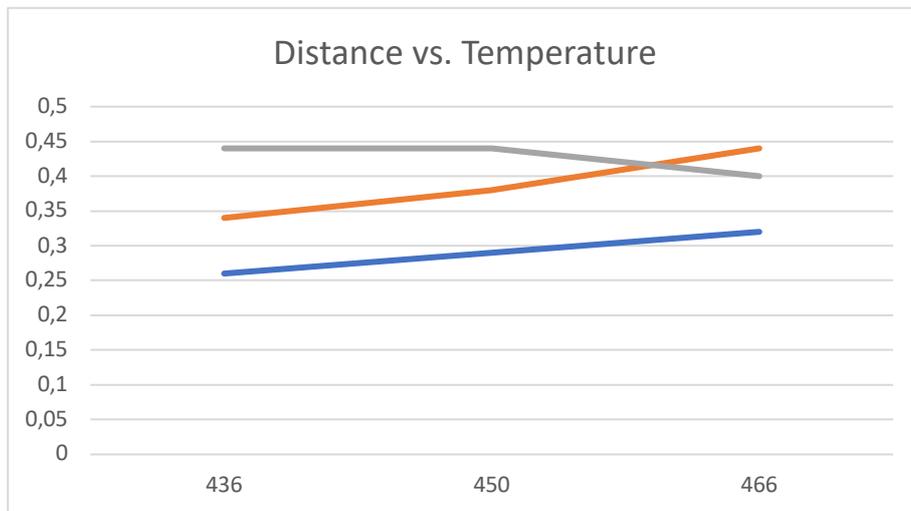


Figure 16. Distance vs. Temperature (Injection molding)

The Flow Distance vs Temperature graph appears to have a trend where the higher the pressure, the higher the distance. It is also observed that as the pressure increases, so does the distance except for our last point at 466K on the line for when the pressure is 275KPa which it is believed that it could be an outlier created with an error in measuring. When both temperature and pressure are at the highest it is anticipated displacement to be higher therefore it is believed to be an outlier and would like to test it again.

- Flow distance(m) vs. Pressure(KPa)

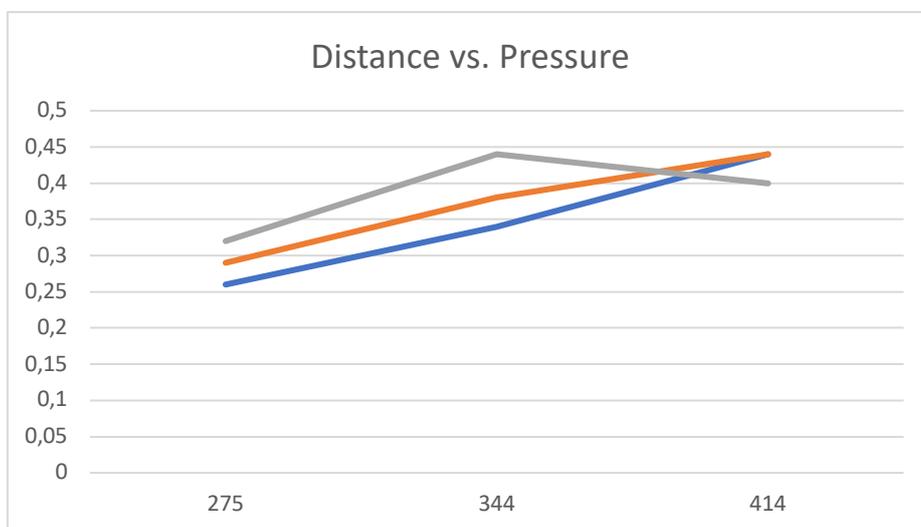


Figure 17. Distance vs. Pressure (Injection molding)

The Flow Distance vs Pressure graph appears to have a trend where the higher the temperature was raised the greater the distance was, a trend that is observed using the data. When it reached a pressure of approximately 344KPa, it is shown that the highest temperature's displacement begins to decrease and eventually falls below the other temperature's distance. It is uncertain if this is a trend that once it reaches a certain ratio of temperature to pressure the distance starts to decrease or if this point was an outlier, possibly due to human error.

When comparing the effect of a change in pressure as opposed to a change in temperature on the displacement, it is seen that when changing the pressure, it will have a greater effect on the distance. The graphs were compared by looking at the slopes. When at a constant temperature of 450K, it is seen that a change of 69KPa from 275KPa to 344KPa has a change of 0.1m while a change of 69KPa from 344KPa to 414KPa is 0.06m. Therefore, making the average change at a constant temperature at 450k of 69KPa is 0.07m. If it was to look at the data so that it was pressure constant at 344KPa, it would be seen that changing the temperature by 15K from 436K to 450K, the change in distance is 0.04m. If it was to look at increasing from 450K to 466K, it is seen a change of 0.05m, making the average change at a constant pressure 0.05m. As it can be seen the average change was greater when the temperature was constant while the pressure changed. This would lead to believe that the increase in pressure would have a greater effect than the change in temperature.

The theoretical confidence of fill got larger as the temperature and pressure were increased. The green area of the confidence was between 62.7% and 63.9%, and the yellow area was between 35.5% and 36.3%, and the red area was between 0.43% and 1.03% of the model. The differences in temperature and pressure did not change the percentages of the total volume with respect to the confidence level. But the volume did increase, and the weight increased by 1,834 after the first temperature and pressure change, and the weight increased by 2,02 after the second temperature and pressure change. This shows a roughly proportional increase in the weight and volume of the injection molded part in this specific mold as the temperature and pressure are increased proportionally as well.

Our actual numbers shown in Table 1 were, at 275KPa and 436K, 0,27m, after increasing KPa by 69 and temperature by 15K we got 0.38m, and after increasing by the respective numbers again we got 0,44m. This information shows that theoretically the volume grows

proportionally but since the green high confidence length is only about 63% of the theoretical length that is what is seen when it is actually injection mold this object.

Furthermore, when looking at the injection molded piece, it is seen that the initial design varied from the final product. There were multiple components that could have caused discrepancies, whether it was issues in gate placement or not creating depths that would allow for plastic to flow through. Also, when the pressure is increased by 69KPa it causes a greater change on the distance flow than if it was only increasing the temperature by 269K. It also did not account for the machine itself, so our results show that the machinery used may cause variances in injections from one mold to another.



*Figure 18. Injection molding machine*



## 4. Motivation

### 4.1. Problem statement

This product aims to roll chip bags so you no longer dirty your sleeves when reaching into bags. Also, it is uncomfortable to have to reach all the way to the end of the bag to get what is inside and it is impossible for more than one person to reach into the bag at the same time.

Moreover, if there is not a mechanism that holds the bag, the bag is all the time falling down and what is inside gets out of it. Furthermore, these types of bags always end up breaking and then can never be stored well.

Finally, it is beneficial for the environment. People could start buying big bags filled with whatever they want and fill a small bag of these that will last a long time without breaking and fit inside this mechanism. Thus, not waste so much plastic.

All in all, it has been looked for a mechanism that allows people to get the chips or whatever is inside of the bag without the need of putting the hand inside. For that, it has been created a new bag roller system that it has been made up.



## 5. Project goals

The main goal of this project is to make this bag roller work. That is to say, to get the bag roll. To achieve this, there were some other goals:

- Get the rollers working. Thus, it was needed to explore how many rollers to use in the system, it was an idea to start with just two, but after trying it and experimenting with the firsts prototypes. Also, find out how big should the ring be and how the bars should be embedded, angled or straight. All this has been analyzed with the DOE (explained below in part 7).
- To make up something that rolls the roller and pull the bag down. Achieve the better of different elastomers, clips and different types of materials to attach the bag to the rollers and the strings. Finally, clips were used for this.
- Get working a tension system to assist in making the machine operable with just 1 or two hands. Is not worth it if is needed more than two people to use it. Tensing the strings on a side in the bottom with a crank could be a good idea. What was achieve was a gear system to attach the strings and pull the bag down.
- Find out the best materials for this mechanism. Also, not very expensive ones so that people can buy it.

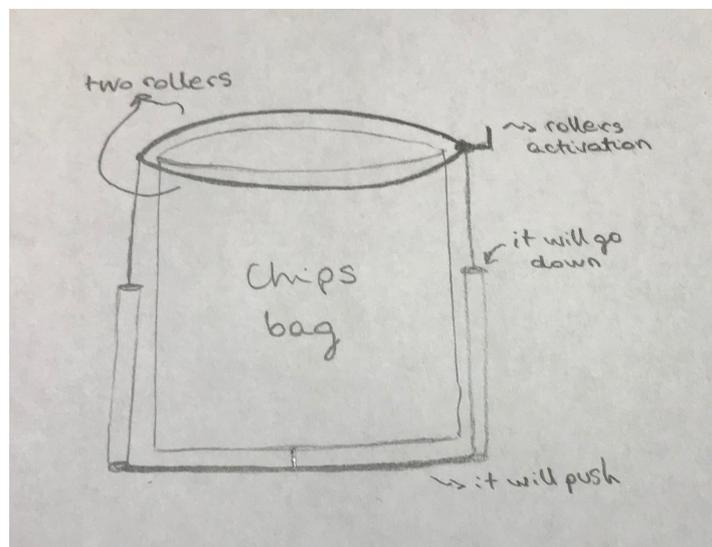


## 6. Design development

This project has been a long development going through different ideas and trying out them to see how it could work. Therefore, it has had different prototypes until it has been found the best one that worked.

### 6.1. Prototype 1

Figure 19 describes the first prototype where the bag was supposed to roll on the rollers while a base structure would push the bag up and the bars would be compressed.



*Figure 19. First prototype sketch*

This first prototype had a roller activation on top of the mechanism attached to two rollers that would make the bag roll from the top while two bars on the side would compressed going down and pushing the bag up.

To see how it could work there has been created CAD models where there has been added two gears with a crank to be able to roll the rollers easily.

Here is the CAD model.

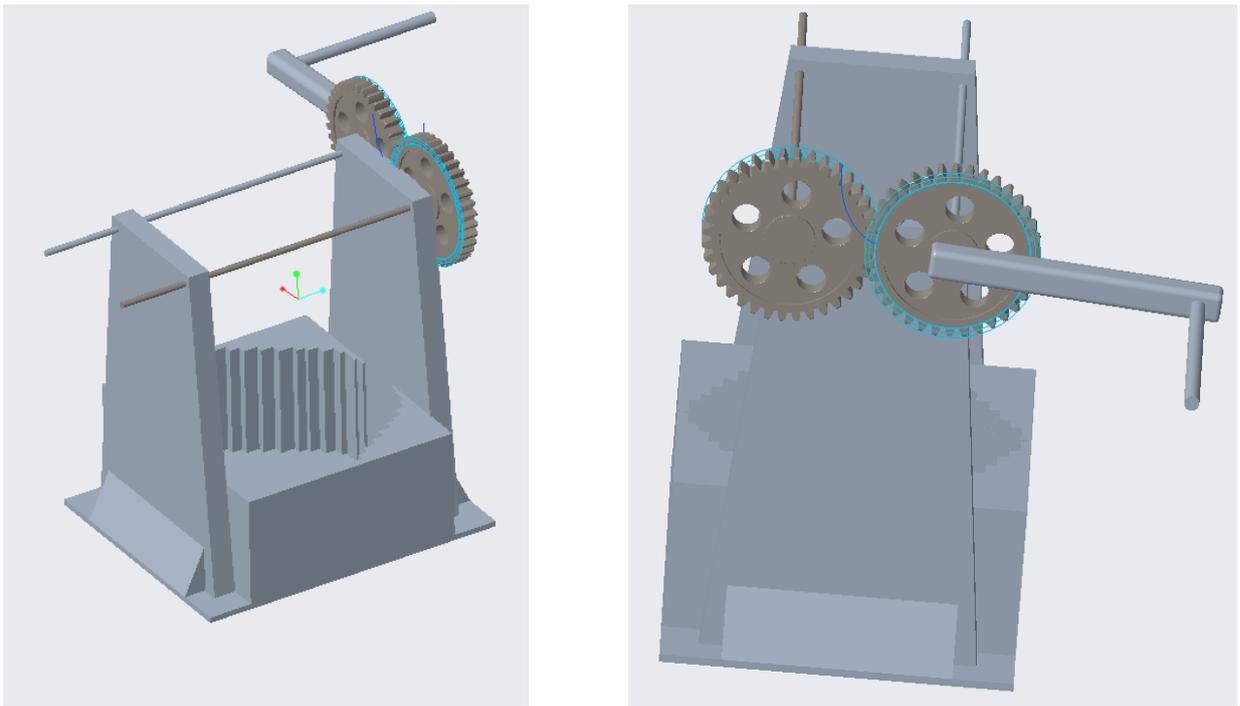


Figure 20. Prototype 1 CAD

However, to see how it worked there has been created with easy and cheap material to achieve, cardboard, strings and two 3D printed rollers (FDM).

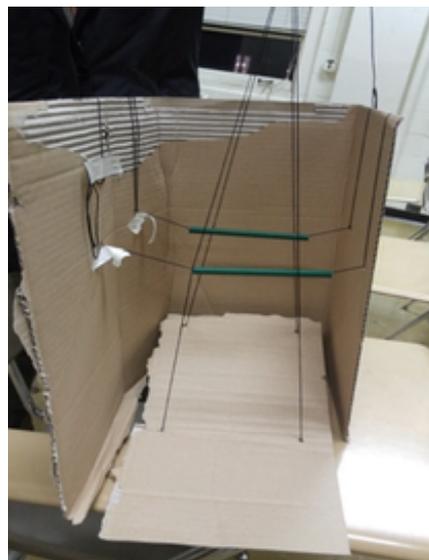
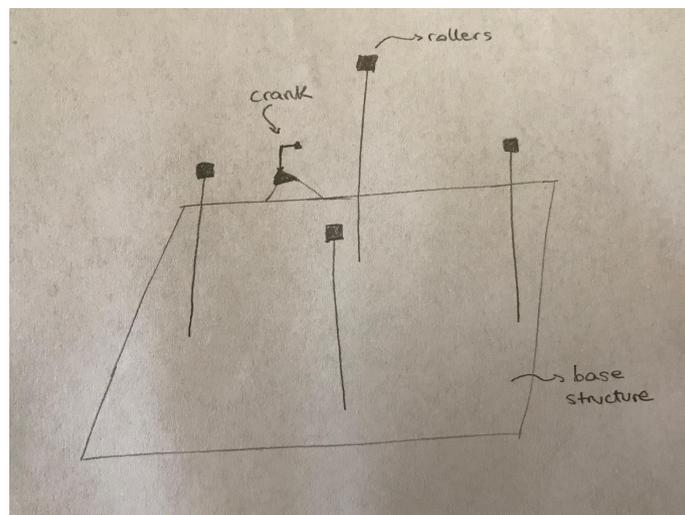


Figure 21. Prototype 1

Once it was created, it has been realized that it wasn't impossible to roll the bag without ripping it. Thus, it didn't work, and more ideas were needed to continue with the next prototype.

## 6.2. Prototype 2

There has been created a new sketch for this next prototype.



*Figure 22. Second prototype sketch*

This second prototype shown in Figure 22 had a base structure with four vertical bars with rollers on the top of each one. Also, it had a system that connected the strings to a crank so as to make the rollers move. The bag would be put inside the bars.

Here are the CAD models of the small rollers, and all together with a base.

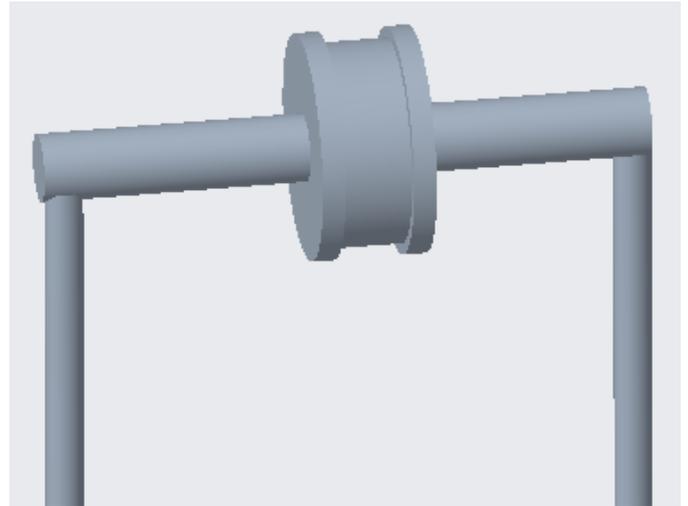
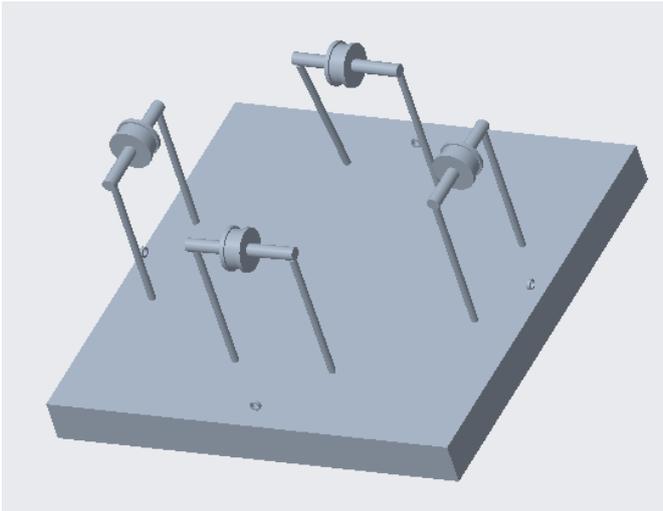


Figure 23. Prototype 2 CAD

Also, as shown in Figure 24, there has been created with cheap material to see how it worked and what changes would be needing to be done.



Figure 24. Prototype 2

Moreover, it has been improved with new ideas and different materials to achieve a better prototype. After analyzing it, there was an idea to keep going with this type of structure, but it should have a mechanism on the bottom to pull the strings to pull down the bag.

This prototype demonstrated that the method of rolling was possible. However, four hands were needed to make it work.

### 6.3. Prototype 3

This prototype had continued with the same structure as prototype 2 but just one hand was needed to make it work. However, it had a base mechanism that was supposed to have the force to pull the strings. There was a bar where the strings were rolled up in it while it turned. The problem was that the clips weren't strong enough to keep attached to the bag while pulling it down. Thus, while someone turned the bar, the strings pulled down the bag, but it didn't work because the clips come loose.

Also, the green 3D printed part that is shown in the pictures, it was supposed to go backwards and pull up the end of the bag. However, that was impossible without something on the bottom of the bag that pull down the bag the other way. Moreover, the propylene balls on the top of the sticks, where there so that the bag could easily slide and roll over them.

All in all, this prototype demonstrated that a stronger force was needed to pull the bag or maybe smoother or more slippery balls. The conclusion was that the next prototype should have a completely different base mechanism and maybe should have a round top, such as a ring, and try if it could be better or not.

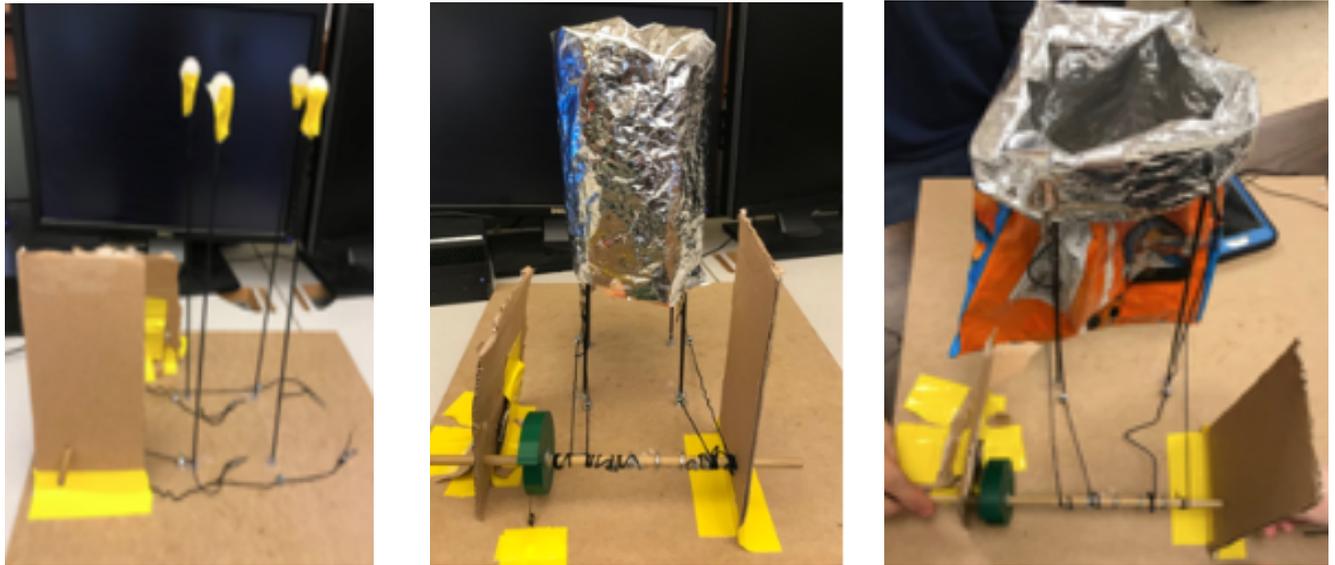


Figure 25. Prototype 3

#### 6.4. Prototype 4

This prototype was much better, the bag started to go down and the clips didn't fall. It had a top ring and the base mechanism was composed of two gears where the six strings were attached to a spool. Someone had to turn one of the gears to make it work. However, the bag did not slip through the ring. Therefore, a thin cloth was put around the ring with which it began to slip, and the prototype worked. Furthermore, the gears were not well attached to the base and when turning they disconnected one from the other. Also, the material for these gears was not the best because they sometimes got stuck.

Here are some pictures of the CAD and the real one for this prototype.

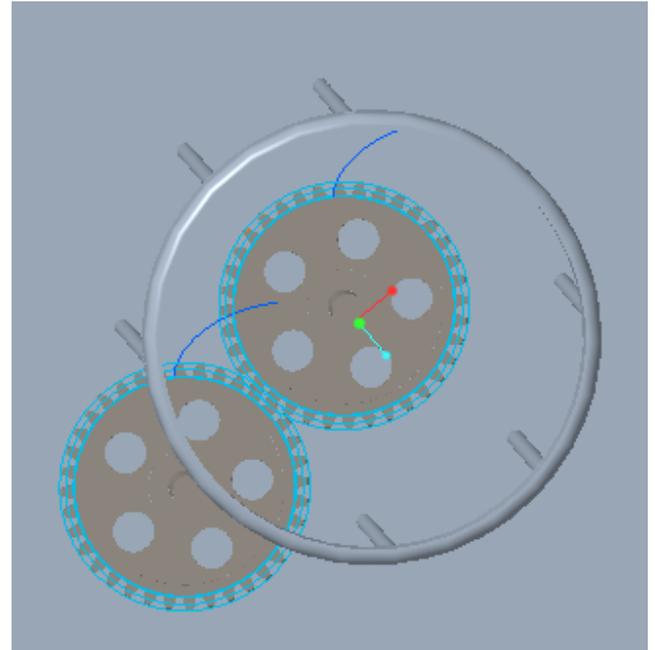
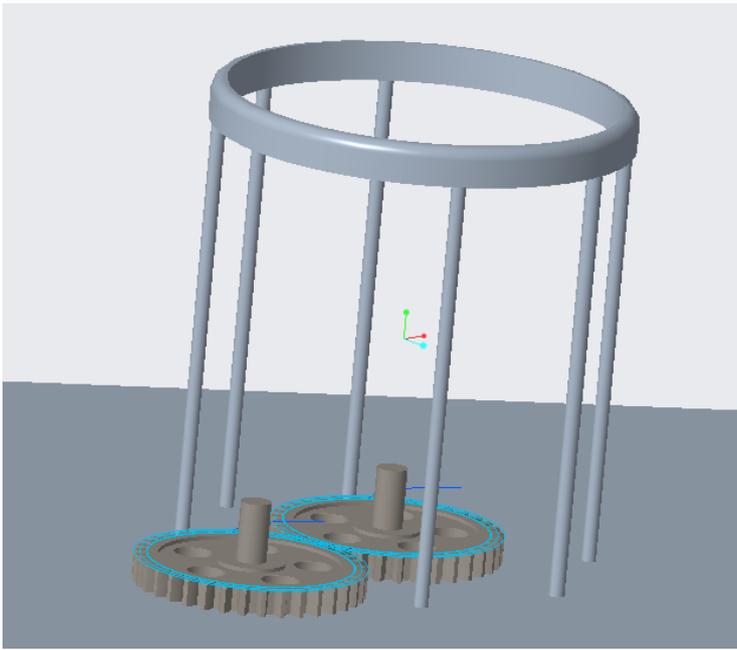


Figure 26. Prototype 4 CAD



Figure 27. Prototype 4

## 6.5. Final prototype

Finally, the last and final prototype that made the project worked. It had the base structure with two gears and a spool where the strings were attached. Also, one of the gears had

a long bar to use it as a crank, to make the gears turn. As well, as shown in the picture, there were two little bars on top of the gears to prevent them from dislodging from the base and leaving. Moreover, the strings were attached to the spool on one side and to the clips on the others side, which were attached to the bag.

It worked with just three strings without the need of more and there were three little rings with two holes, one for the bar and the other for the string, so that they won't get stuck with other things, they would just follow their path.

At last, the top ring was covered little rollers all around it to make the bag easy to go down. And the six bars that hold the bag had little caps on top of them to get attach to the top ring.

Here are some pictures from the CAD and the final real prototype.

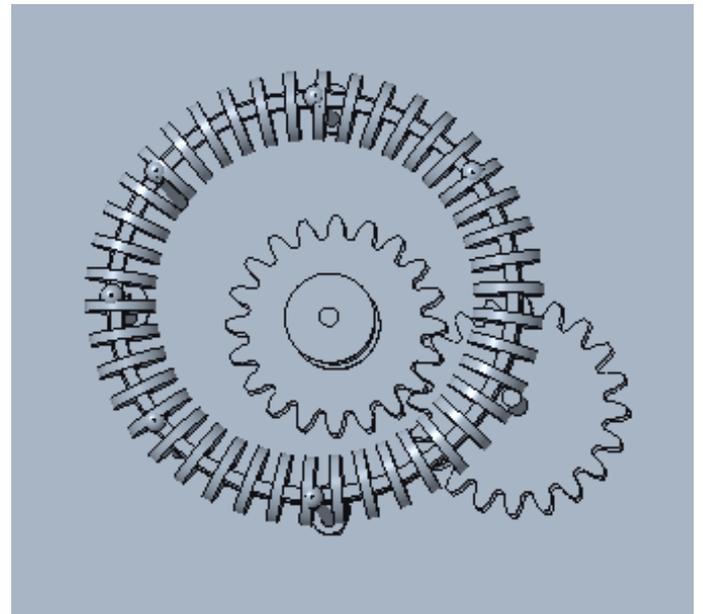
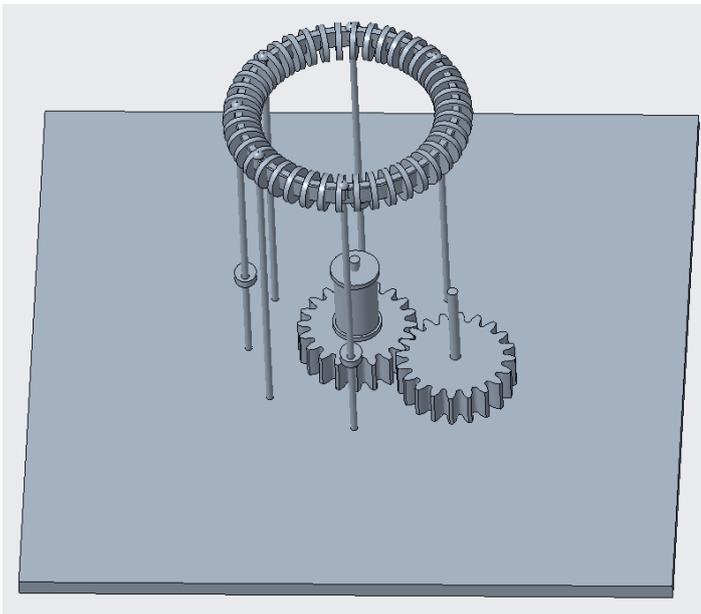


Figure 28. Final prototype CAD

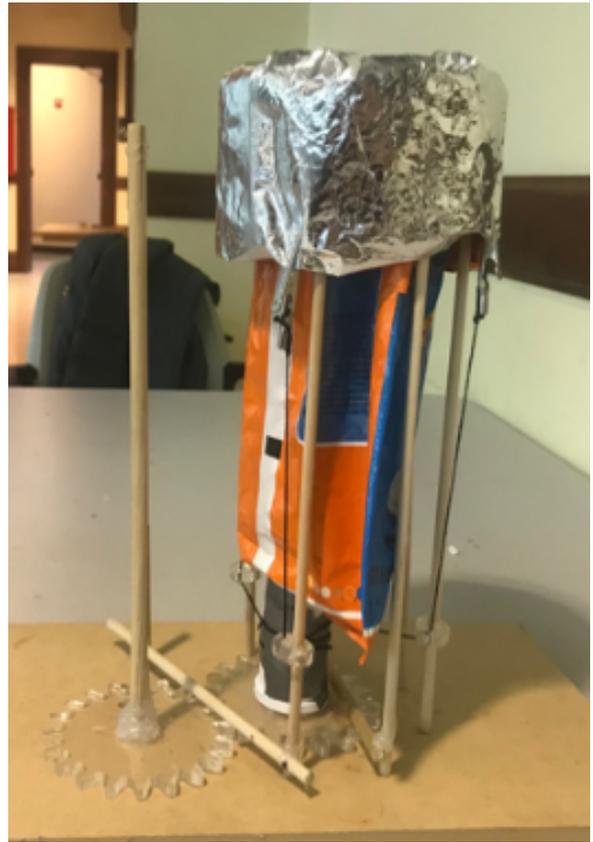
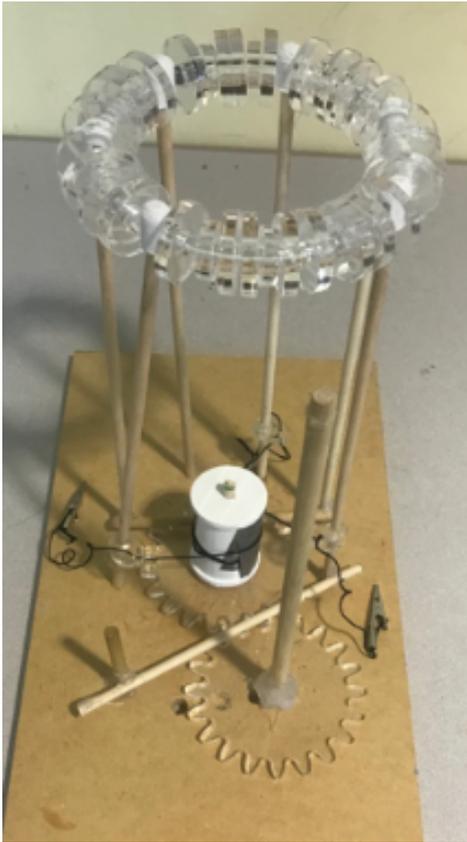


Figure 29. Final prototype

### 6.6. All prototypes together

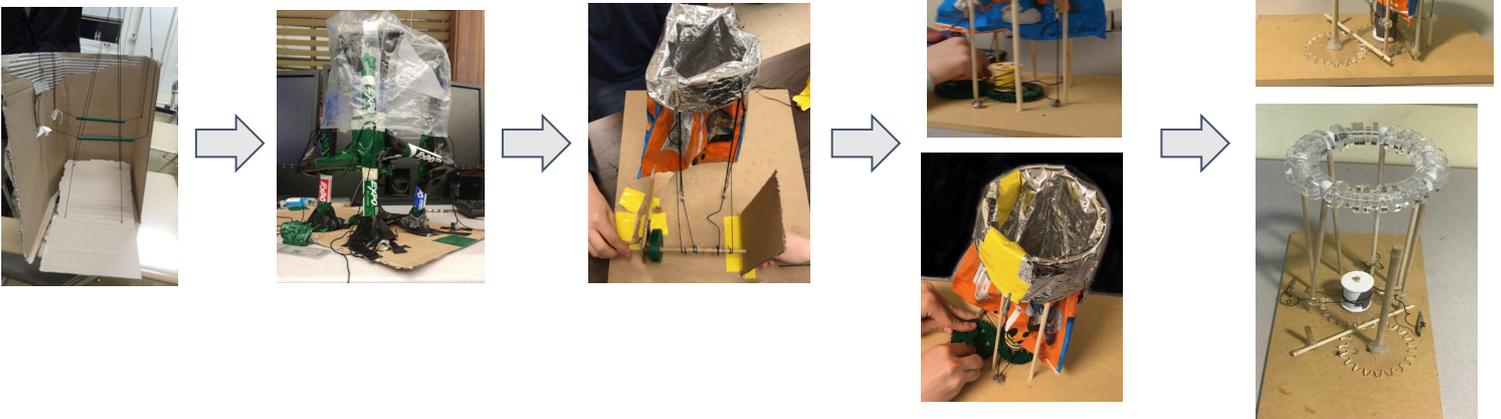


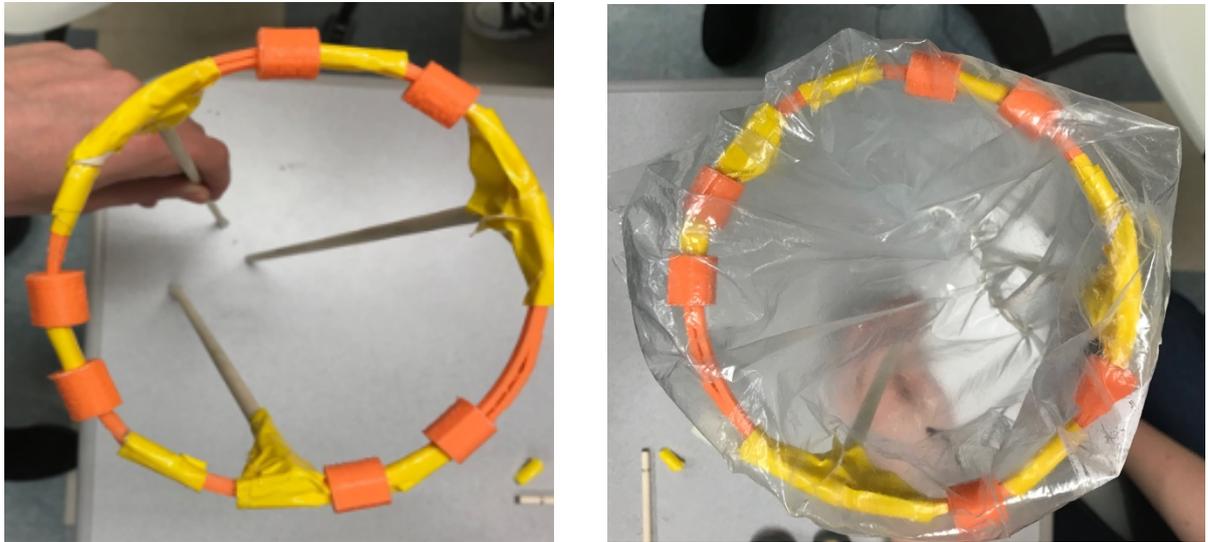
Figure 30. Prototypes trajectory

## 6.7. Video

Here is a video where the process of the project can be seen, going through the different prototypes.

<https://youtu.be/R0XIFF-DSRg>

## 7. Design of experiment (DOE)



*Figure 39. Design of Experiment*

This DOE setup included the prototype with supports and the ring, with a weight scale below that it showed the amount of force needed to pull down the bag with each different variable set up.

The decision to optimize the ring used to pull the bag down over was because it was found that it took a significant amount of force to pull the bag down using our gears. If this got optimized, it would make turning the gears easier and therefore make the prototype more efficient.

The variables were using 10 or 6 rollers on the ring, diameter of 135 mm or 117 mm, and an angled arm or 90-degree arm. The ring diameters were based on the smallest and largest ring the bag could function around, the number of rollers 10 and 6, were because of how many would fit on the ring without it being cluttered, and the angled arm was tested to see if another angle could make pulling the bag down more efficient.

In Figure 32 is shown the way the variables were measured by finding the force it would take to pull the bag down under each circumstance with a weight scale.

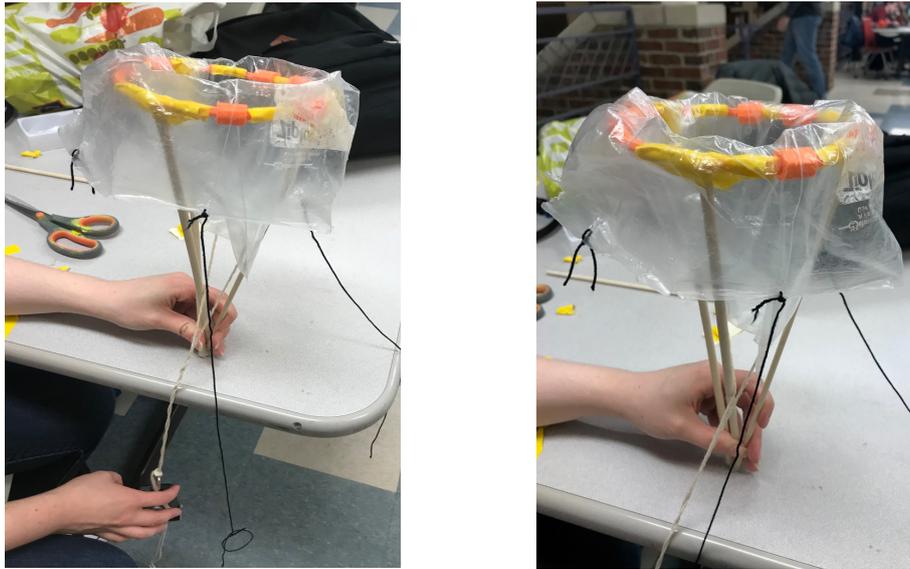


Figure 40. Design of Experiment

In table 2 is shown what was analyzed in this DOE.

Variables	high	low
1.Number of rollers	10	6
2.Diameter ring (mm)	135	117
3.Arm orientation	straight	angled

Table 2. Variables (DOE)

Test	x <sub>1</sub>	x <sub>2</sub>	x <sub>3</sub>	x <sub>1</sub> x <sub>2</sub>	x <sub>1</sub> x <sub>3</sub>	x <sub>2</sub> x <sub>3</sub>	x <sub>1</sub> x <sub>2</sub> x <sub>3</sub>	y <sub>1</sub>	y <sub>2</sub>	y <sub>ave(actual)</sub>
1	-1	-1	-1	1	1	1	-1	7,448	6,860	7,154
2	-1	-1	1	1	-1	-1	1	9,212	8,428	8,820
3	-1	1	-1	-1	1	-1	1	7,056	5,292	6,174
4	-1	1	1	-1	-1	1	-1	7,448	7,644	7,546
5	1	-1	-1	-1	-1	1	1	6,272	5,684	5,978
6	1	-1	1	-1	1	-1	-1	5,096	5,684	5,390
7	1	1	-1	1	-1	-1	-1	6,664	7,056	6,860
8	1	1	1	1	1	1	1	5,292	5,488	5,390
										<b>y<sub>ave</sub></b>
										6,664

Table 3. Analysis (DOE)

Some of the formulas used are:

$$E_1 = \frac{1}{4} * (-7,154 - 8,820 - 6,174 - 7,546 + 5,978 + 5,390 + 6,860 + 5,390) = -1,519$$

$$E_2 = \frac{1}{4} * (-7,154 - 8,820 + 6,17 + 7,546 - 5,978 - 5,390 + 6,860 + 5,390) = -0,343$$

$$E_3 = \frac{1}{4} * (-7,154 + 8,820 - 6,17 + 7,546 - 5,978 + 5,390 - 6,860 + 5,390) = 0,245$$

$$E_{12} = \frac{1}{4} * (+7,154 + 8,820 - 6,17 - 7,546 - 5,978 - 5,390 + 6,860 + 5,390) = 0,784$$

$$E_{13} = \frac{1}{4} * (+7,154 - 8,820 + 6,17 - 7,546 - 5,978 + 5,390 - 6,860 + 5,390) = -1,274$$

$$E_{23} = \frac{1}{4} * (+7,154 - 8,820 - 6,17 + 7,546 + 5,978 - 5,390 - 6,860 + 5,390) = -0,294$$

$$E_{123} = \frac{1}{4} * (-7,154 + 8,820 + 6,17 - 7,546 + 5,978 - 5,390 - 6,860 + 5,390) = -0,147$$

These  $E_n$  are for the main effects. For the noise effects are the same formulas but instead of using  $y_{ave}$  is using the variance.

$$y = \text{max weight necessary to pull in kg} * 9,8$$

$$\text{Variance} = (\text{std dev})^2$$

$$\text{Predicted} = y_{ave} + 0,5 * (x_1 E_1 + x_{13} E_{13}) \text{ (using just the significant values for } x * E)$$

$$\text{Residual} = y_{ave}(\text{actual}) - \text{predicted}$$

Main:	$E_1$	$E_2$	$E_3$	$E_{12}$	$E_{13}$	$E_{23}$	$E_{123}$
	-1,519	-0,343	0,245	0,784	-1,274	-0,294	-0,147
Noise:	$E_1$	$E_2$	$E_3$	$E_{12}$	$E_{13}$	$E_{23}$	$E_{123}$
	-0,403	0,211	-0,365	-0,336	0,336	-0,432	0,403

Table 12. Effects (DOE)

Std Deviation	Variance	Predicted	Residual
0,416	0,173	6,787	0,368
0,554	0,307	8,061	0,759
1,247	1,556	6,787	-0,613
0,139	0,019	8,061	-0,515
0,416	0,173	6,542	-0,564
0,416	0,173	5,268	0,123
0,277	0,077	6,542	0,318
0,139	0,019	5,268	0,123
Ave. Std Deviation	Ave. Variance	2 sigma threshold	
0,559	0,312	1,117	

Table 21. Analysis (DOE)

The 2-sigma significance level marks the effect magnitude value threshold for significance. Thus, in this analysis of the main effects, it is shown how E<sub>1</sub> and E<sub>13</sub> are both significant effects because they are higher than 1,117. Also, it is shown in the graphic below. The two separate points are the significant effects, E<sub>1</sub> and E<sub>13</sub>.

The formula used for the probability is:  $P = \left(\frac{100*(i-0,5)}{2^n-x}\right)$  where i= the rank of the effect and n=the total number of variables used for the experiment. To get x we use:  $(2^n - x) = \text{number divisions out of } 100\%$ , in this case we need 7 to account all the effect values.

Therefore, n=3 and  $(2^n - x) = 7 \rightarrow x = 1$ . Thus,  $P = \left(\frac{100*(i-0,5)}{2^3-1}\right)$ . Moreover, for the standard deviation we used the excel formula `inv.norm(prob, average=0, std dev=1)`.

Rank	Probability	Std Deviation (x-axis)	Rank Main Effects (y-axis)	Effect
1	0,071	-1,465	-1,519	E <sub>1</sub>
2	0,214	-0,792	-1,274	E <sub>13</sub>
3	0,357	-0,366	-0,343	E <sub>2</sub>
4	0,500	0	-0,294	E <sub>23</sub>
5	0,643	0,366	-0,147	E <sub>123</sub>
6	0,786	0,792	0,245	E <sub>3</sub>
7	0,929	1,465	0,784	E <sub>12</sub>

Table 30. Main effects variables

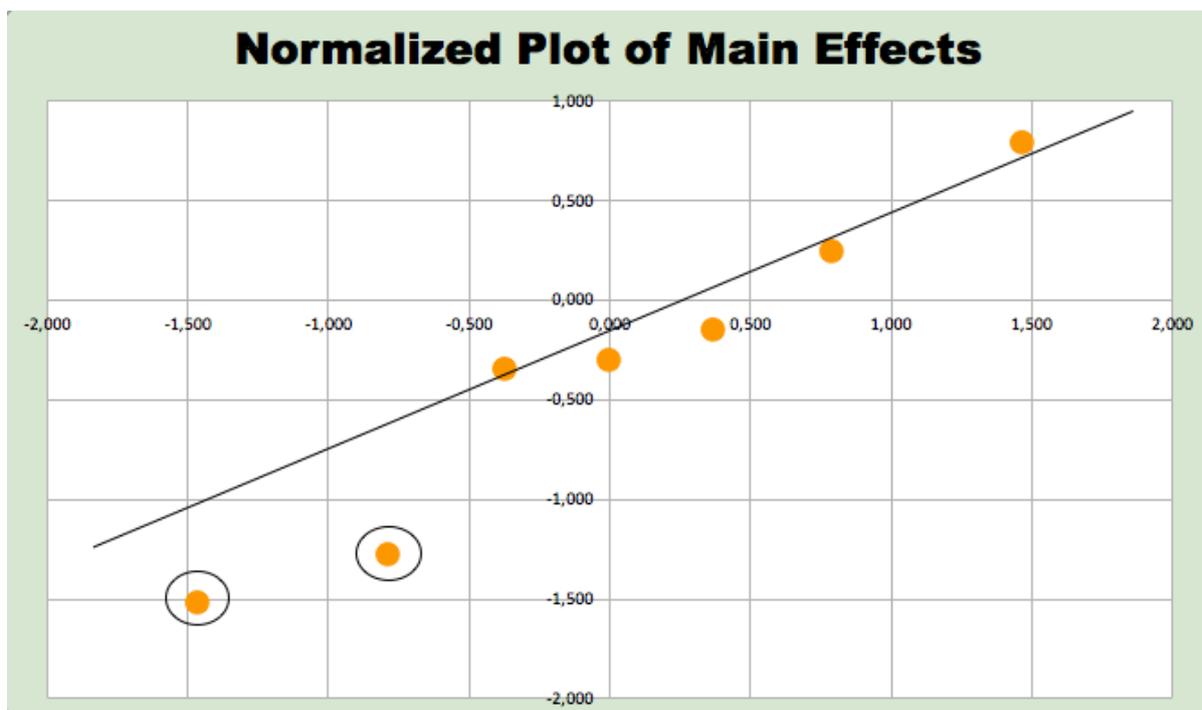


Figure 41. Normalized plot of main effects

In the next graphic for the normalized noise effects, the same formulas were used for probability and standard deviation. Now, they are no significant effects and it can be seen in the graphic how all the effects are all around zero.

As already said, the formula used for residual is:

$$Residual = y_{ave}(actual) - predicted$$

$$Predicted = y_{ave} + 0,5 * (x_1E_1 + x_{13}E_{13}) \text{ (using just the significant values for } x^*E)$$

Rank	Probability	Std Deviation (x-axis)	Ranked Noise Effects (y-axis)	Effect
1	0,071	-1,465	-0,432	E <sub>23</sub>
2	0,214	-0,792	-0,403	E <sub>1</sub>
3	0,357	-0,366	-0,365	E <sub>3</sub>
4	0,500	0,000	-0,336	E <sub>12</sub>
5	0,643	0,366	0,211	E <sub>2</sub>
6	0,786	0,792	0,336	E <sub>13</sub>
7	0,929	1,465	0,403	E <sub>123</sub>

Table 31. Noise effects variables

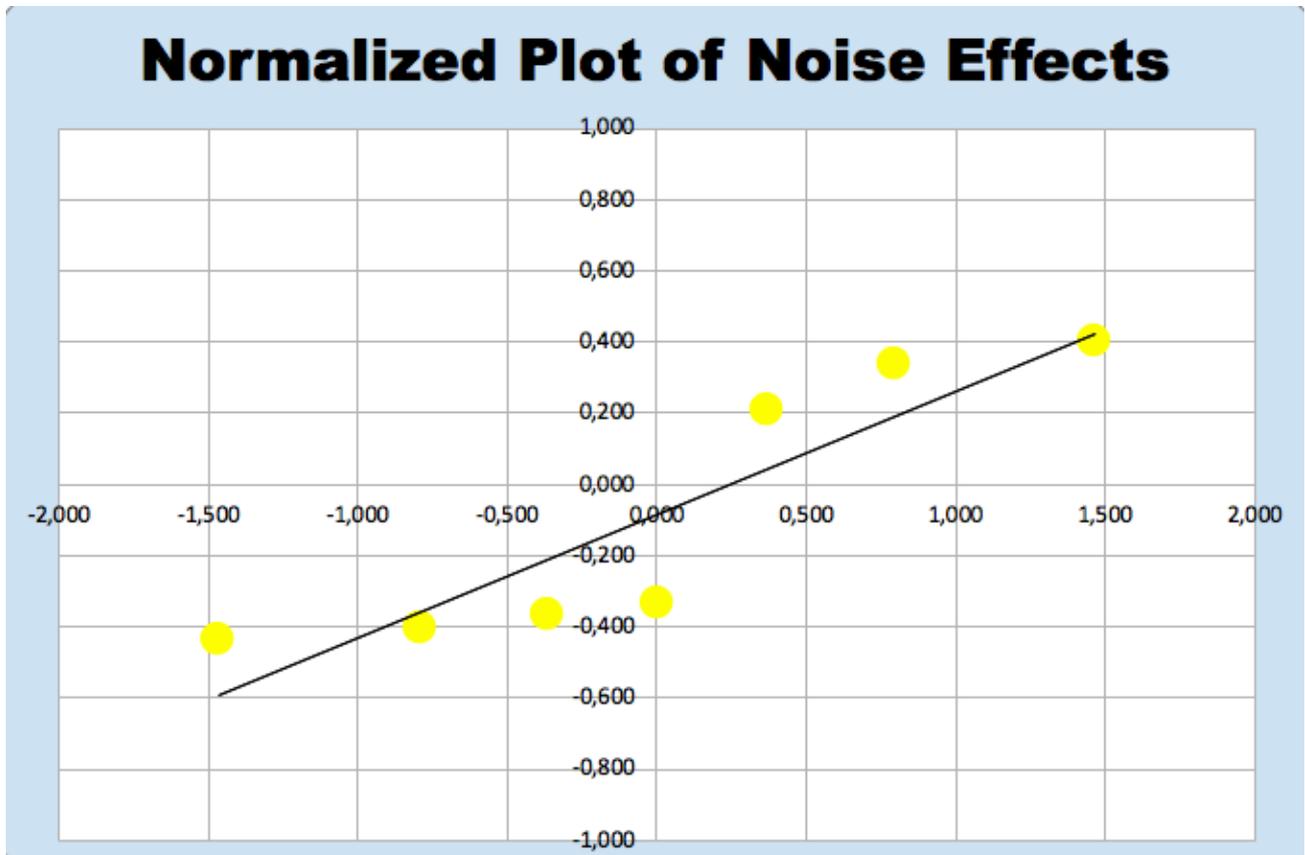


Figure 50. Normalized plot of noise effects

Finally, for the cumulative probability plot of residual, the formulas for probability and standar deviation are the same but in this case we need 8 divisions to account all the residuals. Thus,  $(2^n - x) = 8 \rightarrow x = 0$  and  $P = \left(\frac{100*(i-0,5)}{2^3-0}\right)$ .

To be consider a good model this plot should be a straight line and it should have an  $R^2 > 0.9$ . In this case, we have a very straight line and  $R = 0,9088$ . Therefore, we can use this model to make predictions.

Rank	Probability	Std Deviation (x-axis)	Ranked Residuals (y-axis)
1	0,063	-1,534	-0,613
2	0,188	-0,887	-0,564
3	0,313	-0,489	-0,515
4	0,438	-0,157	0,123
5	0,563	0,157	0,123
6	0,688	0,489	0,318
7	0,813	0,887	0,368
8	0,938	1,534	0,759

Table 32. Residuals table

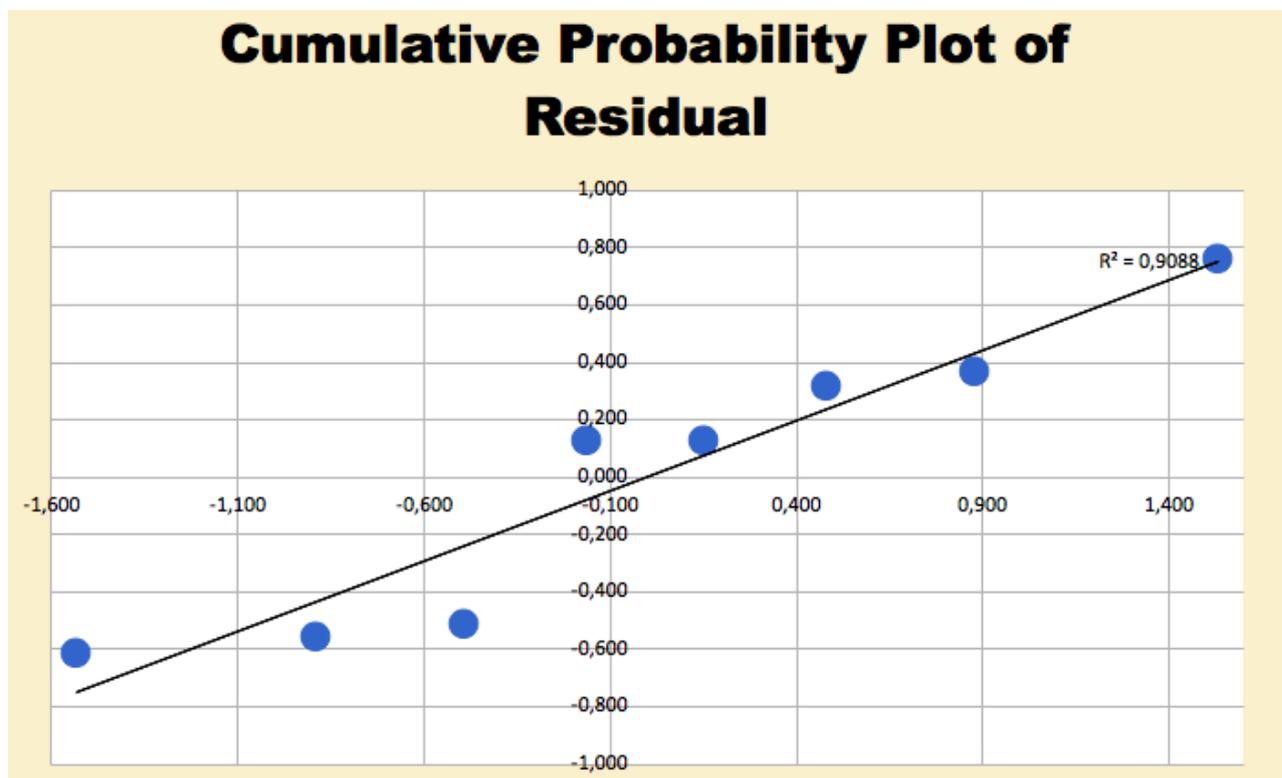


Figure 59. Cumulative probability plot of residual

To achieve the least variance, utilizing the system in test 4 and 8 (0.01928) would be ideal. To optimize the output, the system that required the least weight to pull down were tests 6 and 8 ( $y_{ave}=5,39$ ). Therefore, the combination of 90-degree angle and 10 rollers required the least amount of force downward to roll and the ring size does not appear to affect it. It is anticipated the ring's diameter may have a greater effect on the outcome, but it is uncertain if the rollers were able to roll free due to the bumpers that created to keep them in relatively the same place.

The changing of variables made a difference on the product success, and it is a stepping stone to use in the future by adding rollers to a smaller ring to decrease the weight it takes to pull the bag down over the ring. The main factor that DOE portrayed as being important to the success of the prototype that varied from the initial plan was to increase the number of rollers to assist the bag. These results will allow to make tiny details in the design to ensure that it is requiring the smallest force necessary to pull the bag. It already had a 90-degree arm so that will not change anything. If it was to change how it tested, it should ensure that the rollers won't be inhibited by the bumpers and this could potentially change the results.

Another option for a DOE, could have been done it for the gears on the prototype to make it the easiest and smoothest to operate for the product user, most likely using a 3D printed gear and a laser printed gear with varying sizes and methods of attaching the strings to the gear.



## 8. Design for assembly (DFA)



*Figure 68. Final prototype*

The prototype has nine different type of parts: the wooden supports, the acrylic gears, the steel clips with string, the acrylic ring, the wooden base, the 3D printed spool, the acrylic rollers, the 3D printed caps and the acrylic string path.

The following table, table 9, shows the information of the DFA done for the prototype. And the total time for the assembly was 204.5 seconds. However, this wasn't the final prototype yet and had more clips, caps and string.

Part #	Number of parts	Part name	Theoretical min n° of parts	Alpha (°)	Beta (°)
1	6	Wooden support	3	180	0
2	2	Acrylic gear	2	180	180
3	8	Steel clips with string	4	360	180
4	1	Acrylic ring	1	180	0
5	1	Wooden base	1	180	90
6	1	3D printed spool	1	180	0
7	42	Acrylic rollers	0	180	0
8	6	3D printed caps	3	180	0
9	8	Acrylic string path	3	180	0

Part #	Min dimension (mm)	Max dimension (mm)	Fetch (sec)	Sym (sec)	Size penalty (sec)
1	6,35	400	0,5	1	0,3
2	6,35	114,3	0,5	1	0,5
3	5,58	27,78	0,5	1	0
4	6,35	127	0,5	1	0,5
5	17,5	300	0,5	2	0,3
6	3,81	40	0,5	1	0,5
7	6,35	20,32	0,5	1	0,5
8	6,35	30,23	0,5	1	0,5
9	20	25	0,5	1	0,5

Part #	Difficulty (sec)	Aspect ratio (sec)	Place (sec)	Hole align (sec)	Insert difficulty (sec)	Total time (sec)
1	0	0	0,5	0,3	0,8	3,4
2	0	0	0,5	0,3	0,8	7,2
3	0	0	0,5	0,3	0,8	27,2
4	0	0	0,5	0,3	0,8	3,4
5	0	0,1	x	x	x	2,9
6	0	0	0,5	0,3	0,8	3,6
7	0	0	0,5	0,3	0	117,6
8	0	0	0,5	0,3	0	16,8
9	0	0	0,5	0,3	0	22,4

Table 33. Design of Analysis

Part 1, the wooden support bars, required drilled holes and then attaching them with hot glue to the acrylic ring in order to assemble. There is potentially a more efficient method of assembly with a custom base to decrease attachment time.

Part 2, the acrylic gears, also have drilled holes to attach them to the base. It had slid a wooden rod through the center of the outer gear and a 3D printed spool through the other that has the string attached to it so that it could in turn create tension by the simple twist of a pole. If it was to 3D print the rod, gear and spool combo, it would require less

assembly time, yet this method was not chosen due to the rough and ragged edges that create uneven contact between the gears. These ragged edges increase friction which will then require a greater force to turn the gears.

Part 3, the steel clips with string, have strings that are attached to a spool that will rotate with the gears to create tension. These clips will be the point of contact and where the downward force on the bag will be exerted.

Part 4, the acrylic ring, is secured to the support structure by end caps located at the intersection point.

Part 5, the wooden base, is the basic part since all other parts are built off of this simple rectangle. This part has holes drilled into and could potentially be combined with the support structures for a custom part if it was to take it to mass production. For better purposes, to save time and resources it has been decided to assemble these rods one by one rather than wait for a custom print.

Part 6, the 3D printed spool, is used to tension the strings and does this by rotating with the gear that is attached to. The gear is attached by hot glue and as previously stated these parts could be combined by 3D printing it as one piece, yet the material is not ideal for the creation of gears.

Part 7, the acrylic rollers, are slid onto the ring before the caps are attached, which keeps them stationary while allowing free rotation. In theory, the number of rollers could be decrease by making the ring itself have the ability to rotate or make it frictionless so that it would create the same effect of the rollers.

Part 8, the 3D printed caps, are attached to the ring in order to act as barriers between sections of the rollers to have the bag roll down more smoothly.

Part 9, the acrylic string paths, are attached to the sides of the wooden supports in order to keep the strings on different paths, so as for them to not become entangled with each other.

One significant way to improve the assembly design would be by decreasing the amount of clips and string paths used so it would be easier and cost less to assemble. However, it could lead to a decrease in the force down on the bag. Another thing that could make the design easier to assemble would be to reduce the number of wooden supports and caps to 3, which would decrease total cost and the number of holes that would need to be drilled. Therefore, after performing this DFA analysis, it was decided to lower the number of clips and acrylic string paths to 3 and the performance of the prototype did not change significantly. The cost and time it would take to manufacture our prototype could be successfully decreased. Thus, this would decrease the time to manufacture by 31 seconds which is a significant difference.

## 9. Budget (bill of materials)

For this project we had a maximum budget to expend of \$200 for the 3D printed material or to buy other needed material for the prototype.

As shown in table 10, it has been expended money in 3-D printed parts, clips, polypropylene balls, acrylic latex caulk, spring steel wire, string, wooden bars, acrylic board and an American weight scales used for the DOE. In total, there was an expense of \$78 to get the final prototype.

	Waterfall Budget																		
	Base	Cost (down)	Cash Back (up)	Line 0	Line 1	Line 2	Line 3	Line 4	Line 5	Line 6	Line 7	Line 8	Line 9	Line 10	Line 11	Line 12	Line 13	Line 14	Line 15
<b>Expenses:</b>	\$ 200			\$ 200															
Initial 3-D printed rollers ( long piece with 3 holes)	\$ 200	\$ 0,48		\$ 200	\$ 200														
3D printed Rollers	\$ 197	\$ 3,00		\$ 200	\$ 197														
Alligator Clip (Banana Jack/Crimp/Solder Connection, Nickel Plated Ste	\$ 195	\$ 1,44			\$ 195														
Alligator Clip (Micro Jaw, Banana Jack/Crimp/Solder Connection)	\$ 194	\$ 1,20			\$ 194														
Alligator Clip ( Micro Jaw with 0.22" Opening, Crimp/Solder Connection	\$ 192	\$ 2,16			\$ 192														
Solid Polypropylene Ball, 3/4" Diameter	\$ 183	\$ 8,96			\$ 183														
Alex 10.1 oz. White Painter's All-Purpose Acrylic Latex Caulk	\$ 181	\$ 1,78			\$ 181														
1065 Spring Steel Wire (1/8" Diameter, 3 Feet Long)	\$ 174	\$ 7,39			\$ 174														
String	\$ 170	\$ 3,50			\$ 170														
Wooden bars	\$ 162	\$ 8,00			\$ 162														
3D printed gears	\$ 160	\$ 1,8			\$ 160														
Acrylic board	\$ 140	\$ 20,0			\$ 140														
3D printed rings	\$ 138	\$ 2,5			\$ 138														
American weigh scales	\$ 123	\$ 15,0			\$ 123														
3D printed caps	\$ 122	\$ 1,0			\$ 122														
<b>Remaining</b>			\$ 122																

Table 34. Waterfall budget

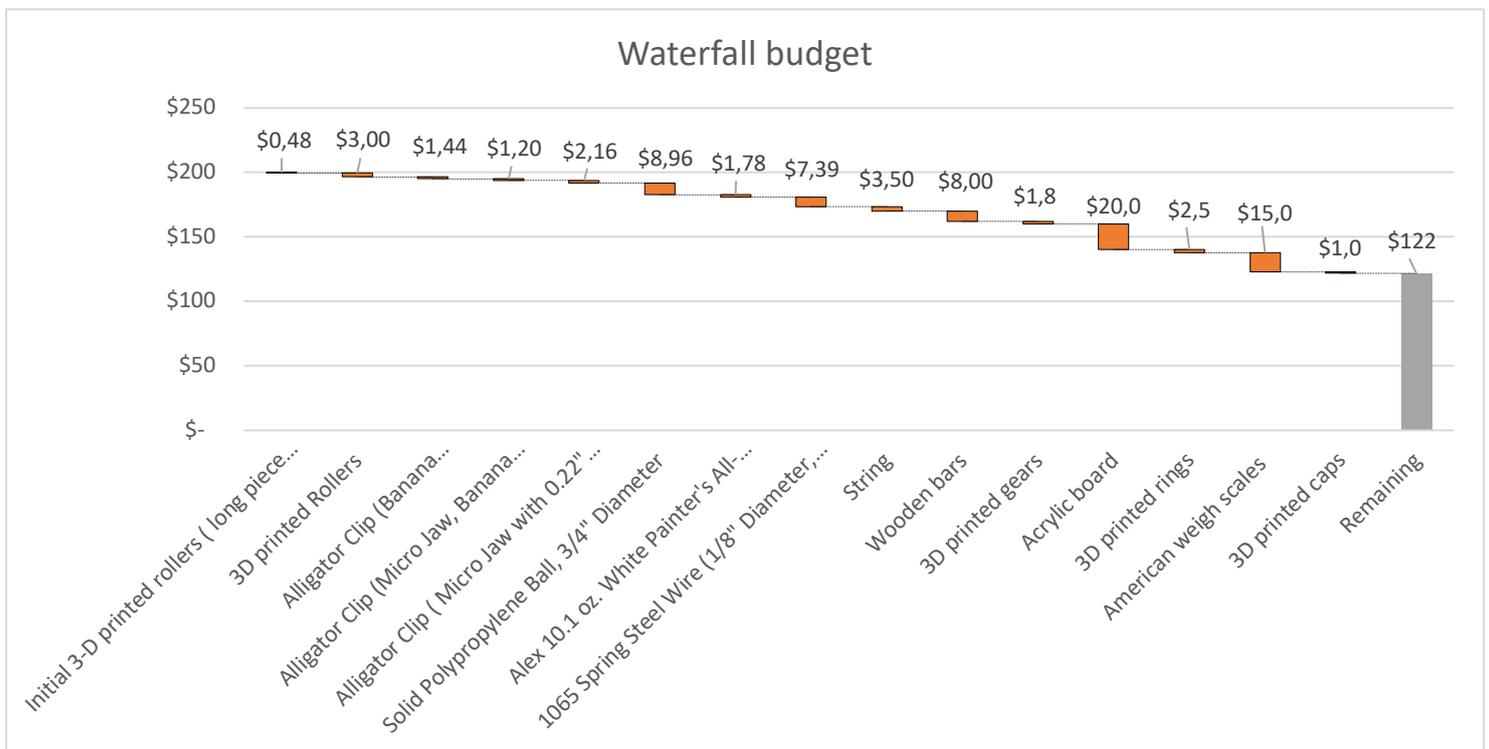


Figure 69. Waterfall budget



## 10. Manufacturing cost

There has been done an economic study to see how much it would cost to create this mechanism, the Snack and Spin bag roller. There has been used a program called A priori. This program calculates the price cost per piece using the CAD. Also, the type of material and process need to be selected.

There has been selected a cheap one so as to be economically accepted. Therefore, there has been chosen plastic molding with Acetal, copolymer for all the parts except for the caps that has been chosen polypropylene Ext. Fiber.

The main material, Acetal, copolymer, was chosen for its good characteristics for this mechanism among which they are:

- High mechanical resistance and rigidity
- Good sliding characteristics and excellent wear resistance
- Great dimensional stability

Moreover, the Polypropylene Ext. Fiber has similar characteristics, but it was cheaper for the caps in this case.

The price was calculated for a volume of production of 1200 bag rollers per year and a product life of 15 years. And the total price is \$20,33. However, we have to add a little extra for the three clips and the string that we have to attach to it. Therefore, the price would be approximately around \$20.

Part	Number of parts per product	Process	Material Composition	Piece Part Cost (\$)
Base	1	Plastic molding	Acetal, Copolymer	2,41
Spool	1	Plastic molding	Acetal, Copolymer	0,63
Gear	2	Plastic molding	Acetal, Copolymer	0,95
Top ring	1	Plastic molding	Acetal, Copolymer	0,84
String path	3	Plastic molding	Acetal, Copolymer	0,23
Cap for the bar	3	Plastic molding	Polypropylene Ext. Fiber	0,14
Rollers	42	Plastic molding	Acetal, Copolymer	0,32

Table 48. Manufacturing costs table



## 11. Management plan

During the semester there has been different laboratories every week and at the end of each lab section a report had to be done. For the project, there has been some presentations from time to time to see how it was going. Here is a plan of what was done during the four months that the project has been done, from the beginning of January until the end of April.

### 11.1. Gantt chart

	January			February				March				April				
	14	21	28	4	11	18	25	4	11	18	25	1	8	15	22	29
Brainstorm ideas	█															
Background research	█															
Project decision: BAG ROLLER		█														
Design of sketches		█														
<b>PROJECT PROPOSAL</b>			█													
<b>Ideation Report</b>			█													
Background research			█													
Research type of materials			█	█												
Design of sketches			█	█												
CAD and 3D printing material for prototype 1				█												
Prototype 1 assembly				█	█											
CAD and 3D printing material for prototype 2				█												
<b>3D Printing Report</b>				█												
Prototype 2 assembly				█	█											
<b>DESIGN REVIEW PRESENTATION</b>					█											
Brainstorm and assign new action items					█											
Design and decide on a prototype 3 design					█											
Research and acquire materials					█											
CAD and 3D printing for prototype 3					█											
Prototype 3 assembly					█											
<b>Machining Report</b>								█								
Design and decide on a prototype 4 design								█								
<b>Injection Molding Report</b>								█								
CAD and 3D printing for prototype 4 (different sizes)								█								
Acieve material for the top ring								█								
Prototype 4 assembly								█								
<b>PROTOTYPE REVIEW PRESENTATION</b>												█				
Design and decide the final prototype design												█				
CAD and 3D printing for final prototype												█				
<b>Design of Experiments Report (DOE) (minimize friction at the top ring)</b>												█				
Looking for different materials (Acrylic printing)												█				
<b>Design for Assembly Report (DFA)</b>													█			
CAD and acrylic printing for final prototype													█			
Acquire potential crank mechanism to tension our strings													█			
Optimize clip strength													█			
Final Prototype assembly													█			
<b>FINAL PROJECT PRESENTATION</b>																█

Table 56. Gantt



## 12. References

[https://en.wikipedia.org/wiki/3D\\_printing](https://en.wikipedia.org/wiki/3D_printing)

<https://www.creativemechanisms.com/blog/injection-mold-3d-print-cnc-acrylic-plastic-pmma>

<https://en.wikipedia.org/wiki/Machining>

<https://www.custompartnet.com/wu/InjectionMolding>

<https://www.ensingerplastics.com/es-es/semielaborados/plasticos-de-ingenieria/pom-acetal>