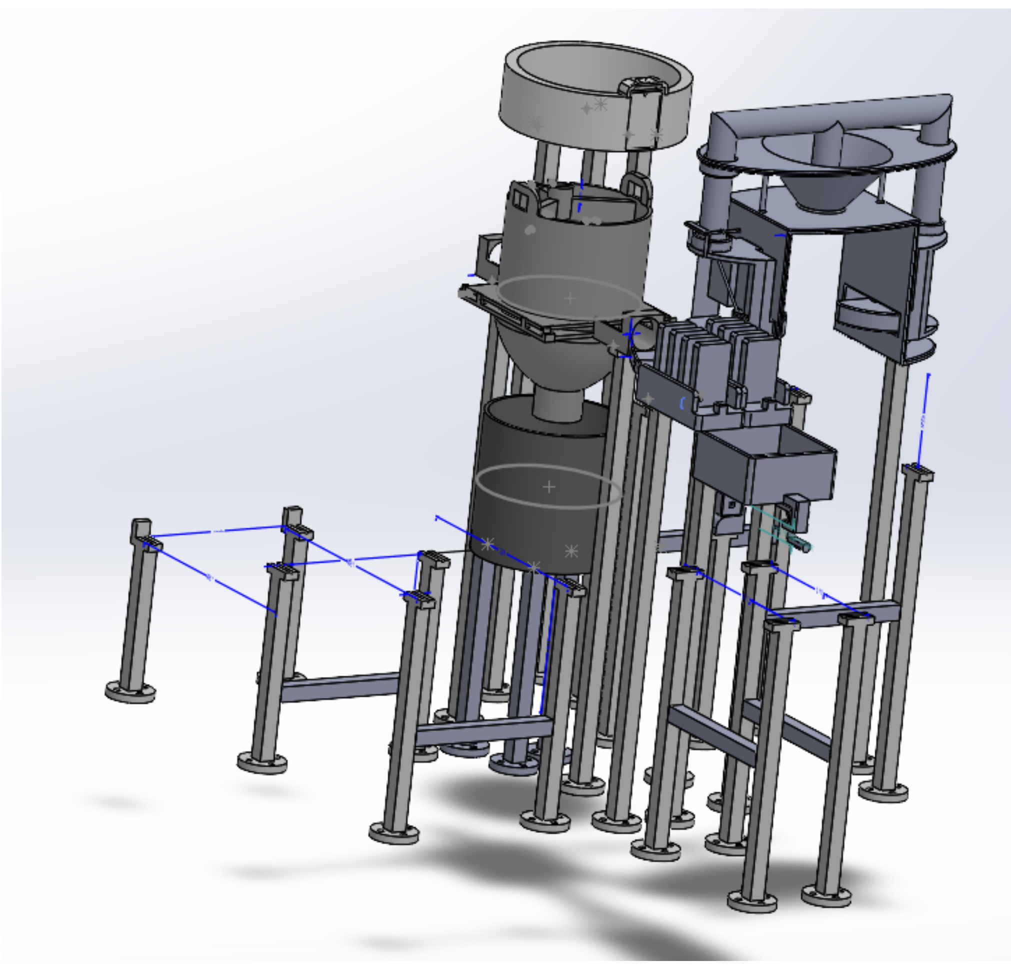
Final Report DBB113 - Kinetic Coffee

Jort Wiersma, Tyga van Overschot, Sanne Jansen, Naomi Nohar

Many of us have seen these kinetic chain reactions in films. Whether they consisted of dominoes, marbles, or other items, children in films often completed the most mundane daily tasks through such kinetic chain reactions. When we were tasked with creating one of our own, we jumped at the chance to transform the daily act of coffee making into a kinetic coffee experience.

Our kinetic coffee maker consists of dominos, marbles, and other chain reactions, all working together to eventually create a cup of coffee. A hanging cup is set onto a pair of rails, and slowly trails down through the different stages. Stage 1 consists of two cylinders that are pushed aside by the cup to open up a plug that lets through milk, which falls into the cup. Stage two consists of a marble and domino collaboration toppling sugar cubes into a basin which is opened when the cup rolls by. At stage 3 the coffee is being made by use of a coffee pad. Finally, you have a steaming cup of coffee, ready to start the day.

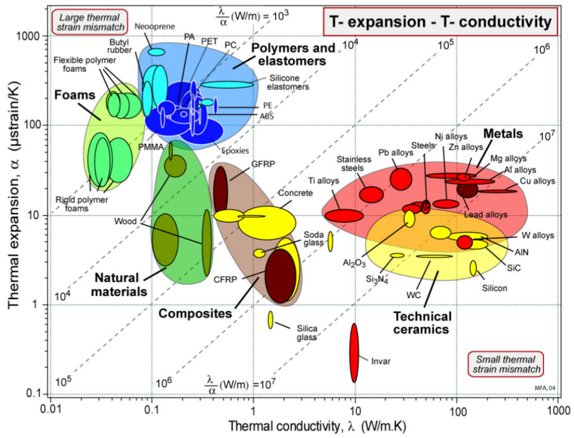


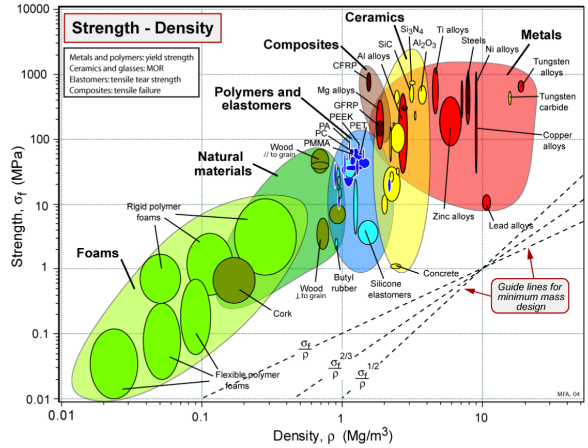
Information about materials

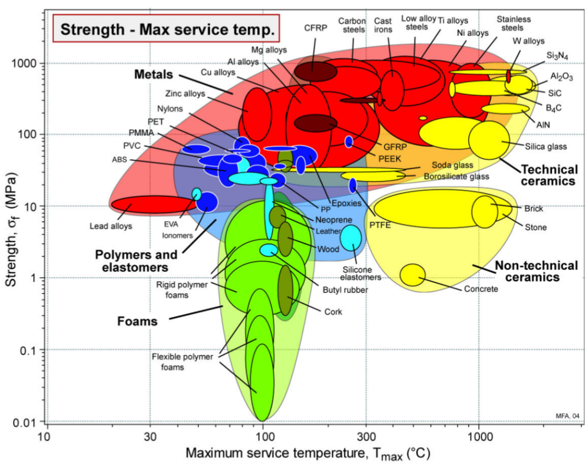
Printed components

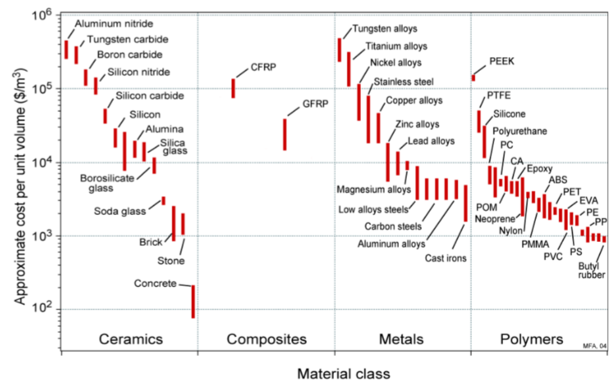
While looking into the manufacturing techniques and materials that are available a few design requirements should be kept in mind while choosing what we will be using. First of all, throughout our entire design miniature wheels and spheres have been used that contain a 0,2 mm margin from one and other. The machine should be able to print within this margin. Furthermore, these wheels and spheres depend on the material to be as smooth as possible to create a limited amount of resistance. As we are working with products that users will consume afterwards the material should be safe to be used in this manner. The material should be able to resist temperatures of 70 degrees Celsius as the coffee should be warm when being served just like the water during the preparation. The material should additionally have limited elastic deformation, as for example within the milk dispenser with the moving rod, is dependent on the stiffness of the material. Yet when being applied in a small thickness it should bend and act as a spring like within the carriage. Lastly, since the batch size is one, one of the main requirements is that the product can be manufactured with accessible manufacturing techniques, being rapid prototyping techniques. It is important that the material used is suitable for mechanical testing and that it can handle the stresses created by the weight of the contents of the cup. The most accessible manufacturing technique seems to be FDM. In addition, laser cutting and milling should be considered.

We chose polymers because they fit the profile we are looking for the best. As the material within our machine is going to be exposed to warm water and coffee the thermal properties are very important. The thermal expansion should be minimal while it should not conduct heat well so that the fluid may stay warm longer. When the thermal expansion would be too significant the construction would change in shape and therefore not function anymore. As polymers are high and very much on the left of the graph it is a very suitable material class on this aspect. We want the product to be strong yet not to dens as the extra mass would add to the stress due to the gravity. The class of polymers scores best for us at this aspect as it is around the middle of the graph. Going back to the need of the material to be resistant to temperatures of around 70 degrees the polymers lie around the 100 degrees point which is perfect for our usage. Therefore polymers would be the most suitable class for our material choice. Lastly, looking into the cost the polymers are relatively affordable per unit of volume which is to our liking as well. (Grantadesign Cambridge UK, nd.)

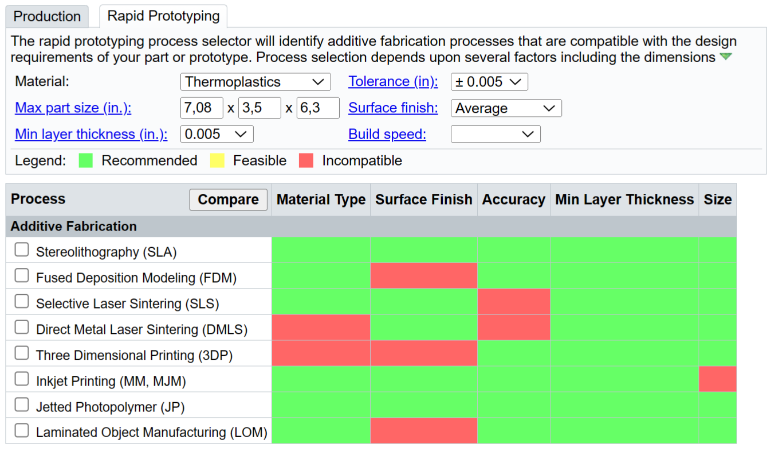








Looking into the manufacturing techniques that could be used with polymers and filling the properties we find important the results down below came out. Only JP and SLA score perfectly on all requirements yet FDM comes very close. Therefore the accessible Fortus 250 mc ABS printer is suitable to use for our machine. As the surface finish does not give a relative amount of resistance in the joints compared to the force that is being applied. (table made on the website: Rapid Prototyping Process Selector (custompartnet.com))(custompart.net, 2023)



Looking at the material properties of common ABS the maximum service temperature lies between 62 and 77 degrees celsius. As the machine makes usage of water with a temperature of 70 degrees it does lie at a critical point. In addition to this the thermal expansion coefficient is quite wide with the upper end being relatively high. (material profiles, nd.) Therefore the shape of our machine has a high chance of changing shape when adding hot water to it. For the components that are concerned with the hot fluids ABSplus-P430 could be used. In the table below it shows that it can hold temperatures up to 82 degrees with certainty, being above the intended temperatures for our model. (Stratasys, 2015) The thermal expansion coefficient is also close to 0 and therefore this material would suit our needs perfectly for the components that are exposed to the hot water, like the cup and the system that makes and transports the coffee. Pricewise comparing the two materials of the supplier Goengineer online store the price for one filament has a difference of 237,95 euros. (Goengineer online store, 2023) As this is a significant difference we will solely use this material for the components that come into direct contact with the hot water.

Composition:
$(CH_2\text{-}CH\text{-}C_6H_4)_n$

General properties				
Density	1,010	–	1,210	kg/m^3
Price	2.4	–	2.6	USD/kg

Mechanical properties				
Young's modulus	1.1	–	2.9	GPa
Yield strength (elastic limit)	18.5	–	51	MPa
Tensile strength	27.6	–	55.2	MPa
Elongation	1.5	–	100	%
Hardness—Vickers	5.6	–	15.3	HV
Fatigue strength at 10^7 cycles	11	–	22.1	MPa
Fracture toughness	1.19	–	4.29	$MPa \cdot m^{1/2}$

Thermal properties				
Glass temperature	88	–	128	°C
Maximum service temperature	62	–	77	°C
Thermal conductor or insulator?	Good insulator			
Thermal conductivity	0.188	–	0.335	$W/m \cdot K$
Specific heat capacity	1,390	–	1,920	$J/kg \cdot K$
Thermal expansion coefficient	84.6	–	234	µstrain/°C

Electrical properties				
Electrical conductor or insulator?	Good insulator			
Electrical resistivity	3.3×10^{21}	–	3×10^{22}	$\mu ohm \cdot cm$
Dielectric constant	2.8	–	3.2	
Dissipation factor	0.003	–	0.007	
Dielectric strength	13.8	–	21.7	10^6 V/m

Eco properties: material				
Global production, main component	5.7×10^6			metric ton/yr
Embodied energy, primary production	90	–	99	MJ/kg
CO_2 footprint, primary production	3.6	–	4.0	kg/kg
Water usage	250	–	277	L/kg
Eco-indicator	350			millipoints/kg

THERMAL PROPERTIES[2]	TEST METHOD	ENGLISH	METRIC
Heat Deflection (HDT) @ 66 psi	ASTM D648	204°F	96°C
Heat Deflection (HDT) @ 264 psi	ASTM D648	180°F	82°C
Glass Transition Temperature (Tg)	DSC (SSYS)	226°F	108°C
Melting Point	- - - - - - - - -	Not Applicable[3]	Not Applicable[3]
Coefficient of Thermal Expansion	ASTM E831	$4.90x10^{-05}$ in/in/°F	$8.82x10^{-05}$ mm/mm/°C

One important aspect is that the machine is serving something to be consumed therefore ABS should be FDA food contact complaint has been determined in a recent Food Contact Substance Notification (FCN). The FDA, Food and Drug Association, has determined that ABS is food contact compliant. Especially MAGNUM™ ABS 3453, ABS 3904 / 3904 Smooth and ABS 8391 / 8391 MED Resins are being advised. (Plastemart, 2015)

The lowest factor of safety found by simulationXpress analysis was about 93 using Nylon PA 6. The analysis shows that the stresses as a result of coffee, milk and sugar in the cup will not result in any dangerous stress levels. This does occur when ABS is used as a material.

The remaining components

As the printing machines in combination with the ABS filaments to print the previously mentioned unique components are relatively expensive we will use less pricey material to build the more common components. For the support structure we will use wood. Wood is a very accessible material that is easily shaped by a single individual by the machines that are accessible to us, in the Vertigo workshop for example. We would not use the milling machine as the design is not complex enough to make the saved time equal out with the added cost.

The rails where the cup is riding on will be made from a aluminum wire with a 3 mm diameter. The reason behind this is that aluminum wire has a very low resistance for the wheels of the carriage as it is very smooth. Furthermore, it is easily shaped by hand into the exact required form. The cost of aluminum is very low as well which made us pick this material for the track . (material profiles, nd.)

Composition

Al_2O_3, often with some porosity and some glassy phase.

General properties

Density	3,800	–	3,980	kg/m^3
Price	18.2	–	27.4	USD/kg

Mechanical properties

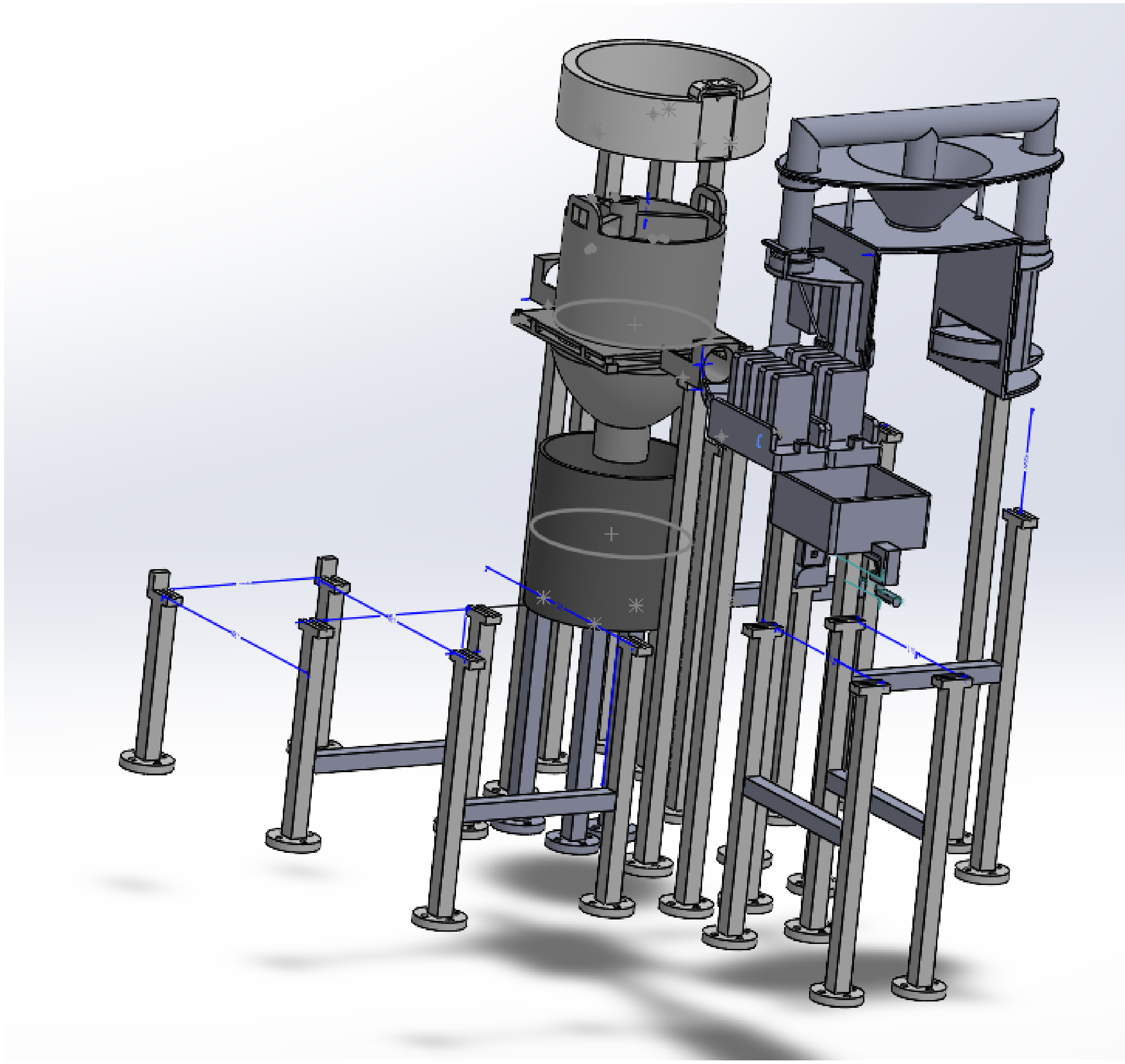
Young's modulus	343	–	390	GPa
Yield strength (elastic limit)	350	–	588	MPa
Tensile strength	350	–	588	MPa
Compressive strength	690	–	5.5e3	MPa
Elongation	0			%
Hardness—Vickers	1.2e3	–	2.06e3	HV
Fatigue strength at 10^7 cycles	200	–	488	MPa
Fracture toughness	3.3	–	4.8	$MPa \cdot m^{1/2}$

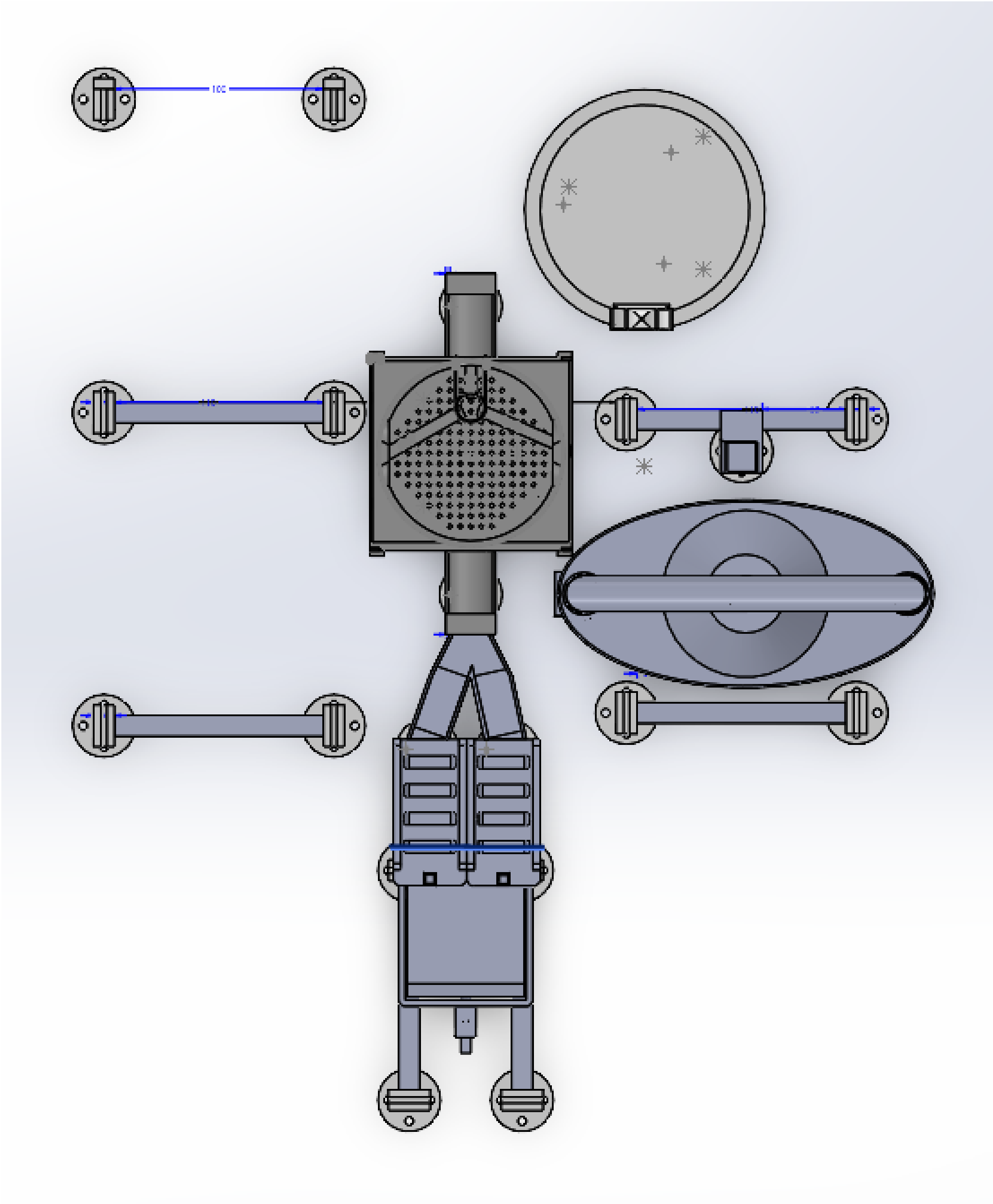
Thermal properties

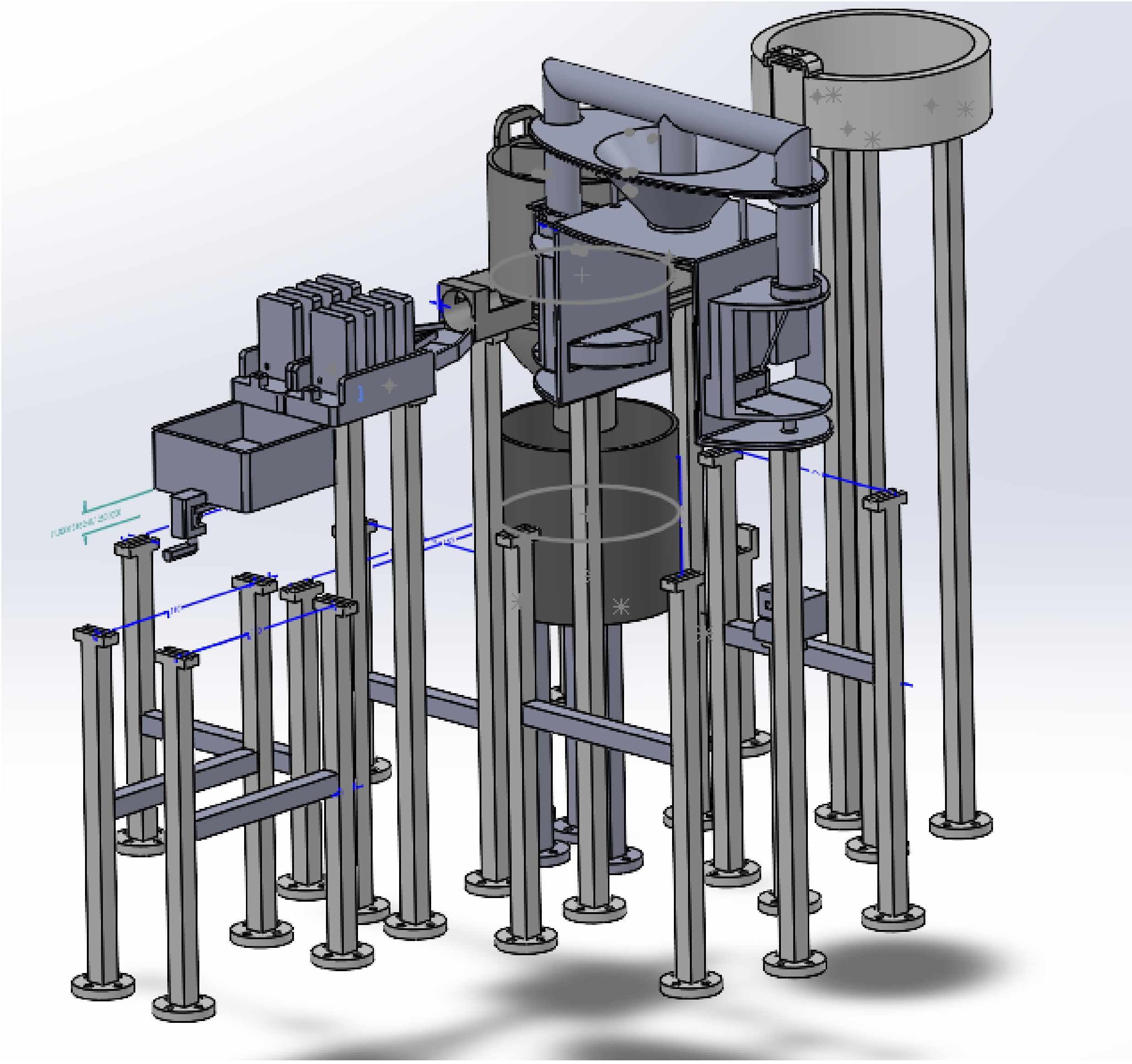
Melting point	2,000	–	2,100	°C
Maximum service temperature	1,080	–	1,300	°C
Thermal conductor or insulator?	Good conductor			
Thermal conductivity	26	–	38.5	W/m · K
Specific heat capacity	790	–	820	J/kg · K
Thermal expansion coefficient	7	–	7.9	μstrain/°C

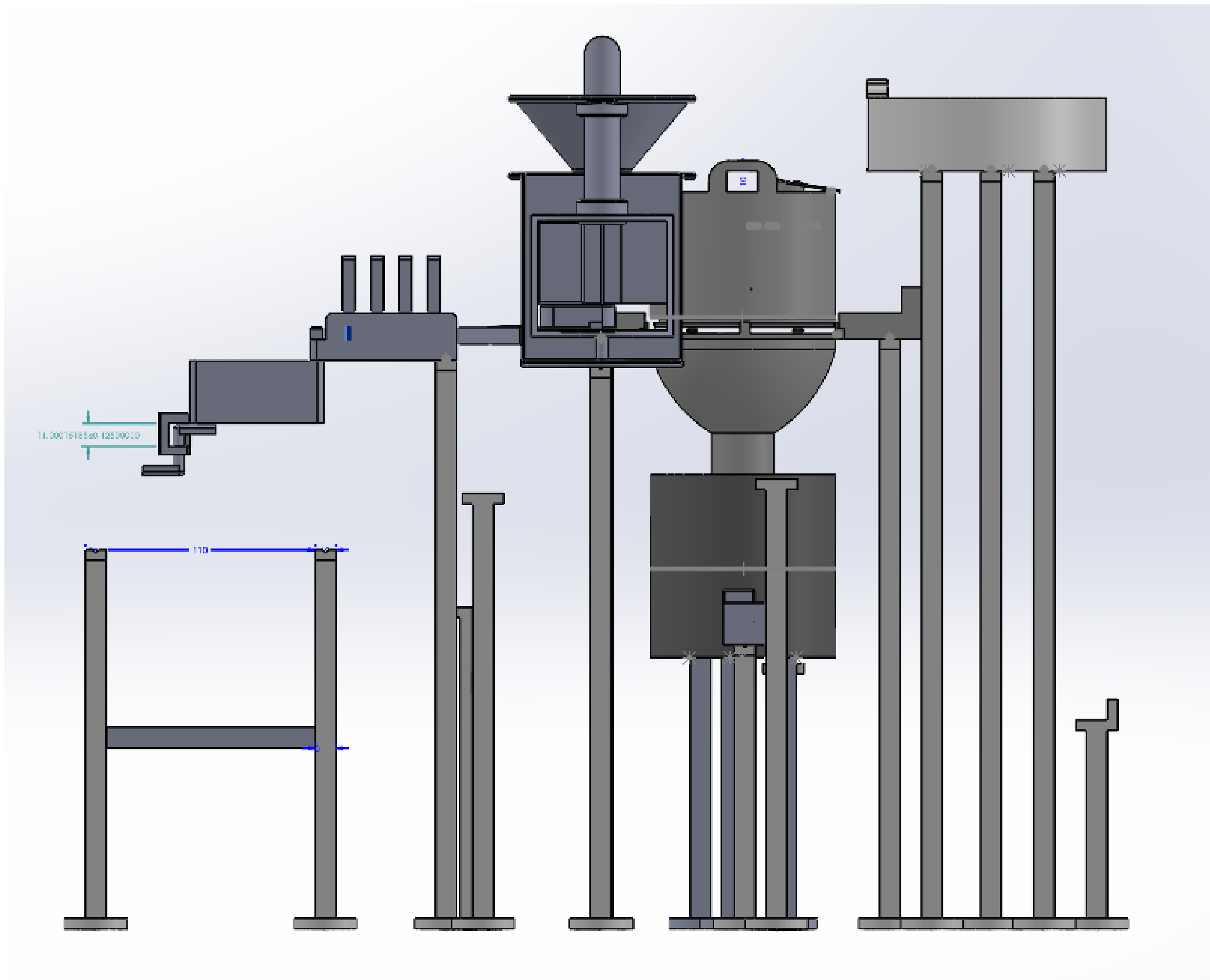
The kinetic art machine as a whole

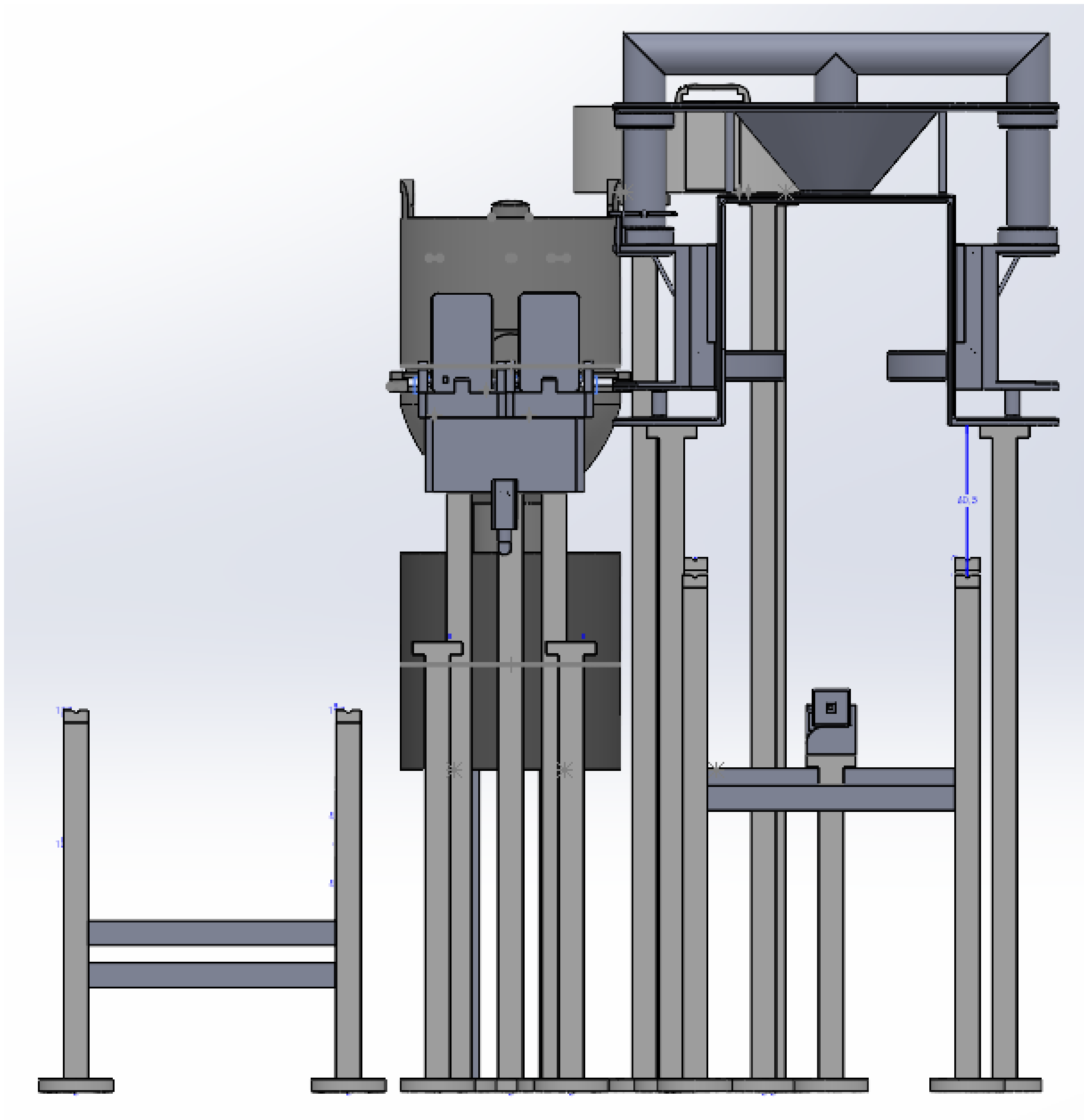
Within the picture many still on their own standing pillars have been depicted. These are these to support the rails on top of which the carriage, that will be in depth explained further on in the report, will ride. These rails will be made using aluminum wire with a thickness of 3 mm. Some components will be connected by plastic tubes that you can buy at the hardware store. As these components will not be printed they have not been added to the digital model.



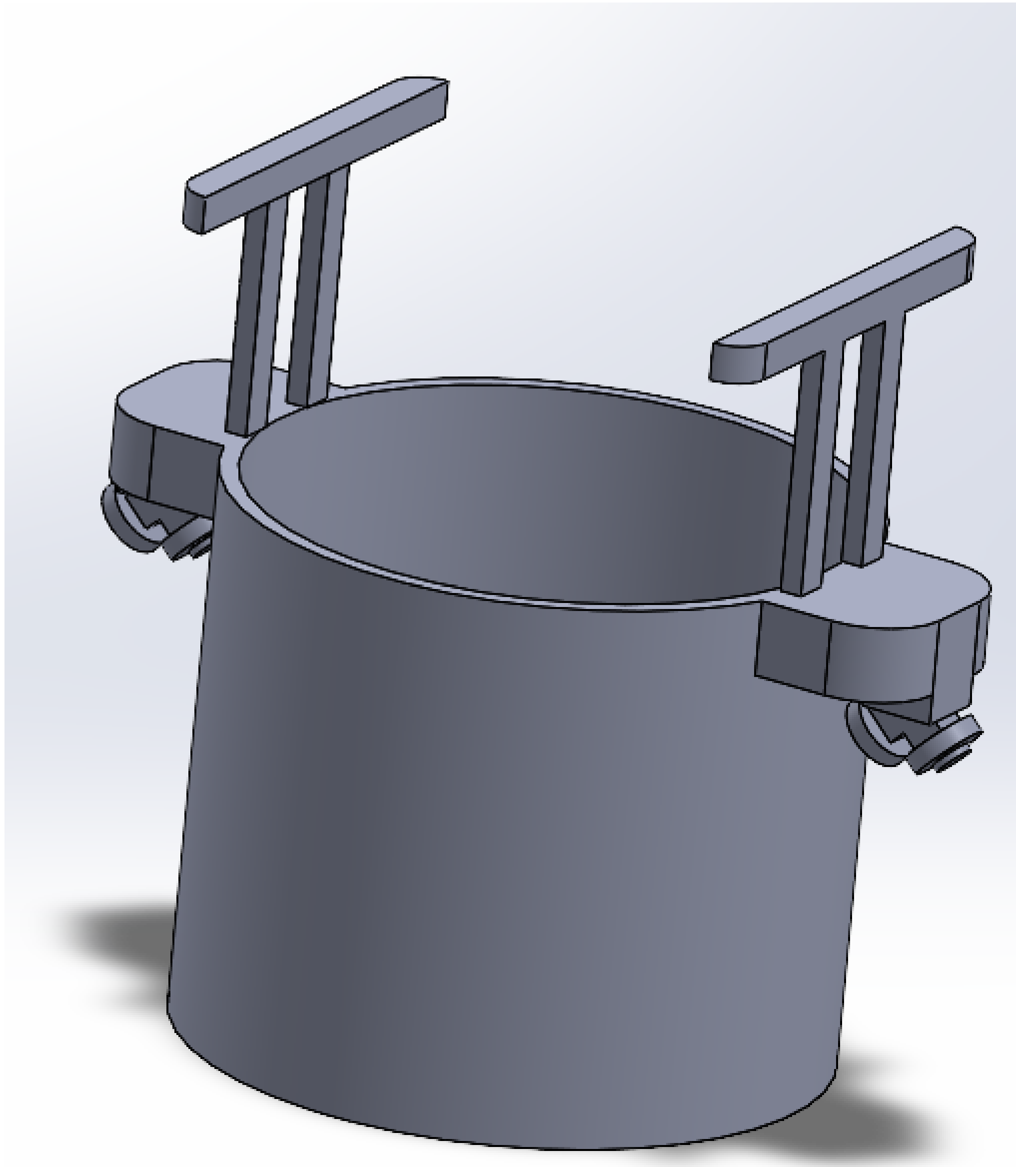





110

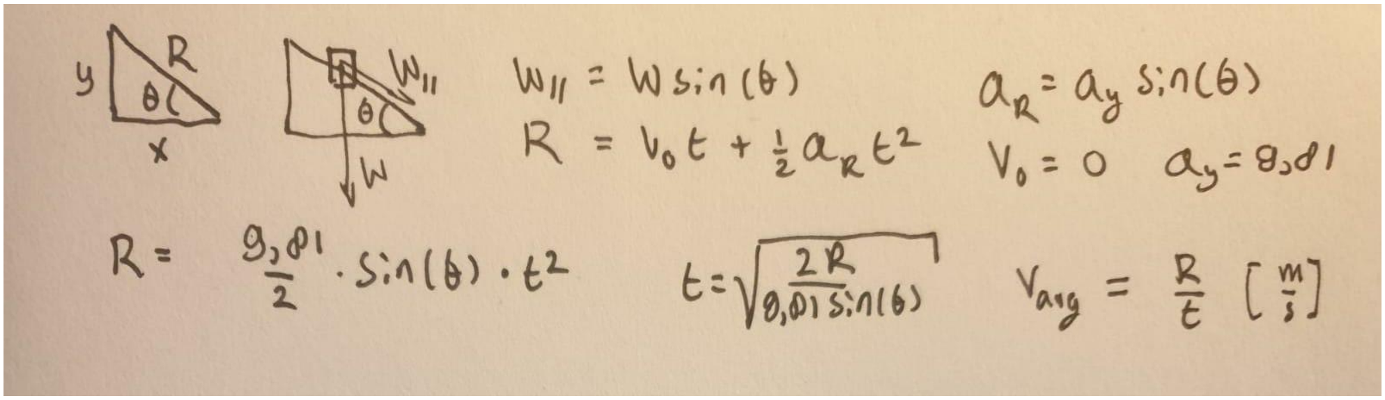


The cart



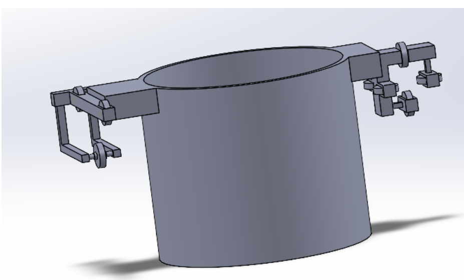
The cart transports all elements involved in the coffee making process: it starts high in the kinetic art machine and moves down, getting filled with milk, sugar, and finally real coffee. The cart has extrusions on its top which will activate the milk dispenser. These extrusions are slightly rounded on the front and back, making it easier for the handles of the milk dispenser to move away (or back) when they are hit. The cup can contain a maximum volume of 0.35 L, and slightly less when it hangs at an angle. The cart has a total mass of 86 grams using a density of 0.00112 kg/cm^2.

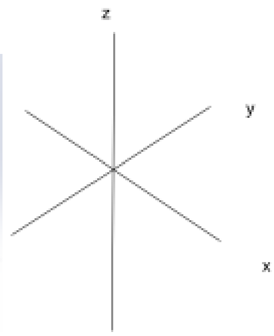
To make calculations to estimate the time it takes for the cart to travel a certain distance over the track, or the speed of the cart.

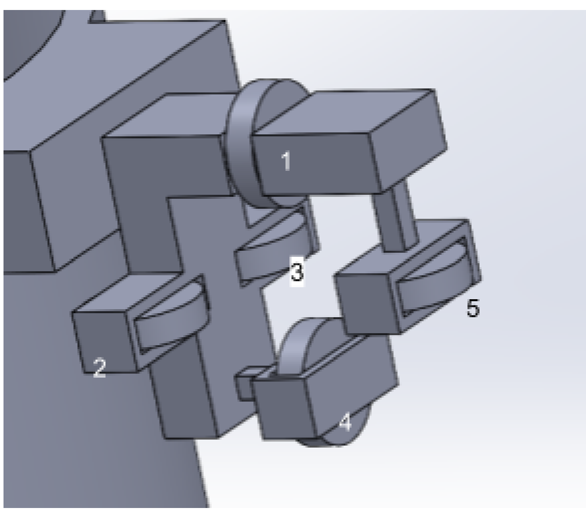


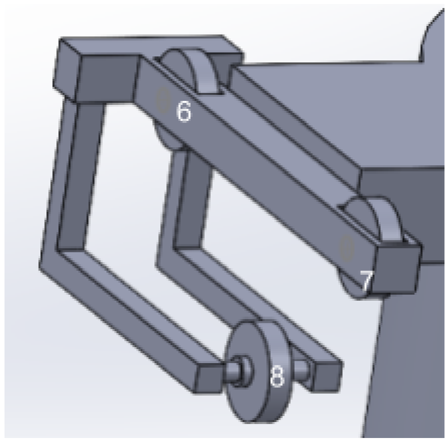
Exact constraint design

Originally, we expected that the card should make fairly complicated movements, which is why the original design was carefully limited in translational and rotational axes.







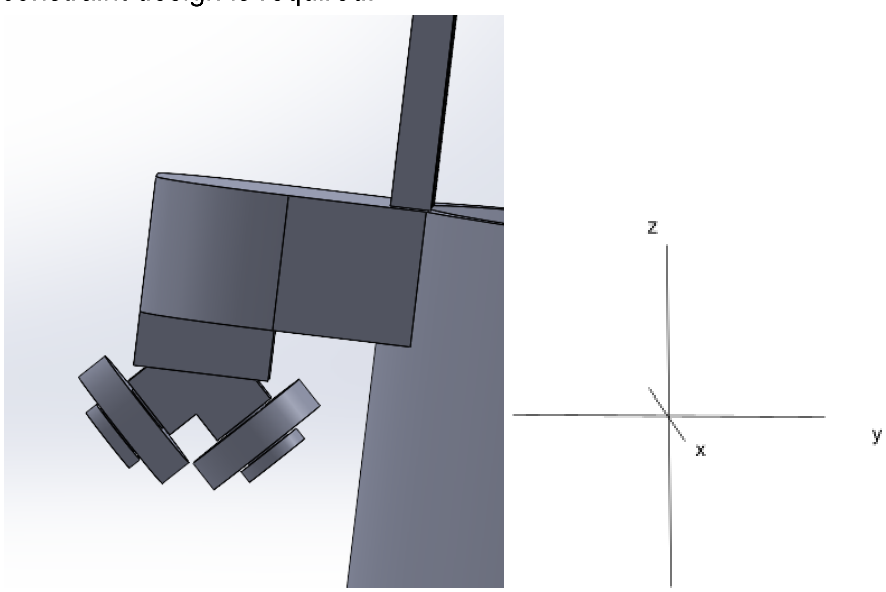


In this version, the following degrees of freedom were constrained:

- Y-translation is limited by wheels 2 or 3, combined with force closure of wheel 5
- Z-translation is limited by wheels 1 combined with force closure of wheel 4
- X-rotation is limited by wheels 6 and 7
- Y-rotation is limited by wheels 1 and 6 or 7
- Z-rotation is limited by wheels 2 and 3

This way, the cup would only be able to follow the direction of the track, being a translation in the X-direction.

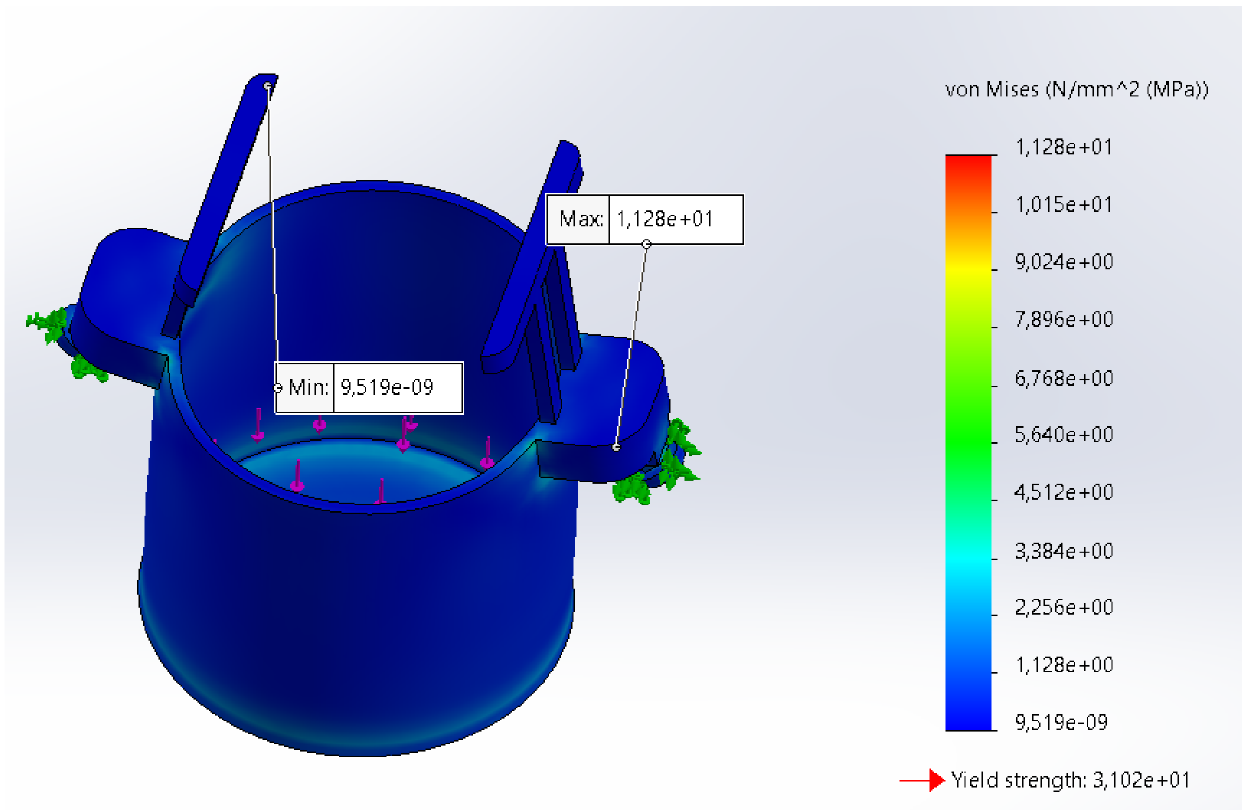
However, since the cup will only move forward and down, slightly less complicated exact constraint design is required:



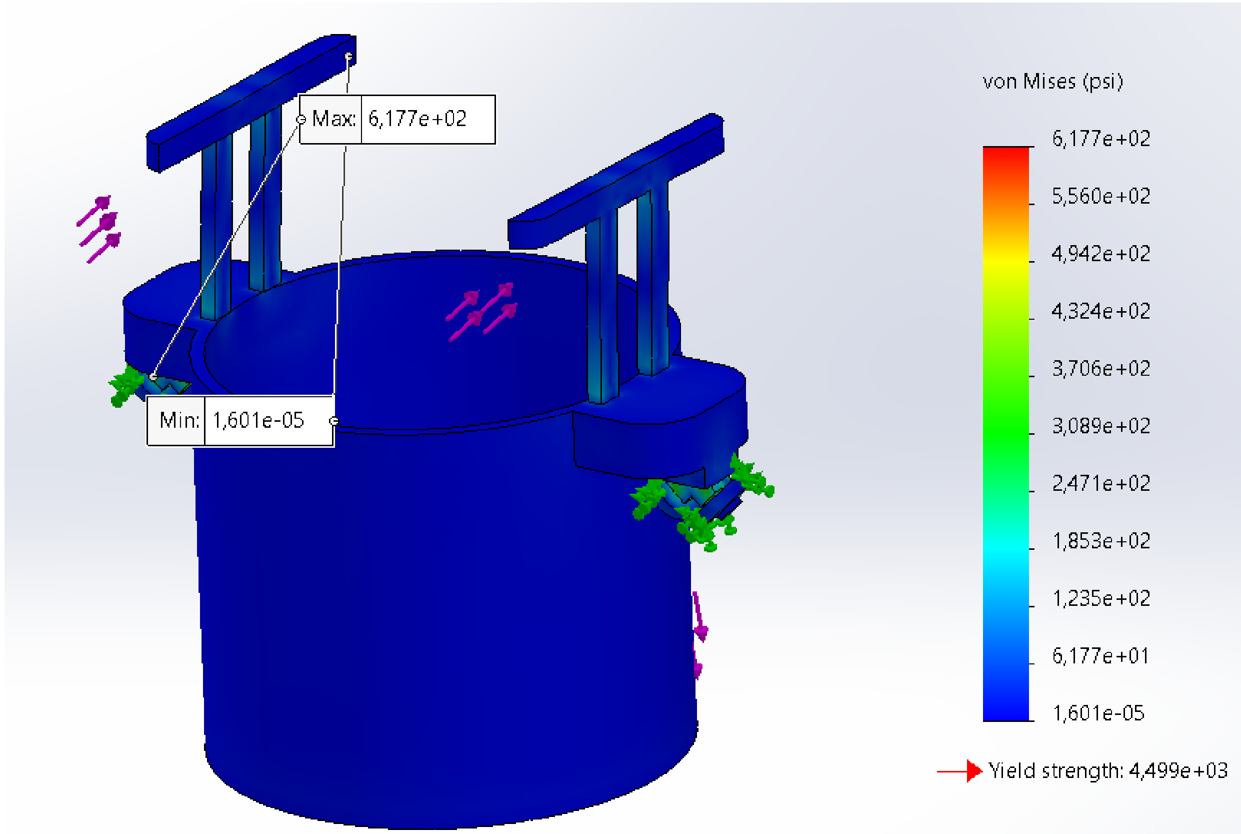
Both sides of the cup share the same system. Since the wheels are placed at a 45 degree angle to the track, both wheels limit Y-translation and Z-translation. Gravity ensures force closure. Since wheels are on both sides of the cup, X-rotation and Z-rotation is limited. Y-rotation is not limited, which is not required because the cup will not engage in complicated movements or experience large forces that could result in Y-rotation.

Stress analysis
What seems to be the most relevant stress is a result of the weight of the coffee on the inside of the cup. This results in a stress on the axes of the wheels. After having some small changes in the size of the axes and having added some additional materials near these axes, we can be certain the part will not break, even with much higher loads than we anticipate. This way, we can add additional weight to the cup to change certain forces in the system, as a means of experimentation or mechanical testing.

The following analysis has fixtures on the wheels of the cup, and different forces on the bottom of the cup. A force of 2.75 N, which would be the case if the cup is filled for 80 percent with water (or another material with a density similar to water), gives a factor of safety of 99.9923. A load of 100N, an extreme example, still results in a factor of safety of 2.74979. The picture below shows the von Mises stress plot, including the minimum and maximum stresses.

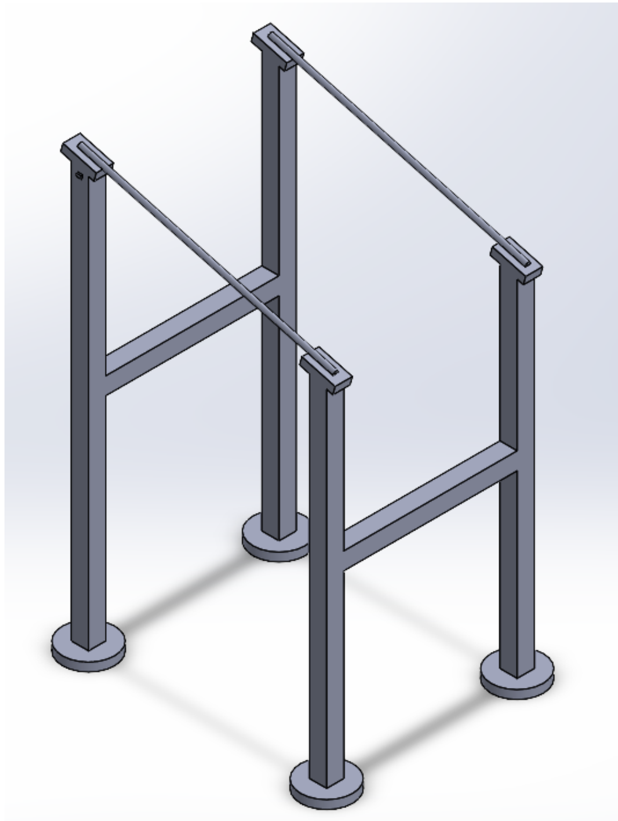
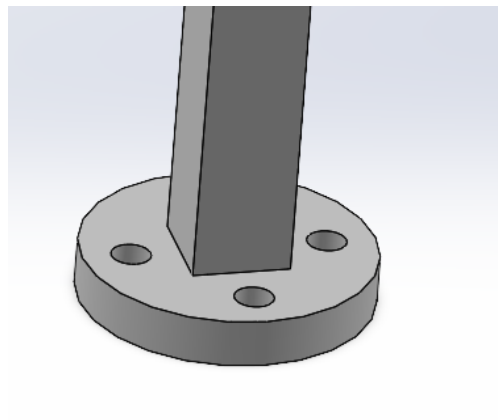


Another analysis has been conducted on the stresses that could exist on the extrusions on top of the cup, if it hits the milk dispenser. Since the milk handles in the milk dispenser will give in and move away when the cup hits them, these forces are likely to be lower than the ones we use for calculations. In addition, since the rotation around the Y-axis has not been fully limited, as has been explained above, the cup is more likely to translate the energy of a force into this rotational movement than in the failure of the extrusions. Still, we conducted this analysis with the previous force of 2.75N, this time both on the ground surface and the front on the extrusions, which is where the cup will hit the handles of the milk dispenser. These forces result in stresses on the pillars on top of the cup, but with a factor of safety of 7.77374 we can expect no danger of breaking these pillars. The picture below shows the von Mises stress plot, including the minimum and maximum stresses.



The track
The track defines the path of the cart. The supporting poles are 3D printed and use (contrary to many other parts of this kinetic art machine) regular ABS. The track itself is a ready-bought 3 mm diameter aluminium wire such as the one available at Vaessen Creative (n.d.).

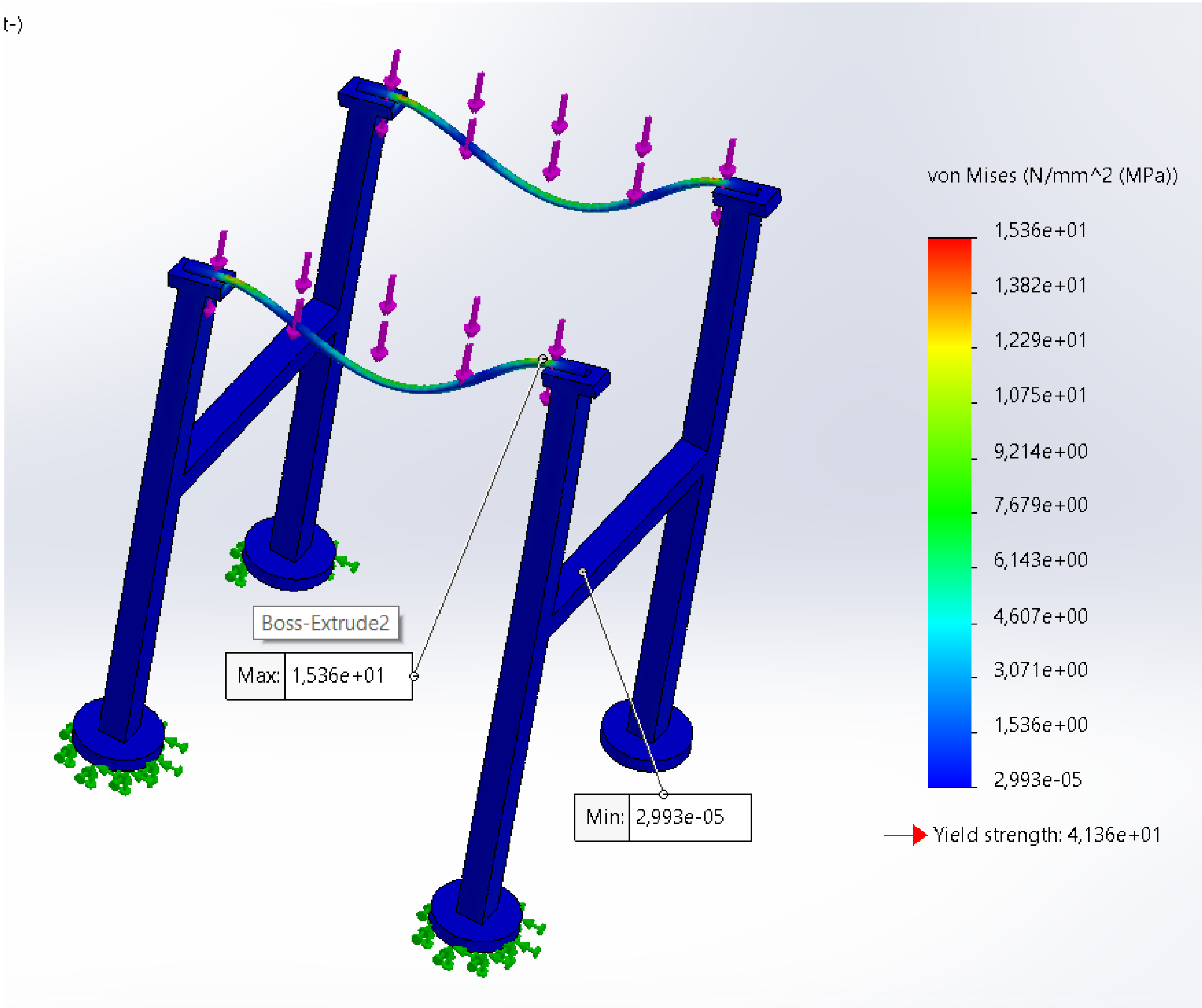
Exact constraint design
It is important that the track cannot move or rotate in any direction. These movements depend on the supporting poles of the track.

This picture shows a small part of the track to describe the constraints. Technically, the mechanical fastening using screws should restrict all degrees of freedom, as four 4 mm screws are used, which is more than required. Still, because large forces near the highest points of the poles would result in failure stresses we added bars between poles to increase impact resistance from the side and thus increase stability. In the other direction, the front, the poles are connected by the track which has a similar effect. These connections are helpful for the stress analysis. The combination of these connections and the mechanical fastening of the ABS poles to the wooden ground will ensure a stable track.

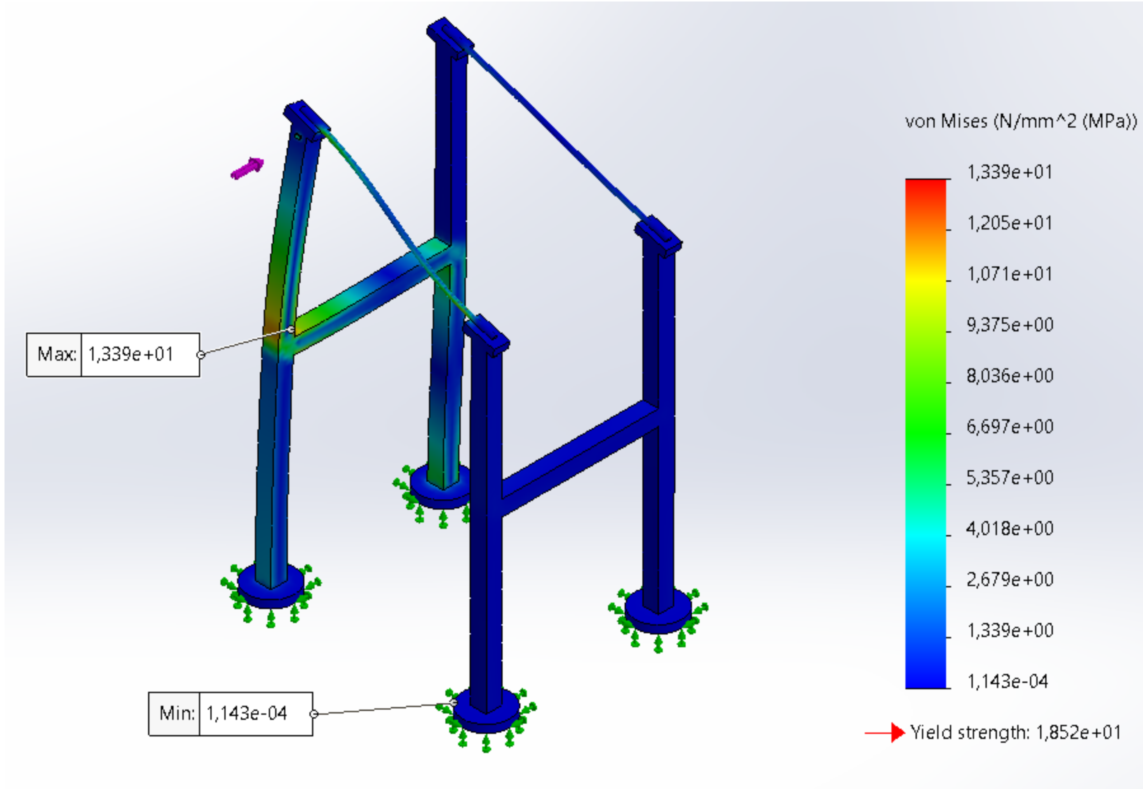
Stress analysis

The first analysis relates to the stress as a result of the cart resting on the track. The track differs slightly at different locations because of different heights and different angles of the track, but the factor of safety we found at the most dangerous part of the track was sufficient. In addition, it should be noted that the cart moves quickly over the track, so forces change very quickly. The poles have been fixed to the ground, and a force of 10N has been applied to the top of the track, resulting in a factor of safety of 2.69326. The minimum and maximum stresses can be found in the picture. For the material of this analysis, we used 3003 Aluminium alloy, which is the most common aluminium alloy, because we were not able to discover the exact aluminium type for the ready-bought aluminium wire (Montijo, 2022).

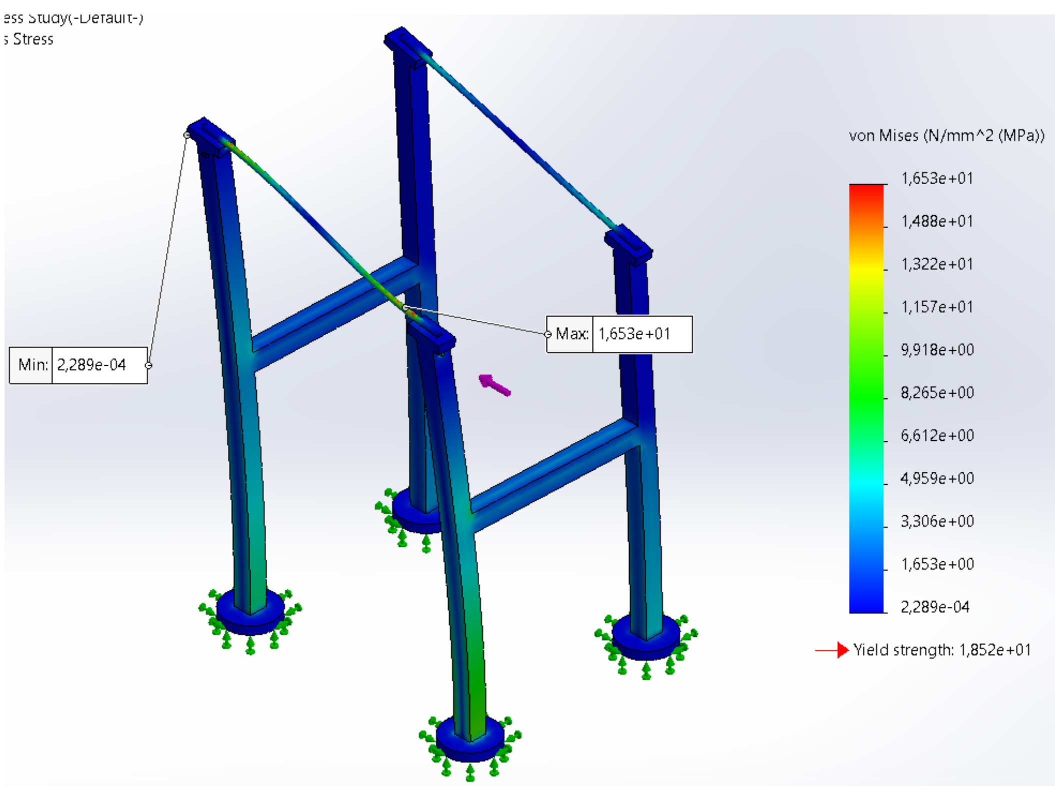


The final two analyses relate to any forces to the poles from the sides. We do not expect such forces, but it is important that the kinetic art machine is stable. Since this analysis aims to conduct research on the stability and possible failure of the poles, we used ABS for the required material properties. More specifically, we made the calculations using the lowest yield strength that can be expected from ABS (188.8 kgf/cm^2) according to Ashby (2020).

The following picture shows the von Mises stress as a result of a 20N force to the side of a pillar. The minimum factor of safety is 1.38244.



The following picture shows the von Mises stress as a result of a 20N force to the front of a pillar. The minimum factor of safety is 1.12008. Note that the highest stress is found on the track instead of the pillar. This track will not be printed, so we can expect somewhat better results.

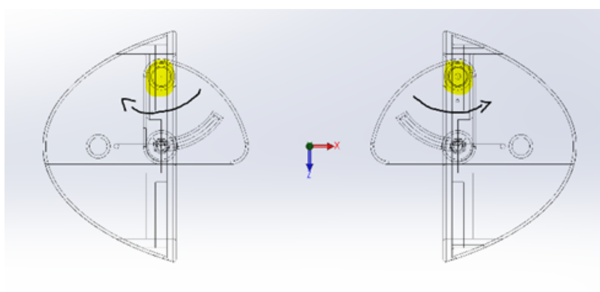


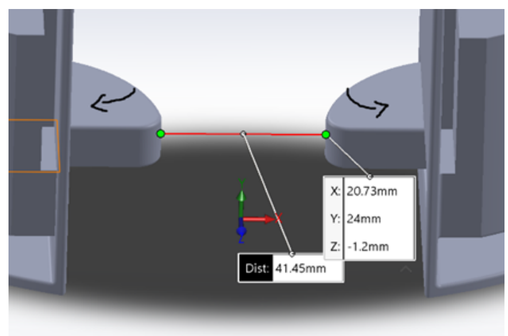
The milk dispenser:

The next step within making a cup of coffee is making sure some milk is added to the cup. The requirements for this component are that it has to pour milk when the cup is underneath the construction and has to stop pouring when it leaves. Furthermore, it should be set in motion by kinetic energy that has been generated earlier on in the machine.

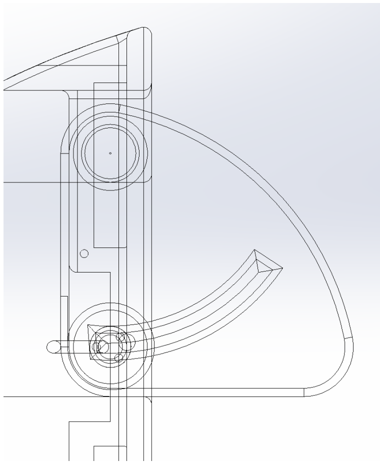
Step 1- the rotating plectra:

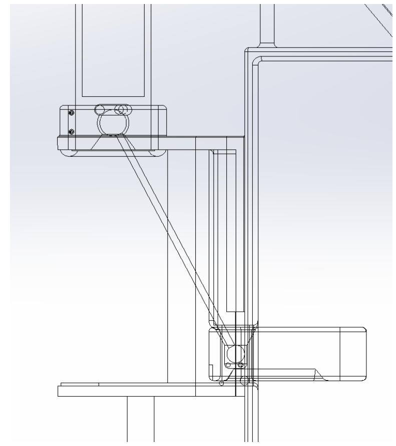
Within the final design the cup passes through the hole in the middle of the construction. The passage between the two cylinders is 41,45 mm while the rod that is above the cup has a width of 85 mm. Therefore it pushes the cylinders on both sides outwards for ((85-41,45)/2=) 21, 78 mm. It rotates around the axis that is highlighted in yellow enabling it to solely rotate around this point along the X- axis.





To enable this motion to run smoothly the plectrum moves on top of two spheres. This limits the resistance the plectrum gets from turning as it would other ways would experience resistance from the entire surface rubbing against the plane it is laying on. As the motion rolling experiences the least resistance I chose to integrate the spheres as the cup should be able to move through the gate as easily as possible. The first sphere runs in a triangular gutter that follows the rotation of the axis, this makes sure that the other side of the plane is also restrained to only follow this rotating motion. The small sphere in the middle supports the plane as the gravity is pressing it down against the lower plane, this sphere prevents this. The gravity makes sure the sphere is pushed down. The rot that is attached to the plectrum (mentioned in the next passage) pushes the plane down as well and limits it from turning further inwards when there is no cup present as the rod is stiff. As the rod can not be pulled out of its sockets it constraints the plectrum from moving into the opposite direction. It also limits it from rotating around the y- axis. Therefore the plectrum is constrained in 5 directions and can move only around the directed axis in this exact rotation and back.



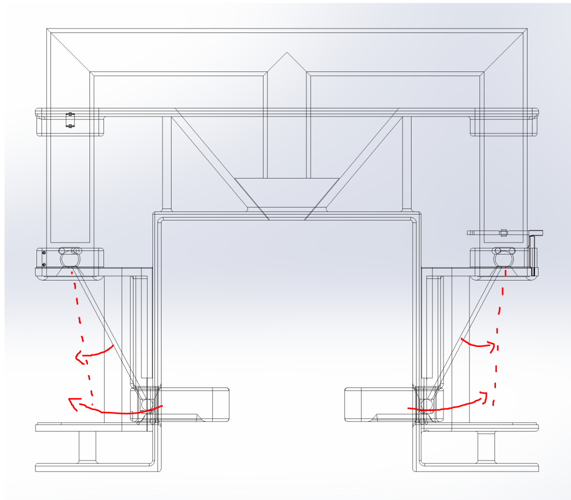


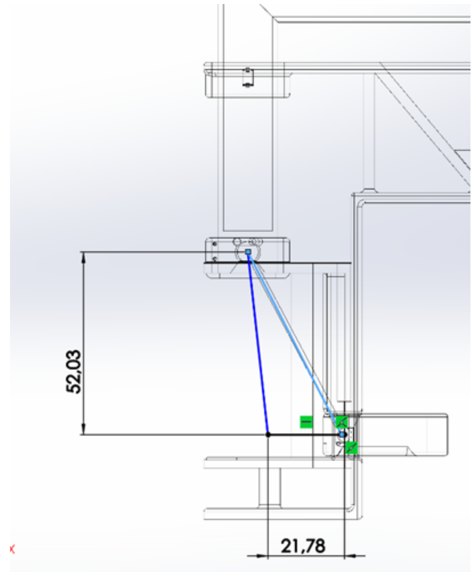
Step 2- pushing the rod into a nearly vertical position

In the plectrum a rod is attached to a brace at the top part of the construction. When the plectrum is being pushed outwards the place where the rod is attached moves inwards as well. Because of the outward motion the rod is being pushed in a more vertical position, which pushes the brace up. Because the rod is moved closer to the position underneath the brace the distance will get shorter. However as the rod is stiff it will push the brace upwards.

Earlier we determined that the plectrum is moving for 21,78 mm on both sides. Making sure that the rod does never end in a vertical position as the remaining angle enables the plectrum to be pushed back into its original position instantly as the cup is gone, so that it will stop pouring milk. In a vertical position the force of the gravity pushes the rod straight down not moving it back, the angle makes sure it will fall right back due to the weight of the brace.

The brace will be moved up 6,12 mm on each side. When the rod moves outwards for 21,78 mm (the back sketch line) the rod will change position from the light blue line to the dark blue line. Within the first position (light blue line) the rod had 58,46 mm space from sphere center to center while within the latter position (the dark blue line) it only had 52,34 mm of space, making the rod push up the brace for (58,46-52,34 =) 6,12 mm on each side. Giving the milk 6,12 mm space to leak through.

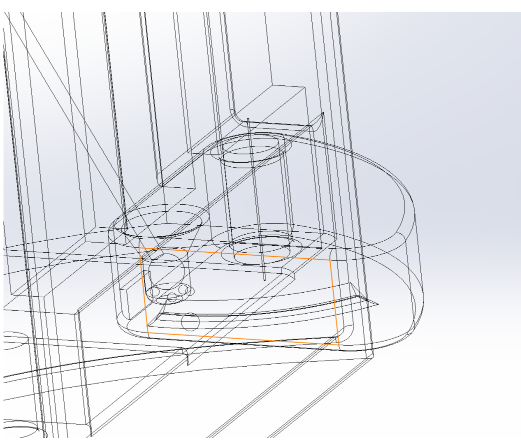


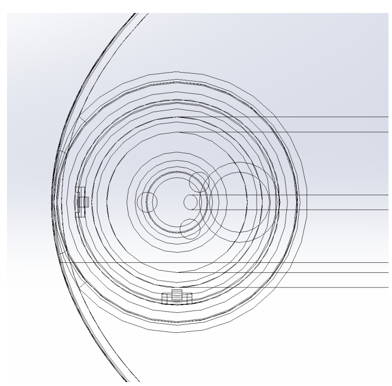


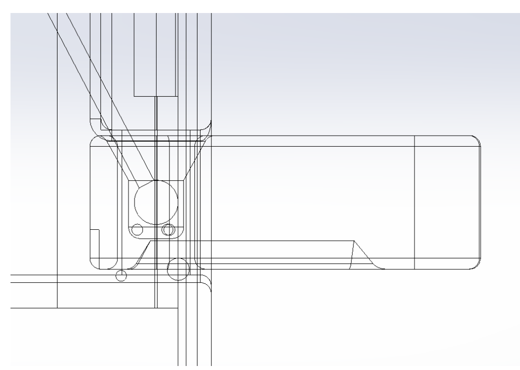
The joints of the rod:

The rod is attached to both the plectrum and the brace by joints. The plectrum moves in a circular motion while the brace solely moves up and down. Therefore the joints must be able to move freely in the horizontal plane. Therefore the rod has a sphere on both ends which rotates on top of three spheres which lie in a triangular shape to guide the rotation and limit the resistance.

On the bottom the gravity in combination with the force that the rot pushes down when the plectrum is moved make sure that the little spheres stay in place underneath the bigger sphere. Because of the restraints within the turning motion of the plectrum the joint motion is restrained as well. A cut out is made to make sure the rod has enough space to move around yet it is

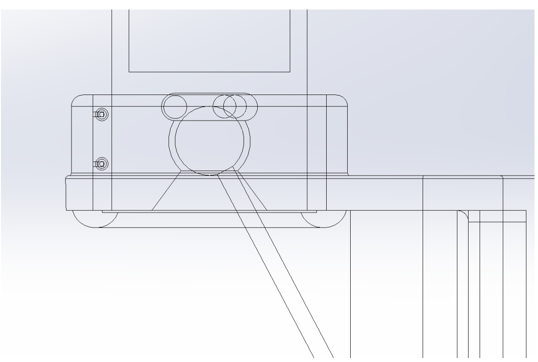


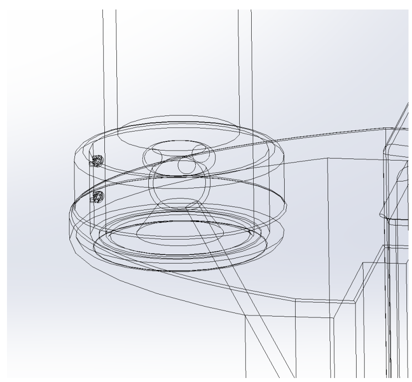


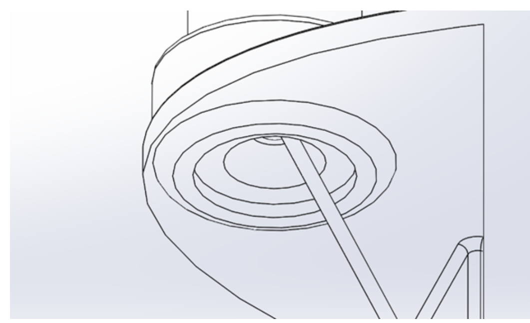


limited to fall back into a bigger angle as the rod lies on the cut out as it is in its most outer position. Because the plectrum is already constrained and the joint lies in this solid the motions from the joint are already set.

The joint that lies within the brace does not have the advantage that the gravity pushes all the spheres in place. However when the plectrum is in motion the rod pushes the attached sphere upwards pushing it against the smaller spheres in place. Therefore a constraint should be made that makes sure that the supporting spheres stay in place when the rod is not in motion and in 'relaxed' position. Therefore this shape differs from the one in the plectrum as it is 'tight' around the bigger sphere as this makes sure that the 3 remaining spheres stay in place when there is no force applied. The spacing is big enough to make sure that the sphere can still move freely yet there is no room for the other spheres to fall through. The space for the smaller spheres is quite open so that these can turn 'freely' with as little resistance as possible to make the motion as easy as possible for the cup to start off.







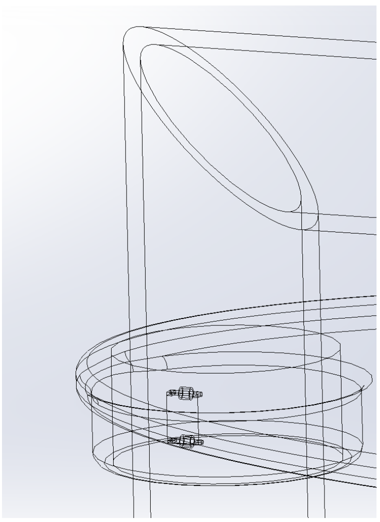
Step 3- the brace moving vertically

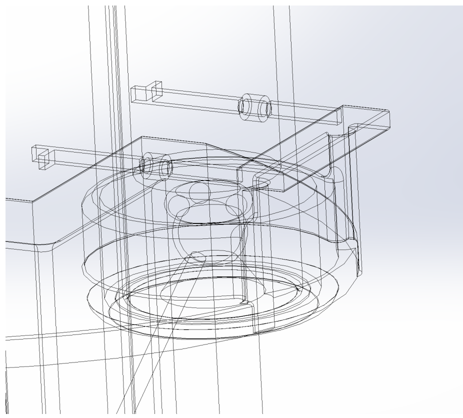
To make sure that the brace will not get jammed because it is over-constrained it lies lose except for a small ring at the end of the tube to make sure that the brace does not fall any further down when the cup is gone. Therefore the plectrum cannot move in the wrong direction. To constrain the brace further two pairs of wheels and a clamp with wheels have been added.

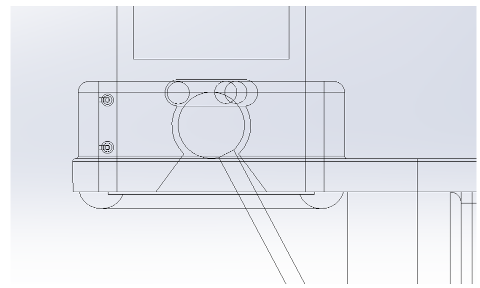
The two sets of wheels at the top and bottom of the brace make sure that the brace can not move in the x direction because the rod already applies a force to the outside the brace will be pressed against those wheels. The rod that is connected to the plectrum constrains the brace from turning over the y axis in a way that the brace does not lie parallel anymore. The clamp on the right is added to constrain the brace from turning over the x axis. The two sets of wheels on the left make sure that the brace is only able to move up and down. Therefore 5 degrees of movement have been constrained.

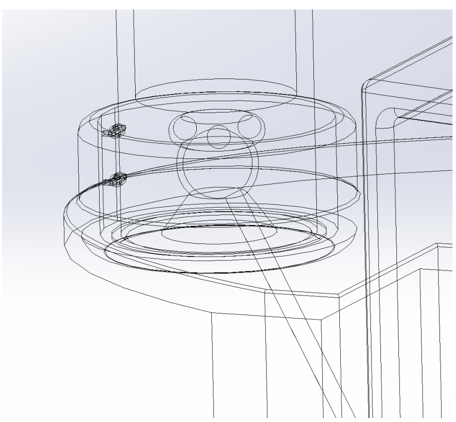
The force for the clamp is applied by an elastic band that will be applied between the two projections on the end. The two rods that the wheels are attached to function as a spring as they are way thinner and are therefore able to bend.

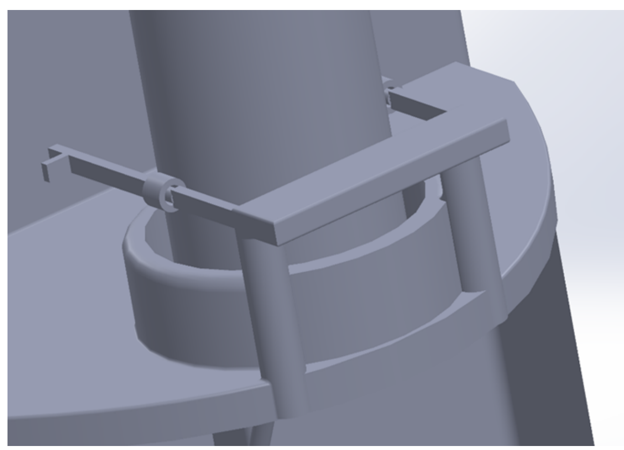
When the brace returns to its initial position it will land back on a small ring to make sure that it can not fall further down than its starting position. From here to brace can only move upwards in the y direction to lift the attached stop that is preventing the milk from spilling through.

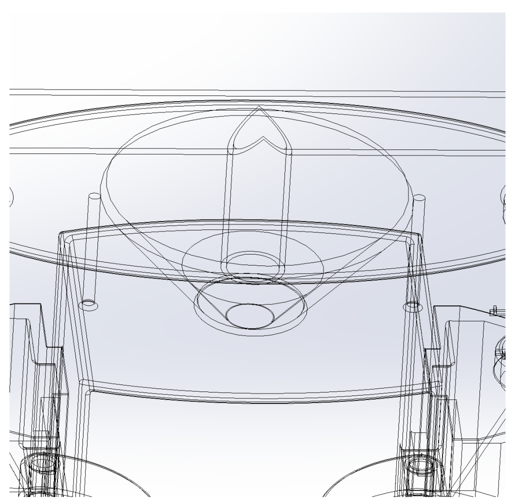








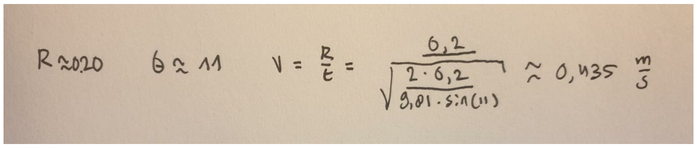




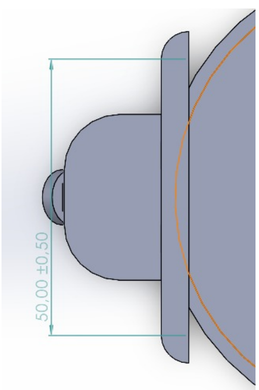
Step 4- Pouring out the milk

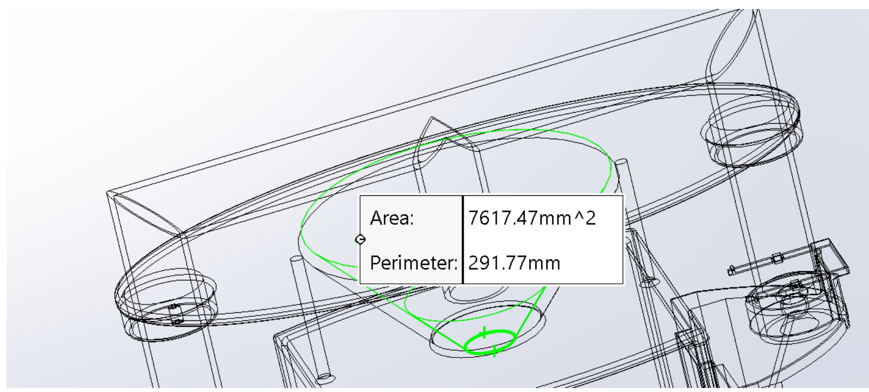
When the brace moves upwards the plug gets lifted out of the milk and an opening appears for the milk to spill through. The plus is that it falls perfectly with the resevoir for the milk, because of the weight of the milk non will spill through the sides, it will be pressed perfectly in place. Because of the weight of the brace it will drop back down when the cup has passed by.

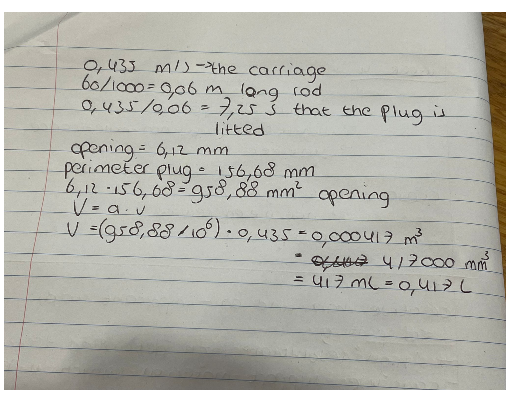
The amount of milk that will land in the cup depends on the speed of the cup on its carriage.

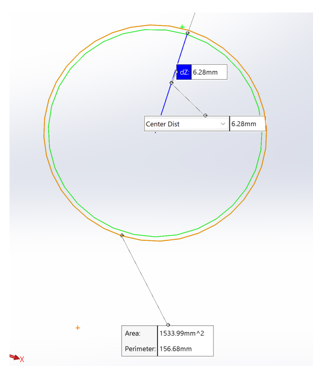


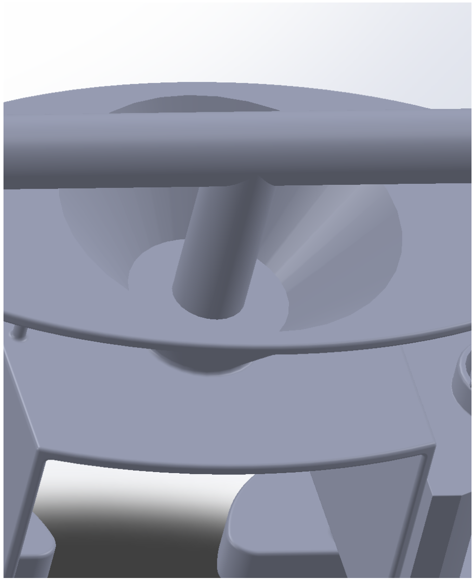
The speed of the cup is 0,435 m/s as has been calculated below. The opening for the milk is 6,12 mm as has been mentioned before. The rod that pushes the plectra to the side is 60 mm in total. So in the calculation below the released amount of milk is 0,417 L. However the rounded sides of the rod have been taken into account as well as this distance is required to open and close the plug again therefore the calculations are not exact. The released amount is therefore less. With a volume of 291,77 mm2 which is 0,291L. Therefore the user can determine the amount of milk in the coffee by the volume they put in the reservoir as all of it will land in the cup.

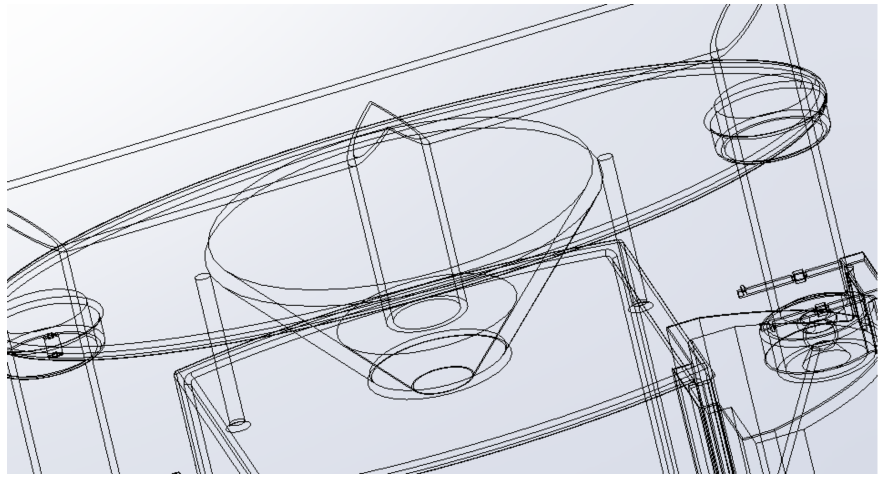


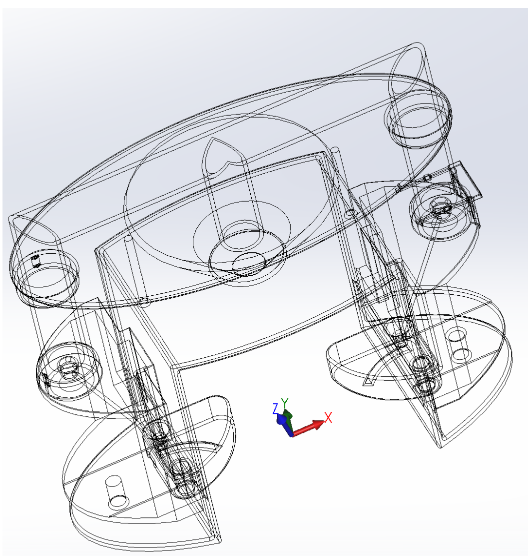


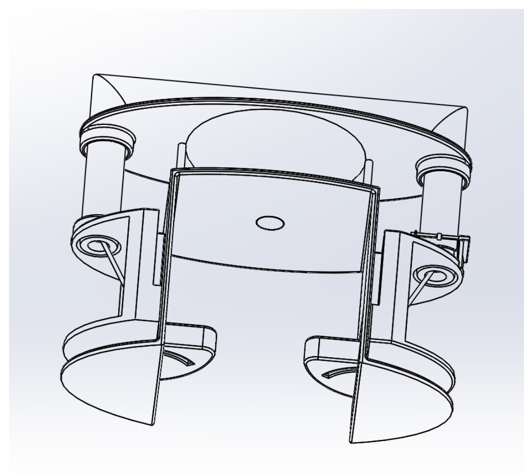




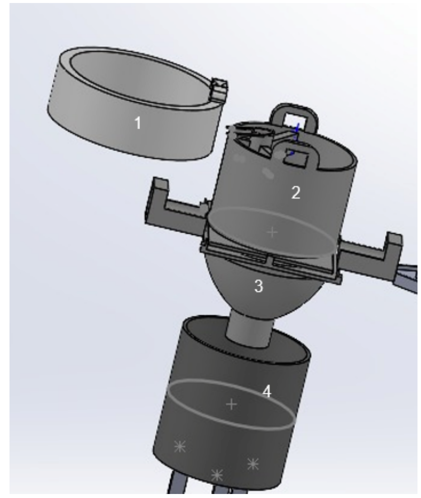





Z
Y
X



The process of making coffee



A part of the kinetic art machine is the process of making coffee. This part of the machine consists of four parts: the water basin (1), basin 1 (2), the funnel (3) and basin 2 (4). Hot water will be poured into the water basin and from this component the water will flow all the way down to basin 2, in which the coffee will be made. Almost every component contains a part that will start to move due to the touch or force of another component.
In this section each component is explained. Each component contains a detailed description of the function, design decisions, exact constraint design and analyses of the parts.

Water basin:
The amount of hot water that will be used in this process is 0.25 L.
The first component of the process of making the coffee is the water basin. This basin is necessary for measuring the amount of boiling water that will be used in this process. There will be a measuring line on the basin itself to measure the amount. Because we first need to measure the amount of water, the water should not immediately flow to the next component. That is why there is a slider (9) in the aperture. This slider will go upwards due to the cup that will move below the rails. A rope will go through two holes (see numbers 1 and 2) and will be tightened with a knot, so that the rope does not slip through the holes. The rest of the rope will go through the next hole that's indicated with number 3. Now the rope will arrive at the plate (figures 2 and 3) which includes the block that will be pushed off the plate by the cup. The rope will go through the hole indicated with number 8. Via hole number 4 and 5, the rope will be tightened around the block that is placed on a plate. The cup will move in the direction of number 6 to 7, so the block will be touched and pushed off the plate. The mass of the block (3,32 grams) is greater than the mass of the slider (1,64 grams), which results in the slider moving upwards. It has the same concept as a pulley.

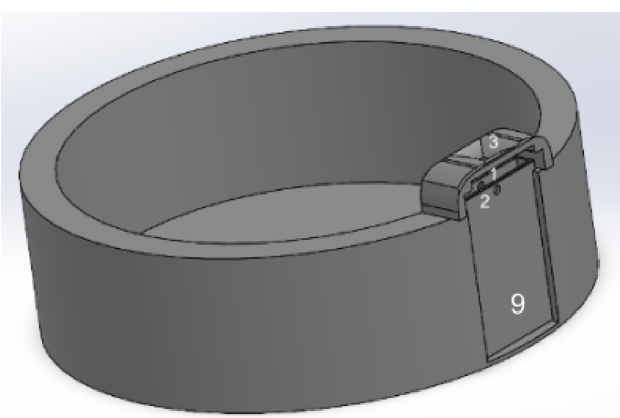


Figure 1

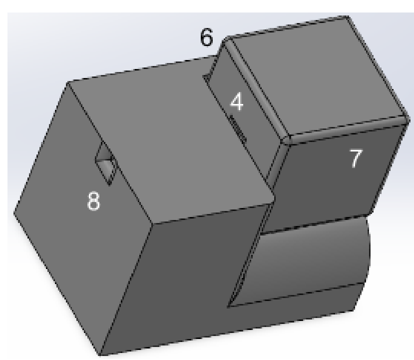


Figure 2

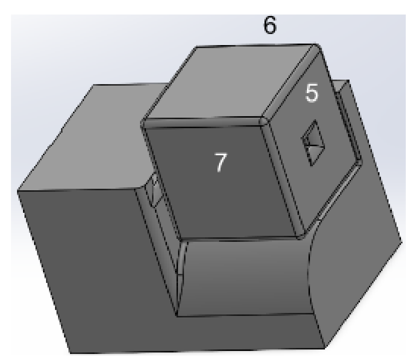
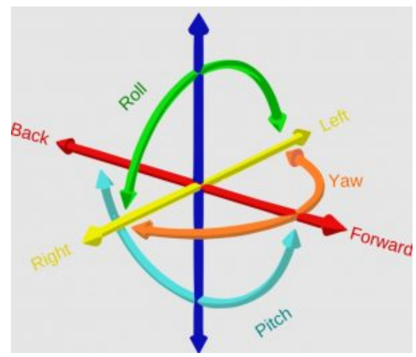


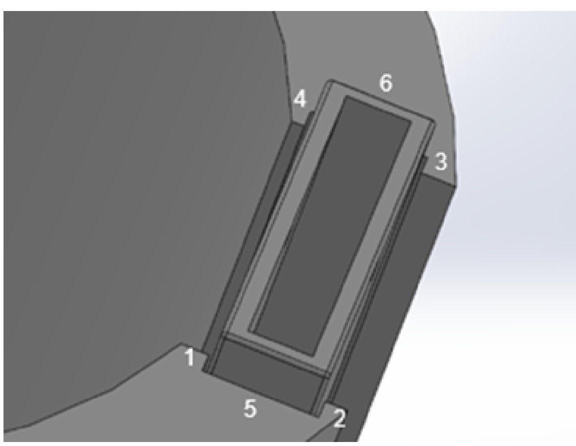
Figure 3

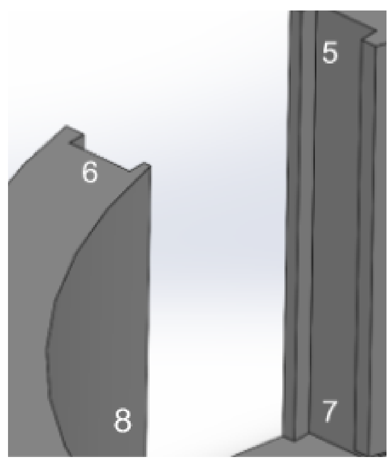
We made an oblique plane to direct the water to the slider. Now that the slider has moved upwards, the water flows to the next component.
To prevent that the slider will move completely out of the aperture, we made a support above the slider. Now it's only possible for the slider to move upwards a distance of 2.8 mm. This distance should be limited, because the bigger the distance, the higher the chance will be that the pipe (which transports the water from the water basin to the next basin) will overflow.
The only problem that can occur in this part, is that a little water may flow past the slider. There needs to be a bit of space between the slider and the edge of the basin, otherwise the slider will get stuck. We have thought about a system that opens the slider due to the force of the water. However, with that system, the principle of measuring the amount of water doesn't exist anymore, because the water will immediately flow through the aperture.

Exact constraint design is being implemented at the design of the slider. The slider is only allowed to move up and down. So all rotational degrees should be limited. The slider is in between four edges (indicated by numbers 1 until 4). The edges of number 1 and 4 limit the rotation in the 'yaw' and 'pitch' direction combined with force closure of the edges indicated with number 2 and 3. Those edges 1 and 4 also limit the translation to the back combined with force closure of the edges 2 and 3. The edges on the left side of the slider (indicated by numbers 5 and 7) limit the rotation in the 'roll' direction and the translation to the left combined with the force closure of number 6 and 8.

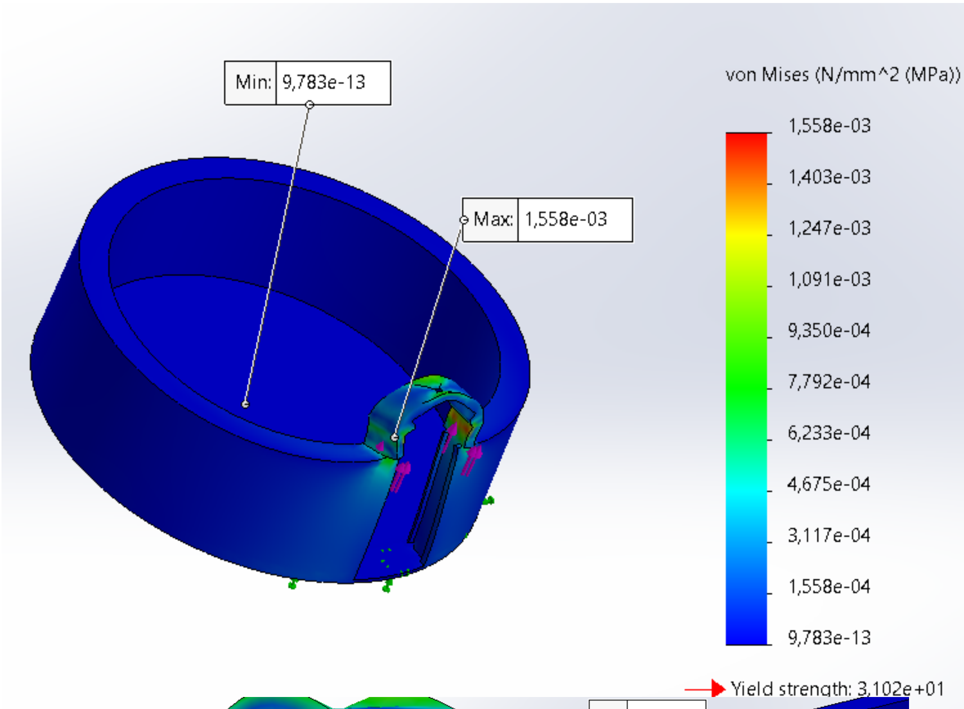


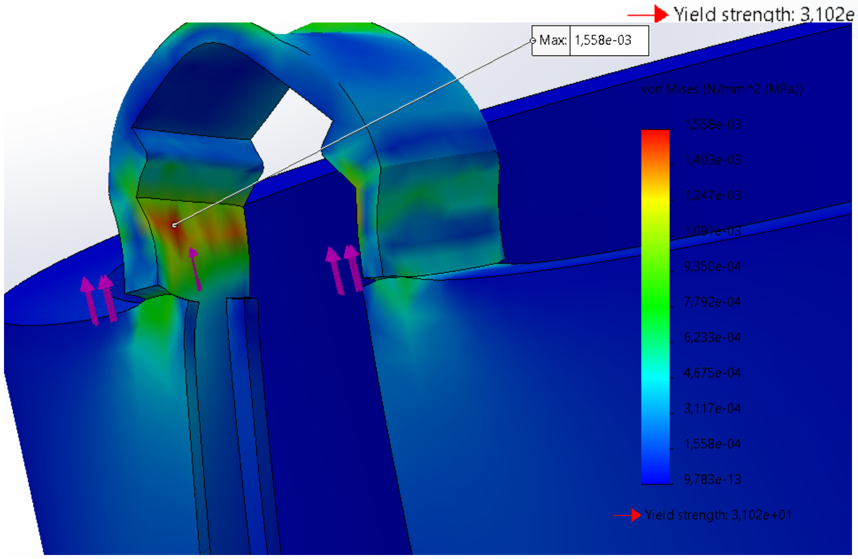
(Kumar, 2022)

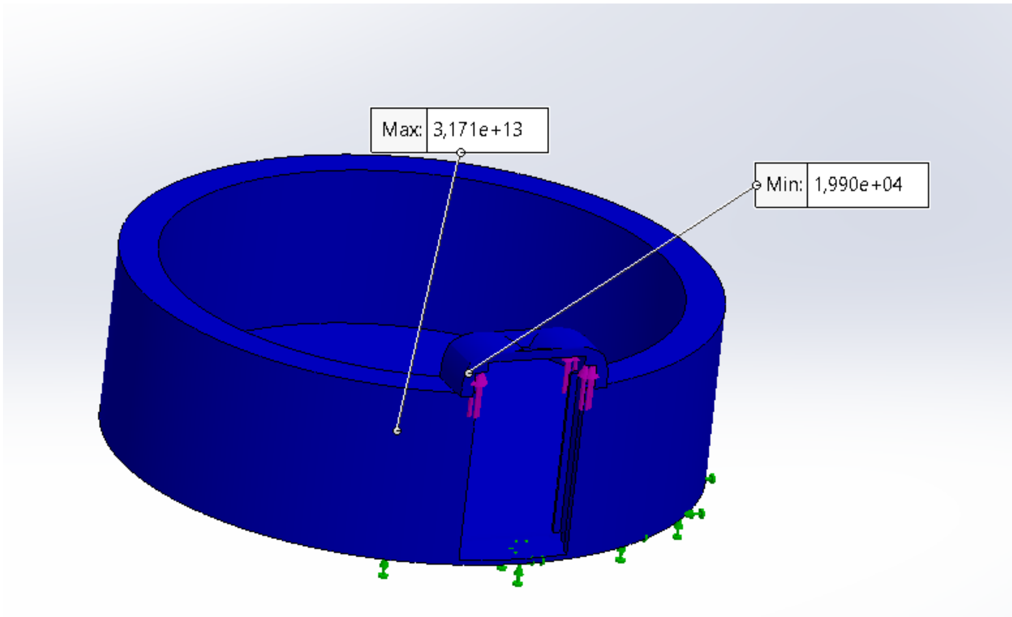




The support above the slider must be able to handle the force of the slider. The force of the slider is equal to: mass slider x 9,81 = 1,64 x 10^{-3} x 9,81 = 1,61 x 10^{-2} Newton. We minimalized the maximal stress of the support. In the beginning, the support was smaller than the edge of the basin. In this case the maximal stress was 2,628 x 10^{-3} MPa. To overcome this problem we thickened the support. That resulted in a maximal stress of 1,558 x 10^{-3} MPa (see figures below). We tried to use fillets on the inside corner where the slider will hit the support, but that resulted in a greater maximal stress, namely 2,437 x 10^{-3} MPa.

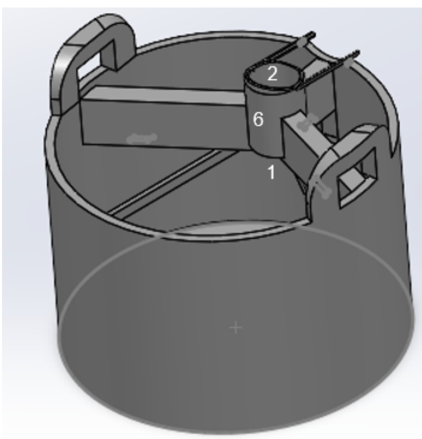


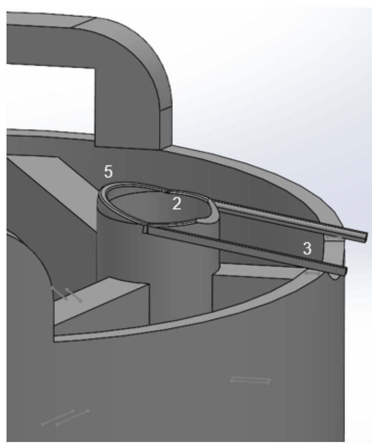


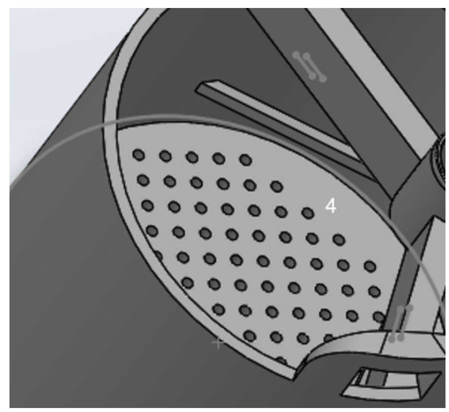


These show the minimal and maximal Factor of Safety (FOS). The minimal FOS is 1,990 x 10^4 so the support won't break.

Basin 1:
The next component is basin 1. The purpose of this basin is to stimulate the next part, the funnel, so that the water can flow through.
The water will flow through the pipe from the water basin to basin 1. The basin includes: filter (4), cylinder (6), ping pong ball with a pin and a marble. There is a ping pong ball, with a pin in it, underneath the cylinder indicated with number 1. Due to the water that flows in the basin, the ping pong ball will float (in the direction from number 1 to 2). That results in the pin touching the marble, which rests on top of the cylinder, indicated with number 2. The marble will move in the direction of the rails (3). A deformable tube will be connected onto the rails, so that the marble will reach the funnel. The marble causes a part of the funnel to move.
There is a filter in the basin (4), however the water will not immediately flow to the funnel. The funnel contains a moveable filter. The filter of the funnel is placed 2.5 mm to the right. This ensures the water will not flow to the funnel immediately. The water needs to wait until the funnel's filter is placed right underneath the filter of basin 1. The marble will cause the appropriate placement of the filter. When the marble reaches the funnel and pushes the filter, the filter will move 2.5 mm to the left, so that the holes of the filters are underneath each other. Now the water will continue flowing.





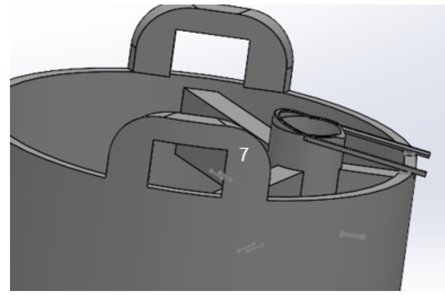


The cylinder needs to be smaller than the marble for the system to work. The marble is 16 mm in diameter so a cylinder of 13 mm is used. The cylinder also contains an oblique plane (5) that ensures that the marble will move towards the rails (3).

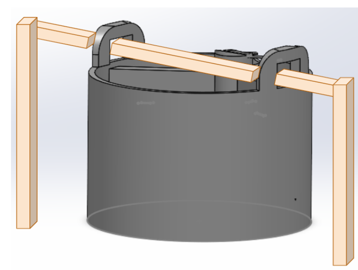
The distance from the cylinder to the bottom of the basin should be as short as possible. This to ensure that the ping pong ball, with the pin in it, does not slide underneath the cylinder and float somewhere else in the basin. The ping pong ball has a diameter of 40 mm, so the distance should be at least 40 mm. However, the ball needs to be able to float somewhat, so the distance should not be exactly 40 mm. That is why the distance is 42,5 mm. The ping pong ball can float 2,5 mm to touch the marble.
Besides that, the distance from the middle of the cylinder to the side of the basin should be at least 20 mm, because of the radius of the ping pong ball (20 mm). The ball with the pin in it should be located in the middle of the cylinder to pass force to the marble. If the distance is

smaller than 20 mm, the pin in the ball will make a slanted angle and the pin will not fit in the cylinder. That is not the intention.

The cylinder will be placed between three supporting plates. The forces of the cylinder will now divide itself over those plates. We needed to take into account that the force that will be divided, is not only from the cylinder itself, but also the marble that rests on the cylinder. The force that will be divided is the following: (mass cylinder + mass marble) x 9,81 = (1,04 x 10^{-3} + 6,00 x 10^{-3}) x 9.81 = 6,91 x 10^{-2} Newton.

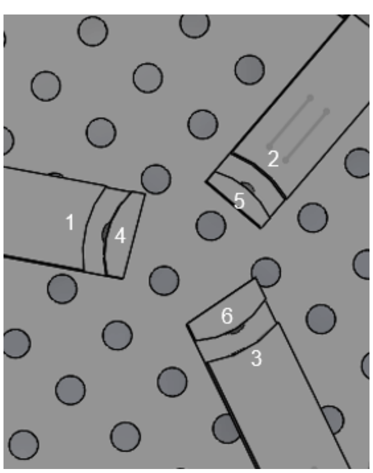


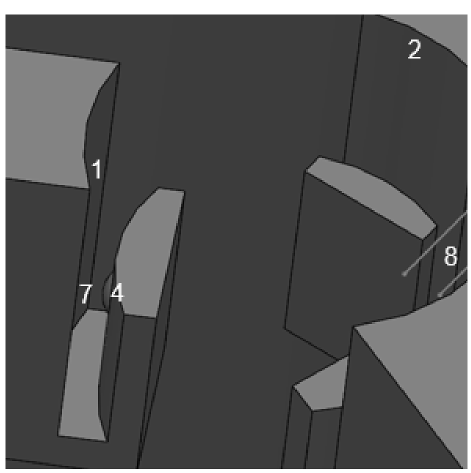
At first we only made one supporting plate, but that resulted in the cylinder being imbalanced. However, for the future, we could have made the cylinder in the middle of the basin, so that the basin is also in balance. Right now, the basin is a bit imbalanced, because the mass on the right side is greater than the left side. That also verifies the place of our maximal stress that is pointed at number 6 (also see the figure of the maximal stress on the next page).

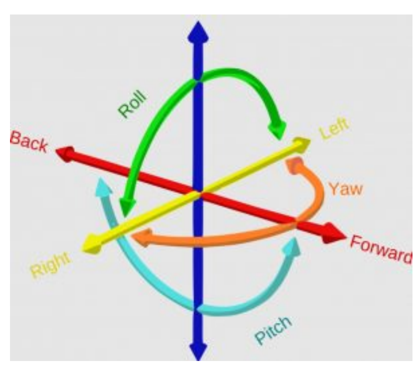


The basin also consists of two handles. Those are necessary for installing the basin to the plate, to which everything is attached. The frame is made out of wood and has the concept that is shown in the figure on the right.

Exact constraint design is being implemented by designing the cylinder to fit onto the support plates. One requirement is that the cylinder must be able to pull out of the support plates, because the pin that is placed in the ping pong ball should be located in the cylinder. Due to the small distance from the cylinder to the bottom of the basin, you can not place the pin into the cylinder when the cylinder is stuck in between the support plates.
In short, the cylinder is only allowed to move up and down. The cylinder is located between six edges indicated with numbers 1 until 6. The small plate with the sphere in it, will behave as a spring, due to its difference in length with the rest of the support plate. As a result the cylinder is pushed towards the edge indicated with numbers 1, 2 and 3. So the edges 1 and 7 limit the translation back and forth and the 'yaw' rotation, combined with the force closure of the spring (4). The edges 2 and 8 limit the translation to the right combined with the force closure of 5. The edges 1, 2 and 3 limit the rotation in the 'roll' and 'pitch' direction combined with the force closure of 4, 5 and 6.

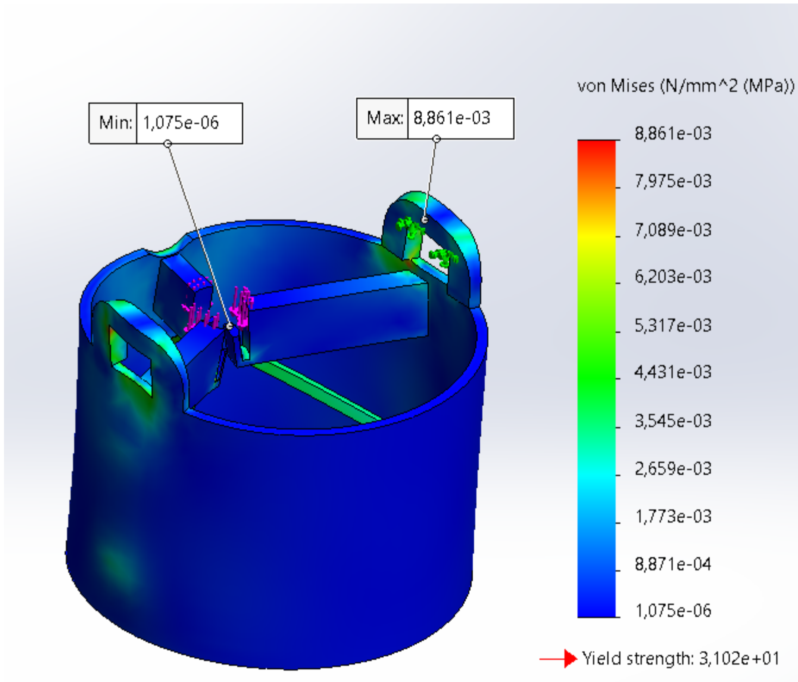


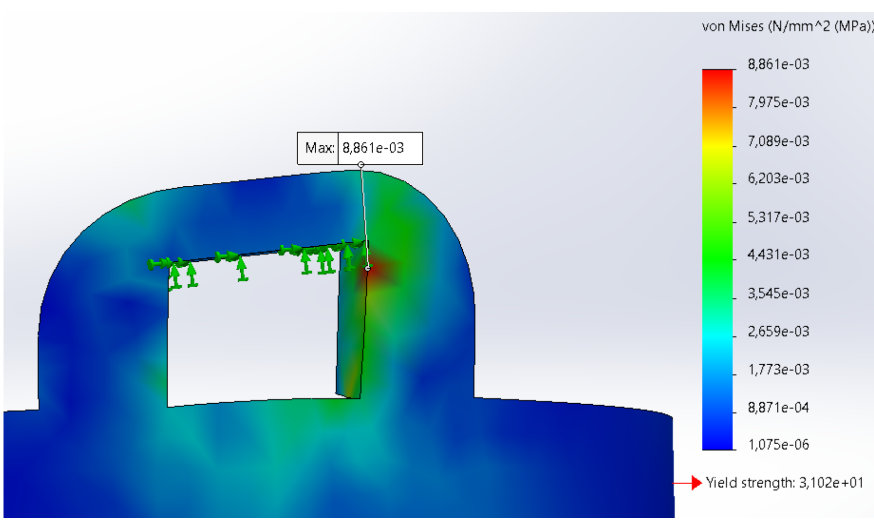


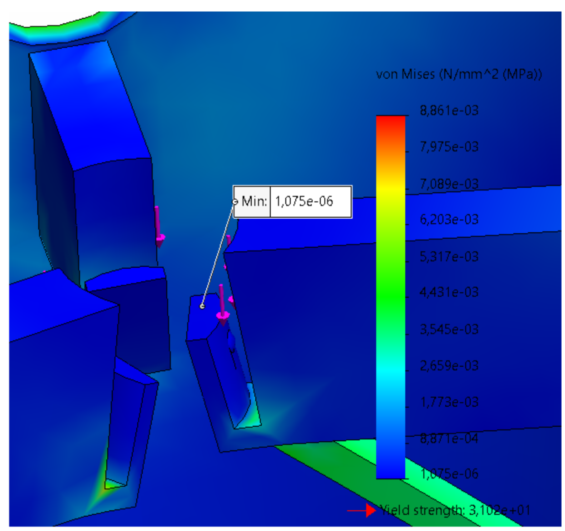


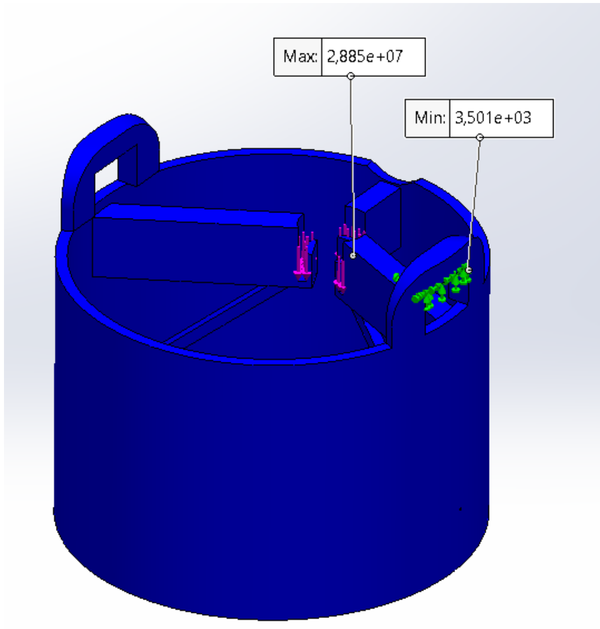
(Kumar, 2022)

The support plates need to be able to handle the force of the cylinder and the marble. That force is equal to: When measuring the maximal stress, the maximal stress is located at one of the handles. As explained before, it is a result of the imbalance of the basin due to mass differences. The maximal stress is 8,861 x 10^{-3} MPa. The handles had the same width as the edge of the basin in the beginning. The maximal stress was 1,434 x 10^{-2} MPa in that situation. To minimalize this stress, we thickened the handles and the plates indicated in green in the figure below That resulted in the maximal stress of 8,861 x 10^{-3} MPa.



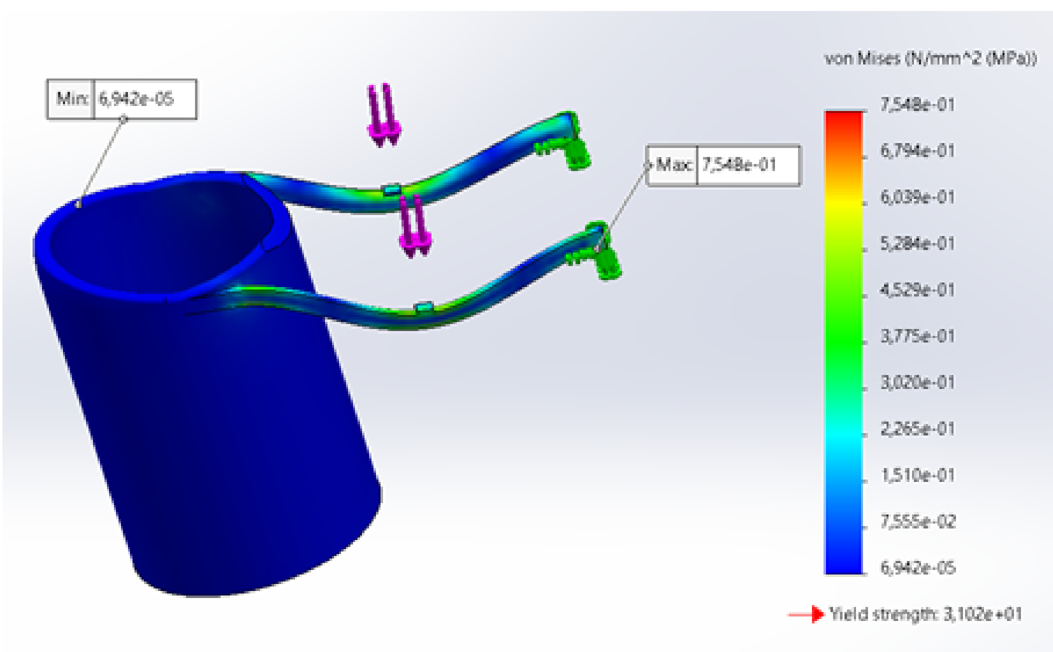


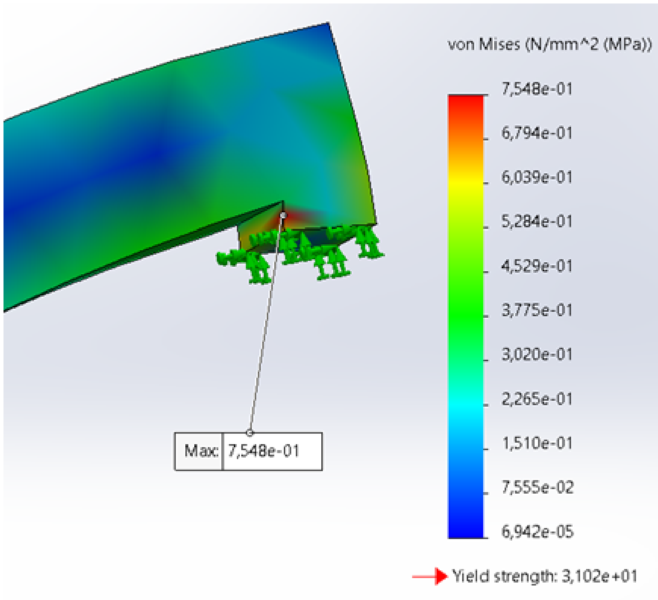


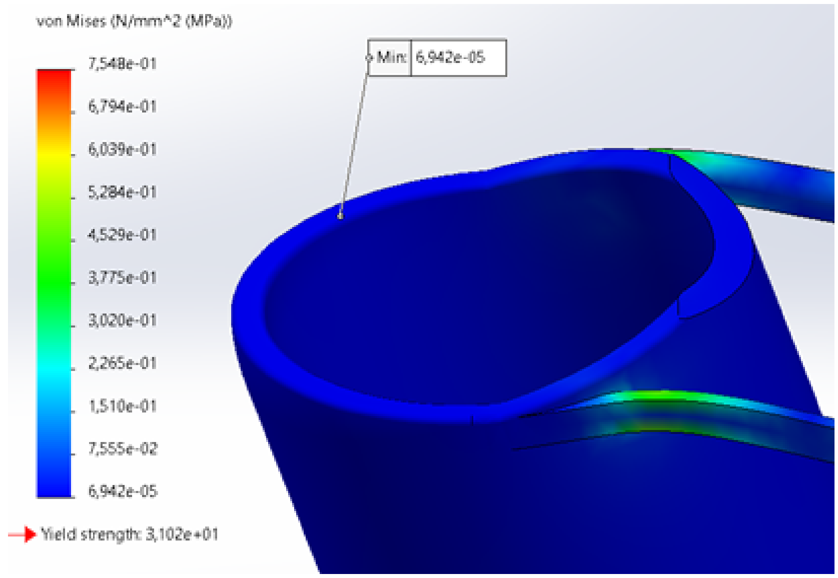


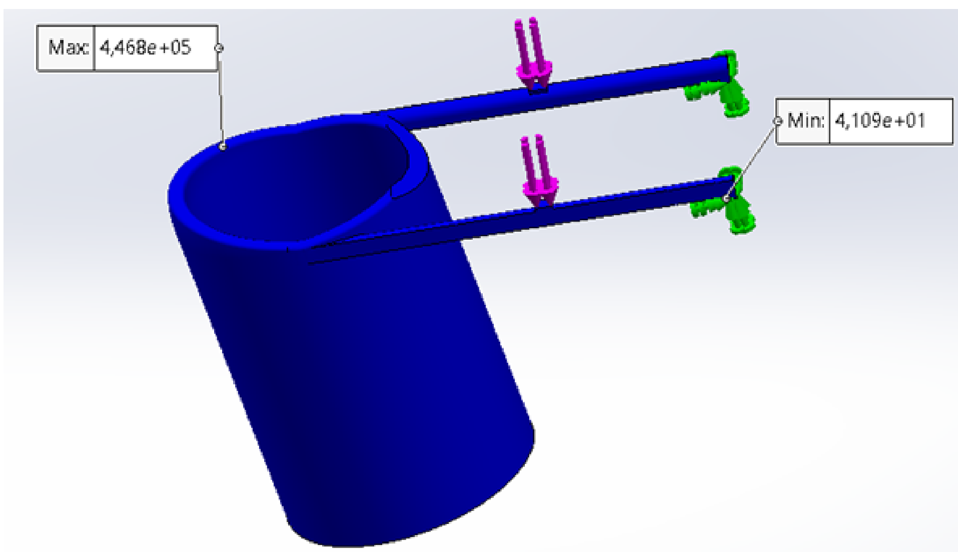
These show the minimal and maximal Factor of Safety (FOS). The minimal FOS is 3,501 x 10^3, so the handle won't break.

It is also important that the rails won't break, so it needs to be able to resist the force of the marble. The force will be equal to: mass marble x 9,81 = 6,0 x 10^{-3} x 9.81 = 5,89 x 10^{-2} Newton. We analyzed the stress on the rails. The maximal stress was not on the rails itself, but on the place where the rails are attached to the deformable pipe, which transports the marble to the funnel. The maximal stress is 7,548 x 10^{-1} MPa.





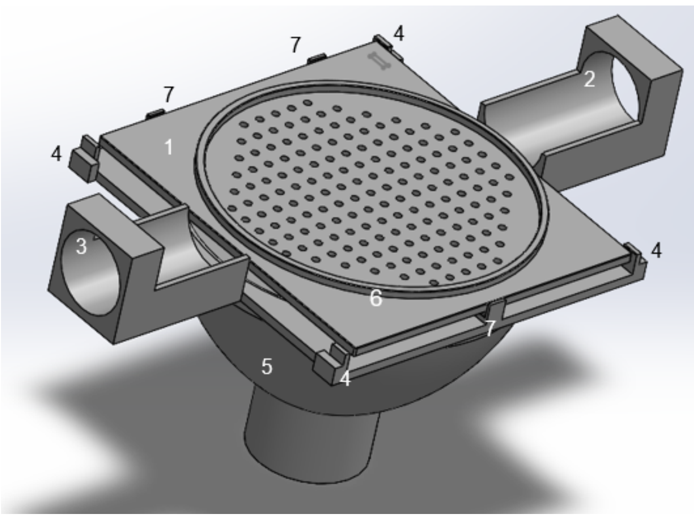


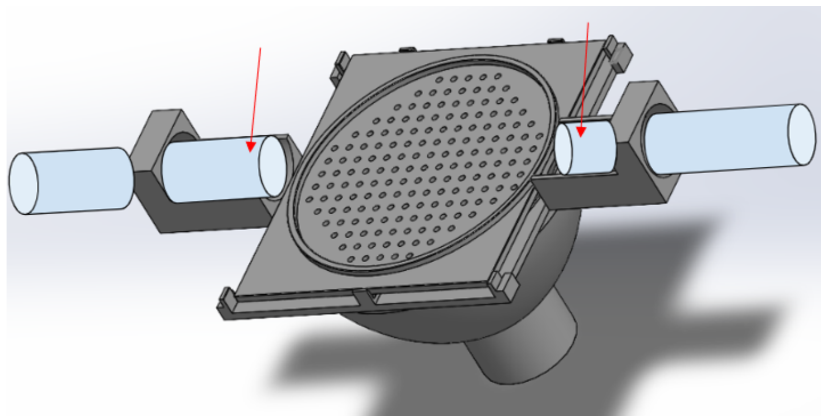


These show the minimal and maximal Factor of Safety (FOS). The minimal FOS is equal to $4,109 \times 10^1$, so the rails won't break.

Funnel:
The marble from basin 1 causes the filter of the funnel to move to the other side, as explained earlier. This results in the water flowing through the funnel. Besides that, the filter causes another marble to move, so that the 'sugar system' will start.

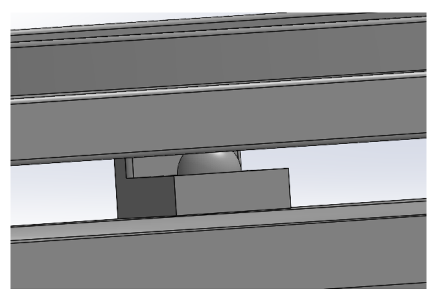
The funnel consists of the filter (1), the entrance (2) for the marble that will push the filter to the other side, the exit (3) of another marble, support plates (4) at the corners and the funnel (5) itself. Another marble is located at the other side of the filter. When the filter is relocated due to the marble that entered at the entrance, the marble at the exit will move. This marble is able to move, because of the force of the filter and the marble at the entrance. The marble at the exit will move to the 'sugar system' through another flexible pipe.





The flexible pipes are located inside the hole as shown in the figure above. The flexible pipes need to have a gap on top of the pipe (see red arrows) to ensure that the user can reuse the marbles. These gaps are loathed at two places:

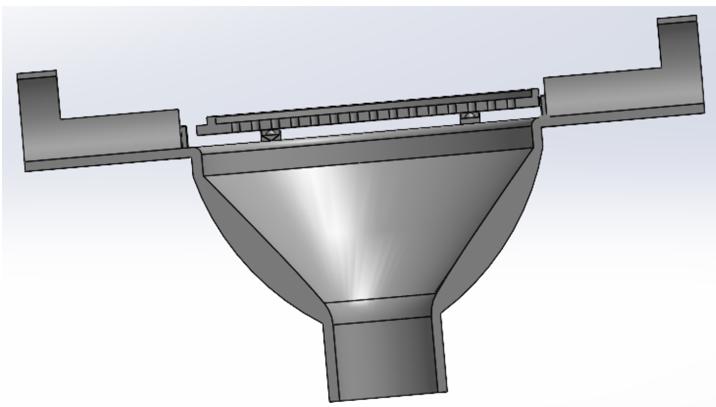
1. At the entrance, because the user can pick up the marble to place it onto the cylinder at basin 1.
2. At the exit, because the user can place the marble behind the filter.

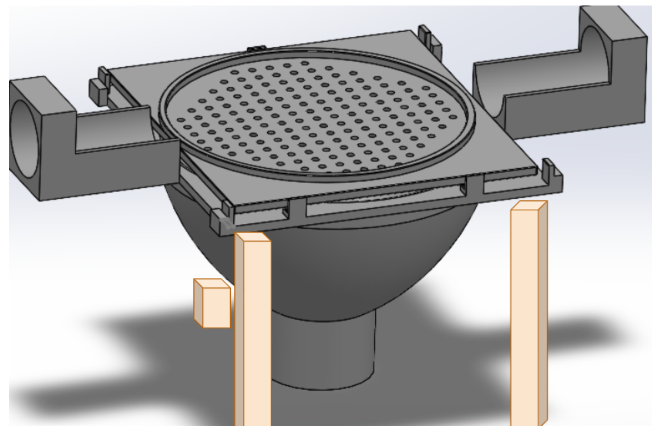


We have made small balls on which the filter will move. We made a hole in the shape of a triangle with a small ball located in it. This ensures smooth movement of the filter. There are 3 of them located in a triangle for stability (7).

Support plates will also be made. Those ensure that the filter will not move more than 2,5 mm. That is necessary, because the filter needs to move precisely 2,5 mm, so that the holes of the filter are located exactly below the holes of the filter from basin 1. The filter contains a small edge around the holes indicated with number 6. This ensures that the water will stay in between those edges and flow through the holes. The intention is that the water will flow through the holes, but when the filter is being moved, the water will end up on the filter. However, there are no oblique planes, which can cause some water to stay on the filter. So for a design in the future we need to make sure that there are some oblique planes, to ensure that all water will flow through the filter.

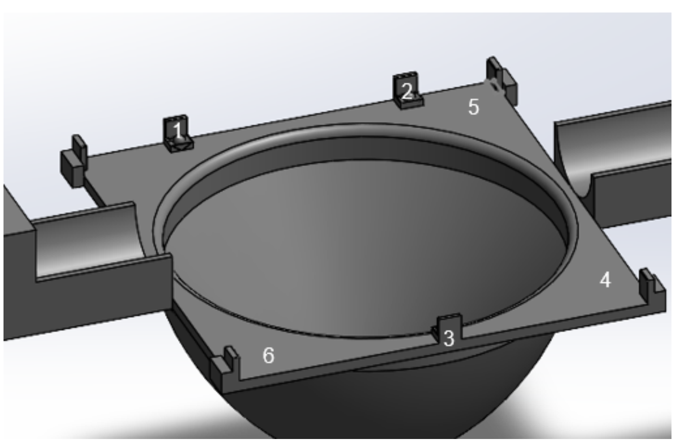
When the water has passed through the filter, it arrives in the funnel. The funnel has slanted sides, so that the water will not stay in the funnel and flows to the next component. See below for a section view.

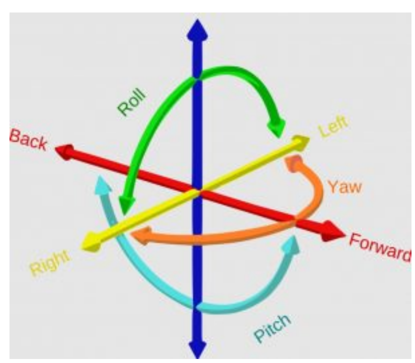




A wooden frame will support the funnel as shown in the figure above. It is also necessary to install the funnel to the plate, to which everything is attached.

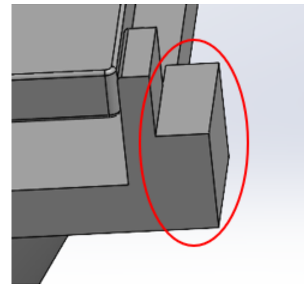
Exact constraint design is being implemented by designing the filter onto the funnel. The filter is only allowed to move to the left and the right.
The translation up and down is limited due to gravity. The edges 1 and 2 limit the translation back and forth and the rotation in the ‘yaw’ direction, combined with the force closure of edge 3. Basin 1 will be located above the filter. The distance will be 0,5 mm. The edges 4 and 5 of the plate limit the rotation in the ‘roll’ direction. The edges 4 and 6 of the plate will limit the rotation in the ‘pitch’ direction.

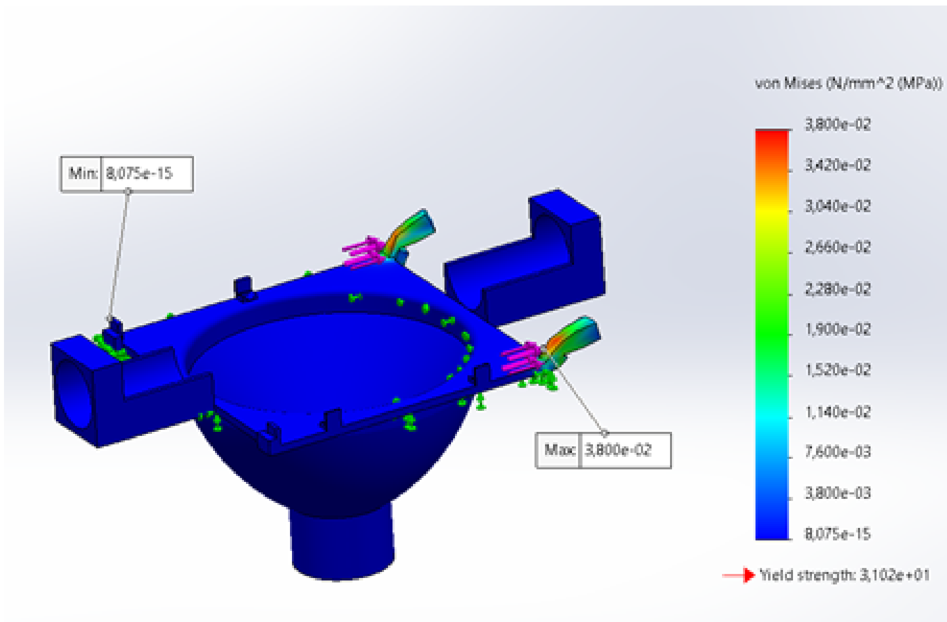


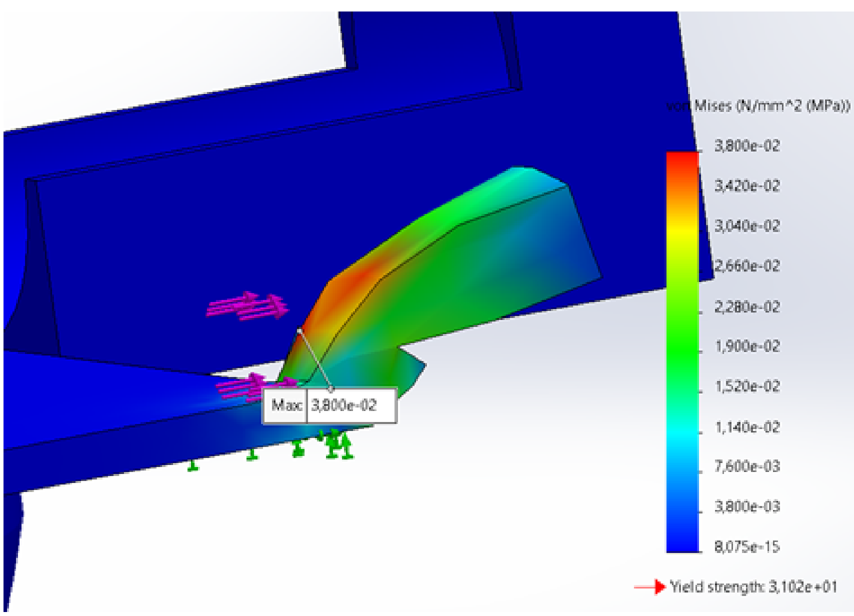


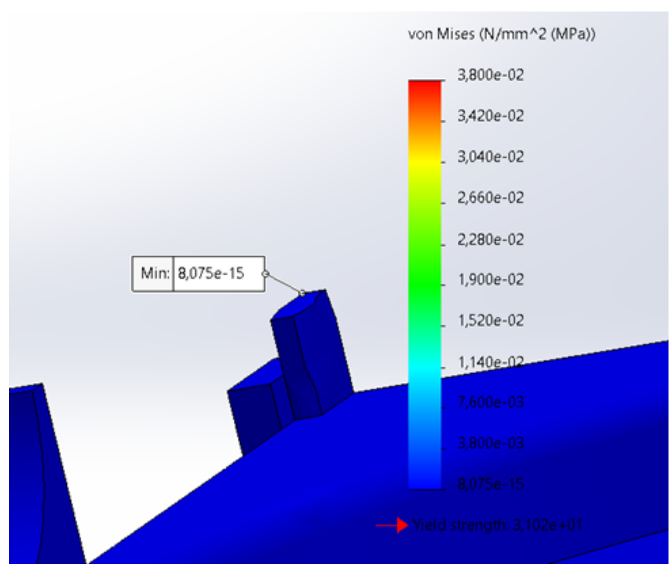
(Kumar, 2022)

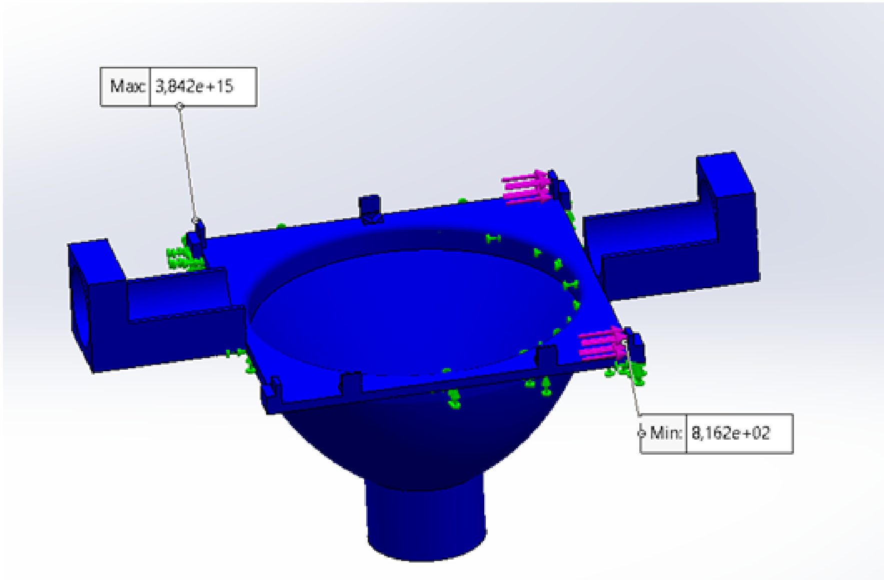
The support plates should not break when the filter moves against it. It needs to be able to resist the force from the filter and the marble. This force will be equal to: (mass filter + mass marble) x 9.81 = (20,26 x 10^{-3} + 6,0 x 10^{-3}) x 9.81 = 0,26 Newton. The maximal stress is equal to 3,800 x 10^{-2} MPa. There was no block behind the supporting plates in the beginning. The maximal stress was 1,128 x 10^{-1} MPa in that situation. Because we want to minimize the maximal stress, we created this block. Inserting this block resulted in a maximal stress of 7,482 x 10^{-2} MPa. However, we made the block larger and that resulted in our final stress of 3,800 x 10^{-2} MPa.





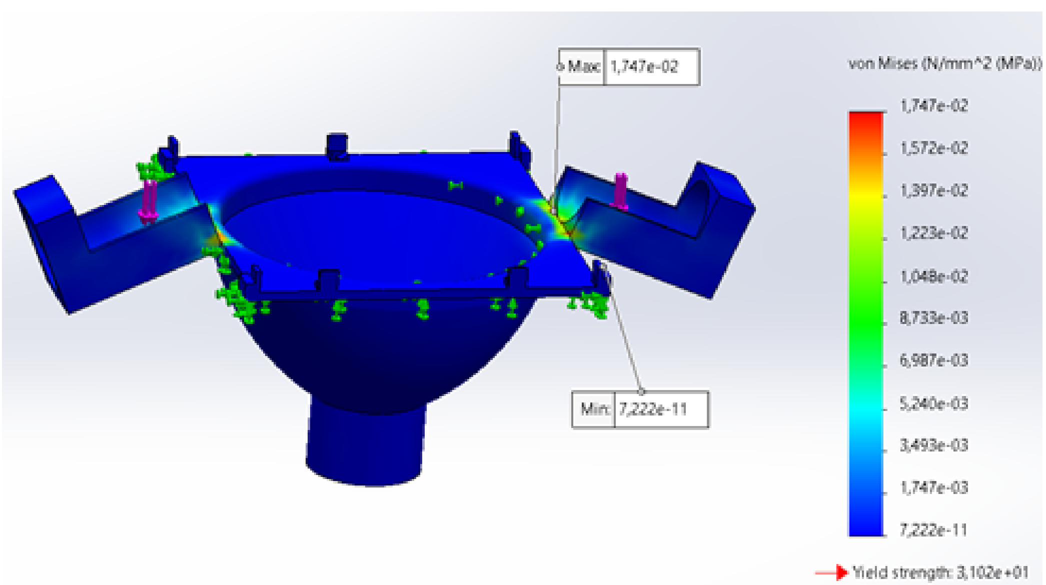


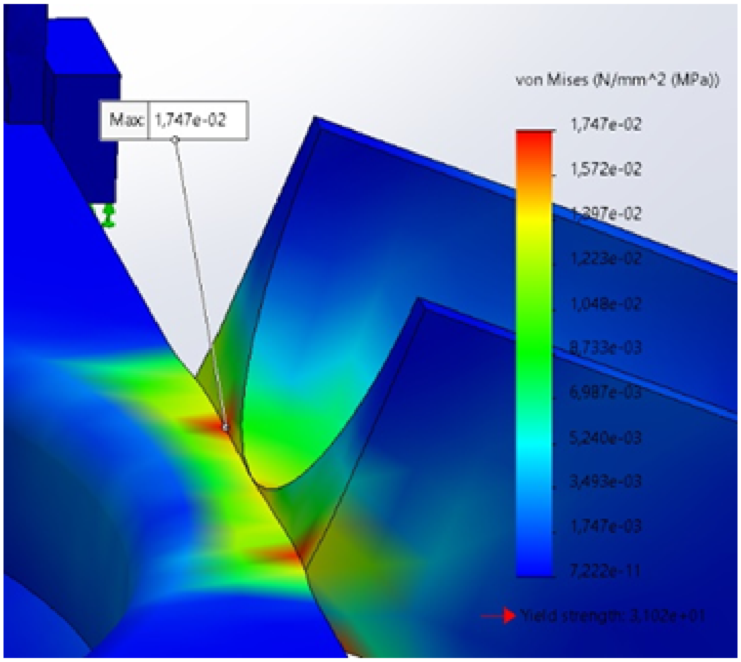


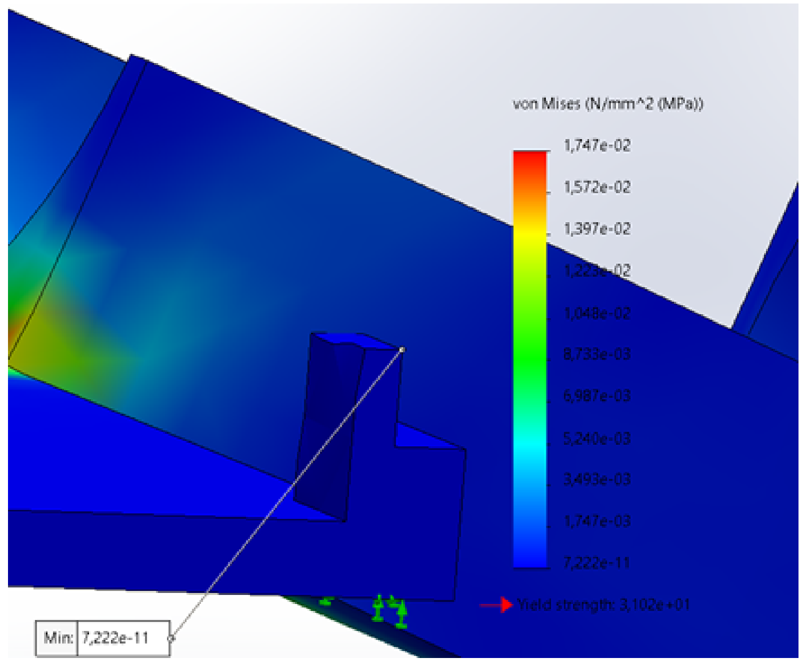


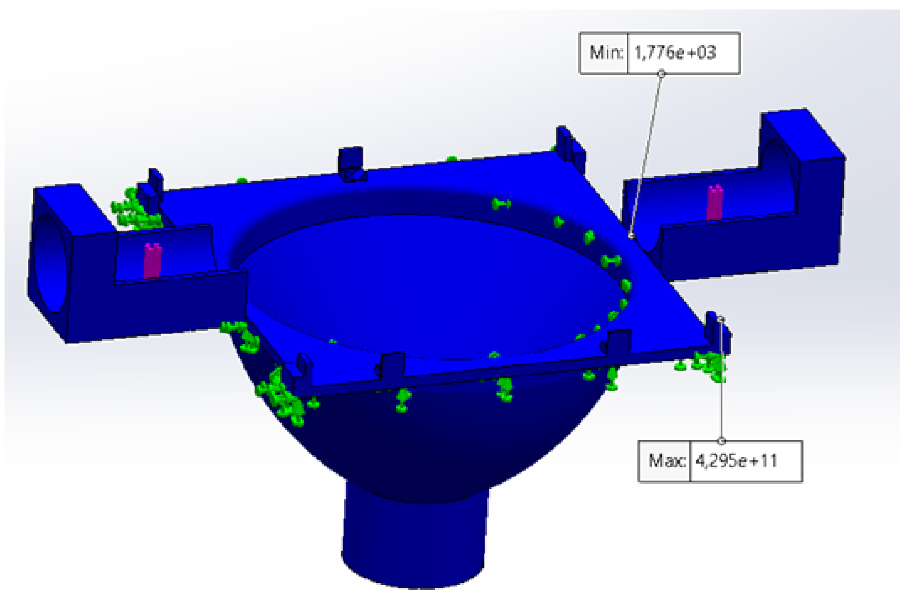
These show the minimal and maximal Factor of Safety (FOS). The minimal FOS is equal to 8,162 x 10^2, so the supporting plates won't break.

Another important aspect is to ensure that the entrance and exit will not break. It needs to be able to resist the force of the marble. The force will be equal to: mass marble x 9,81 = 6,0 x 10^{-3} x 9.81 = 5,89 x 10^{-2} Newton. The maximal stress is equal to 1,747 x 10^{-2} MPa. We tried to make a supporting layer underneath the entrance and exit, but that did not result in a lower maximal stress. In this situation the maximal stress was equal to 2,954 x 10^{-2} MPa. Also the use of fillets did not decrease the maximal stress. The maximal stress was equal to 6,285 x 10^{-2} MPa in that situation.



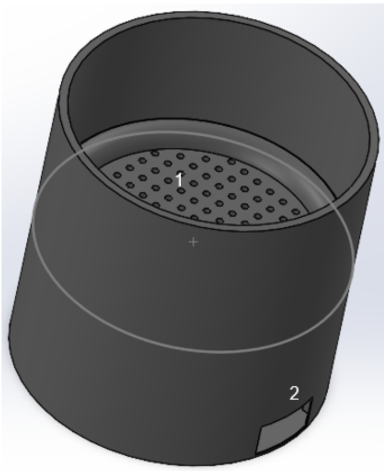


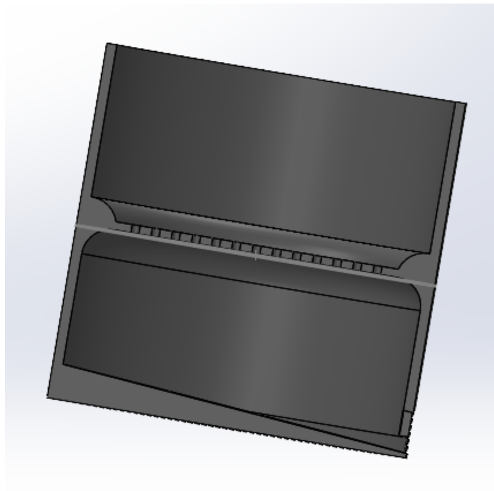
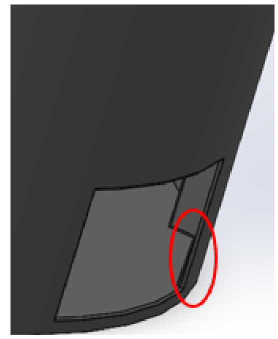




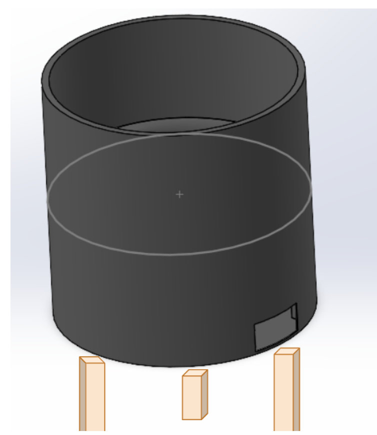
These show the minimal and maximal Factor of Safety (FOS). The minimal FOS is equal to 1,776 x 10^3, so the entrance won't break.

Basin 2:
The last component of the process of making coffee is basin 2. When the water has flown through the funnel, the water will arrive at basin 2. The purpose of basin 2 is to make the actual coffee. The basin contains a coffee pad, a filter (1) and an exit for the eventual coffee (2).



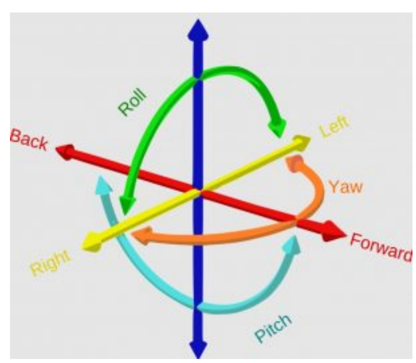



The coffee pad is located onto the filter. The water will then flow through the coffee pad after which it will flow through the holes of the filter. The filter ensures that only the water will flow through, and not the debris inside the coffee pad. A fillet is being made inside the basin above the filter, to ensure that the filter will not move inside the basin.



The bottom of the basin consists of an oblique plane, so that the water will flow towards the exit of the basin (see figure above for a section view). However, the edge of the basin at the exit is very thin and has a straight side, as shown, in the figure above, with the red circle. This can leave some water behind those edges. After all, this is not a problem, because this amount will be very small.

A wooden frame is used to install the basin to the plate, to which everything is attached. There will be supporting plates underneath the basin, as shown in figure on the right.

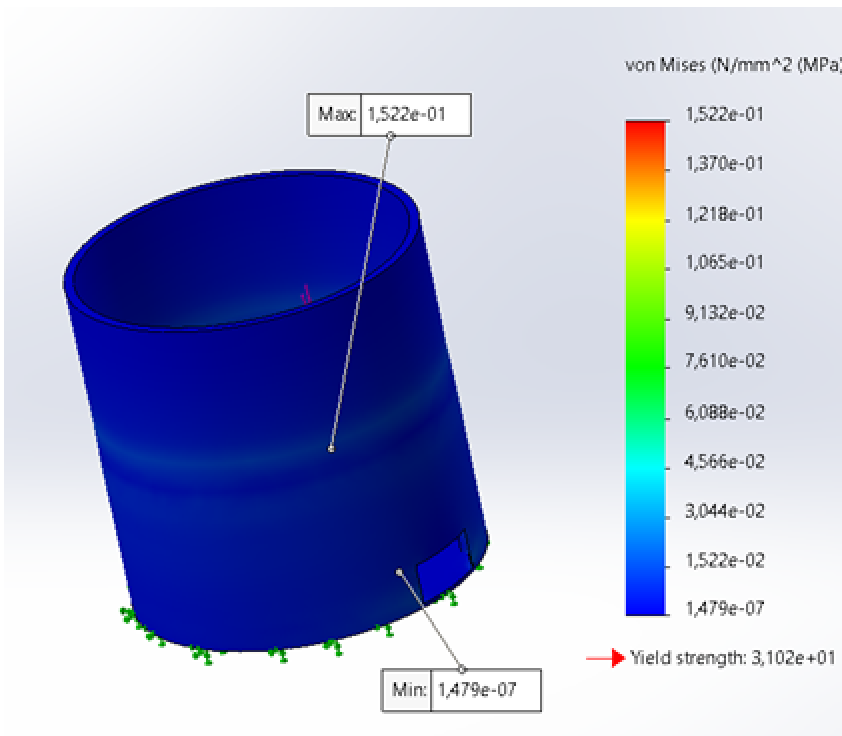


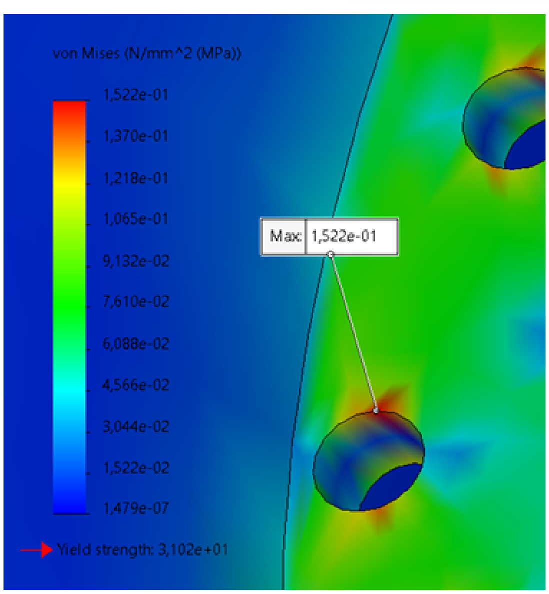
(Kumar, 2022)

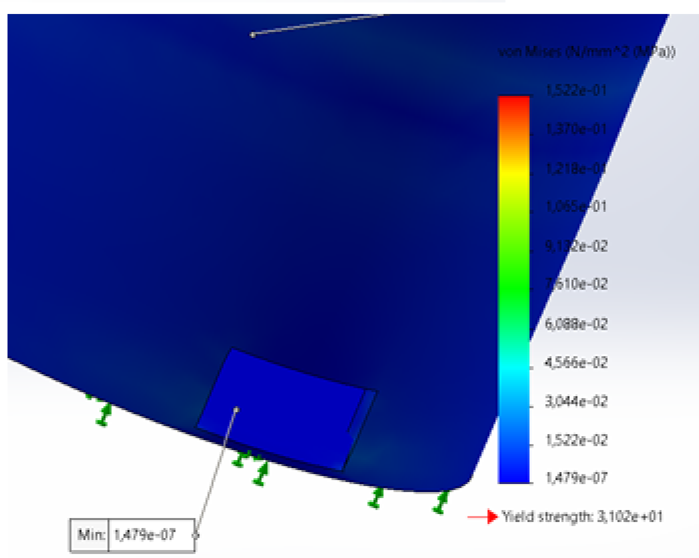
Exact constraint design is being implemented at the place of the coffee pad. One requirement is that the coffee pad needs to be replaceable, otherwise the system will only work once.
Translation to the left and right, and back and forth is being limited due to the side that is made with a fillet.
The rotation in the 'yaw' direction is limited due to gravitational forces of the coffee pad and the force of the water onto the coffee pad. The same goes for the rotation in the 'roll' direction.

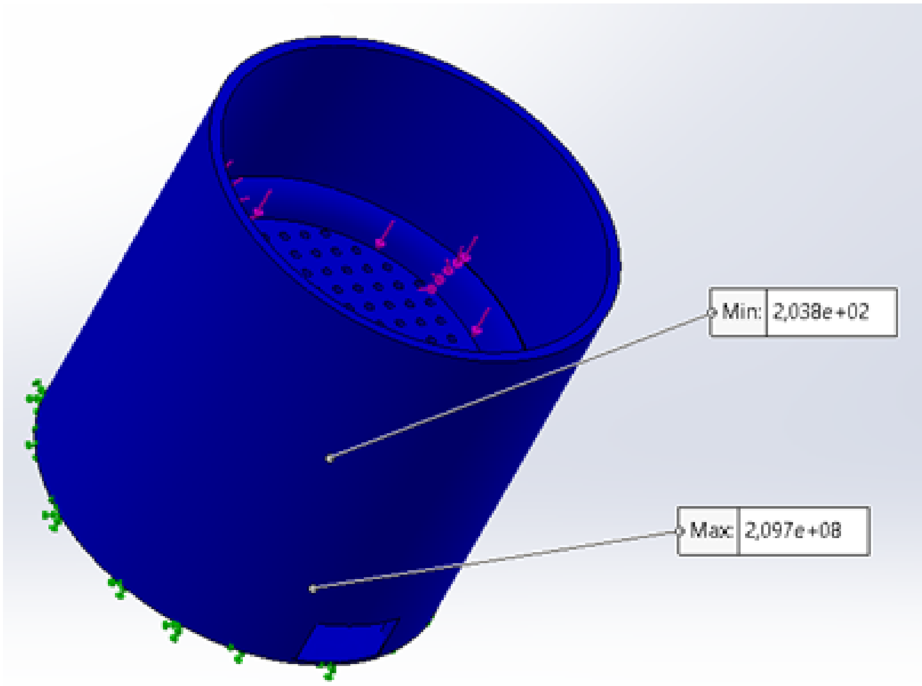
The edges of the filter limit the rotation in the ‘pitch’ direction combined with the force closure by the force of the water.

The filter needs to be able to resist the forces of the coffee pad. This force is equal to: mass coffee pad x 9,81 = 7,0 x 10^{-3} x 9.81 = 6,87 x 10^{-2} Newton. Besides that, the filter and the fillet need to be able to resist the force of the water. This force is equal to: mass (total amount of) water x 9,81 = 0,25 x 9.81 = 2,45 Newton. The force of the water is divided between the filter and the fillet. We analyzed the maximal stress. The maximal stress is equal to 1,522 x 10^{-1} MPa. In the beginning, there were more holes in the filter. Half the holes were underneath the fillet, which resulted in a higher maximal stress. In this situation the maximal stress was equal to 2,114 x 10^{-1} MPa. To minimize this stress we got rid of these holes and made a fillet underneath the filter. This resulted in our final maximal stress of 1,522 x 10^{-1} MPa.





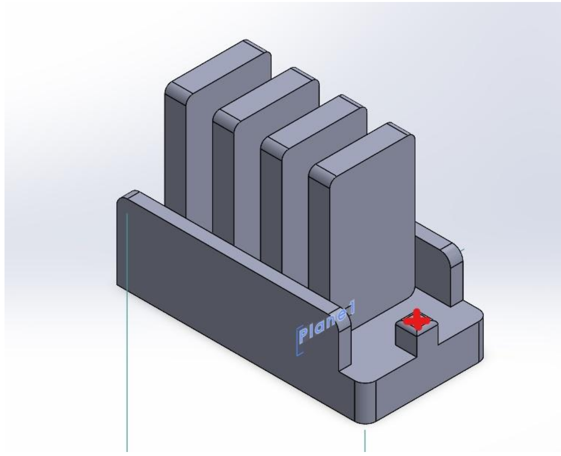




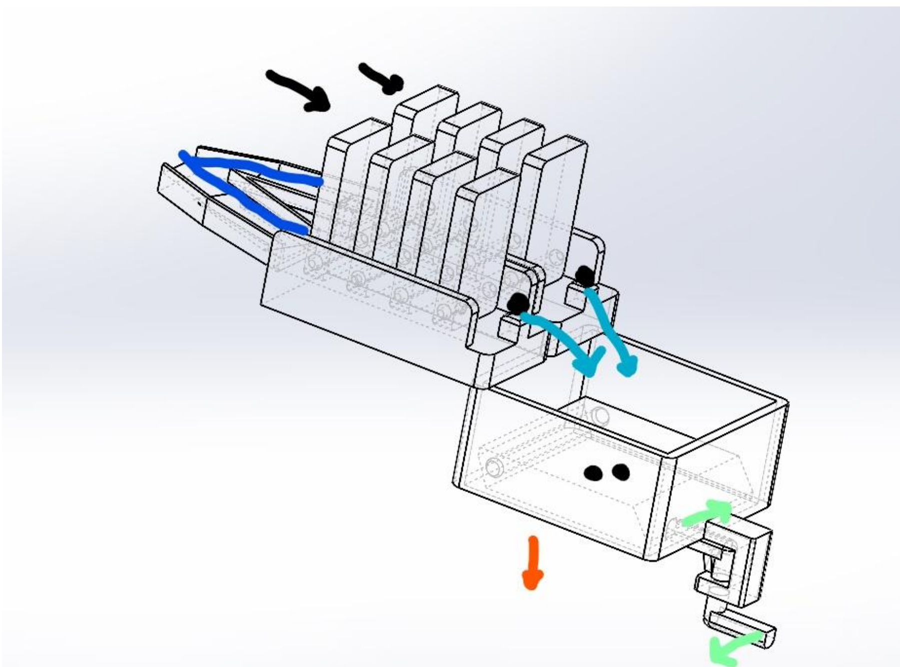
These show the minimal and maximal Factor of Safety (FOS). The minimal FOS is equal to 2,038 x 10^2, so the entrance won't break.

Adding Sugar

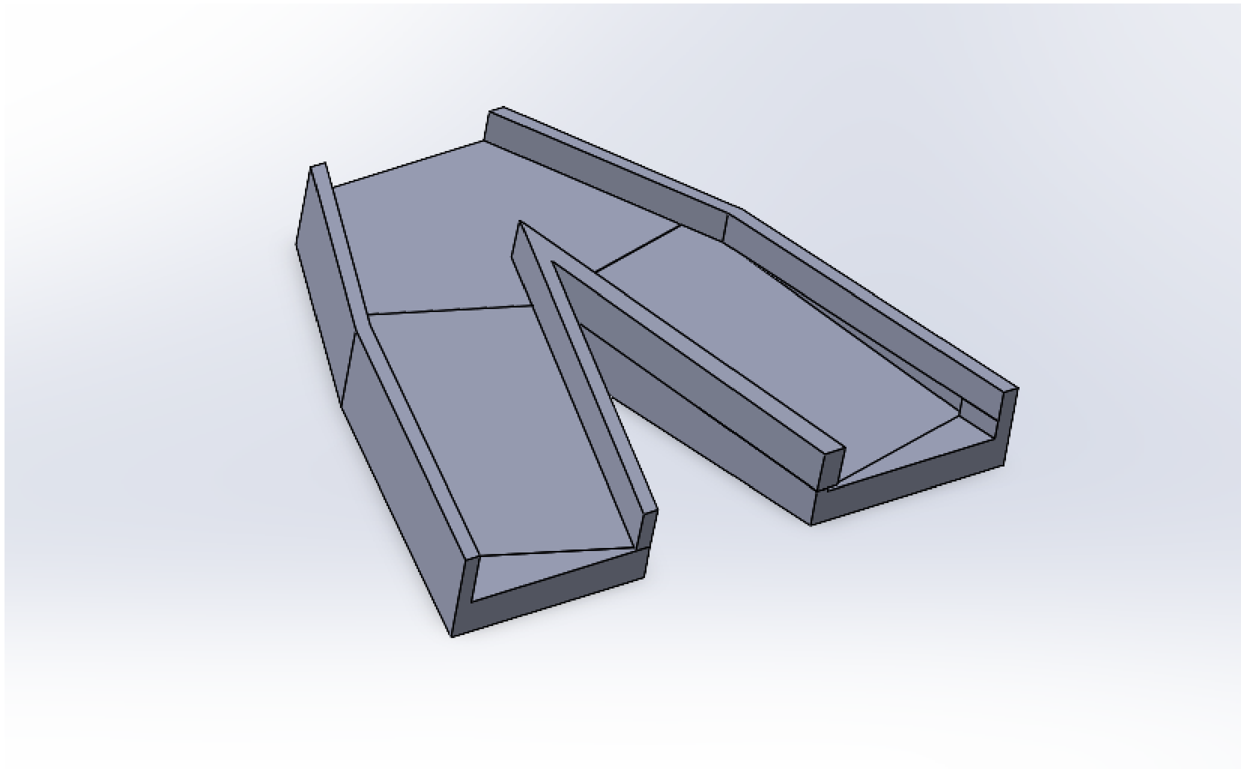
The second step of the process consists of adding sugar to the milk. This requires some preparation from the user's point. The user needs to place the wanted amount of sugar on the x marked in the below diagram, if they want to use more than two cubes these need to be stacked.



Two domino systems are attached to a sugar basin. A marble, originating from the Milk step, rolls down through the tube (dark blue path) and knocks against two different marbles. These then in turn roll down individual tubes and knock down the dominos (black arrows), these topple over and push the cubes (black cubes) into the sugar basin (light blue arrows). The basin will contain the sugar cubes until the cup of coffee passes by and opens (green arrows) the bottom of the basin. The cubes fall into the cup (red arrow), it continues on going to the next step of the process.



Ramp:

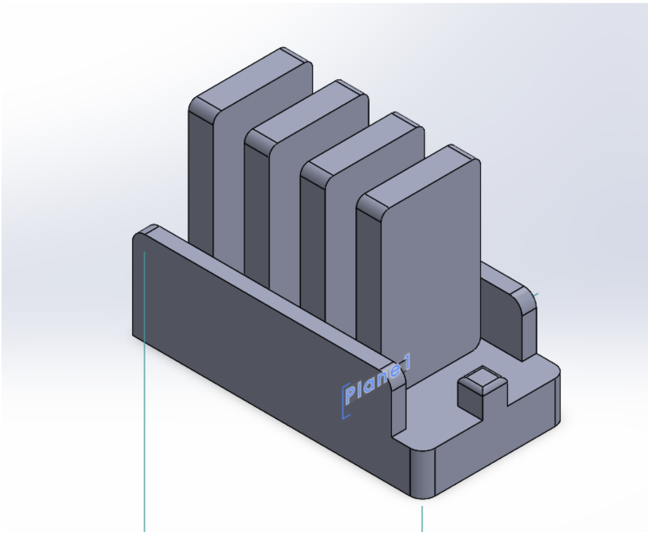


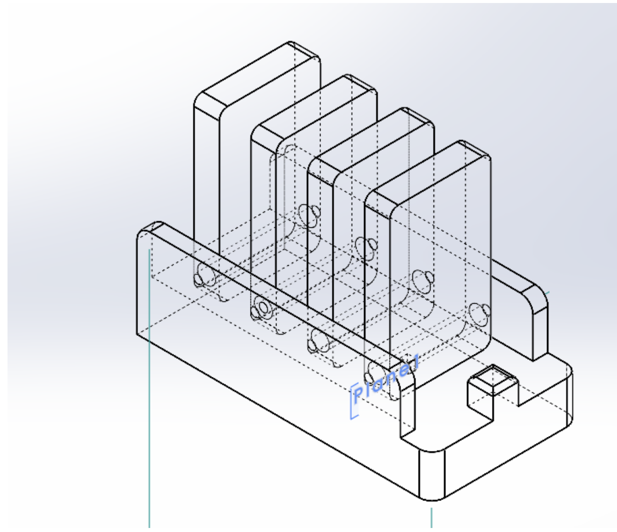
Two marbles are placed on the flat upper edges, those will be knocked by one marble and will in turn roll down the ramp. This design was made like this because the marbles needed to stay in their place until knocked, this makes sure that the sugar chain reaction isn't started before the cup with milk starts to make its way to the sugar basin.

The first domino has a mass of 5.43g. This means that it needs a force of 0.0532N to be toppled. The marble (8.00g) rolling down at this angle will create a force of 0.0785N, thus enough to topple the domino and start the chain reaction.

Some possible issues with this part of the design is where the marble will go after it has started the chain reaction. The marble will either stay within the domino contraption or roll out and likely fall to the bottom of the kinetic coffee machine. A possible solution for this would be to create a collection box at the back of the domino contraption which would catch the falling marbles.

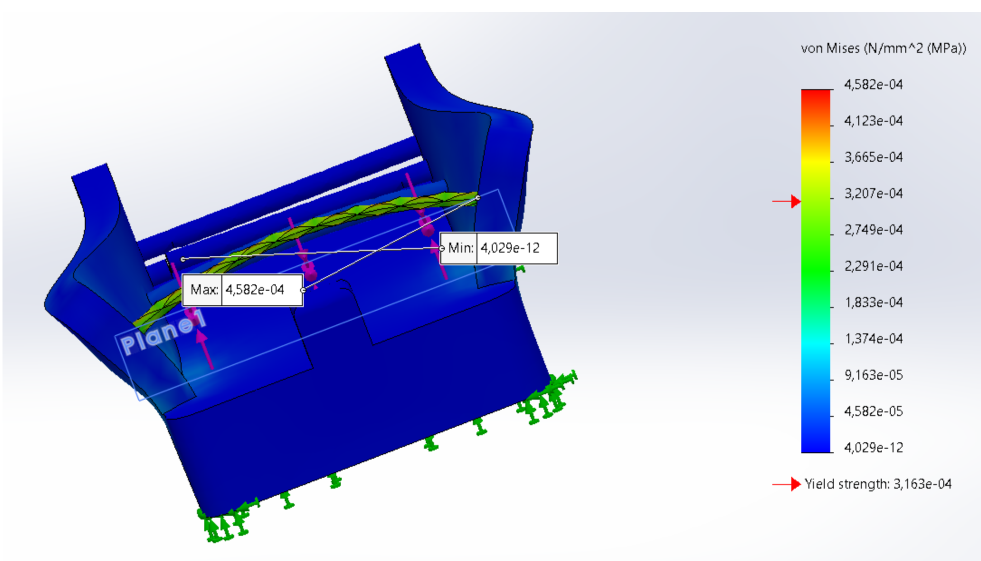
Domino Blocks:



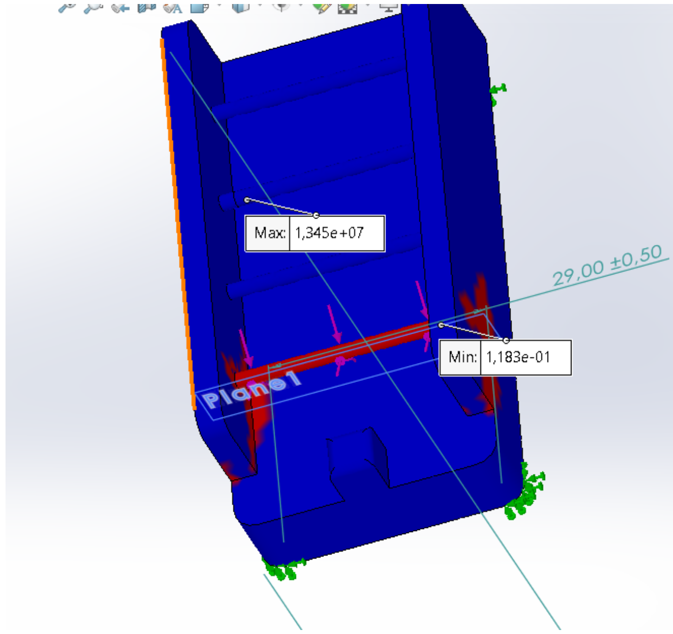


Pushed by a marble with a force of 0.0785N the dominos topple each other over and eventually push a sugar cube off of the edge (the sugar is perched on top of the shown cube). This design choice was made to create some variation within our model. Rather than it just being another 'marble run' this, and the concept of creating coffee, was intended to set it apart and increase its appeal.

A possible issue with this is that because the dominos are attached onto the axis, and the space between them is too small, there is no constraint on the backside, meaning if something were to run into the system they could topple the other way too. Regardless, the decision to use axis was made to make resetting the system easier. This way users only have to place them upright, rather than placing them in the correct position as well.



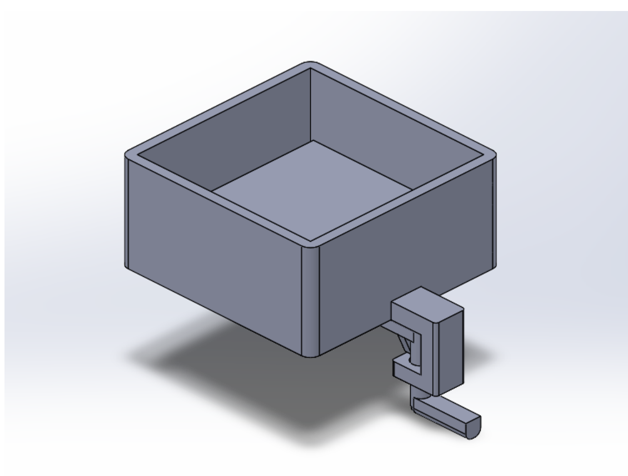
The largest amount of stress in the domino section is 4.56e-4 MPa. This is in the middle of the axis that holds the dominos. It makes sense that the most strain is there because it is the center of the axis, so the distance is the furthest away from the attached part. Also the amount of force from the dominos is the largest here because they don't apply force to the sides of the axis. The least amount is 4.03e-12 MPa. This is at the point where the axis are connected to the side of the body of the domino holder.

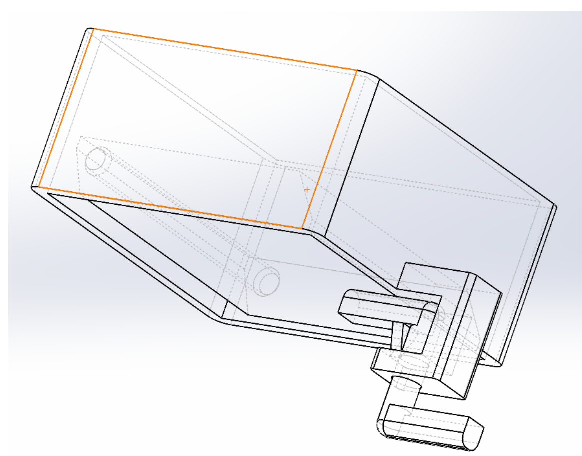


According to the right pictured FOS the axis is at risk of breaking. However, I think that this may have been done incorrectly due to the force on the axis being so minimal that this seems out of order.

The dominos are constrained in this manner so that they can only move forwards and backwards. The axis makes sure that they can't rotate or move into other positions. The distances on the sides of the axis are large enough that the dominos aren't clamped in on both sides, yet small enough that they don't move out of position and are not able to topple each other anymore.

Sugar reservoir:

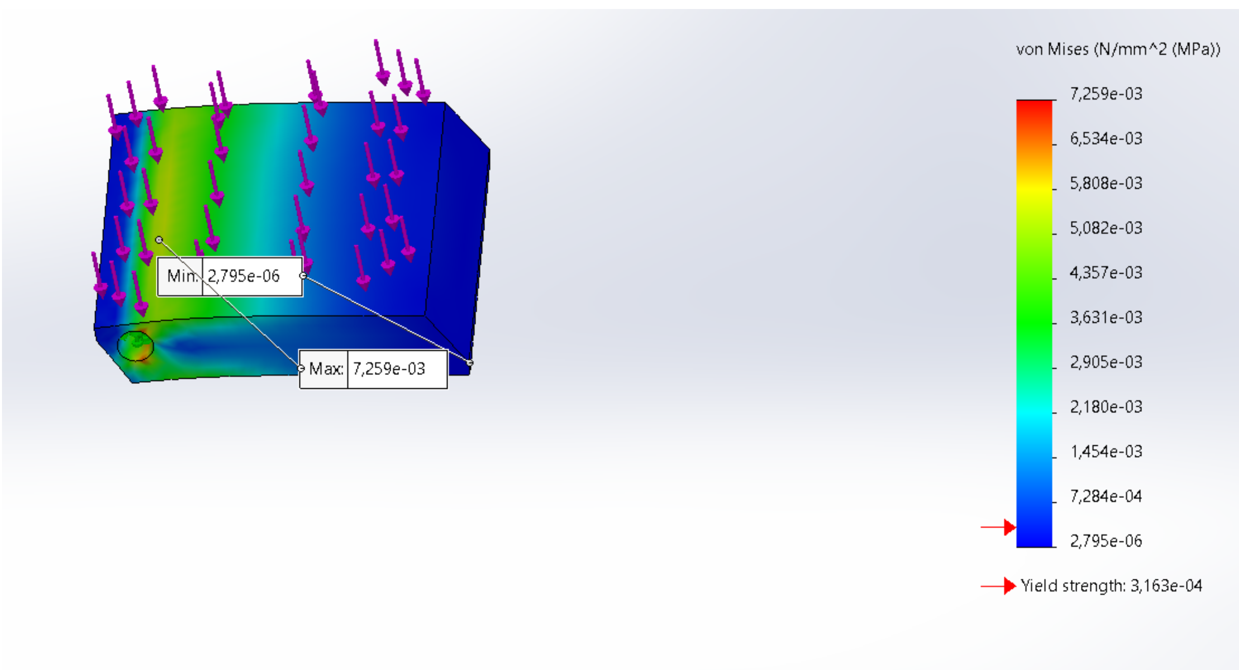




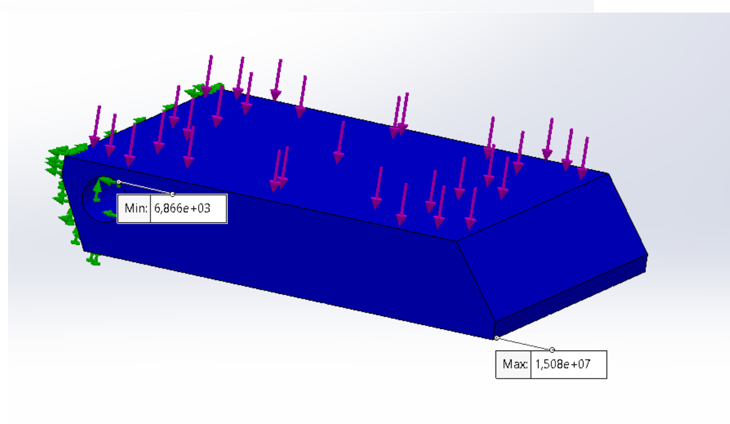
The sugar cubes topple into this basin which collects them until the cup of coffee comes by on its rails. On the right side of the basin you can see a hinge contraption. Once the coffee cup on the rails comes in the direction of the sugar basin it hits the hinge, turning it so that the trapdoor in the sugar basin falls open, and the cubes inside fall into the cup.

The choice of the hinge stems from the fact that we needed to incorporate a way to time the sugar correctly and make sure it actually fell into the cup. Other possible ideas we had were having the marbles roll around in a tube, very slowly, and to time that correctly so that they would hit the dominos right before the cup came around and the sugar would fall into the cup directly. This was a rather tricky calculation with a tiny margin of error, so we came up with a different solution.

Possible issues with this solution is that the trapdoor is basically launched into a free fall, besides the axis holding it up. Because of this the trapdoor may possibly fall and come into contact with the rails of the coffee cup. A possible solution for this would be to create a second constraint that catches the trapdoor, however this has not been incorporated into our current design.

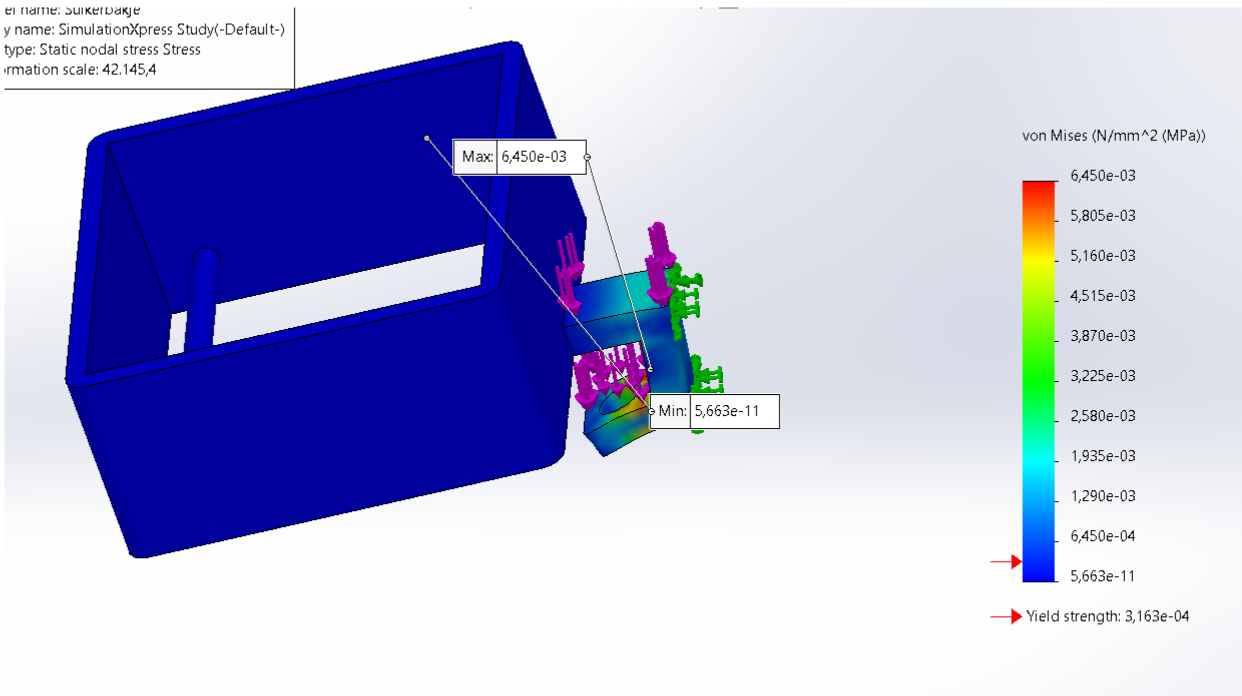


The largest amount of strain can be found on the farthest edge, which is 7.26e-3 MPa. The least amount of strain is found in and around the axis at 2.80e-6 MPa. The FOS is at its largest 1.509e7 and at its smallest 6.966e3.

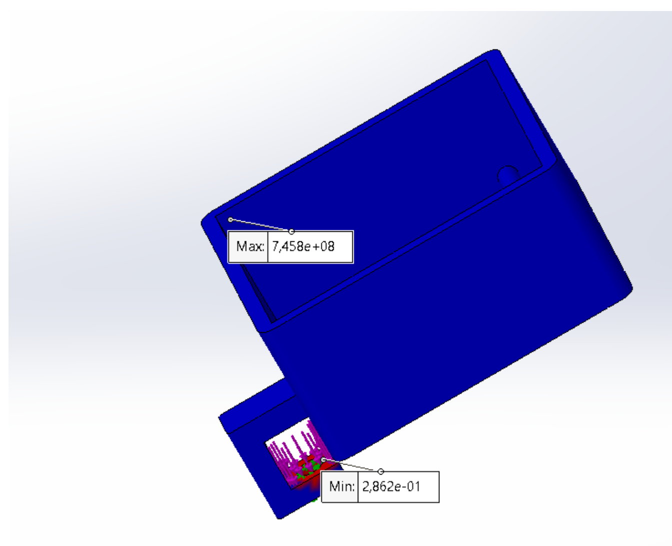


The hinge is a very important part because it makes sure the timing between the cup of coffee and the sugar is correct. The coffee on the rails has a special attachment which hits against the hinge, twisting it. The hinge was made so that it could correlate with the timing of when the sugar basin needs to open.

A possible issue with the hinge is that it needs to be reset manually after the coffee cup has passed. This means the user needs to lift up the trapdoor and twist the hinge to come under it again.



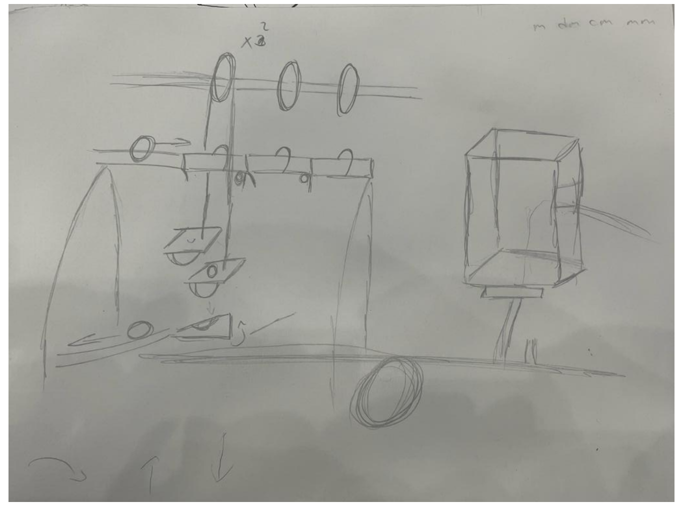
The max strain is 6.450e-3 MPa, the min is 5.663e-11 Mpa. The force of the hinge on the holder is 0.029N. The factor of safety is max 7.450e8 and min 2.82e-1.



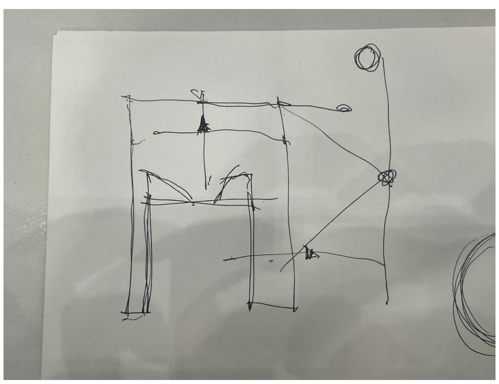
Due to its double sided L shape the hinge is and the size of the holder of the hinge it is constrained and can only move left and right. Furthermore the hinge has a small triangular piece constraining it in the holder and making sure it can't move up or down and fulfills its function as holding up the trap door.

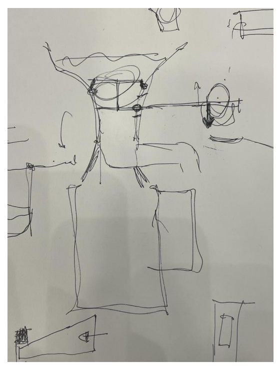
The Design Process

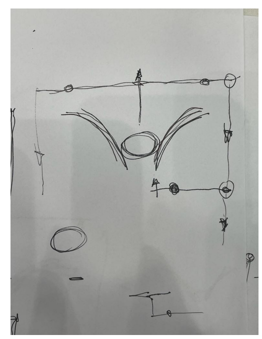
The design iterations for the milk dispenser



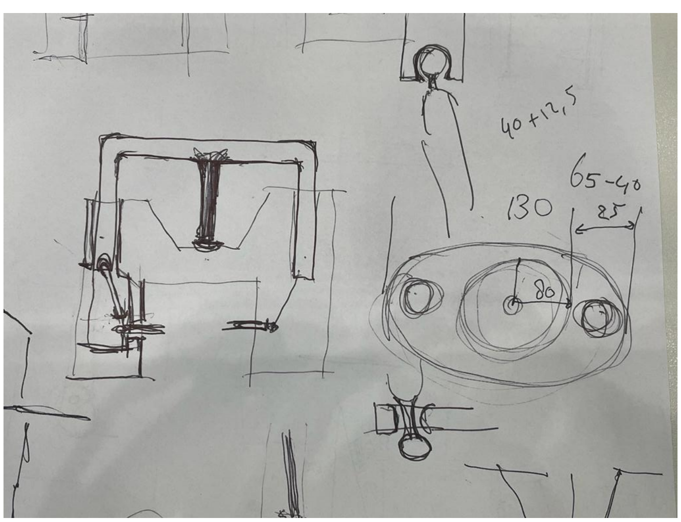
While designing the milk dispenser the first idea was to use marbles to start off the motion, however timing this in combination with shutting down the milk pour again seemed very difficult. Therefore the sketch with the marble track was thrown out.
When the idea arose to let the cup set the action in motion the initial movement was linear underneath the milk basin. To determine how the force should be turned there was the question whether to let the plug be lifted out of the opening or by letting it fall down. To make sure that the plug will close off the basin entirely the plug could rather be pulled out as it will then automatically close off by the force of gravity.

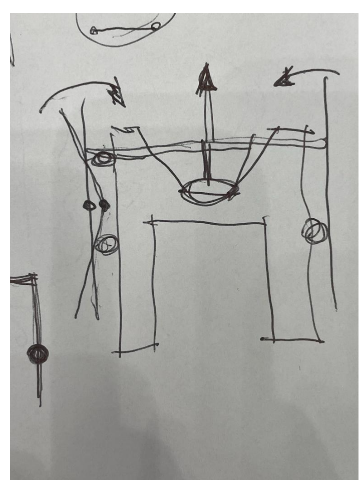






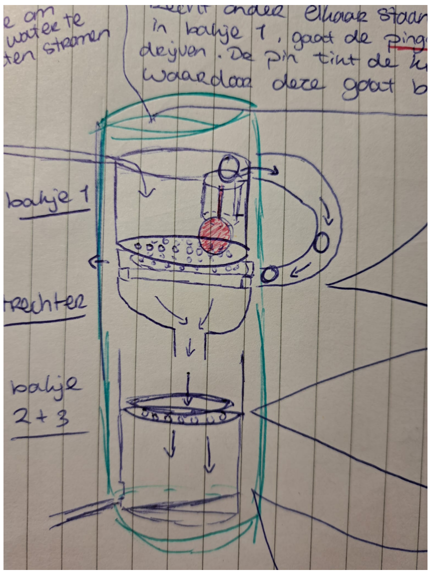
To turn the force from a pushing motion to a lifting force three joints must be added or one rod with two joints could be used. Therefore less turning points are needed which makes the motion less complex and makes the chance of crashing lower.

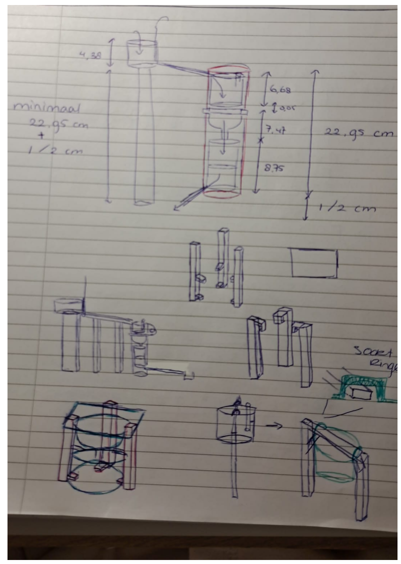




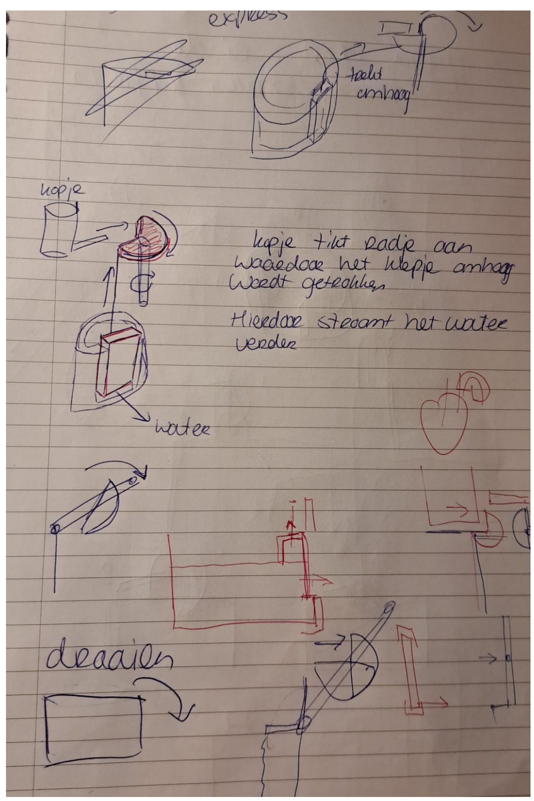
Design iterations of the process of making the coffee

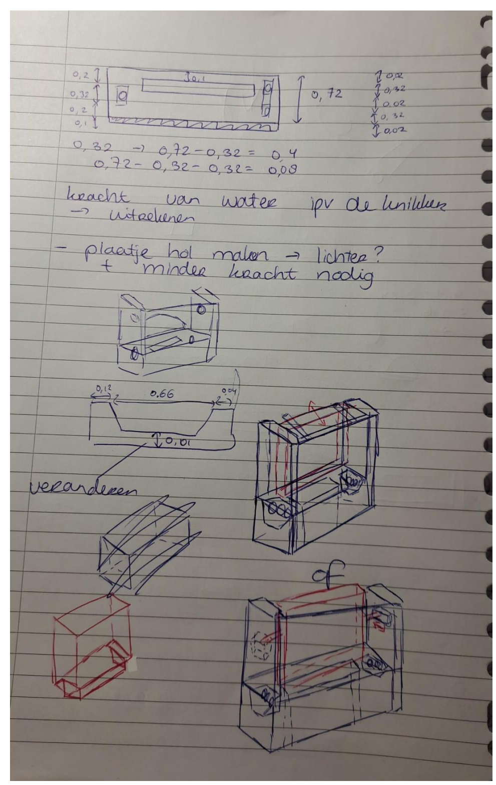
During the design process a lot of sketches were being made and designs were being changed. The first idea of the process was that all components were located in a cylinder, so that we had a base to work with. However, later on we recognized that this was not practical. Holes needed to be made in the cylinder. Next to that, we needed to think about how we were going to attach all the components onto the cylinder, and that was very hard. That is why we are using wooden frames right now.





One part of the process that caused some problems was the opening of the water basin. At first the idea was to start the process due to the force of the water, but that was not practical with measuring the amount of water. That is why we used the pulley concept to prevent this problem.





Reflection

Often teamwork is a point of conflict within a group's process. This time around however, this was one of our major strengths. Because our teamwork was so solid, the issues we faced were more regarding issues of who we are as people and how we handled tricky situations.

The communication within our team was a breath of fresh air. We met up with ease, people were on time and we stuck to the agreements that we made. The teamwork and atmosphere in our group was good and we worked well together. Working with a group that interacted in a manner like this was a good experience in the sense that it set a bar for what teamwork should and can be like. In the future, all of us can use this project as a reference point for what interactions and communication should be like.

One of these would be that we weren’t tough enough on ourselves and each other when it came to setting solid deadlines. The amount of freedom given for this project was immense, so we struggled with setting reasonable deadlines. We did however, stick to the deadlines we made. It was tough to create deadlines and have a proper idea of what our timeline should look like when we were still struggling to visualise what the project really looked like, what was expected of us and how we were going to carry this out. Because we weren’t strict and disciplined enough we had to work very hard in the days approaching the deadline. A better way to handle this in the future would be to invest more time in brainstorming and really understanding the task. Then we would make a concrete plan, showing which tasks would need to be completed within which time frame and to what extent. Being more tangible with our deadlines and placing more importance on them would have potentially drastically increased the quality of our final product.

Another thing that would have increased the quality of our final product would have been spending more time and energy within solidworks. As first time designers, solidworks was new to all but one of us. As a whole, we experienced that the interface and user system of solidworks can be quite intimidating to start off with. Whilst endless options and capabilities are usually a good thing, to first time users they came across as overwhelming. This in turn led to some of us putting off the use of solidworks until we could no longer go without. This avoidance led to the quality of the products we put out being less than it could have been, because of a lack of experience and a lack of time put into it. This is definitely a lesson for all of us, that although things may seem intimidating, avoiding them will only make the inevitable confrontation worse. In future projects, facing things that are new head on and with an open mind is an attitude we will all try to adopt for the sake of bettering ourselves as designers.

We were very complimentary to each other within our skill sets. Where some group members were better regarding the technical insight, others were stronger on the creative level. This created a nice cohesion. This is not something you often experience when choosing a group, so it would be good that all of us take into account that this isn’t the standard and that that’s okay. Part of being a good designer is being adaptable to the ever changing world around us, and adjusting to different people with different skill sets is just another skill that helps us navigate society.

Bibliography

- *ABSplus-P430 P R O D U C T I O N - G R A D E T H E R M O P L A S T I C FOR DESIGN SERIES 3D PRINTERS*. (2015). stratasys. Geraadpleegd op 26 januari 2023, van https://www.utwente.nl/en/rpl/Data%20sheets/UPrinter/MSS_FDM_ABSplusP430.pdf

- Ashby, M. F. (2020). *Materials and the Environment: Eco-informed Material Choice* (3rd ed.). Butterworth-Heinemann.
- *FDA approval for ABS resins for food contact*. (2015, 20 augustus). plastemart.com. Geraadpleegd op 26 januari 2023, van http://www.plastemart.com/news-plastics-information/fda-approval-for-abs-resins-for-food-contact/27532#:~:text=ABS%20Resin%20grades%20are%20now,Contact%20Substance%20Notification%20(FCN).&text=For%20some%20manufacturers%2C%20such%20as,packaging%2C%20this%20compliance%20is%20essential

- (Kumar, 2022) Degree of Freedom in Statistics: Meaning & Examples - Data Analytics (vitalflux.com)
- Montijo, S. (2022, September 7). *A Guide to the Most Popular, All-Purpose Aluminum Alloys - Kloeckner*. Kloeckner Metals Corporation. https://www.kloecknermetals.com/blog/a-guide-to-the-most-popular-all-purpose-aluminum-alloys/
- *P430 ABSplus Model Cartridge / Fortus 250mc / Dimension Elite / 1200ES BST / 1200ES SST*. (z.d.). GoEngineer Store. https://store.goengineer.com/products/p430-absplus-model-cartridge-black-56-cu-in
- *Rapid Prototyping Process Selector*. (z.d.). https://www.custompartnet.com/rapid-process-selector

- *Vaessen Creative • Aluminiumdraad 3mm 3m Silver*. (n.d.). Vaessen Creative. https://www.vaessen-creative.com/nl/vaessen-creative-aluminiumdraad-3mm-3m-silver?queryID=db3c079a41ae94533cf0b6476c90af2b