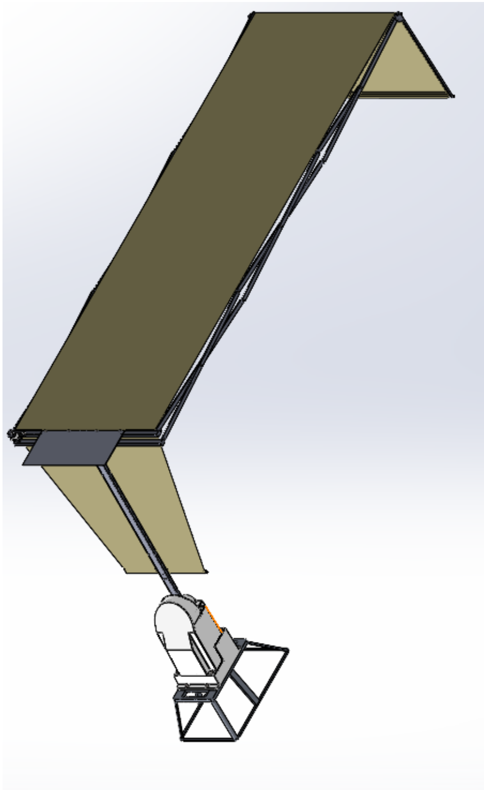
Project Milestone 3: Project Documentation

Group Project No. 2

Faculty of Technology and Bionics

B-Matic Shade



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In addition, we would also like to proclaim that the documentation of this project is the result of the hard work and dedication of our team collaboration, researching about, and developing the project concept and further milestones. All the external sources used are documented and cited in the reference section. We completely abide by the copyright and plagiarism laws; fully aware of the fact that any attempt of piracy or theft would lead to serious consequences.

Cleve,
29.06.2021

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Executive Summary

Sun umbrellas are one of the most extensively used commodities in our century, having been used for many years at beaches, resorts, residences, or swimming pools, and are easily available to a wide variety of people. Although there was evidence of exponential development in engineering and technology in other fields, no one seemed particularly worried about making this simple home item better. The project's mission is to design the "**B-Matic Shade**," a sun shade that has been upgraded to integrate autonomous functionality to this common product.
The objective has been summed up as "**Set it and forget it**," meaning that after the machine is set up according appropriately, there is no need for the user to interact with it. The umbrella provides continuous shade to a person sitting on a chair at the beach by detecting sun movement through light-dependent resistor sensors, whose data is sent to and processed by a microcontroller. The microcontroller then instructs the motor, which rotates the shade around a single axis to its desired position. All of this is powered by a built-in battery that will be recharged by a solar panel mounted on top of the shade. The system only activates the motor once every 10 minutes due to the slow motion of the sun and to minimize power consumption on the battery. There is also a supporting mechanism that keeps the shade fixed while the shade is not rotating by directly locking in the teeth of the gear mechanism. The 36:1 gear ratio employed in the construction of this product offers it the advantage of being able to use smaller motor and other electrical components, resulting in a lightweight, durable, and optimum design.
The design process has been focused in making this device light weight, extremely portable, energy efficient, and safe for use by incorporating all electrical devices, wiring system, and gear mechanisms in a fully enclosed housing that protects it from dust and water. Likewise, the costs of the product have been kept as low as possible in order to allow for price competition in the marketplace. Because it is a high-end product, its target customers are primarily beach resorts and hotels, with the target sales area being coastal countries in Europe and the United States, as these countries have many beaches, beach lovers, and purchasing power. Last but not least, this project is the product of four engineers from a variety majors working together in their own disciplines and specialties.

Keywords:
Sun shade, Autonomous functionality, Light sensors, Energy efficient, high-end product

Contents

1.1 Conceptual Design

1.1.1 Concept Description and Sketch

The purpose of the product is to provide shade for a person laying on a sun chair while adjusting the shade in response to the movement of the sun across the sky. The objective is to provide shade only for the person on the chair, and to ensure that the person will always enjoy the shade without having to either adjust the shade or adjust their position so as to be within the shifting shadow. A key point here is the automatic function. The user should not need to interact with the device once it has been properly set and activated. We have summarized this idea in the slogan “Set it and forget it!”.

The crucial requirements for the proper functioning of the device are knowing what the relative position of the sun is and being able to adjust the shade depending on the sun position. The adjustments should be done continuously, or failing that, should be done in increments so small as to function effectively as continuous adjustment. Other requirements for the product are that the cast shadow should not exceed by more than 10% the area of the covered sun chair, the device should be easily portable and it should work without any connection to external power sources.

With these requirements in mind, we settled on what has been named an “orbiting shade” design. The idea consists of a frame which holds a canvas shade that rotates around the person. According to the plans of a common sun chair, a person laying on such a chair is elevated roughly 800mm above the ground. Therefore, the rotation of the shade is centered around an axis elevated 800mm above ground as shown in ***Figure .1.1.1*** and ***Figure 1.1.1.1***. Rotating around this axis, the position of the shade frame will be automatically adjusted by measuring the relative position of the sun to the shade using a solar sensor. The adjustments are made so as to keep the shade perpendicular to the incident sun rays. This can be seen in ***Figure 1.1.1.1***.

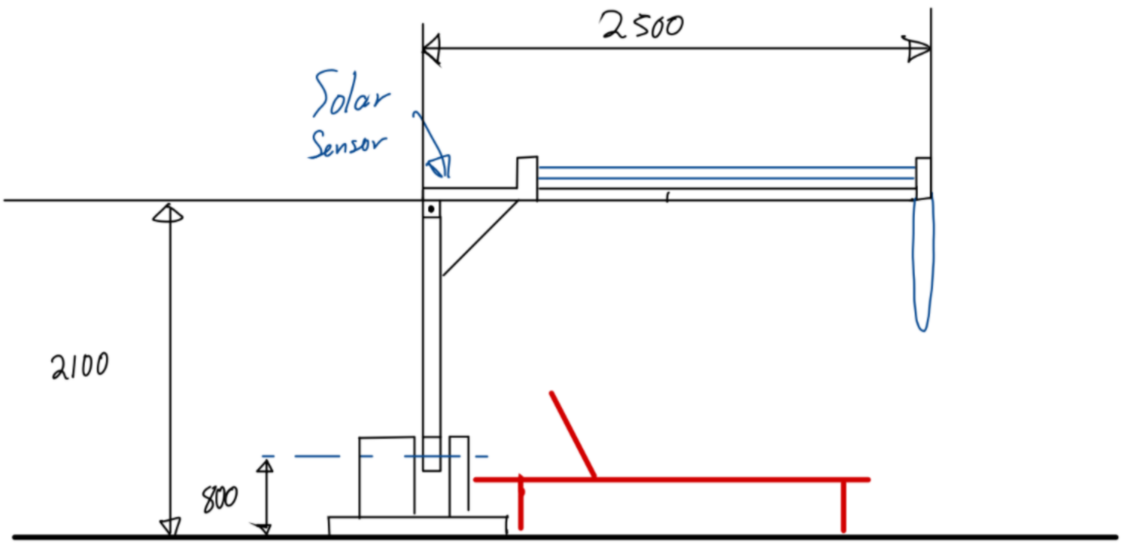


Figure 1.1.1.1

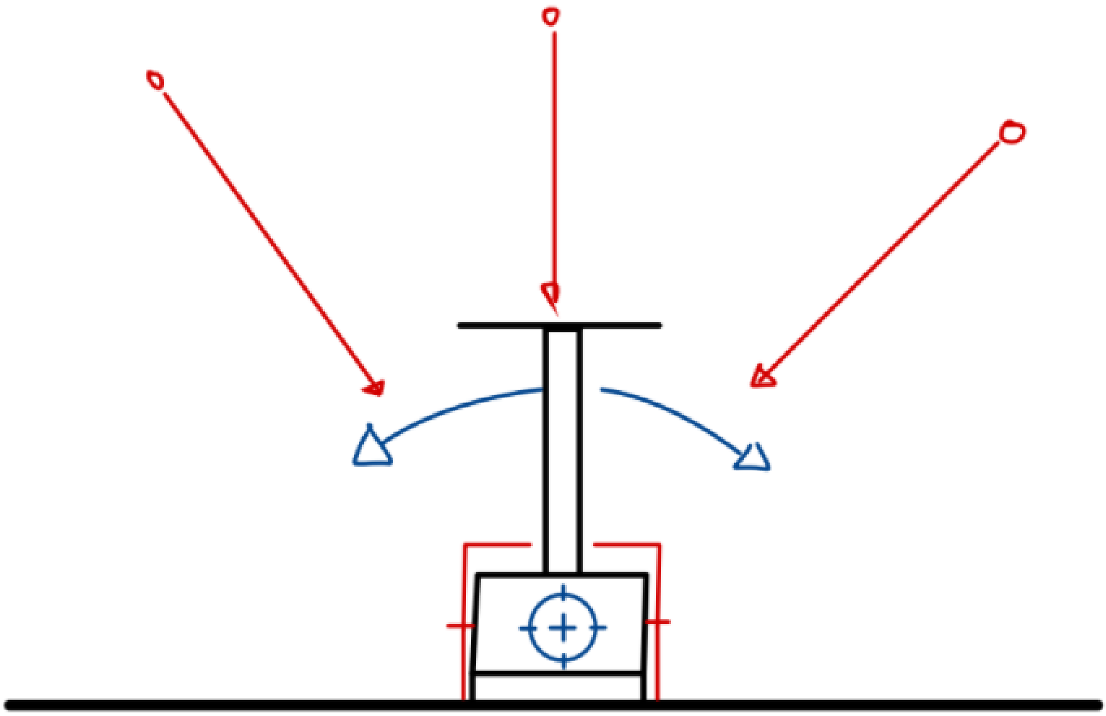


Figure 1.1.1.1

The rotation will be propelled by an electric motor in the base of the device. In this base there will also be the necessary battery and computer controller unit required to operate the whole ensemble. An estimate of the largest static moment from the weight of the shade when tilted is of 13.95Nm, which will be reduced using a spur gear mechanism with a ratio of 3:1. This means the effective largest static moment on the motor would be 4.65Nm. This can easily be handled by a stepper motor. However, there is still the concern of holding the shade in place when not moving. If tilted, the shade will naturally try to rotate downwards. Countering this with torque from a motor would lead to a large and continuous drain from the battery. In order to avoid these, a locking mechanism has been conceived which has a linearly moving pin that locks with one of the gears previously mentioned. A spring keeps the pin in the locking position, but will be temporarily released by a solenoid when the motor is working to move the shade. The conceptual design of this mechanism is depicted in ***Figure 1.1.1.2***. The pin would likely have to be made out of steel as it will be under considerable shear stress. As it is a relatively small piece, adding much weight is not a concern despite the high density of steel. After checking the strength of the pin, it has been determined that the stresses on it are small enough that steel is not necessary and plastic can be used. These calculations are detailed out in the Strength Assessment section.

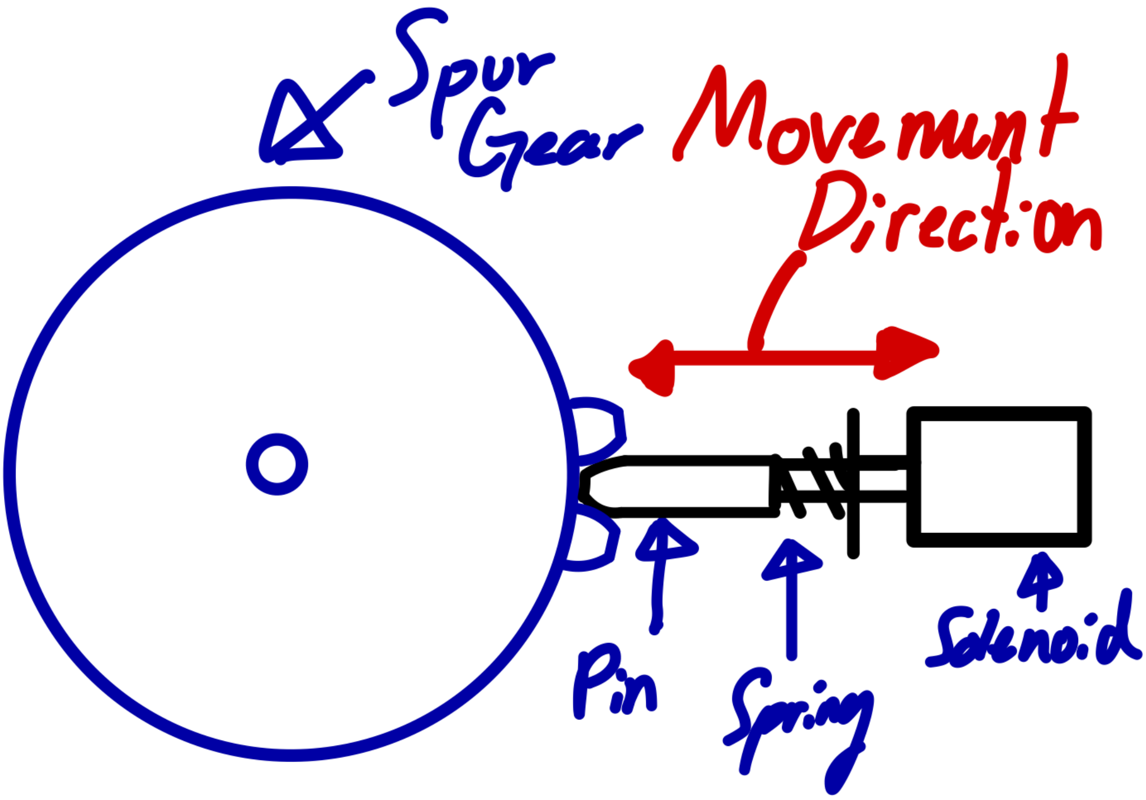


Figure 1.1.1.2

The design was also made with serious concern for the transportability of the device. The shade has been designed using an accordion design in order to make it retractable and lightweight. The frame is made out of Nylon. This material was chosen mostly for its low density with sufficient strength. The first conceptual CAD model is shown in Figure 1.1.1.3. Its estimated weight is 2 kilograms.

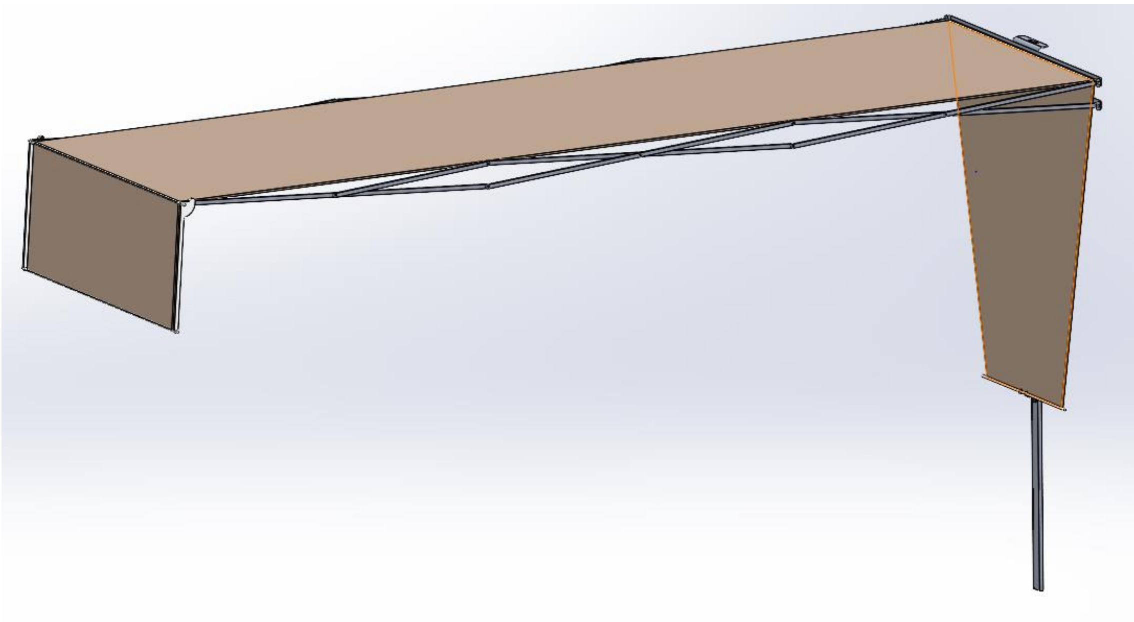


Figure 1.1.1.3

The shade can be attached in two forms to the base. One is the one already depicted in which the shade hangs over the person for the use of the device, the second is folding the frame and attaching it to a second mounting base connected to the main body of the device for transportation. The main body will have wheels which allow it to be pulled like a piece of luggage or a vacuum cleaner. Much like common vacuum cleaners have a mounting base where the wand can be mounted for easy transport, the device is designed so that the shade frame can be folded, attached to the base and then the base be pulled on its wheels for transportation. The reason for this comes down to weight. It is estimated that the total weight of the device will be 10kg once taking the motor, the batteries and the shade itself into account plus a margin for the added weight of the shell and other minor elements. We consider that this weight and size wouldn't be easy for a single person to carry from a parking lot to a beach front. However, this same weight and size could be easily managed if it is pulled in a luggage-like format. The wheels must also be relatively large and wide if they are to be used on the beach because of the possibility of narrow wheels sinking into the sand and becoming stuck. *Figure 1.1.1.4* shows a sketch of this luggage concept.

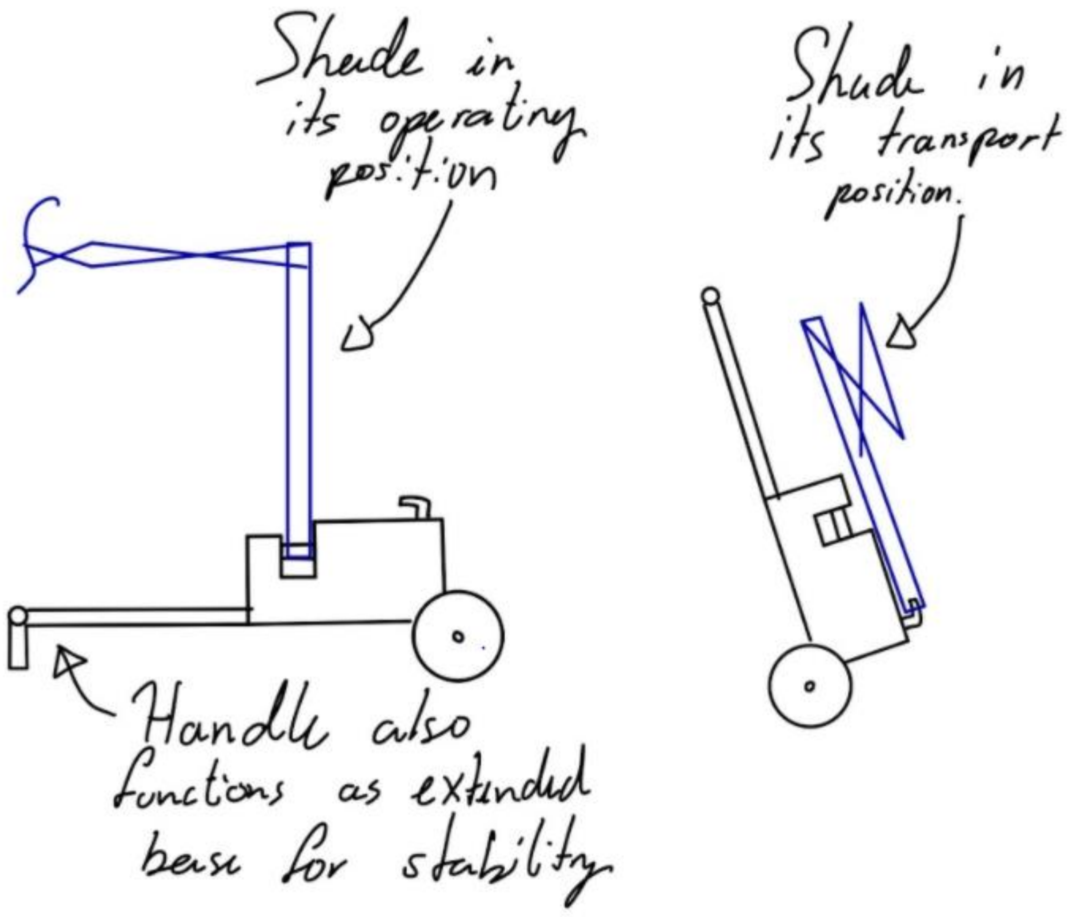


Figure 1.1.1.4

1.1.2 List of main components and estimated Quantities

1. Stepper Motor (1)
2. Battery (1)
3. LDR Sensors (2)
4. Microcontroller (1)
5. Wires/connectors
6. Spur Gears (2)
7. Shafts
8. Shade canvas
9. Bearings
10. Locking Mechanism/Solenoid Actuator (1)
11. Convertors (Quantity not yet determined)
12. Shade frame (Scissor folding mechanism)
13. Wheels (2)
14. Housing

1.2 Preliminary Strength Assessment

From the preliminary Solidworks model we get the mass of the frame and canvas excluding the main vertical support:

19.03N

Solidworks also tells us the position of the center of mass of this frame. This will be useful for the bending moment calculations.
Possible forces for wind will also be taken into account. We will assume the wind always strakes the shade from a horizontal direction. This can be the front, back and either side. The possible area for the wind to strike from the side is minimal, as shown by figure 1.2.1. Therefore, the wind force from the sides will be neglected. The same cannot be said for wind impacting from the front. Here, there is a considerable area where wind impacts and produce a force on the device.

Figure 1.2.1

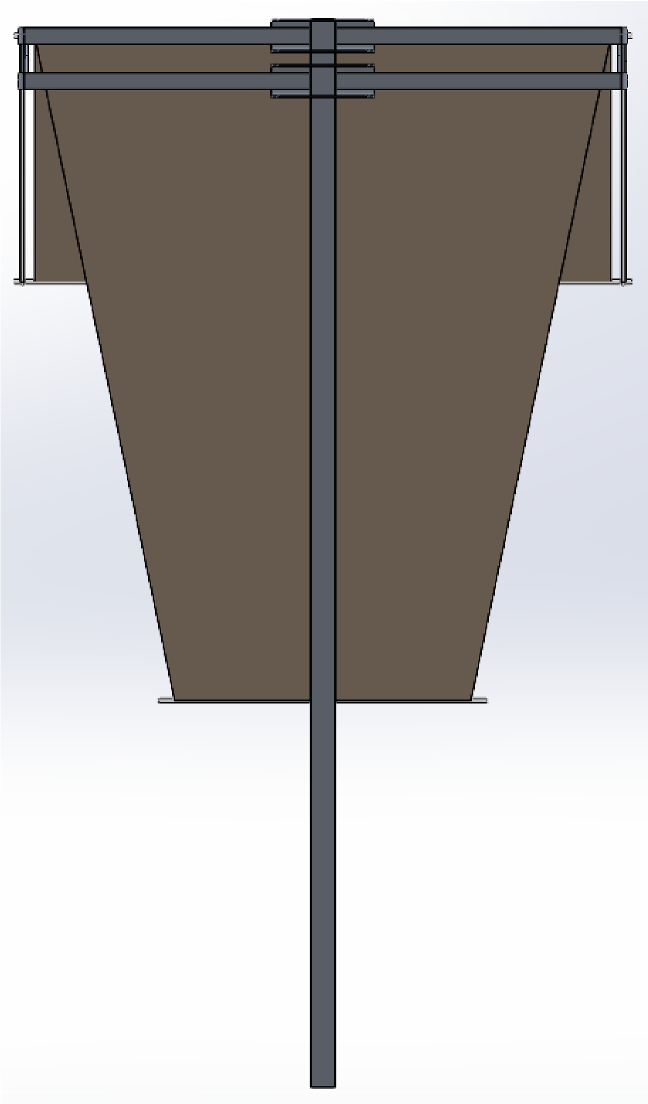
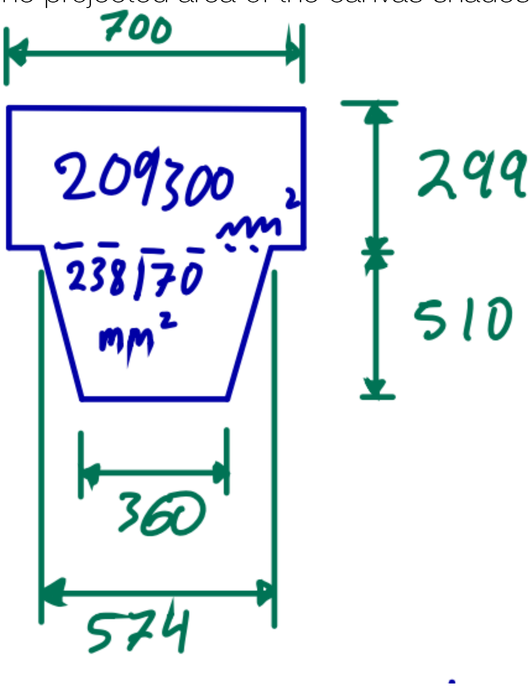


Figure 1.2.2: Front view of preliminary model

The projected area of the canvas shades as measured by solidworks is:



$$A = 209300\ mm^2 + 238170\ mm^2$$
$$= 0.447\ m^2$$

We are assuming the wind is impacting head on in the direction shown in Figure 2. We approximate the force produced with the following equation:

$$F = \frac{1}{2} \cdot v^2 \cdot A \cdot C_D \cdot \rho$$

Wind velocity for Beauford 4:

$$20\ Kph \leq v \leq 28\ Kph$$

For these calculations, the upper limit will be used:

$$v = 28\ kph \approx 7.78\ m/s$$

Drag coefficient for a flat plate[1]:

$$C_D = 1.28$$

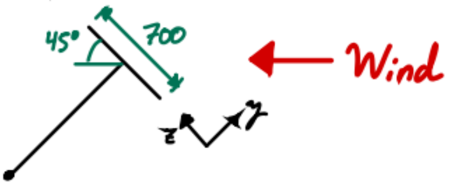
Standard density of air at sea level and 15ºC is 1.225kg/m^3

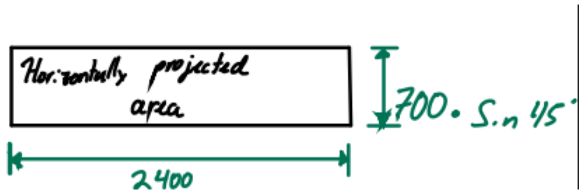
Therefore, the force of wind is:

$$F_{wz} = \frac{1}{2} (7.78\ m/s)^2 \cdot 0.447\ m^2 \cdot 1.225\ kg/m^3 \cdot 1.28$$

$$F_{wz} = 21.21\ N$$

For simplicity, this force will be represented as uniformly distributed force on the rear of the frame labeled **Fwy**. Consideration must also be made for force created on the top canvas when it is tilted sideways.





For this tilted area, the C_d will change. According to the same NASA source, since both shapes are flat platesm the inclined C_d can be derived from the C_d of a flat plate perpendicular to the wind by multipling it by the sine od the inclination angle.

$$C_{D,i} = \sin 45° \cdot C_D$$
$$= 0.905$$

[1] "Shape Effects on Drag", NASA, NASA, "www.grc.nasa.gov/www/k-12/airplane/shaped.html"

The projected area is:

$$A_i = 2400_{mm} \cdot 700_{mm} \cdot \sin 45^\circ = 1{,}19\, m^2$$

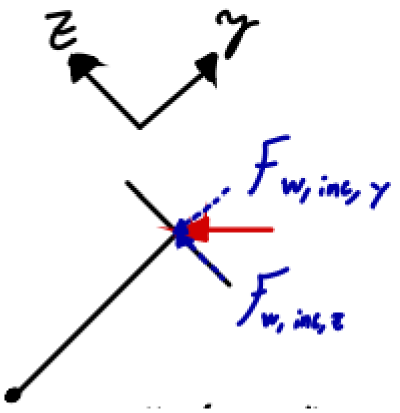
Thus, the force produced in this case is:

$$F_{w,inc} = \frac{1}{2} v^2 \cdot A_i \cdot \rho \cdot C_{Di}$$

$$= (1/2)(7.78_{m/s})^2 \cdot 1{,}19_{m}^2 \cdot 1.225 kg/m^3 \cdot 0.905$$

$$= 39.93\ N$$

This will be projected into components perpendicular to the frame:

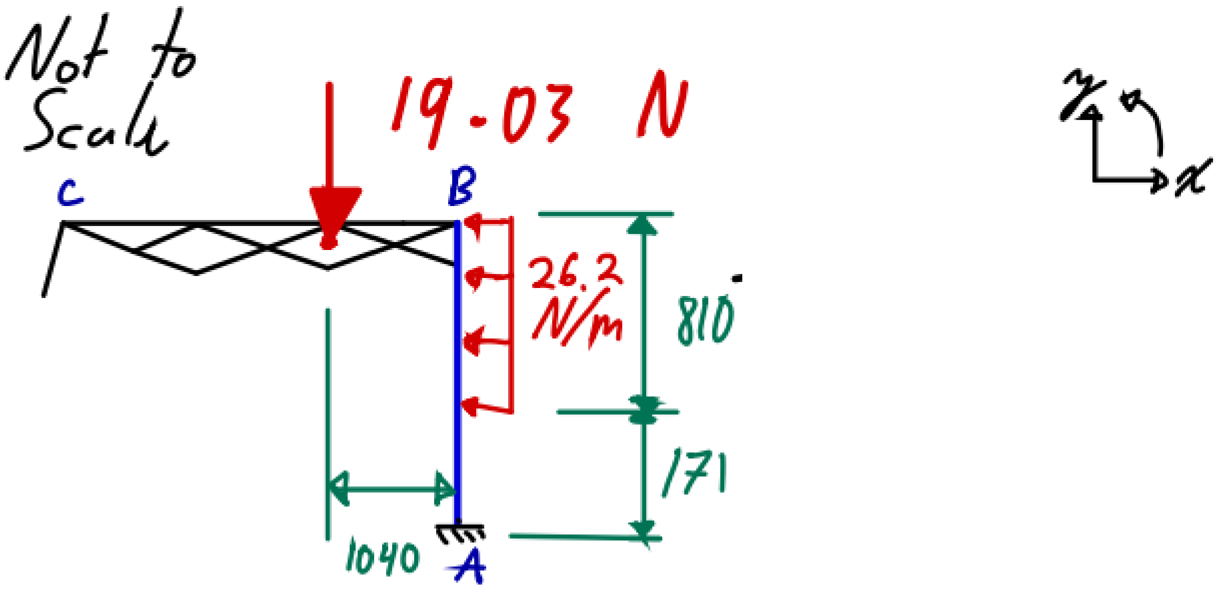


$$F_{w,inc,y} = -\cos 45^\circ \cdot F_{w,inc} = -28.23\ N$$

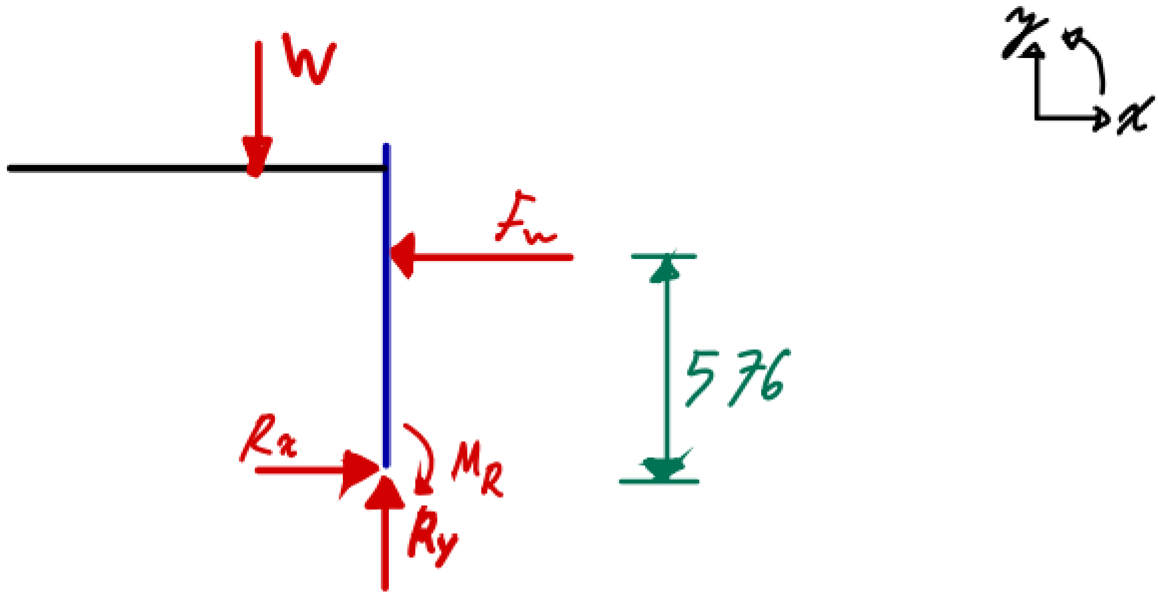
$$F_{w,inc,z} = \cos 45^\circ \cdot F_{w,inc} = 28.23\ N$$

Because these forces occur under circumstances completely different to the wind impacting head on the front of canvas, these two cases will be analyzed separately. First, case 1 will be the case of wind on the frond canvas, and case 2 will be the inclined case.

1.2.1: Case 1



For clarification, this image shows a hand drawn representation of the structure in order to show the location of the forces. The structure is not a truss, but rather an accordion type mechanism that folds and extends. The top horizontal element is the canvas shade, which is in no way a load bearing member. The crisscrossing elements are not two-force members since they have hinges at both ends and also in the middle, which allows for the accordion-like folding and extending in an orderly fashion, but also makes truss analysis not applicable.

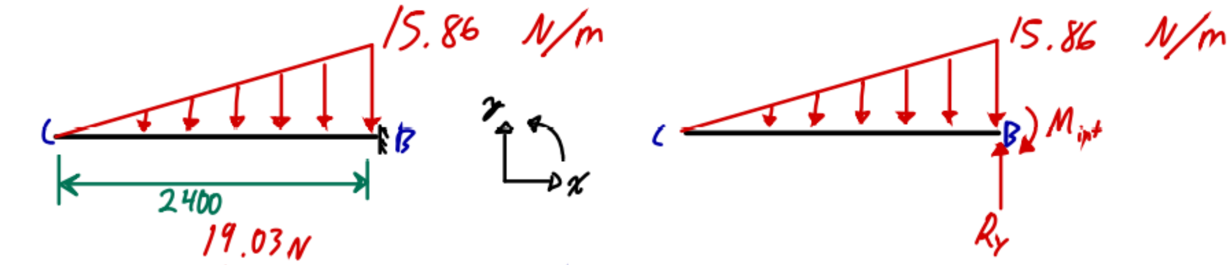


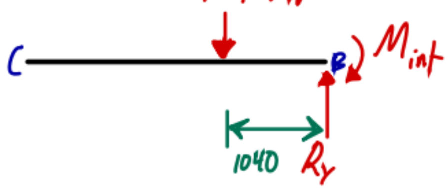
$$\sum F_y = 0 = R_y - W$$
$$\rightarrow R_y = W = 19.03\ N$$

$$\sum F_x = 0 = R_x - F_w$$
$$\rightarrow R_x = F_w = 21.21\ N$$

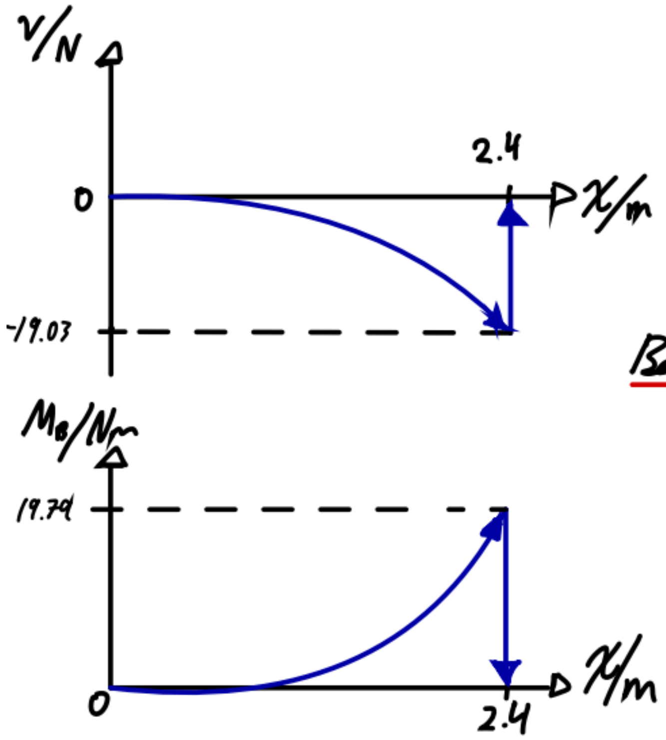
$$\sum M_A = 0 = F_w \cdot 0.576\,m + W \cdot 1.040\,m + M_R$$
$$\rightarrow M_R = F_w \cdot 0.576\,m + W \cdot 1.040\,m$$
$$M_R = 27.50\ Nm$$

Now, both the simplified horizontal member and the vertical member will be analyzed in more detail to find the shear force and bending moment on them. They are connected by a fixed connection allowing no relative movement or rotation. The weight force here is represented as a linearly increasing distributed force because there are more accordion elements on the right end. This is backed by the solidworks indicating that the center of mass for this set of elements is about two thirds of the way to the right.





$$\sum M_B = 0 = 19.03\,N \cdot 1.04\,m - M_{int}$$
$$\rightarrow M_{int} = 19.79\,Nm$$



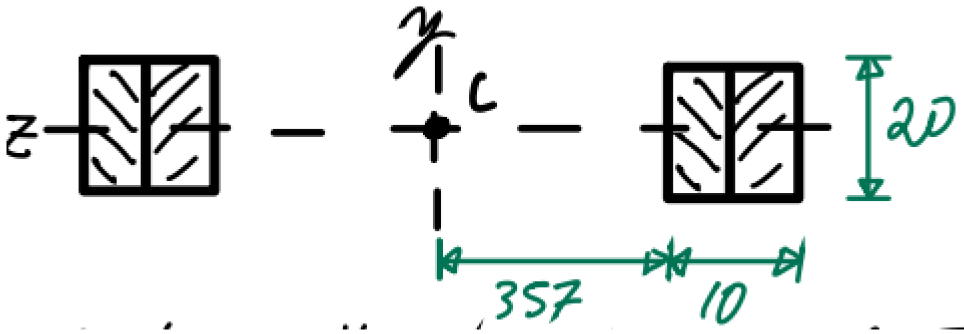
Shear Force Diagram

$$|V_{max}| = 19.03\ N$$

Bending Moment Diagram

$$|M_{B max}| = 19.79\ Nm$$

As discussed earlier, the horizontal element is in reality composed of four bars (two on each side) which form an accordion mechanism. Each bar has a solid cross-sectional area of 10X5mm. To check for the highest bending stress, we analyze at the position with the smallest area moment of inertia. This is at the hinge point where the mid-lengths of two parallel bars cross. In other words, where all bars are side by side with each other and are crossed by the centroidal surface, and not one above and one below. This proximity to the z-axis results in the smallest area moment of inertia around that same axis:



Since the bending moment acts around the z-axis, the separation of the bars from the y-axis has no effect on the area moment of inertia we are interested in.

$$I_z = \frac{b \cdot h^3}{12} = \frac{20mm \cdot (20mm)^3}{12} = 13\ 333\ mm^4 = 1.3333 \cdot 10^{-08}\ m^4$$

$$\sigma_{x,max} = \frac{M_{B,max} \cdot y_{max}}{I_z} = \frac{19.79Nm \cdot 0.010m}{1.333 \cdot 10^{-8} m^4} = 14,846,211\ N/m^2$$

$$\sigma_{x,max} = 14.85\ MPa$$

Compare this against the yield strength of Nylon 101: 80MPa.

$$\frac{\sigma_{z,max}}{S_y} = 19\,\%$$

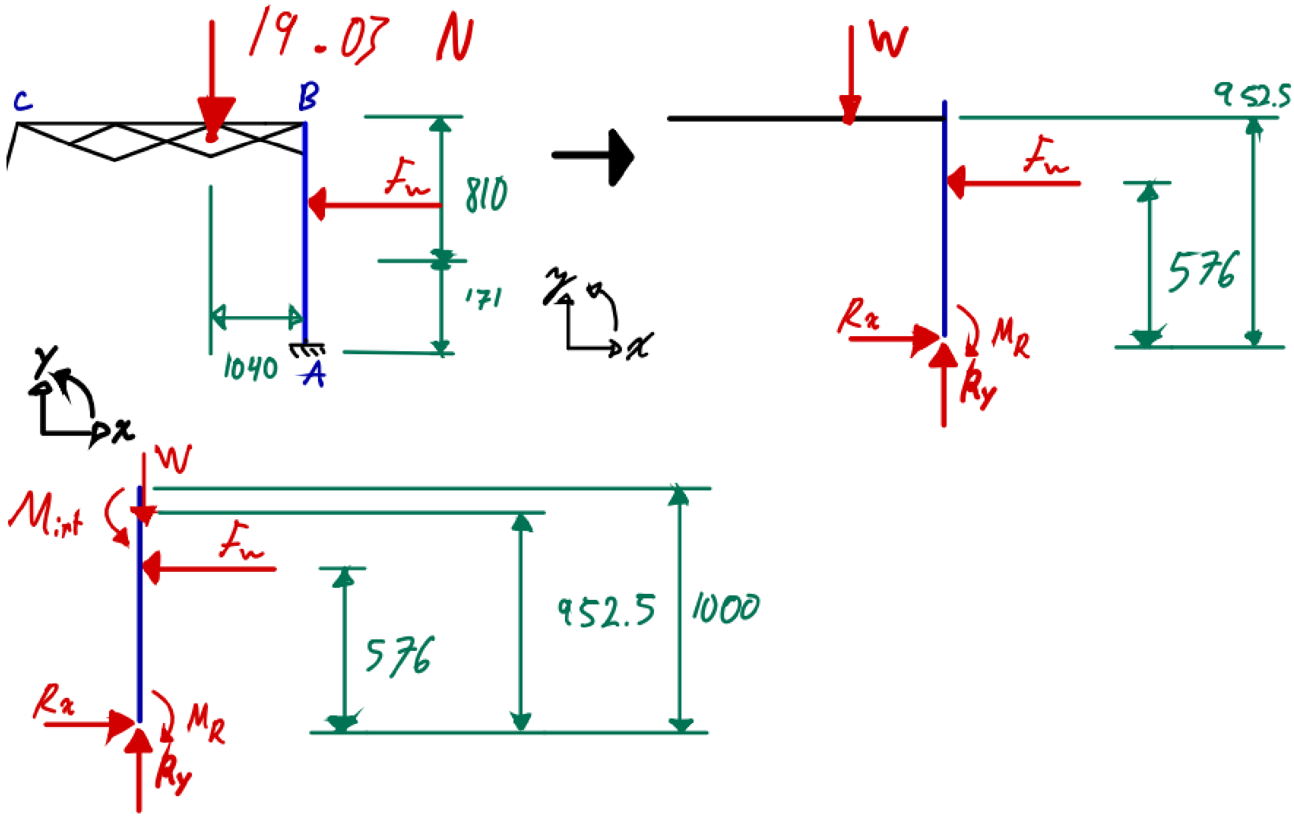
Even this number is more than the real bending stress at that location since the maximum bending moment is not present there. However, if this calculation shows that this location can handle the load safely, any other area with a larger area moment of inertia will be able to handle its respective load with even more ease. The bending moment diagram shows that the maximum bending moment occurs at the point where the accordion elements are fixed to the vertical element. To check for shear stresses, the equation is used:

$$\tau_{max} = \frac{3V_{max}}{2\,A} = \frac{3\cdot 19.07\,N}{2\cdot 20mm\ \ 20mm}$$

This formula assumes uniform stress concentration along the z-direction of the cross-section and stresses perfectly perpendicular to the neutral axis. Since the cross-section is composed of small rectangles, this assumption is not rejected.

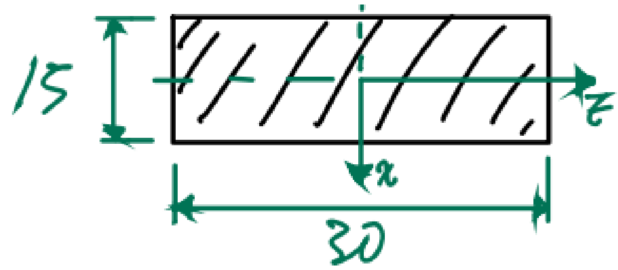
$$\tau_{max} = 0.072\ N/mm^2 = 0.072\ MPa$$

Neither of these stresses are anywhere close to being a concern given the material choice, so we declare the design safe for this load case. Now the strength of the vertical element (A-B) is checked:



First, the compressive stress originating from axial forces W and Ry will be calculated

$$\sigma_{comp,y} = \frac{W}{A}$$



$$A = 450\,mm^2$$

$$\sigma_{comp,y} = \frac{19.03\,N}{450\,mm^2} = 0.042\,MPa$$

Next, the shear force and bending moment diagrams will be drawn. We measure the y direction with point A as the origin.
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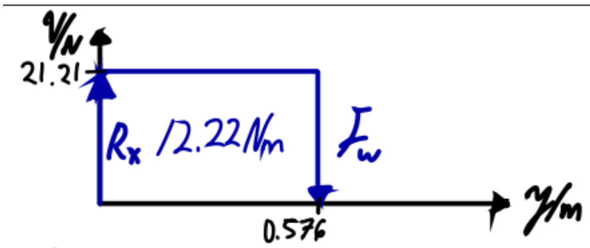
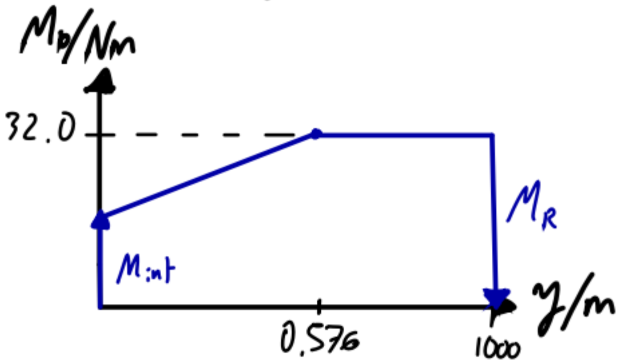


Shear Force Diagram

$$|V_{max}| = 21.21\,N$$



Bending Moment Diagram

$$|M_{b,max}| = 32.0\,Nm$$

The area moment of inertia of the previously depicted cross-section around the z-axis is:

$$I_z = \frac{bh^3}{12} = \frac{30 \cdot 15^3}{12} = 8437.5\,mm^4 = 8.44 \cdot 10^{-9}\,m^4$$

$$\sigma_{bending,y} = \frac{M_{b,max} \cdot x_{max}}{I_z} = \frac{32.0\,Nm \cdot 0.0075\,m}{8.44\,m^4} = 28{,}444{,}444\,N/m^2$$

$$\sigma_{bending,y} = 28.4\,MPa.$$

Since there is also a compressive stress, these must be combined. However, because the compressive stress is several orders of magnitude smaller, this step will be neglected. Shear stress is found:

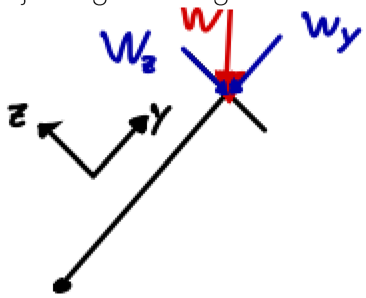
$$\tau_{max} = \frac{3 \cdot V_{max}}{2 \cdot A} = \frac{3 \cdot 21.21\,N}{2 \cdot 450\,mm^2} = 0.07\,N/mm^2 = 0.07\,MPa$$

Like before, this shear stress is so small that it can be neglected for evaluating the strength of the design for this load case. We compare and see that this element is also safe:

$$\frac{\sigma_{y,max}}{S} = \frac{\sigma_{bending,max}}{S} = \frac{28\ MPa}{80\ MPa} = 0.355$$

1.2.2: Case 2

Projecting the weight force on components on the coordinate system we get:

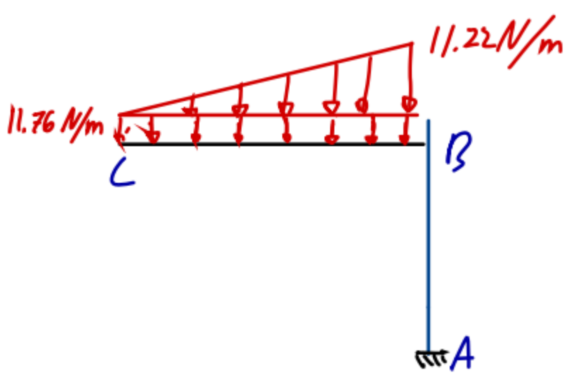


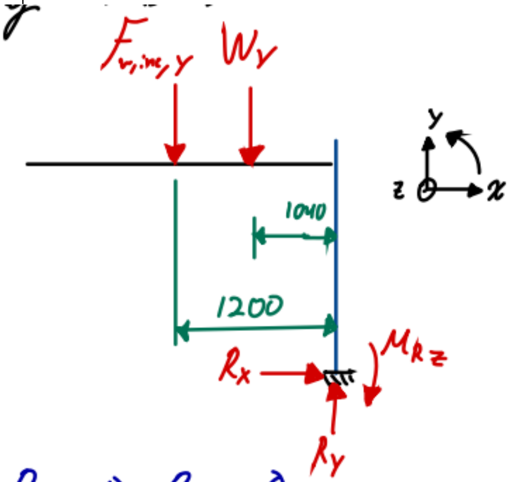
$$W = 19.03\,N$$

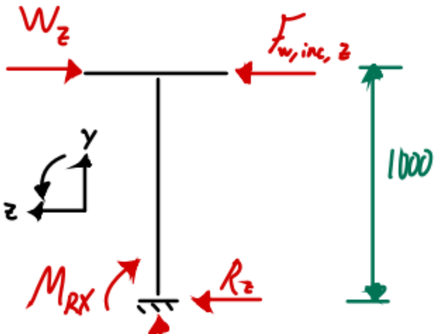
$$W_z = -W \cdot \cos 45° = -13.46\,N \qquad |F_{w,inc,y}| = |F_{w,inc,z}| = 28.23\,N$$

$$W_y = -W \cdot \sin 45° = -13.46\,N$$

With this we make the following FBDs, having the wind force as an evenly distributed force and the weight force as linearly distributed as explained earlier:







$$\Sigma F_x = 0 = R_x \rightarrow R_x = 0$$

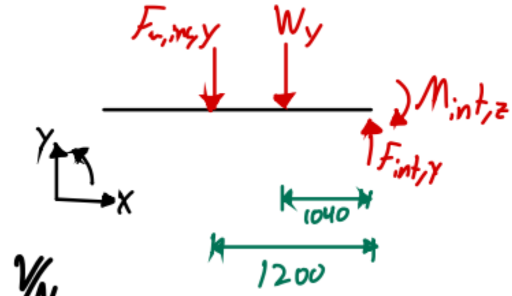
$$\Sigma F_y = 0 = -F_{w,inc,y} - W_y + R_y$$
$$R_y = F_{w,inc,y} + W_y$$
$$R_y = 41.69\,N$$

$$\Sigma F_z = 0 = R_z + F_{w,inc,z} - W_z$$
$$R_z = W_z - F_{w,inc,z} = 14.77\,N$$

$$\Sigma M_{z,A} = 0 = F_{w,inc,y} \cdot 1.2\,m + W_y \cdot 1.04\,m - M_{Rz}$$
$$\rightarrow M_{Rz} = 47.87$$

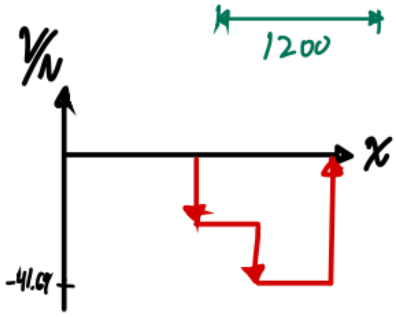
$$\Sigma M_{x,A} = 0 = (F_{w,inc,z} - W_z) \cdot 1\,m - M_{Rx}$$
$$M_{Rx} = -14.77\,N$$

The FBDs show that both the horizontal element and the vertical element will be under combined bending and shear stresses. First, the horizontal element will be analyzed.



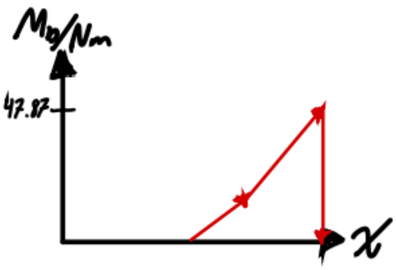
$$M_{int,z} = M_{Rz} = 47.87\ Nm$$

$$F_{int,y} = F_{w,inc,y} + W_y = 41.69\ N$$



Shear Force Diagram

$$|V_{max}| = 41.69 N$$



Bending Moment Diagram

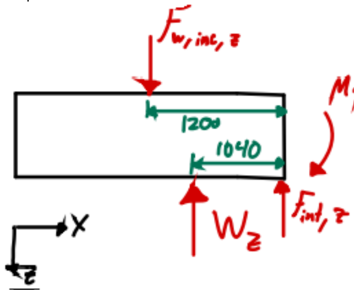
$$|M_b| = 47.87\ Nm$$

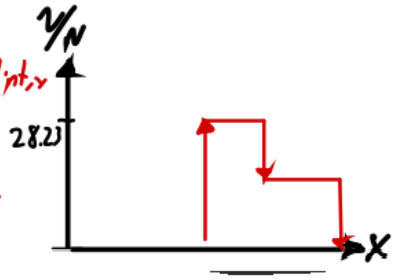
The bending stresses are:

$$\sigma_{x,max} = \frac{47.87\ Nm \cdot 0.01\ m}{1.3333 \cdot 10^{-8}\ m^4} = 35{,}900{,}000\ N/m^2$$

$$\sigma_{x,max} = 36\ MPa$$

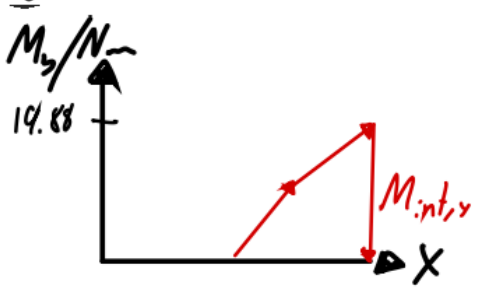
Top view to find lateral bending moments:





Shear Force Diagram

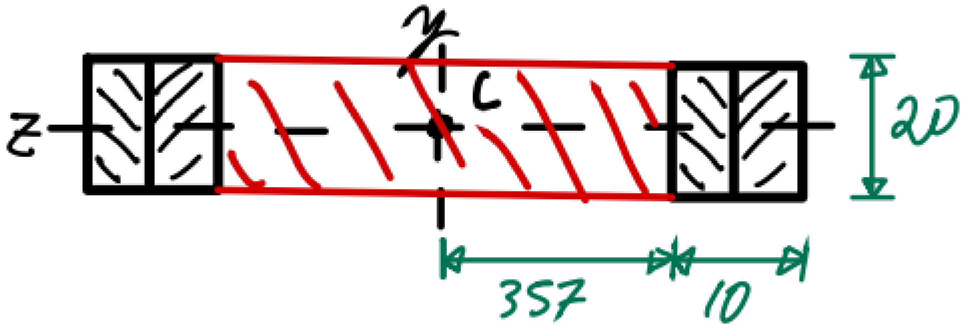
$$|V_{max}| = 28.23$$



Bending Moment Diagram

$$|M_{b,max}| = 19.88\ Nm$$

The area moment of inertia around the y axis must be found in order to find these lateral bending stresses:



Finding the Iy of the combined black and red rectangles, subtracting the Iy of the red area:

$$I_z = \frac{1}{12} \cdot 20_{mm} \cdot (734_{mm})^3 - \frac{1}{12} \cdot 20_{mm} \cdot (714_{mm})^3$$

$$I_z = 524\,209{,}733 \ mm^4 = 5.24 \cdot 10^{-5} m^4$$

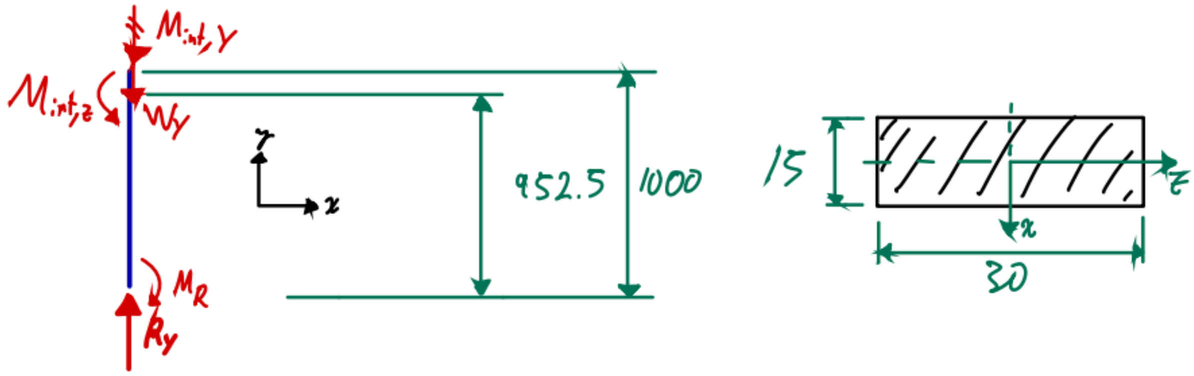
Finding the lateral bending stress:

$$\sigma_{bending,y} = \frac{19.88 Nm \cdot 0.367 m}{5.24 \cdot 10^{-5} m^4} = 132{,}232 \ N/m^2 = 0.132 \ MPa$$

It is no surprise that this stress is so small comparatively since the beam elements are so far from the y-axis. This value, like the pure shear in case 1 is considered negligible for the assessment of material.

$$\frac{36 \ MPa}{80 \ MPa} = 0.45$$

Moving on to the vertical element. Here, the bending moment $M_{int,y}$ will act as a torsional moment:



First, compressive stresses are checked:

$$\sigma_{comp} = \frac{R_y}{A} = \frac{41.69 N}{450 mm^2} = 0.093 \ MPa$$

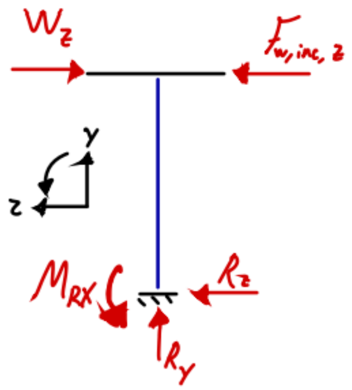
Since no shear forces act externally on the beam, it is under pure bending and no shear diagrams are made to determine the maximum bending stress around the z-axis:

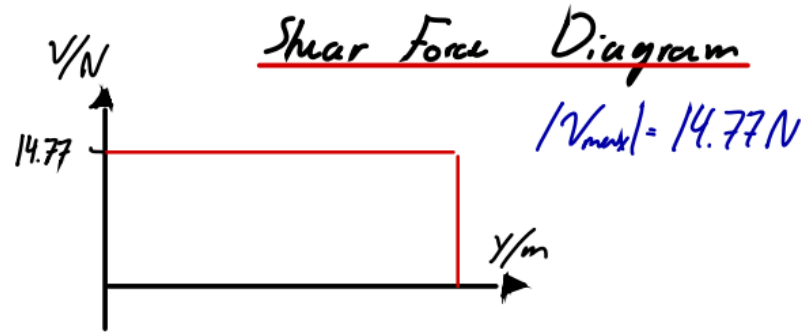
$$|M_{b\,max}| = M_{Rz} = M_{int,z} = 47.87\,Nm$$

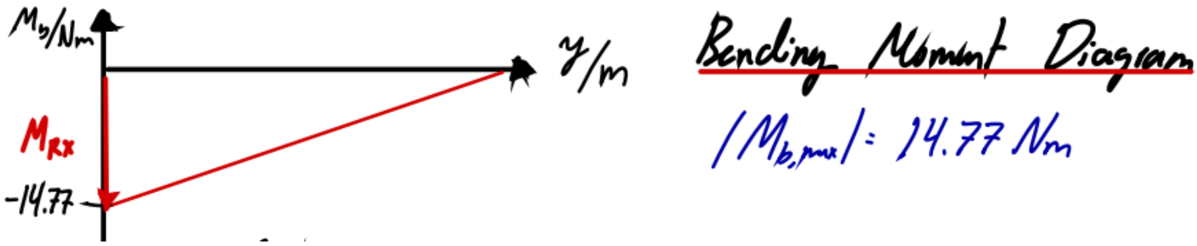
$$\sigma_{b,z} = \frac{47.87\,Nm \cdot 0.0075\,m}{8.44 \cdot 10^{-9}\,m^4} = 42{,}538{,}507\,N/m^2$$

$$= 42.5\,MPa$$

There are also bending forces around the x-axis:







To find these stresses, the area moment of inertia around the x-axis is needed:

$$I_x = \frac{15\,mm \cdot (30\,mm)^3}{12} = 33\,750\,mm^4 = 3.375 \cdot 10^{-8}\,m^4$$

$$\sigma_{b,x} = \frac{14.77\,Nm \cdot 0.015\,m}{3.375 \cdot 10^{-8}\,m^4} = 6{,}564{,}444\,N/m^2$$

$$= 6.6\,MPa$$

Last, we find the stresses due to torsion:

$$\tau_{torsion} = \frac{T \cdot c_{max}}{J} \qquad T = M_{int,y} = 19.88\,Nm$$

$$J = \frac{b \cdot h(b^2+h^2)}{12} = \frac{15mm \cdot 30mm\,(15^2_{mm} + 30^2_{mm})}{12} = 42188\,mm^4 = 4.22 \cdot 10^{-8}\,m^4$$

$$\tau_{torsion} = \frac{19.88\,Nm \cdot 0.0168\,m}{4.22 \cdot 10^{-8}\,m^4} = 7,900,420\,N/m^2 = 7.9\,MPa$$

The axial stresses from bending combine to 49.1MPa. This value is used together with the shear stress due to torsion to find the Von Mises reference stress. This is applicable since there is one corner of the rectangular cross-section where the positive max bending stresses in both directions and the maximum shear from torsion all coincide.

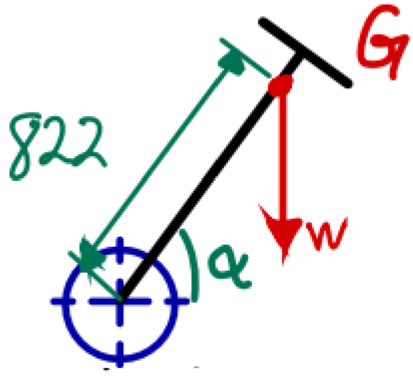
$$\sigma_{vm} = \sqrt{(49.1\,MPa)^2 + 3(7.9\,MPa)^2} = 51\,MPa$$

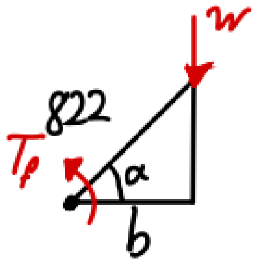
$$\frac{\sigma_{vm}}{S} = \frac{51\,MPa}{80\,MPa} = 0.63$$

The element is deemed safe.

1.2.3: Motor Torque Requirements

The motor driving the rotation of the shade has to be able to overcome the static moment produced by the weight of the shade when inclined in order to be able to move it. The static torque will depend on the inclination angle α. It will be estimated using the weight of the entire frame (including the vertical pole) acting as a point force at the center of gravity as calculated by solidworks. Using the device´s maximum inclination of α=20º:





Torque acting on shade frame : T_f

$$\Sigma M = 0 = T_f - b \cdot W$$

$$b = 822\,mm \cdot \cos 20° = 772\,mm = 0.772\,m$$

$$W = 9.81\frac{m}{s^2} \cdot m = 9.81\frac{m}{s^2} \cdot 1.841\,kg = 18.06\,N$$

$$\Sigma M = 0 = T_f - 0.772\,m \cdot 18.06\,N$$

$$\rightarrow T_f = 0.772\,m \cdot 18.06\,N$$

$$T_f = 13.95\,Nm$$

This will be the torque at the base of the frame, but it will not be the motor´s output torque since a pair of spur gears will be used in between the frame and motor with a reduction ration of 3:1. Therefore, the required torque from the motor will be 4.65Nm. Since the device need not rotate the shade quickly, only a small excess of motor torque over those 4.65Nm is needed.

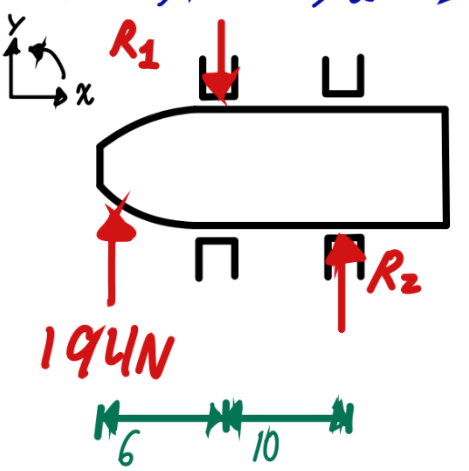
1.2.4: Locking Pin Strength

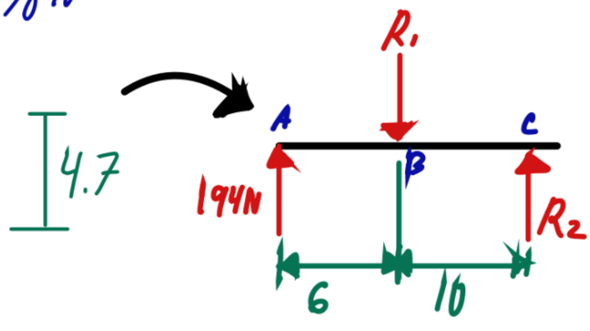
Choosing gears of module m3, the tooth thickness(es) is given as[2]:

$$S = \pi \cdot m/2^{*} = 4.7\,mm$$

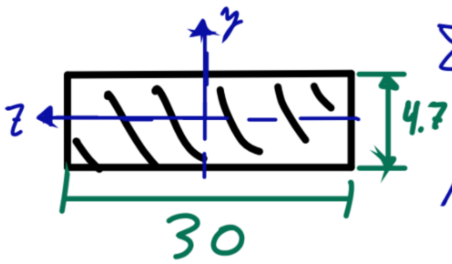
The force on the pin is calculated knowing the torque on the gear and the diameter (36mm):

$$F = M/r = M \cdot 2/d = 258\,N$$





$$\sum M_B = 0 = 0.01m \cdot R_2 - 0.006m \cdot 258\,N$$
$$R_2 = 154.8\,N$$



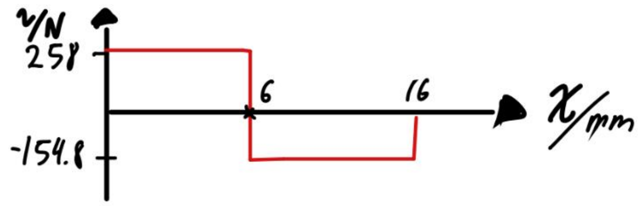
$$\sum F_y = 0 = 258\,N + R_2 - R_1$$
$$R_1 = 412.8\,N$$

$$A = 141\,mm^2$$

$$I_z = \frac{30mm \cdot (4.7mm)^3}{12} = 259.5\,mm^4 = 2.60 \cdot 10^{-10}\,m^{-4}$$

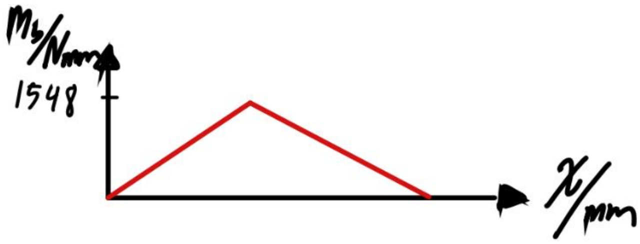
It is worth mentioning that 4.5mm is the tooth thickness at the point of contact between pin and gear, but it would taper to a larger thickness. Nonetheless, the smaller thickness will be used for the calculations as a safety precaution.

2 * "Basic Gear Terminology and calculations". KHK Gears, khkgears.net/new/gear_knowledge/abcs_of_gears-b/basic_gear_terminology_calculation.html.



Shear Force Diagram

$|V_{max}| = 258\ N$



Bending Moment Diagram

$|M_{b,max}| = 1548\ Nmm$
$= 1.548\ Nm$

$$\sigma_b = \frac{1.548\ Nm \cdot 0.00235\ m}{2.60 \cdot 10^{-10}\ m^4} = 13{,}991{,}538\ N/m^2 = 14.0\ MPa$$

Shear stress Calculations:

$$\tau = \frac{3V}{2A} = 2.7\ N/mm^2 = 2.7\ MPa$$

This stress is small enough that the initial idea of using a still pin can be discarded. The same plastic used for the structural components, Nylon 101, has a tensile strength over 4 times larger than the induced stress.

1.3 Functional Structure

1.3.1 Portable Automated Shade Function

Based on our conceptual design, we are well equipped to demonstrate the input and output of our sun shade and the interdependencies between various components with the functional structure diagram (Fig – see below). The input to our system is sunlight. We use LDR solar sensor(s) that detects the sun movement / sunlight when photons are incident on these sensors whereas, the system is integrated with one stepper motor which serves the purpose of the output to move the shade automatically to keep the chair under shade at all times. When the photons strike the sensor(s), there is a proportional current produced by them depending upon the amount of incident sunlight. Then, this data from the sensors serves as an input to the microcontroller (Arduino UNO) at regular time intervals, which is our central processing unit. The microcontroller then compiles, combines and compares the data from the sensor(s), thus controlling the direction of movement of the motor (clockwise/counter clockwise) as well as actuating the unlocking mechanism. Thus, allowing the gears and the motor shaft to rotate with an increment in well-defined steps. Once the shade position is set, the solenoid actuator locks the gear mechanism again, hence preventing the shade from movement. Data from the sensor(s) is obtained at regular time intervals so as to keep the best possible precision of shade on the chair all times. ***Figure*** shows the broad description of the working of our product with various inputs and outputs. ***Figure*** depicts a detailed version and interdependencies amongst major components.

1.3.2 Functional Structure Diagram

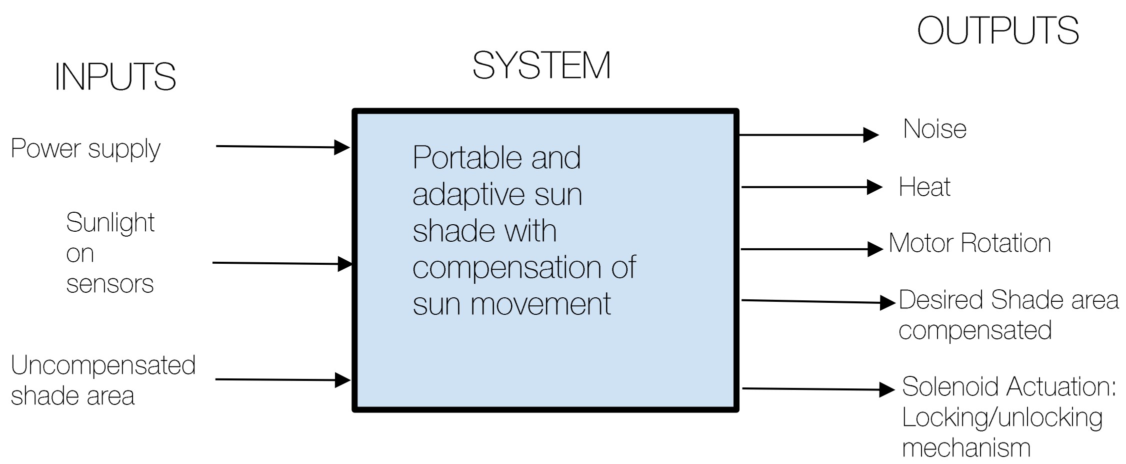


Figure 1.3.2.1: General Function Structure showing inputs and outputs

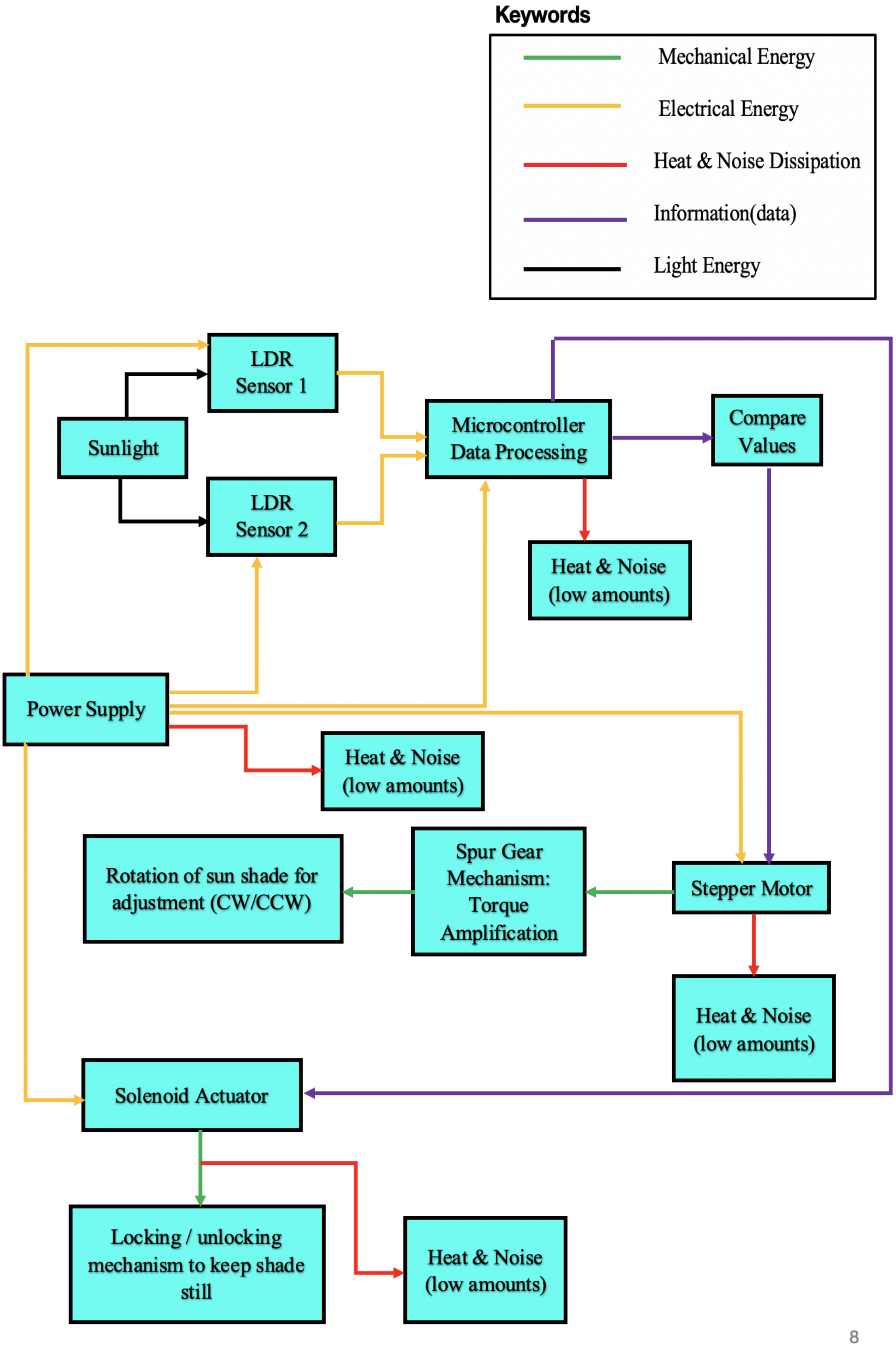


Figure 1.3.2.2: Functional Structure Diagram

1.4 Design – Failure Mode and Effects Analysis

1.4.1 What is D-FMEA?

D-FMEA stands for Design Failure Mode and Effects Analysis. It's a procedure of enlisting the components of the System under Design in a tabular format and analyse the potential failure modes of individual components along with their causes and effects. In the following FMEA table ratings of severity, probability of occurrence and detectability are done on a scale of 1 to 10 and ultimately the RPN (Risk Probability Number) is evaluated at the end which is the product of individual scores of severity, probability and detectability.

RPN = Severity x Probability of Occurrence x Detectability

The sole aim of this FMEA worksheet is not just the evaluation of failure modes of the elementary units but also the actions taken to mitigate the risks of overall product failure. Below is the list of components being used to develop our product as per the requirement of the concept design (both mechanical and electrical) and the FMEA worksheet is formulated with appropriate description. Accompanying the FMEA worksheet, the description table for severity, probability and detectability is also given.

1.4.2 D-FMEA Severity

Reference: Prof. Klein, T&B Faculty, HSRW.

Effect	Severity of Effect	Ranking
None	No effect	1
Very Minor	System operable with slight degradation of performance	2
Minor	System operable with moderate degradation of performance	3
Very Low	System operable with significant degradation of performance	4
Low	System inoperable without service interruption	5
Moderate	System inoperable with slight service interruption without stopping health care delivery.	6
High	System inoperable with moderate service interruption without stopping health care delivery.	7
Very High	System inoperable with significant service interruption without stopping health care delivery.	8
Hazardous with warning	A potential failure mode affects safe system operation, or completely stops health care delivery, with warning.	9
Hazardous without warning	A potential failure mode affects safe system operation, or completely stops health care delivery, without warning.	10

Figure 1.4.2.1: D-FMEA Severity Table

1.4.3 D-FMEA Probability of Occurrence
[3]

Probability of Failure	Failure Probability	Ranking
Remote: Failure is unlikely	No system failure expected	**1**
	One system failure expected in .25% (2.5 per 1000) of execution instances or will result in infrastructure component downtime of up to 1 hour per month	**2**
Low: Relatively few failures	One system failure expected in .5% (5 per 1000) of execution instances or will result in infrastructure component downtime of up to 2 hours per month	**3**
	One system failure expected in 1% (10 per 1000) of execution instances or will result in infrastructure component downtime of up to 5 hours per month	**4**
	One system failure expected in 2% (20 per 1000) of execution instances or will result in infrastructure component downtime of up to 8 hours per month	**5**
Moderate: Occasional failures	One system failure expected in 5% (50 per 1000) of execution instances or will result in infrastructure component downtime of up to 24 hours per month	**6**
	Repeatable system failures expected in 10% (1 per 10) of program execution instances or will result in infrastructure component downtime of up to 36 hours per month	**7**
High: Repeated failures	Repeatable system failures expected in 20% (2 per 10) of program execution instances or will result in infrastructure component downtime of up to 48 hours per month	**8**
	Failures expected in 30% (3 per 10) of program execution instances or will result in infrastructure component downtime of up to 72 hours per month	**9**
Very High: Failure is almost inevitable	Failures expected in 50% (5 per 10) of program execution instances or will result in infrastructure component downtime of up to 96 hours per month	**10**

Figure 1.4.3.1: D-FMEA Probability of Occurrence Table

[3] Reference: Prof. Klein, T&B Faculty, HSRW.

1.4.4 D-FMEA Detectability[4]

Detection	Detectability	Ranking
Almost Certain	Design control will detect potential cause/mechanism and subsequent failure mode	1
Very High	Very high the design control will detect potential cause/mechanism and subsequent failure mode	2
High	High chance the design control will detect potential cause/mechanism and subsequent failure mode	3
Moderately high	Moderately high chance the design control will detect potential cause/mechanism and subsequent failure mode	4
Moderate	Moderate chance the design control will detect potential cause/mechanism and subsequent failure mode	5
Low	Low chance the design control will detect potential cause/mechanism and subsequent failure mode	6
Very Low	Very low chance the design control will detect potential cause/mechanism and subsequent failure mode	7
Remote	Remote chance the design control will detect potential cause/mechanism and subsequent failure mode	8
Very Remote	Very remore chance the design control will detect potential cause/mechanism and subsequent failure mode	9
Absolute certainty	Design control cannot detect potential cause/mechanism and potential failure mode	10

Figure 1.4.4.1: D-FMEA Detectability Table

[4] Reference: Prof. Klein, T&B Faculty, HSRW.

1.4.5 D-FMEA

DESIGN-FMEA

Part-Function	Potential Failure Mode	Potential Effects of Failure	SEV	Potential Causes	PROB	Current Controls	DET	RPN	Recommended Actions
Stepper Motor	Motor Burnout	Loss of function due to coil winding burnout	4	Unstable power supply leading to surges in current/voltage	2	Quality converters and power supply elements (wires, batteries, etc.)	7	56	Appropriate usage of power convertors and rated electrical power supply
	Impact Damage	Loss of function	7	External high impulsive force on the motor would lead to a damage	2	Placement of the motor in the housing	8	112	Good stiff design of housing under industrial guidelines to keep the internal components safe from any external damage
Housing	Water leaking in/ dust accumulation	Short circuiting in the electrical components	7	Improper sealing, impact damage or wear over time	4	Housing design includes lips, gaskets and drainage holes	1	28	None-risk is low
	Impact Damage	Housing breaks open hence exposing the internal parts and making them suseptible to physical damage	4	Any external impact on the housing while usage or during transportation	4	The housing design is such that it can withstand considerable amounts of forces and stresses. Good stiff material used. Designed under the industry guidelines	4	64	Using good quality material while desiging according to boundary conditions and design elements such as ribs to reinforce the housing.
Battery	Battery runs out of energy	Entire device stops working	5	Device is used for a long time without pausing for recharging	3	Check the battery usage from time to time	1	15	None-Battery charge will be communicated to the user who is then resposible for charging the device when not in use.

	Power Fade	Energy supply to the device dwindles over time and will not be sufficient for proper operation	4	Exposure to high temperature for long periods during operation. Limited lifetime of cycles	4	Proper battery usage according to the product manual. Placing of the battery in a thermally insulated housing	9	144	Buying a battery with a long lifetime and charge cycles. Proper heatsinks or vents for heat dissipation in the housing
LDR sensors	Logical Error	Loss of function	8	Incorrect wiring	2	Testing and rechecking the wiring systems	1	16	Product check before final rollout in the market
	Electrical failure	Loss of function	8	Incorrect power supply voltage or overloading	4	Proper supply of voltage through convertors	2	64	Testing of the sensors via the code alongwith proper calculations on correct power supply and appropriate convertors
	Water/liquid/dust penetration and accumulation	Loss of function	8	Improper/broken housing	4	Housing design with good material and under the industry design guidelines	1	32	Following the design guidelines and usage of good quality material
Microcontroller	Technical Failure	Improper functioning of the product	8	Syntax error, runtime error,logical error, memory overflow,bad coding methods	2	Testing of the code and its effiiciency	1	16	Multiple testing of the code
	Short Circuit or electrical failure	Loss of function	8	Incorrect power supply voltage or electrical interference	2	Usage of appropriate convertors and correct supply of voltage as rated in the datasheet	8	128	Appropriate convertors to be used. Proper Quality checks before product rollout
	Thermal Failure	Loss of function	8	Extreme environmental temperature	3	Microcontrollers are placed in a thermally insulated housing	7	240	Placing all the electrical components in a cool place under the rated ambient temperature. Proper dissipation of heat

Electrical Power Converters	Short circuit or Electrical failure	Loss of function	8	Electrical overloading or extreme voltage fluctuation or using it beyond its rating	3	Maintaining a constant supply through a reliable battery as a power source	9	216	Maintaining a constant supply through a power source. Negotiating with the supplier for quality
	Thermal Failure	Loss of function	8	Extreme environmental temperature	2	The convertors are placed in a thermally insulated housing thus preventing this problem	8	168	Placing these electrical components in a cool place.Proper dissipation of heat
Wires/Connectors	Short circuit or electrical failure	Loss of function of the electronic circuit hence the overall product damage or harm to human life (sparks / fire)	3	Inappropriate cable selection for the desired application	1	Cables are selected according to desired current and voltage usage	10	30	Taking good precautions and margins while doing electrical calculations so that appropriate cable selection can be done
	Thermal Failure	Loss of function of the electronic circuit hence the overall product damage or harm to human life (sparks / fire)	5	Overheating/ electrical overloading due to prolonged usage	7	Good quality cable selection to withstand high temperature	4	140	The machine should be given some rest after usage
	Short circuit or electrical failure	Loss of function of the electronic circuit hence the overall product damage or harm to human life (sparks / fire)	10	Moisture in insulation	1	Wires are laid inside housings which prevent the moisture reaching the cables	10	100	Proper housing design and trying to keep exposed cables(if any) away from moisture

	Mechanical failure	Loss of function of the electronic circuit hence the overall product damage	8	Physical damage during the assembly	1	Cables are laid such that risks for physical damage are extremely low	8	64	Careful handling during product assembly
	Wear and tear	Loss of function of the electronic circuit hence the overall product damage or harm to human life (sparks / fire)	10	Aging or deterioration of the insulating material	2	Usage of good quality cables with proper insulation	2	40	Regular checks and buying wires/cables from a reliable supplier with certified quality control
Spur Gears	Cracking and breaking of gear teeth	Torque transfer or locking mechanism become impossible depending on which gear fails	8	Material fatigue over long periods of use	3	The gears are selected in cooperation with the supplier to ensure that they can safely handle the expected loads	2	48	Select gears and suppliers that are known for quality and reliability
Shaft	Material failure	Torque transfer or locking mechanism become impossible depending on which shaft fails	8	Material fatigue over long periods of use	2	The shaft dimmensions and materials are chosen following design guidelines regarding the expected loads	2	32	Shafts are designed following industry guidelines and material properties are ensured by suppliers
Shade Frame	Deformation damage to frame	Inability to fold or extend the shade fully.	4	High Impact Damage	2	Material Choice	3	24	None - Risk is low since a very high impact force would be needed to significantly deform the solid aluminium frame

Locking Mechanism(Solenoid Actuator)	Mechanical failure	Loss of function	8	Deformation/breakage of the actuator if the gear rotates or tries to rotate when the system is locked	2	Proper coding ensures that first system is unlocked and then the motor shaft rotates	1	16	The sequence of execution of various actions should be clear during the design phase
	Electrical failure	Loss of function	8	Incorrect power supply/ Electrical surges	4	Proper electrical supply under desired ratings through convertors	1	32	Usage of safety devices if possible to cut the power supply during an electrical surge
	Thermal failure	Loss of function	7	Extreme environmental temperature	2	Placed in a thermally insulated housing	1	14	Placing the components in a cool place.Proper dissipation of heat
Canvas Shades	Tearing	The shades lose their shape and allow sunlight through holes and tears	3	Damage from sharp or pointy objects	3	Visual inspection of canvas material when recieving it from supplier	1	9	Careful negotiation with canvas suppliers to settle on the expect quality control standards
Bearings	Mechanical failure	Increased resistance to the turning of the shafts	4	Bearing fatigue from excessive forces and high cycle count	1	None- The bearings must be properly dimmensioned taking their loads into account. Cycle counts for this device are minimal because of its design, less than one full rotation each day. The risk of bearing fatigue is minimal.	6	24	Negotiation with supliers to settle the standards of quality and quality and control that are expected
Wheels	Mechanical failure	Loss of function/ transportability	4	High impact damage by any unwanted high force or stress during usage	4	Good quality wheels used and designed under the industry guidelines	1	16	Preventing it from sudden jerks and impulsive forces
	Wear and tear	Loss of function/ transportability	4	Prolonged usage/ using it on very rough surfaces	7	Good quality wheels used and designed under the industry guidelines	1	28	Trying to avoid carrying it on very rough surfaces

1.5 Market Analysis

1.5.1 Market Research

According to the research of Business Industry Report, European countries and USA were the major umbrella importers ("Global Umbrella Market"). In addition, Germany is accounted for ranking first in umbrella trading in Europe. In 2020, parasols with a telescopic shaft took up 19.8% out of the entire market volume in Germany which made a total sale of 39 million USD or 32 million Euros ("Trend Economy"). Furthermore, according to a study, some countries in Europe spend relatively higher than the others on luxury furniture or products for traveling such as Germany, Switzerland, Italy, and Spain (Sinus Institute).

Meanwhile, the USA imports the most umbrellas as an individual country. Aside from the fact that the USA has a large coast, 4.1% of people or around 13 million people in the USA own a pool in their backyard (Kennedy). However, due to the current pandemic of COVID-19, the umbrella market has also experienced significant loss in production due to lockdown and travel restriction. Distribution channels all over the world were able to sell much less than the original sales plan in last year. Nevertheless, experts assume that the umbrella market will increase again after lockdown and is predicted to have a compound annual growth rate of 2% over the time of 2019 to 2025 ("Umbrella Market Segmentation by Product Type").

1.5.2 Market Decision

Since the product, Portable and adaptive sun shade with automated compensation of sun movement, is considered to be a luxury product, it is assumed to be bought by people who have an income for more than approximately 33,600 € or in the other word, a person who is in the top 20% (Hendriksz). As mentioned, people from countries such as the USA, Germany, Switzerland, Italy, and Spain are more likely to buy a luxury product for furniture or traveling. By this, we aim to sell our product, a so-called smart umbrella, in the mentioned countries. Another important decision is price, the company has to make sure that the price will cover production cost and at the same time be able to generate profit. The price is set to be 250 Euro, which is slightly higher than the existing high-end parasol. In the first year, the company will produce 50,000 umbrellas. The total sales number was predicted by the target customers in the chosen area who are more likely to buy the product in the first year. This means that the target revenue of the first year is 12,500,000 Euros.

1.6 Project Planning

1.6.1 Work Breakdown Structure and Responsibilities

The tasks for completing each milestone are determined by the study program of each member. The task related to market decision or production planning will be conducted by Industrial engineering student, Ariya Arbhabhirom. The task related to mechanical knowledge will be conducted by Mechanical engineering student, Gerardo Cabrera. Lastly, the tasks related to electrical knowledge will be conducted by Mechatronics System engineering students which are Anmol Singh and Youssef Abdelrazak Ismail Ali.

	Work Breakdown Structure	Responsible member
1	Concept design	
1.1	Project plan	Ariya Arbhabhirom
1.1.1	Distribute tasks to each member	
1.1.2	Create GANTT-chart	
1.2	Overall product concept	Gerardo Cabrera
1.2.1	Group meeting	
1.2.2	Researching the mechanical and electrical mechanism	
1.2.3	Create basic sketch with written description	
1.2.4	Create a list of main components	
1.3	Preliminary strength assessment	Gerardo Cabrera
1.3.1	Calculate material strength to validate product concept	
1.3.2	Decide final product concept	
1.4	Marketing decisions	Ariya Arbhabhirom
1.4.1	Researching the market and price of similar product type	
1.4.2	Determine market area and price	

1.5	Functional Structure	Anmol Singh Youssef Abdelrazak Ismail Ali
1.5.1	Connect interdependencies between components	
1.5.2	Design a function structure including both mechanical	
1.6	D-FMEA	Anmol Singh Ariya Arbhabhirom Gerardo Cabrera Youssef Abdelrazak Ismail Ali
1.6.1	Create a list of potential failure in D-FMEA	
2	Product design	
2.1	Complete 3D model	Gerardo Cabrera
2.1.1	Group meeting	
2.1.1	Create 3D model using Solidworks and CAD	
2.1.3	Describe functional principle	
2.2	UML	Anmol Singh Youssef Abdelrazak Ismail Ali
2.2.1	Create activity diagram, class diagram or state machine	
2.3	Circuit diagram	Anmol Singh Youssef Abdelrazak Ismail Ali
2.3.1	Create circuit diagram for electrical mechanism	
2.4	Make-or-Buy decision on component basis	Anmol Singh Ariya Arbhabhirom Gerardo Cabrera Youssef Abdelrazak Ismail Ali
2.4.1	Researching information about existing component	
2.4.2	Researching information about possible machine and material used for manufacturing	
2.4.3	Decide Make-or-Buy for each component	
2.5	Technology selection for “make” parts	Gerardo Cabrera
2.5.1	Select machine type based on previous research	
2.6	Requirements manual for “buy” parts	Anmol Singh Youssef Abdelrazak Ismail Ali
2.6.1	Create manual required for "buy" part	

3	Complete project documentation	
3.1	Technical drawings for main assembly	Gerardo Cabrera
3.1.1	Group meeting	
3.1.2	Create a technical drawing using Solidworks in 1st angle projection (DIN 406)	
3.2	Pseudo-Code	Anmol Singh Youssef Abdelrazak Ismail Ali
3.2.1	Create Pseudo-Code	
3.3	Production planning	Ariya Arbhabhirom
3.3.1	Capacity calculation	
3.4	Fatigue assessment for most critical parts	Gerardo Cabrera
3.4.1	Calculate fatigue for critical parts	
3.5	Bill of material	Anmol Singh Youssef Abdelrazak Ismail Ali
3.5.1	Create Mechanical Bill of Material	
3.5.2	Create Electrical Bill of Material	
3.6	Cost calculation	Ariya Arbhabhirom
3.6.1	Calculate total cost for production	
4	Product Presentation	
4.1	Video creation	Anmol Singh Ariya Arbhabhirom Gerardo Cabrera Youssef Abdelrazak Ismail Ali
4.1.1	Group meeting	
4.1.2	Create video based on previous discussion	
4.2	Product presentation	Anmol Singh Ariya Arbhabhirom Gerardo Cabrera
4.2.1	Present the video during class	

		Youssef Abdelrazak Ismail Ali

1.6.2 GANTT-Chart

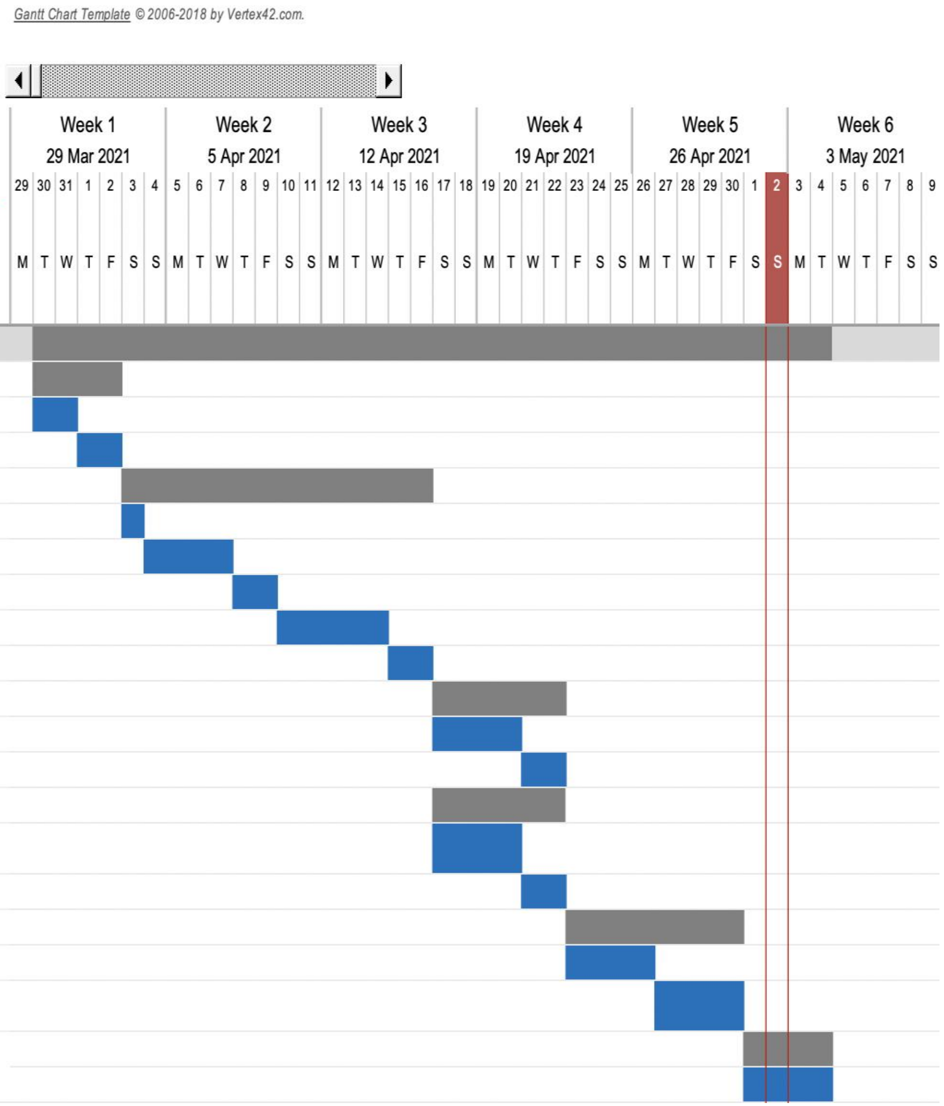
[Project Name] Project Schedule

[Company Name]

Project Start Date 3.30.2021 (Tuesday)

Display Week

WBS	TASK	Member	START	END	DAYS	WORK DAYS
1	**Concept design**		Tue 3.30.21	Tue 5.04.21	36	26
1.1	Project plan	Arbhabhirom	Tue 3.30.21	Fri 4.02.21	4	4
1.1.1	Distribute tasks to each member		Tue 3.30.21	Wed 3.31.21	2	2
1.1.2	Create GANTT-chart		Thu 4.01.21	Fri 4.02.21	2	2
1.2	Overall product concept	All	Sat 4.03.21	Fri 4.16.21	14	10
1.2.1	Group meeting		Sat 4.03.21	Sat 4.03.21	1	0
1.2.2	Researching the mechanical and electrical mechanism		Sun 4.04.21	Wed 4.07.21	4	3
1.2.3	First decision of product concept		Thu 4.08.21	Fri 4.09.21	2	2
1.2.4	Create basic sketch with written descriotion		Sat 4.10.21	Wed 4.14.21	5	3
1.2.5	Create a list of main component		Thu 4.15.21	Fri 4.16.21	2	2
1.3	Preliminary strength assessment	Cabrera	Sat 4.17.21	Thu 4.22.21	6	4
1.3.1	Calculate material strength to validate product concept		Sat 4.17.21	Tue 4.20.21	4	2
1.3.2	Decide final product concept		Wed 4.21.21	Thu 4.22.21	2	2
1.4	Marketing decisions	Arbhabhirom	Sat 4.17.21	Thu 4.22.21	6	4
1.4.1	Researching the market and price of similar product type		Sat 4.17.21	Tue 4.20.21	4	2
1.4.2	Determine market area and price		Wed 4.21.21	Fri 4.23.21	3	3
1.5	Functional Structure	Singh, Ali	Sat 4.24.21	Fri 4.30.21	7	5
1.5.1	Connect interdependencies between components		Sat 4.24.21	Mon 4.26.21	3	1
1.5.2	Design a function structure including both mechanical and electrical mechanism		Tue 4.27.21	Fri 4.30.21	4	4
1,6	D-FMEA	All	Sat 5.01.21	Tue 5.04.21	4	2
1.6.1	Create a list of potential failure in D-FMEA		Sat 5.01.21	Tue 5.04.21	4	2



[Project Name] Project Schedule

[Company Name]

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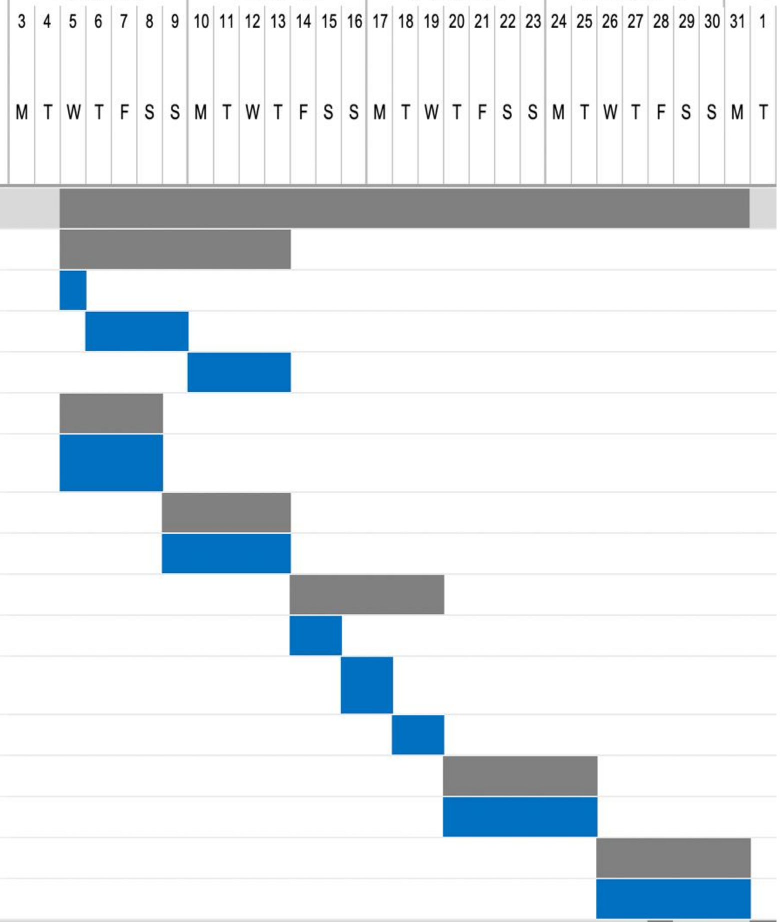
Project Start Date: 3.30.2021 (Tuesday)

Display Week

Week 6	Week 7	Week 8	Week 9
3 May 2021	10 May 2021	17 May 2021	24 May 2021

Row	WBS	TASK	Member	START	END	DAYS	WORK DAYS
29	**2**	**Product design**		Wed 5.05.21	Mon 5.31.21	27	19
30	2.1	Complete 3D model	Cabrera	Wed 5.05.21	Thu 5.13.21	9	7
31	2.1.1	Group meeting		Wed 5.05.21	Wed 5.05.21	1	1
32	2.1.2	Create 3D model using Solidworks and CAD		Thu 5.06.21	Sun 5.09.21	4	2
33	2.1.3	Describe funtional principle		Mon 5.10.21	Thu 5.13.21	4	4
34	2.2	UML	Singh, Ali	Wed 5.05.21	Sat 5.08.21	4	3
35	2.2.1	Create activity diagram, class diagram or state machine diagram		Wed 5.05.21	Sat 5.08.21	4	3
36	2.3	Circuit diagram	Singh, Ali	Sun 5.09.21	Thu 5.13.21	5	4
37	2.3.1	Create circuit diagram for electrical mechanism		Sun 5.09.21	Thu 5.13.21	5	4
38	2.4	Make-or-Buy decision on component basis	All	Fri 5.14.21	Wed 5.19.21	6	4
39	2.4.1	Researching information about existing component		Fri 5.14.21	Sat 5.15.21	2	1
40	2.4.2	Researching information about possible machine and material used for manufacturing		Sun 5.16.21	Mon 5.17.21	2	1
41	2.4.3	Decide Make-or-Buy for each component		Tue 5.18.21	Wed 5.19.21	2	2
42	2.5	Technology selection for "make" parts	Cabrera	Thu 5.20.21	Tue 5.25.21	6	4
43	2.5.1	Select machine type based on previous research		Thu 5.20.21	Tue 5.25.21	6	4
44	2.6	Requirements manual for "buy" parts	Singh, Ali	Wed 5.26.21	Mon 5.31.21	6	4
45	2.6.1	Create manual required for "buy" part		Wed 5.26.21	Mon 5.31.21	6	4



[Project Name] Project Schedule

[Company Name]

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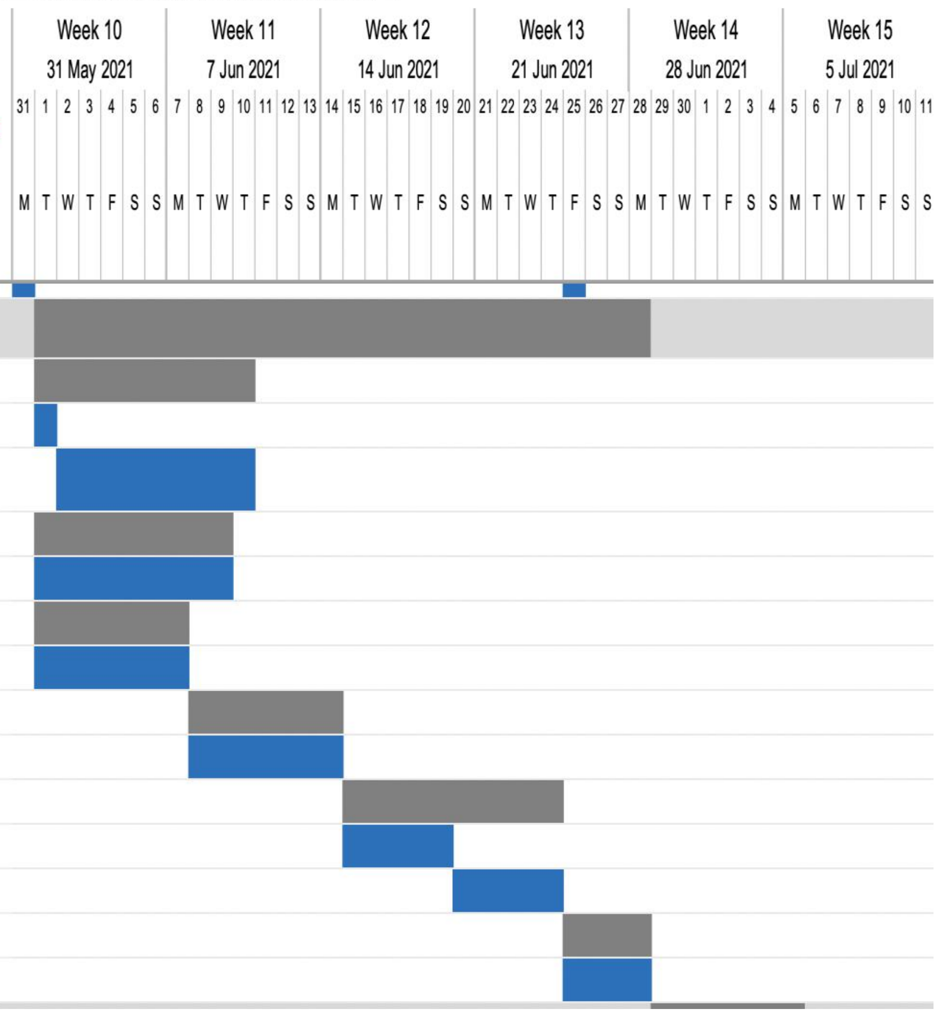
Project Start Date: 3.30.2021 (Tuesday)

Display Week

	WBS	TASK	Member	START	END	DAYS	WORK DAYS
46	3	**Complete project documentation**		Tue 6.01.21	Mon 6.28.21	28	20
47	3.1	Technical drawings for main assembly	Cabrera	Tue 6.01.21	Thu 6.10.21	10	8
48	3.1.1	Group meeting		Tue 6.01.21	Tue 6.01.21	1	1
49	3.1.2	Create a technical drawing using Solidworks in 1st angle projection (DIN 406)		Wed 6.02.21	Thu 6.10.21	9	7
50	3.2	Pseudo-Code	Singh, Ali	Tue 6.01.21	Wed 6.09.21	9	7
51	3.2.1	Create Pseudo-Code		Tue 6.01.21	Wed 6.09.21	9	7
52	3.3	Production planning	Arbhabhirom	Tue 6.01.21	Mon 6.07.21	7	5
53	3.3.1	Capacity calculation		Tue 6.01.21	Mon 6.07.21	7	5
54	3.4	Fatigue assessment for most critical parts	Cabrera	Tue 6.08.21	Mon 6.14.21	7	5
55	3.4.1	Calculate fatigue for critical parts		Tue 6.08.21	Mon 6.14.21	7	5
56	3.5	Bill of material	Singh, Ali	Tue 6.15.21	Thu 6.24.21	10	8
57	3.5.1	Create Mechanical Bill of Material		Tue 6.15.21	Sat 6.19.21	5	4
58	3.5.2	Create Electrical Bill of Material		Sun 6.20.21	Thu 6.24.21	5	4
59	3.6	Cost calculation	Arbhabhirom	Fri 6.25.21	Mon 6.28.21	4	2
60	3.6.1	Calculate total cost for production		Fri 6.25.21	Mon 6.28.21	4	2



[Project Name] Project Schedule

[Company Name]

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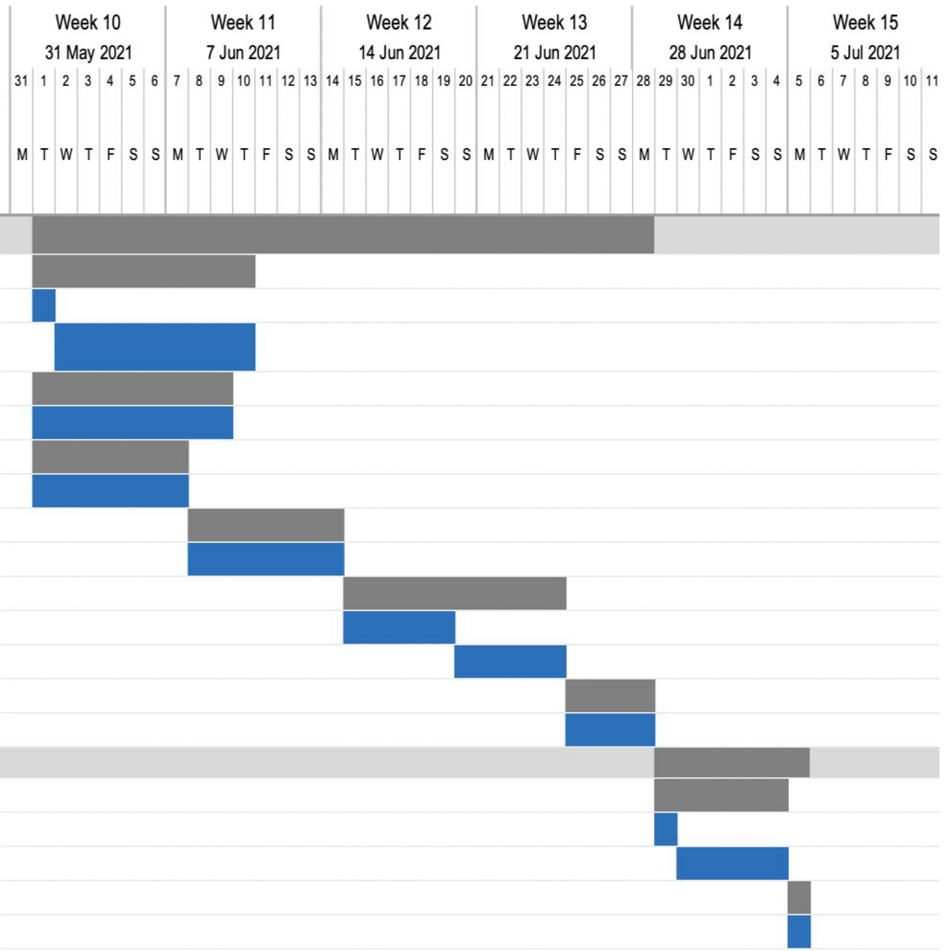
Project Start Date: 3.30.2021 (Tuesday)

Display Week

WBS	TASK	Member	START	END	DAYS	WORK DAYS
3	**Complete project documentation**		Tue 6.01.21	Mon 6.28.21	28	20
3.1	Technical drawings for main assembly	Cabrera	Tue 6.01.21	Thu 6.10.21	10	8
3.1.1	Group meeting		Tue 6.01.21	Tue 6.01.21	1	1
3.1.2	Create a technical drawing using Solidworks in 1st angle projection (DIN 406)		Wed 6.02.21	Thu 6.10.21	9	7
3.2	Pseudo-Code	Singh, Ali	Tue 6.01.21	Wed 6.09.21	9	7
3.2.1	Create Pseudo-Code		Tue 6.01.21	Wed 6.09.21	9	7
3.3	Production planning	Arbhabhirom	Tue 6.01.21	Mon 6.07.21	7	5
3.3.1	Capacity calculation		Tue 6.01.21	Mon 6.07.21	7	5
3.4	Fatigue assessment for most critical parts	Cabrera	Tue 6.08.21	Mon 6.14.21	7	5
3.4.1	Calculate fatigue for critical parts		Tue 6.08.21	Mon 6.14.21	7	5
3.5	Bill of material	Singh, Ali	Tue 6.15.21	Thu 6.24.21	10	8
3.5.1	Create Mechanical Bill of Material		Tue 6.15.21	Sat 6.19.21	5	4
3.5.2	Create Electrical Bill of Material		Sun 6.20.21	Thu 6.24.21	5	4
3.6	Cost calculation	Arbhabhirom	Fri 6.25.21	Mon 6.28.21	4	2
3.6.1	Calculate total cost for production		Fri 6.25.21	Mon 6.28.21	4	2
4	**Product Presentation**		Tue 6.29.21	Mon 7.05.21	7	5
4.1	Video creation	All	Tue 6.29.21	Sun 7.04.21	6	4
4.1.1	Group meeting		Tue 6.29.21	Tue 6.29.21	1	1
4.1.2	Create video based on previous discussion		Wed 6.30.21	Sun 7.04.21	5	3
4.2	Product presentation	All	Mon 7.05.21	Mon 7.05.21	1	1
4.2.1	Present the video during class		Mon 7.05.21	Mon 7.05.21	1	1



2.1 3D CAD Model

The CAD model presented with this report serves two main purposes. One is to show the functional principles that make the product work and the necessary components for it. The second is to serve as a precursor for the files that will be used for manufacture of the make-parts, for example, the creation of the moulds for injection moulding. Any modifications that might be made to any of the parts for final production would be minor in nature. Keeping this in mind, effort was focused on the precision of the make-parts. Therefore, buy-parts such as the motor, batteries, gears, etc. have been modelled in low detail. The main concerns for those were getting the dimensions, size and shapes correct so as to show that all components fit properly without clashes for space, and to show their locations for assembly. This is especially true for the gears, whose teeth have been modelled very roughly, but in reality, the shape is standardized based on teeth count and module, which have been specified in the buying manual. Some other, even more standard parts such as screws and nuts were not modelled, but taken from the Solidworks Toolbox. However, the positions of all these parts in the model are proper. One clarification regarding vocabulary. By “shade” we refer to the rotating assembly which holds the cloth that actually provides the shadow. This is to contrast the entire system, which we will refer to as “device” or “product”.

The side view of the final model turned out as follows:

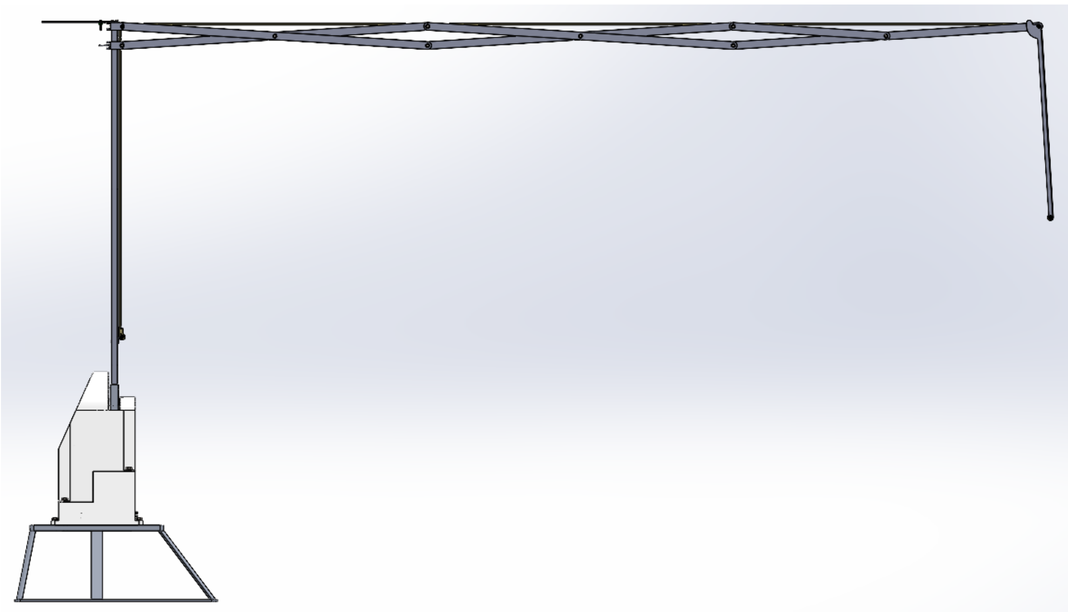


Figure 2.1.1: Side view of the final CAD Model

Here it can be seen that the main concept that was explained in the previous milestone has been closely followed. Nonetheless, some changes have been made that must be mentioned. One very notorious one is the lack of the wheels that had been considered. These were included in the original concept because the weight of the unit was expected to be large, and carrying the product wouldn´t be very comfortable for the user. Now that the CAD model has been finished, the weight has turned out to be 10.3 kg. We consider this weight to be easier to carry than we expected, and by adding handles for ease of carrying, we believe that the wheels are no longer necessary. This comes with some advantages, such as a simpler design with less parts and the fact that there is no more concern about the wheels being wide enough so as not to sink into the sand of a beach.

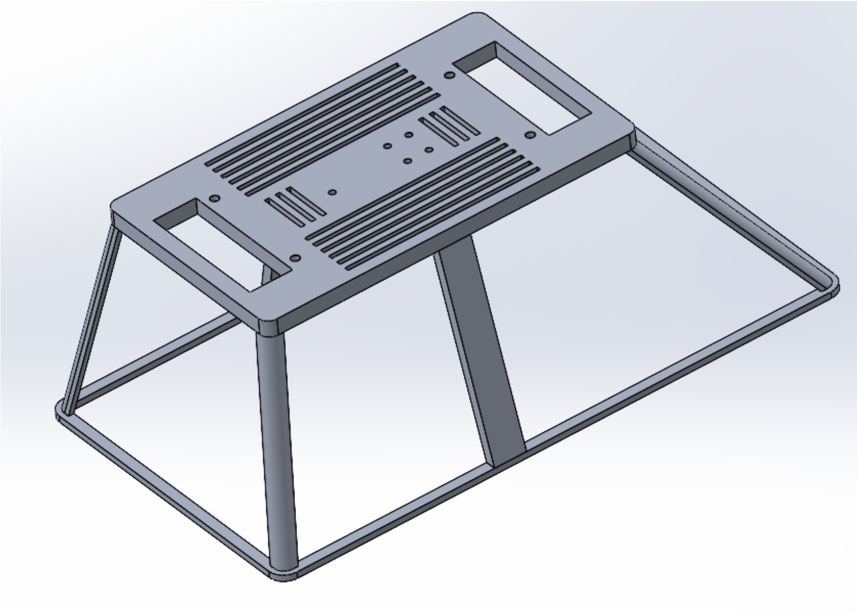


Figure 2.1.2: Base of the device

Looking at the base, there are some unexpected decisions too. The main one is that it has a flat bottom rather than any kind of spike to stick into the sand. The reason for this is adaptability. We believe that the user could just as likely want to use this product in an environment where perforating a spike into the ground would not be viable. An easy example of this is a pool area or a patio which would have brick or concrete surfaces. This base has a flat bottom that can be used on any kind of surface. For stability, we made the bottom of the base wide and long, particularly in the forward direction where the weight of the shade pulls. This has stability against tipping over, but also the wide area protects from any substantial sinking into sand when used at a beach. The perforations seen in the image have been made thin so as to allow air into the shell so as to prevent overheating of the electrical components, but not allow any material in that could affect the functioning of the device. The large rectangular perforations are there to permit easy holding of the device. This will make it natural for the user to lift the device from the sturdy base rather than any other part which may not be structurally designed for lifting.

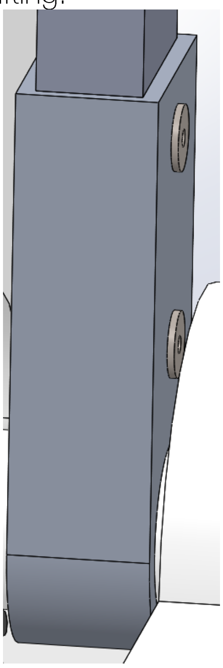


Figure 2.1.3: Mounting Hub

Another important change is the removability of the shade from the base for easy transport that was mentioned in the concept description. We have maintained the ability to fold the shade using the accordion mechanism that holds it. However, the plan to make the entire shade detachable from the bottom unit with the motor, battery, etc. has been discarded. Instead, it is now held in place using two rivets. This decision was motivated by the necessity to have the sunlight sensors and the solar panel mounted on the rotating shade for them to get proper readings and charging. This in turn required cables to connect these elements on the shade to the controller and batteries in the bottom housing. Having these cables connecting the two major parts makes it pointless to make them separable, since the separation will be restricted by the length of the wires. However, the total height of the device is small enough for it to be easy to transport in the back of a car or pick-up truck when the accordion frame is folded as well as to carry from a parking lot or local storage to the pool or beachfront.

Perhaps the most important note regarding the CAD model is the high quantity of intersections between bodies detected when the interference detection function is used. All of the detected intersections have been checked to verify that they fit into one of the acceptable categories. These categories are:

- Threaded Connections: Items such as bolts and nuts or screws that mesh with tapped threads in bigger parts are only rendered schematically in the CAD model, so the threads interfere, although in reality it would simply be the proper mating of threads. This type of interference accounts for the vast majority of those detected because of the large number of threaded fasteners used.
- Retaining Rings: A few retaining rings have been used in this model´s shafts. The rings have been selected based on the size of the shaft in which they are placed, following the guidelines of the supplier's catalogue (these are buy-parts). These guidelines include the width and depth of the grooves in which the rings are to go. The CAD models for the rings used here are those supplied in the seller´s website, and show the rings in their relaxed state, meaning what they look like when not placed around anything. Therefore, the internal diameter of the model is smaller than the diameter of the groove on the shaft since the ring is supposed to press tightly against the shaft. This explains the interference between the rings and their respective shafts.
- Switches: Two identical switches have been included in the design of the device. Since these are buy parts, the CAD models used have been taken directly from the supplier´s website. The model includes small tabs that are used to snap-fit the switch into its desired position. Seeing this, there are small interferences between elements of the switch model and the housing into which they fit that reflect this pressed fit and hence are not a concern.

Another point to mention is that of minor electrical components. By minor we do not mean unnecessary or unimportant, but rather very small in size. This includes electrical components such as cables or small diodes and resistors added directly to the breadboard. These elements have been included in the component lists and buy-part manual, but not the CAD model since they are so reduced in size, and in the case of cables, their geometry in the model is not completely knowable since they are so flexible and bendable. Nonetheless, the design still keeps them in mind by leaving the spaces that are deemed to be sufficient for the placement of these elements. An example of this is the small groove that is found on the main vertical beam of the shade, which has been made in order to allow the cables for the solar panel and sensors to run down, where they will not obstruct the movement of the moving crossbeam or get tangled with anything else.

This moving crossbeam moves between two positions in order to allow for the extending and retracting of the shade. The principle of this mechanism is described in the concept description in the first milestone. Now this concept has been developed into its detailed form. It consists of a quick release pin, of the spring-loaded ball kind, which can be placed through the moving crossbeam and through the vertical beam in one of its two perforated locations. This idea was inspired by the weightlifting machinery commonly found in fitness-studios, which use quick release pins and perforations in the machinery frames in order to allow for adjustments for the user. The mechanism used in this project is basically a direct copy of this idea. The pin includes a ring (this is a buy part, and the pin and ring are sold together.). Much like those pins in the fitness equipment, the pin used here will be secured to the device via a string that ties one end around the ring, and the other end around a small perforation made in the centre of the moving crossbeam precisely for this reason. This string hasn´t been modelled for the same reason the cables have not been modelled. The following image shows the ring and the hole in question together.

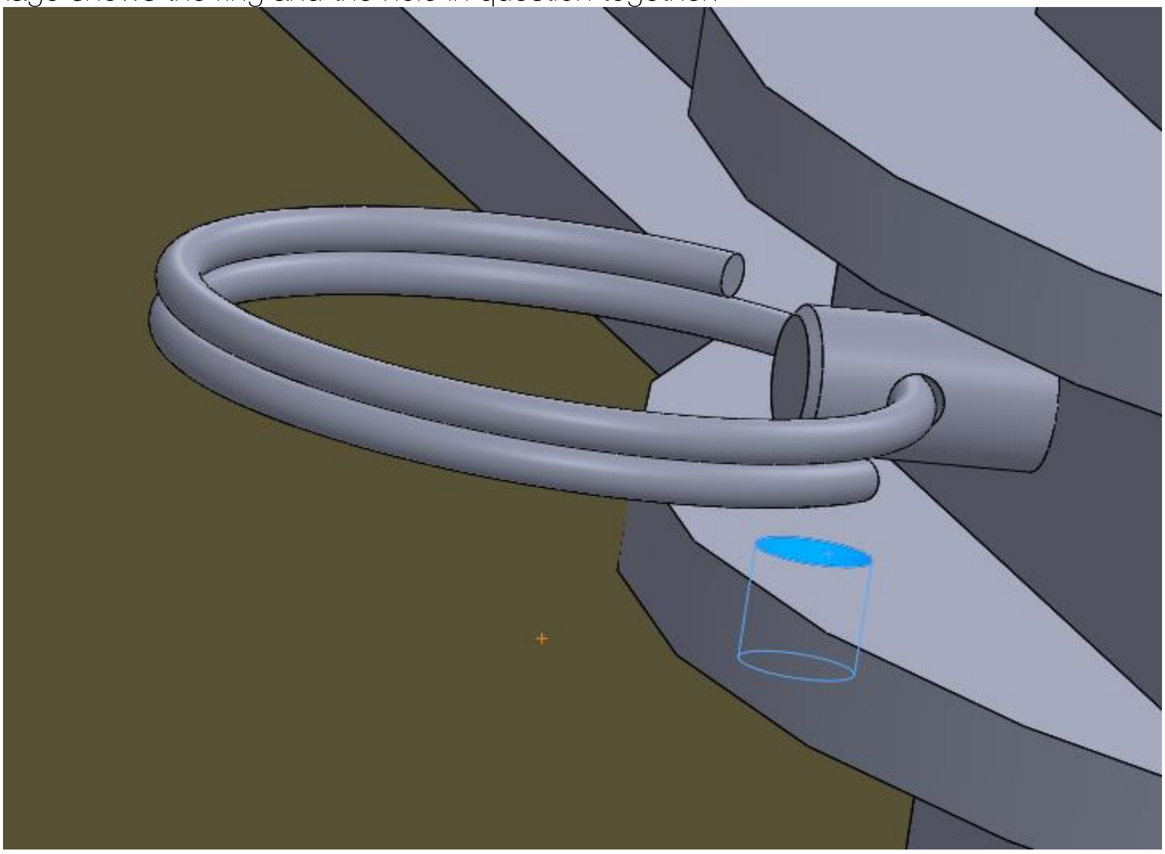


Figure 2.1.4: Quick Release Pin

The electrical components that are shown as mounted directly on the shell we have decided will be glued directly on using industrial grade adhesive in order to use the available space in the shell more effectively. The structural shell has been made out of PPS. PPS is a strong engineering plastic which can be conductive if treated under special methods, but is otherwise electrically insulating by nature. Because of its electrical insulation and high mechanical strength, we chose it since we consider that it will keep the electrical components and the user safe from unwanted electrical discharges. It is also fairly resistant to UV radiation, which is necessary for a product used outdoors. Other parts which are not structural or are covered by the gear shell have had their materials chosen based on required strength or low density if not structural, but not regarding UV radiation since they are covered from the sun.

In the CAD file there is a part called “Sensor cable end”. The purpose of this part is to show that there is enough space for the cable ends over the terminals of the light sensors. This part is not a real individual part, but rather is a component of the wires, which are buy parts. Hence, they have not been included individually in the make/buy list or any other list, but are implicitly there as part of the wires which have been included in the documentation.

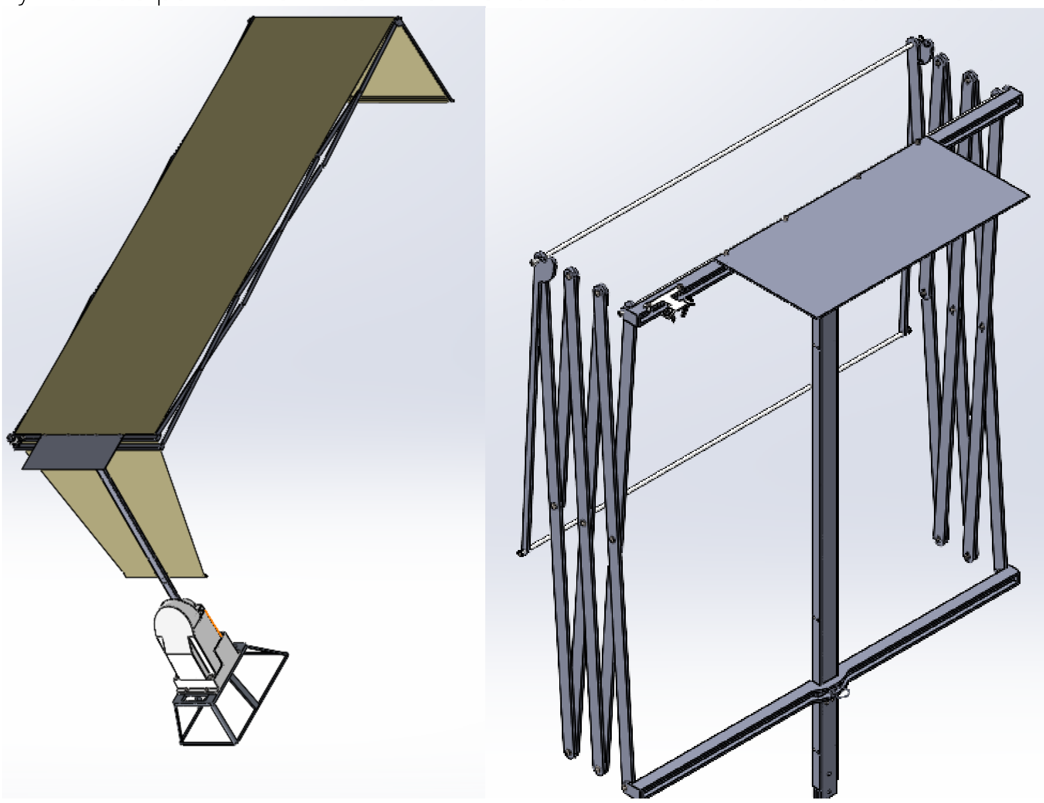


Figure 2.1.5: Isometric view of the sun shade CAD model in extended position (left) and folded view of the shade (Right).

These final images show the extended and folded configurations. For the folded configuration, the canvas has been omitted to better show how accordion mechanism allows for folding. In order to fold the shade from its extended position, the user needs only take out the quick-release pin from its position, pull the mobile cross-beam down to the bottom perforation and secure it once again with the same pin. Additionally, the front shade sticks can be adjusted to their compact position to save even more space.

2.2 Unified Modelling Language (UML) Diagram

2.2.1 Overview

Unified Modelling Language diagram uses the power of graphical representation to describe the function of the whole mechatronic product, here in our case the B-Matic Shade in a very comprehensive manner to understand the overall functionalities in detail with the intention to visualize its main actions in a flow chart format with the help of vivid graphical symbols, each conveying a special meaning thus adding to elaborated understanding of the system capabilities. The design of such diagrams is mainly used in the fields of software engineering and it's accomplished prior to the software design of the product as it provides an extensive structural layout plan for the software engineers to carry out their tasks in a well organised format.

For this project, to explain the functionalities of our sun shade, **"UML Activity Diagram"** has been chosen which explains the workflows and stepwise activities and actions to be taken at the desired point of time. For simplicity and a purpose of explaining the serviceability of the product in detail we have split the whole UML into 2 parts: Sensor Activity Diagram and Mechanical Activity Diagram.

The following graphical symbols convey a special meaning used during the construction of the diagram.

- **Ellipse:** means actions.
- **Arrows:** means that they run from start towards end and represent the order in which activities happen.
- **Diamonds:** means decisions.
- **Black Circle:** means start/initial node.
- **Encircled Black Circle:** means end/final node.
- **Rectangle**: means an object PS*: Not used in our case.*
- **Horizontal Bar:** Parallel processes accomplished through multithreading.
  PS: Not used in our case.

In the following UML diagrams, only diamonds and ellipses have been used to depict decisions and actions taken along with black and encircled black circle which represents the start and end node.

2.2.2 Sensor Activity Diagram

The sensor activity diagram basically consists of the electrical and information flow through the circuit accompanied by the logic with which the controller works in order to control the actuation of the output element(motor) based on the input data received from the input element(sensors) thus compensating the shade as per the requirement. The product becomes functional as long as the system is powered up/switched on and there is adequate power supply through the battery to the electrical components. Once the system comes to life, it works in a fully autonomous manner therefore, the UML diagram indeed describes the functionalities when the device is powered up.

In order to save some power usage from the battery, the controller turns off the motor during its rest mode period i.e.- when the device is not under use as it's the only electrical device with maximum power consumption. Because the sun movement is not really fast, the code would be designed in a manner that it checks the values from the sensors every 10 min when it turns the motor on, rotates the shade as per requirement and disables the motor again and this process keeps on repeating over and over again until the device is under usage and the shade is within its boundary limit. As soon as the shade reaches the boundary limit position it will stop.

The detailed sensor activity diagram can be seen below.

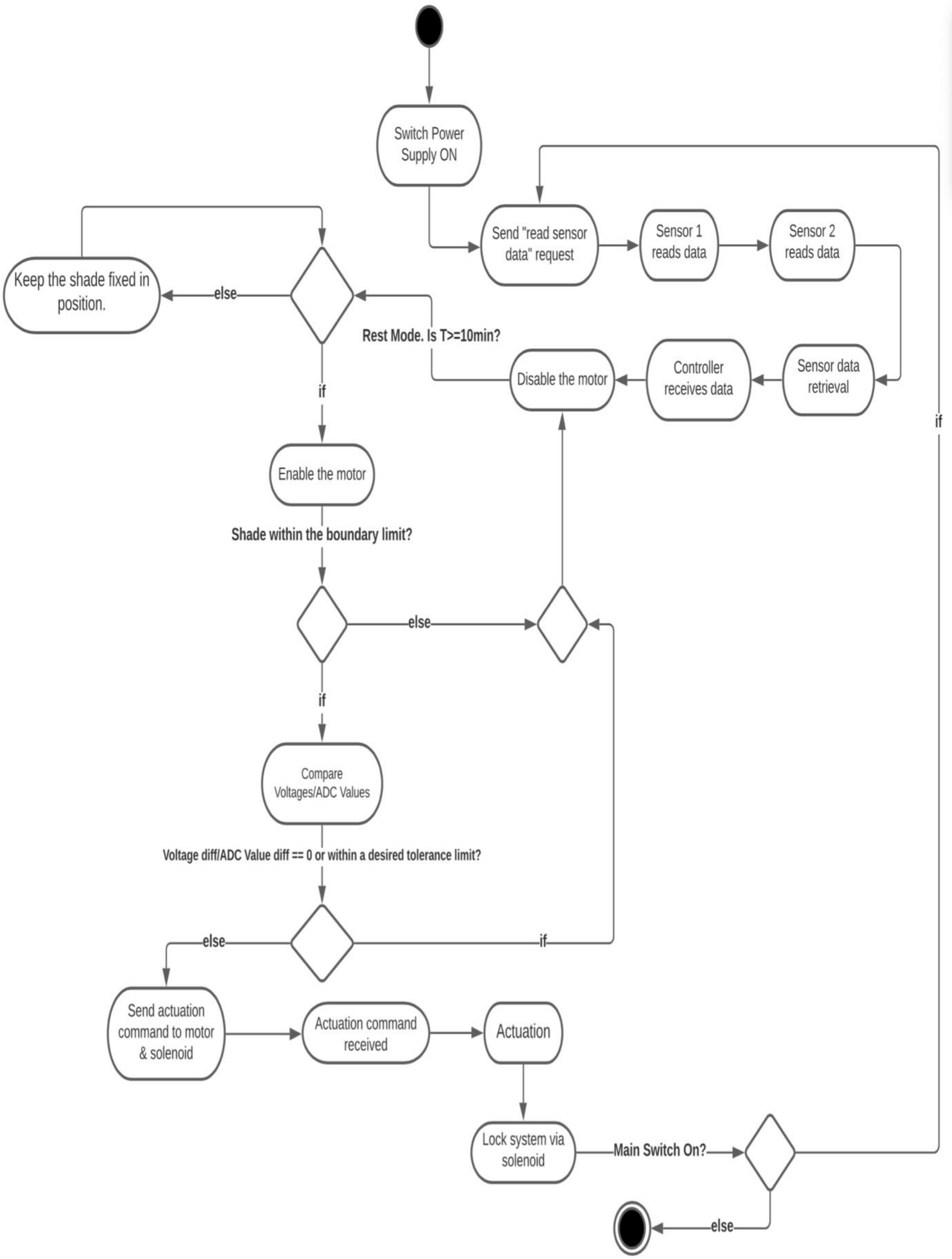


Figure 2.2.2.1: Sensor Activity UML Diagram

2.2.3 Mechanical Activity Diagram

The mechanical activity diagram consists of the movement of the single axis sun shade depending upon the logic decision made by the controller which in turn depends on the voltages produced by both the sensors.

Accordingly, 2 cases have been classified as:

1. Motor turns clockwise.
2. Motor turns anticlockwise.

A very important point to be considered here is that this project deals with just a single axis sun shade. The elevation of the sun above the horizon in different countries on different latitudes would be controlled mechanically by putting canvas on the front and back end of the shade as well, whose description would be laid on in detail in the 3D CAD model section.

Secondly, this mechanical UML diagram consists of a locking/unlocking mechanism which works in a series of steps as follows:

Locking Mechanism:
Stop the torque
Lock via solenoid
Disable the motor

Unlocking Mechanism:
Enable the motor
Unlock via solenoid
Actuate torque

The above steps have been done in series as a safety mechanism to have the shade held in place at all times without the slightest possibility for it to fall down.

NOTE: The final control code of the system would be designed by combining both sensor and mechanical activity UML diagrams. The UML's have been split into two for simplicity and ease in understanding.

The details of the mechanical activity diagram can be seen below.

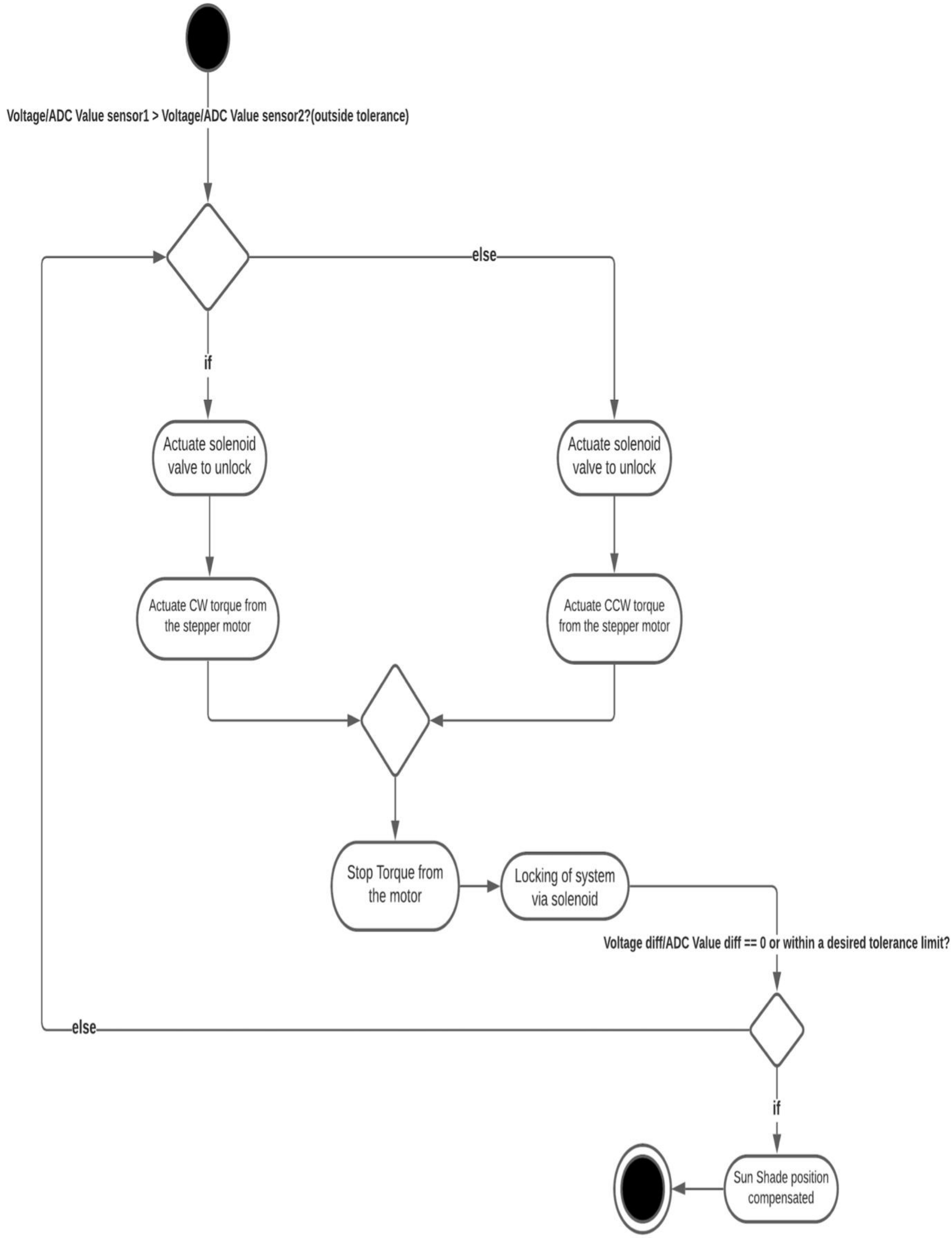


Figure 2.2.3.1: Mechanical Activity UML Diagram

2.3 Circuit Diagram

2.3.1 Overview

The electrical schematic circuit diagram has been designed by the students of mechatronic systems engineering in the group on Fritzing software which is very well known for its capabilities of being able to design electrical schematics, PCB designs as well as breadboard layouts. Generally, it contains the schematics of almost all the components but if not, then there is possibility to design it with a blank IC chip and customizing it according to the requirements. Below in Section 3.2, you find a brief explanation to the electrical circuit diagram as well as a schematic layout displaying all the relevant components and their connections. All the electrical components except the solar panel and sensors would be placed in a secured housing at the base of the device which would allow the control of the whole device. The sensors have been mounted on a bracket which lays at the top of the shade as well as the solar panel which lays at the roof of the shade.

2.3.2 Circuit Diagram Details

System Overview

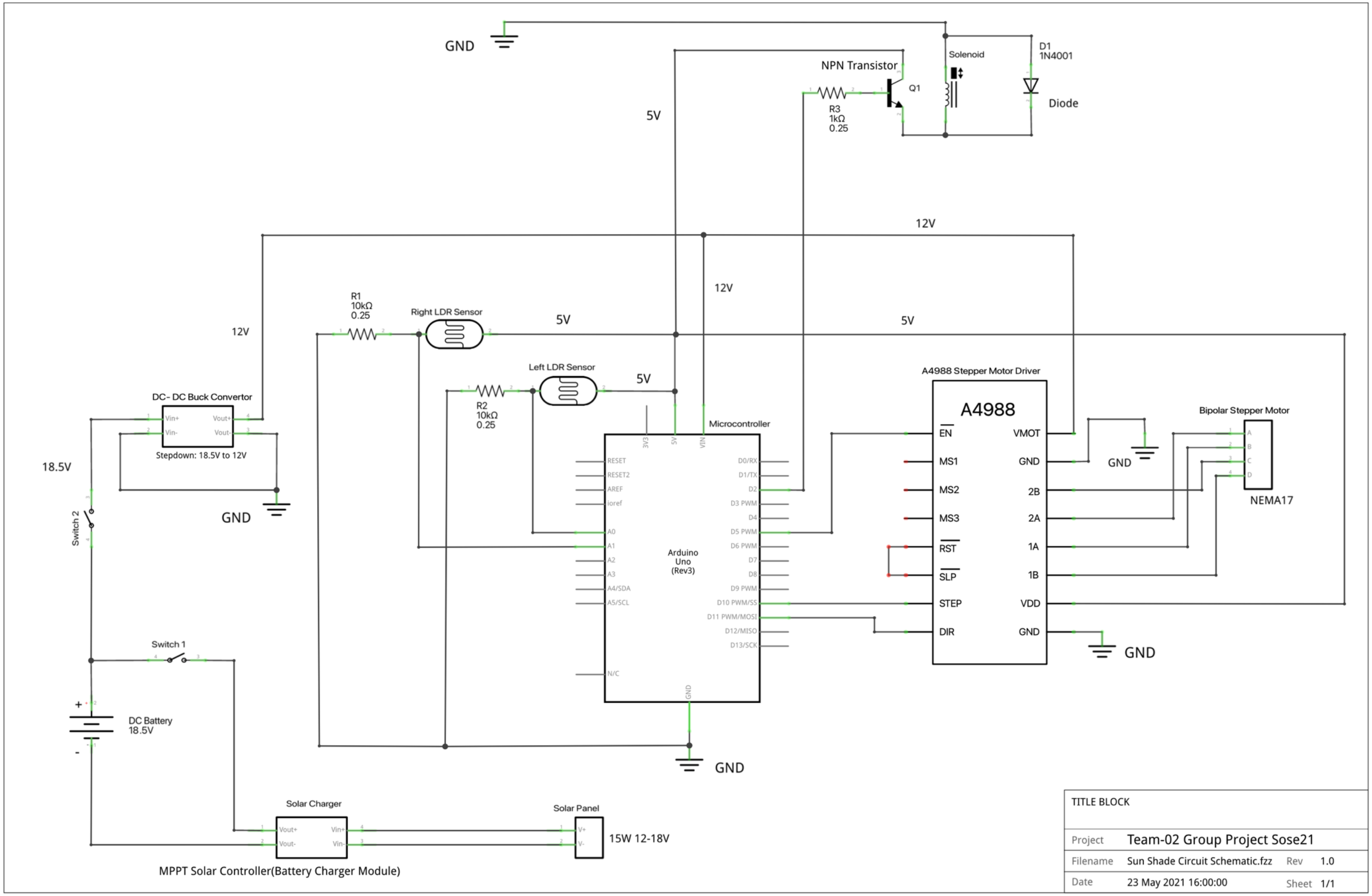
The automated sunshade device includes sensors and actuator systems consisting of two Light dependant resistor (LDR) sensors, a stepper motor and a solenoid actuator. The LDR sensors provide information to a microcontroller, which in turn controls the stepper motor via a stepper motor driver. The solenoid actuator is also an active element which locks the gear movement to keep the sun shade in place when the motor is at rest mode. All the electrical components are powered up by an 18.5V lithium-ion rechargeable battery which is the component being charged by the solar panel. Therefore, the solar panel charges the 18.5V battery using a solar charge convertor. In between the battery and the electrical components, a DC-DC buck convertor has been used to lower down the voltage from 18.5V to 12V so as to supply power to the microcontroller and the stepper motor at 12V. The rest of the electrical components such as sensor, solenoid and stepper motor driver have been connected through the Arduino which provides them their desired low working voltages of 5V.

Specifications, pictures and calculations for every single component have been given for ease of understanding the report in the requirements manual section.

Connections

For the connections of the electrical components of the device, breadboard, jumper cables have been used for connections related to the microcontroller i.e.: microcontroller to solenoid, LDR sensors, stepper motor driver as they all are running on 5V easily handled by jumper cables. The stepper motor connects to the stepper motor driver with the cables received with the motor itself. As per the electrical requirements for the heavier electrical components shown in this circuit schematic, wires have been selected accordingly. Keeping in mind the maximum current through the circuit for power transmission as well as a safety factor i.e.: from the battery, solar panel, solar charger through the buck convertor to the microcontroller (which powers up at 12V) and the stepper motor (which also powers up at 12V); a 14-gauge wire has been selected which can support a maximum of approximately 6A current through it keeping it absolutely safe for the functioning of the product. They are well insulated so it is completely safe for human use.

All the connections(wiring) to the battery and other electrical components as well as the components itself have been bundled up and placed in the housing itself which is made out of an insulating material making it completely safe for use. The housing has been sealed to prevent dust or water entry. Only perforations underneath the electrical components have been left to allow some air to enter to cool them. Additionally, care has been taken the housing shell is absolutely dry during the placement of these components. Only the sensors and solar panel are mounted at the roof of the sun shade and have wires running down to the housing in a very safe and secured manner unexposed to the environment. These wires are placed underneath a plastic plate called the “wire cover” which serves as an insulating and physical barrier to prevent electrical show to the user and physical damage to the wires. These wires remain under this cover until they go within the mounting hub, where holes have been left to run the wires directly into the inside of the gear shell, which is also plastic and insulating. Inside this shell they run to a hole in a vertical face of the shell which contains all other electrical components. They enter through this hole in a vertical face so as to prevent any water or liquid that may be splashed in from falling into this shell containing sensitive electrical components. This is a splash-proofing measure, but it should not be confused as an indication that this product is submersible in water, and it should never be left under rain for any long periods of time.


GND
5V
NPN Transistor
Q1
R3
1kΩ
0.25
Solenoid
D1
1N4001
Diode
12V
12V
R1
10kΩ
0.25
Right LDR Sensor
5V
5V
12V
Left LDR Sensor
5V
R2
10kΩ
0.25
DC- DC Buck Convertor
Vin+
Vin-
Vout+
Vout-
Stepdown: 18.5V to 12V
18.5V
GND
Switch 2
Microcontroller
3V3
5V
VIN
RESET
RESET2
AREF
ioref
A0
A1
A2
A3
A4/SDA
A5/SCL
N/C
D0/RX
D1/TX
D2
D3 PWM
D4
D5 PWM
D6 PWM
D7
D8
D9 PWM
D10 PWM/SS
D11 PWM/MOSI
D12/MISO
D13/SCK
Arduino
Uno
(Rev3)
GND
A4988 Stepper Motor Driver
A4988
EN
MS1
MS2
MS3
RST
SLP
STEP
DIR
VMOT
GND
2B
2A
1A
1B
VDD
GND
GND
GND
Bipolar Stepper Motor
NEMA17
Switch 1
DC Battery
18.5V
GND
Solar Charger
Vout+
Vout-
Vin+
Vin-
Solar Panel
V+
V-
15W 12-18V
MPPT Solar Controller(Battery Charger Module)
TITLE BLOCK
Project
Team-02 Group Project Sose21
Filename
Sun Shade Circuit Schematic.fzz
Rev
1.0
Date
23 May 2021 16:00:00
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fritzing

2.3.3 Electrical Calculations for Total Power Consumption

Sun movement calculation across the sky during the day

Typical day lasts from: 6AM-6PM = 12hrs

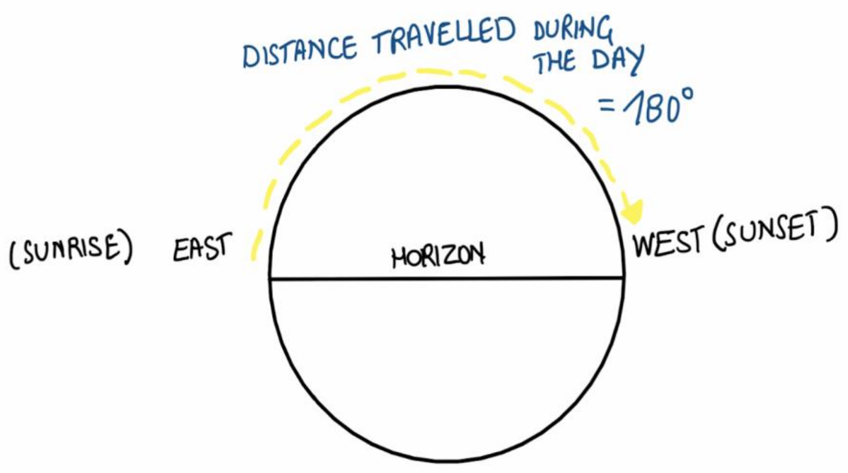


Figure 2.3.3.1: Depicting the earth and horizon

12hrs = 12*60*60sec = 43200sec.
Sunrise to sunset ----> 180deg movement of the sun

Speed of sun across the sky = 180deg/43200sec = 0.00416 deg/sec
According to the product design we check and activate the motor every 10 min as the sun movement is relatively slow.

10 min = 10*60sec = 600sec
Angular Displacement = Angular velocity * time
Angle swept by the sun in 10 min = 0.00416deg/sec * 600sec = 2.5deg
Sun moves approximately 2.5deg in 10min
Typical usage time of the product: Approximately 140 deg angle swept by the sun

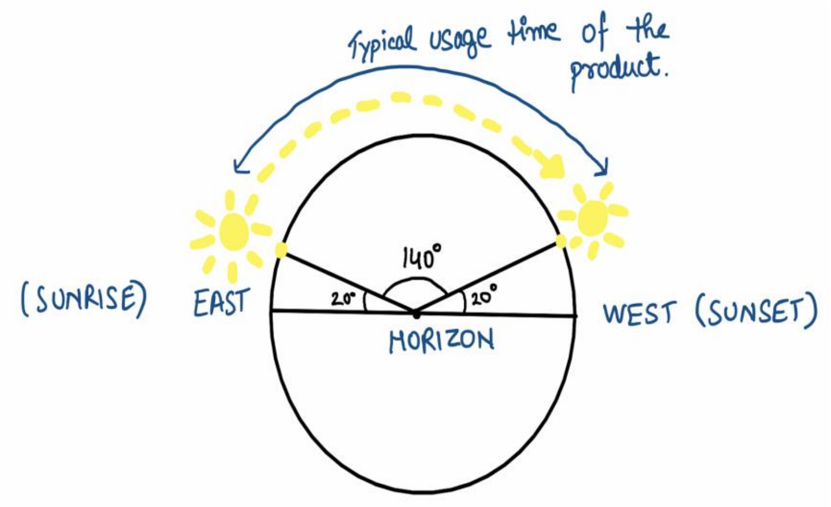


Figure 2.3.3.2: Typical usage time of the device

Time = Angular Displacement/Angular velocity
Time taken by the sun to sweep 140deg through the sky during day: 140deg/0.00416deg/sec =33653.846sec = 560min = 9.34hrs
Motor actuation to compensate shade on chair is done: every 10 min
Angle swept by the sun in 10 min = 2.5deg **(So we need a rotation of 2.5deg at the shaft shade after every 10min)**
Total number of times motor actuation needed during the whole day = 140deg/2.5deg = 56 times

Gear ratio: 36:1 (total drive)
Explanation: 1 rotation of the shade per 36 rotations of the motor **OR** 1 tooth at the motor equals 1/36th tooth at the shade.

Gear at the motor = 24deg/tooth
Total number of teeth at motor gear = 360/24 = 15

36deg rotation at the motor ------> 1deg rotation at the shade
1 tooth jump at the motor --------> 1/36deg at the shade
24deg at the motor --------> 24deg/36 = 0.666666deg rotation at the shade
Number of teeth to be moved at the motor for 2.5deg shade movement: 2.5deg/0.66666deg = 3.75 teeth = 4teeth (approximately)
Total angle swept by the motor shaft in one movement at every 10min = 4*24deg = 96deg (approximately)

Energy calculations for battery size selection

Overall calculations are easy as everything is being dealt in DC Voltage.
Electrical components directly connected to the battery: Microcontroller and stepper motor.
So, we need to calculate the power consumption by these two components in order to calculate the overall battery size. The rest are connected via Arduino so we do not have to calculate power consumption from them.

Microcontroller:

Input Voltage provided: 12V
DC Current per I/O pin: 40mA
Power = Voltage * Current = 12V *40mA = 0.48W
Total Usage time/Active time of the microcontroller during the day = 10hrs (roughly)
Energy consumption = Power * time = 0.48W * (10 * 60 * 60) sec = 17280J
3600J -----> 1Wh
Energy in Wh Per day = 17280J/3600J = 4.8 Wh/day

Stepper Motor:

The motor is activated every 10 min and the rest of the time it is shut down completely in order to save power.
Total motor actuations per day: 56
One time angle swept by motor shaft: 96deg
Number of steps required = 96deg/1.8deg = 53 steps

Assumption: The total time taken by the motor to complete one time actuation = 30 sec (Approximately)

Total Active time of the motor = 56 * 30sec = 1680 sec
Input Voltage to the motor = 12V
Current = 1.5A
Total Power Consumption by the motor: Power = Voltage * Current
P = 12V * 1.5A = 18W
Energy consumption = Power * time = 18W * 1680 sec = 30240J
3600J -----> 1Wh
Energy in Wh Per day = 30240J/3600J = 8.4Wh/day

Total Energy Consumption per day = 8.4Wh + 4.8Wh = 13.2Wh/day = 14Wh/day (roughly)

Battery requirements: 12V DC to be able to deliver 14Wh energy consumption.
Since it is known that a 12V battery always gives an output lesser than 12V, we need to choose a battery with higher voltage than the requirements.

Final Battery requirements: 18V DC, 14Wh energy consumption.
Calculation of Ah rating for the battery:

Energy = Voltage * Capacity
Capacity = Energy/Voltage

Capacity = 14Wh/18V = 0.777 Ah

We finally need a battery having 18V DC supply and 0.777Ah rating.
The details and specifications of the battery and other electrical components have been mentioned in the requirements manual for buying parts.

Note: Severe round offs have been done in order to have sufficient battery size which would last the device for more than a day and give enough time for solar panels to recharge the battery to the desired voltage.

2.4 Make-or-Buy Decisions on Component Basis

2.4.1 Overview

A make-or-buy decision is made by the product designers when the system is under design phase if the parts need to be manufactured in house or be bought from an outside supplier. This decision is a strategic choice made based on a single criterion: if the part is sold and available in the market as a standard component (buy part) or if it has a custom design and must be made in house (make part). When this question is answered for each and every single component existing in the whole product, jumping to a make-or-buy decision becomes easy.

Apart from the above question asked during developmental phases, the designers also consider an outsourcing decision to compare the costs and advantages of producing the components in house or buying it from an external supplier. In most cases, the most cost-efficient methods are preferred to cut short the production cost wherever possible on the basis of which make-or-buy decisions are made.

Nevertheless, there are many other factors as well which have to be taken into consideration while jumping to the above decision as they also have a big impact to play in this crucial situation. Those reasons are:

Labour costs
Lack of Expertise
Storage and Logistics Costs
Supplier Contracts
Cost factor
Resources to manufacture
Available finances at hand
Availability of the components as standard one
Good Quality Control
Finding Authorized Suppliers
Time Factor to meet deadlines
Integrability of the components in the product
Changing to meet new demands
Adapting to changing markets

Each make part and buy part has its own pros and cons.

On one hand, the manufacturing of components is advantageous because if the item has been invented for the first time and hasn't existed anywhere before then manufacturing the components in house is the only option. While launching the product the engineering team has an opportunity to introduce the newly designed parts and its features from start to end. Lastly, there is no trouble of scheduling or suppliers failing to fulfil the deal as per the requirements or on time from their ends. The manufacturing can be supervised and conducted easily as it is under the control of the designing team itself.

On the other hand, buying strategy has the advantage of finding a supplier holding an expertise in manufacturing those particular components so there is no anxiety about the quality control of the product if it's obtained from a well-known authorized vendor. They are easily available as standard components which are available worldwide and easily integrable in the product. Additionally, the problem of time factor to meet the deadlines in a project is ruled out as it takes shorter time to buy components directly and also the worry of collecting the resources to manufacture them.

In this project, all the electrical components are "buy" parts with their specifications enlisted in the requirements manual for "buy" parts as they are easily available as standard components worldwide whereas some mechanical components are just "make" parts because of their unique design just existing in our product while others are buy ones as standard components and dimensions. The details of individual parts are mentioned in the respective section.

2.4.2 Electrical Components "Make" or "Buy" Parts Decision Table

No.	Part Name	Make	Buy	Material	Quantity	Make-or-Buy Explanation	Supplier Links & Comments
1.	Microcontroller - Arduino UNO		X	Details of these buy parts to be found in section 6 - Requirement manual for buy parts.	1	Requirements are known from the calculations. Easily available at cheap prices. They exist as standard components in the market	Controller
2.	Stepper Motor		X		1		Motor
3.	Stepper Motor Driver		X		1		Motor Driver
4.	LDR Sensor		X		2		Sensor
5.	Push/Pull Solenoid		X		1		Solenoid
6.	Lithium-ion Rechargeable Battery		X		5		Battery
7.	Solar Panel		X		1		Solar Panel
8.	Solar Charger		X		1		Solar Charger
9.	DC Buck Convertor		X		1		Convertor
10.	Mini Breadboard		X		2		MiniBreadboard
11.	Diode		X		1		Diode

12.	NPN Power Transistor		X	Details of these buy parts to be found in section 6 - Requirement manual for buy parts.	1	Requirements are known from the calculations. Easily available in the market at reasonable prices.	Transistor
13.	Rocker Switch		X		2		Switch
14.	Resistor 1k		X		1		Resistor
15.	Resistor 10k		X		2		Resistor
16.	Wires: Jumper Cables		X		25: 4wires 1.5m each and the rest 0.5m each.		Wires
17.	Wires: Power Transmission		X		1 roll (5m)		Wires

2.4.3 Mechanical Components “Make” or “Buy” Parts Decision Table

No.	Part Name	Make	Buy	Material	Quantity	Make-or-Buy Explanation	Supplier Links & Comments
1.	Accordion Stick	X		Nylon 101	10	Unique-design components are in the “make” part category while standard components are in the “buy” part category.	
2.	Auxiliary Bearing Holder	X		Polyphenylene (PPS)	1		
3.	Base Plate	X		6060 Alloy	1		
4.	Beam	X		Nylon 101	1		
5.	Bearing Support 1	X		Acrylonitrile Butadiene Styrene (ABS)	1		
6.	Bearing Support 2	X		Acrylonitrile Butadiene Styrene (ABS)	1		
7.	Bearing Support 3	X		Acrylonitrile Butadiene Styrene (ABS)	1		
8.	Bearing Support 4	X		Acrylonitrile Butadiene Styrene (ABS)	1		
9.	Sensor Bracket	X		Acrylonitrile Butadiene Styrene (ABS)	1		
10.	Black-Finish Steel External Retaining Ring_98541A118		X		5		https://www.mcmaster.com/98541A118/

11.	Black-Finish Steel External Retaining Ring_98541A410		X		2	Unique-design components are in the “make” part category while standard components are in the “buy” part category.	https://www.mcmaster.com/98541A410/
12.	Canvas Holder	X		Acrylonitrile Butadiene Styrene (ABS)	4		
13.	Canvas Sheet		X	Nylon 2oz cloth	1		
14.	Clevis pin		X		16		
15.	Cotter Pin_98350A211		X		16		https://www.mcmaster.com/98350A211/
16.	Cross Beam	X		Nylon 101	1		
17.	Distancing Bushing 1	X		Acrylonitrile Butadiene Styrene (ABS)	1		
18.	Distancing Bushing 2	X		Acrylonitrile Butadiene Styrene (ABS)	1		
19.	Distancing Bushing 3	X		Acrylonitrile Butadiene Styrene (ABS)	1		
20.	Front Shade Stick	X		Nylon 101	2		
21.	Hex Flange Bolt		X		16		
22.	Hex Flange Nut		X		16		

23.	M4 Hex Nut AB		X		6	Unique-design components are in the “make” part category while standard components are in the “buy” part category.	
24.	M2 Hex thin Nut AB		X		4		
25.	Locking Pin	X		Polyphenylene (PPS)	1		
26.	Lower Canvas Mount A	X		Nylon 101	1		
27.	Lower Canvas Mount B	X		Nylon 101	1		
28.	Lower Shaft	X		6060 Alloy	1		
29.	Metric Quick-release Pin_95335A512		X		1		https://www.mcmaster.com/95335A512/
30.	Middle Shaft	X		6060 Alloy	1		
31.	Mobile cross beam	X		Nylon 101	1		
32.	Motor Mount	X		Polyphenylene (PPS)	1		
33.	Mounting Hub	X		6060 Alloy	1		
34.	Gear PS2-15		X		2		https://khkgears.net/pdf/ps_psa.pdf
35.	Gear PSA2-90		X		2		https://khkgears.net/pdf/ps_psa.pdf

36.	Plastic Ball Bearing_6455K118		X		2	Unique-design components are in the “make” part category while standard components are in the “buy” part category.	https://www.mcmaster.com/6455K118/
37.	Plastic Ball Bearing_6455K137		X		1		https://www.mcmaster.com/6455K137/
38.	Plastic Ball Bearing_6455K138		X		3		https://www.mcmaster.com/6455K138/
39.	Polycarbonate Plastic Washer_90940A117		X		8		https://www.mcmaster.com/90940A117/
40.	Rivet_97525A232		X		2		https://www.mcmaster.com/97525A232/
41.	Rivet_97525A246		X		1		https://www.mcmaster.com/97525A246/
42.	Rounded Machine Key_2977N19		X		2		https://www.mcmaster.com/2977N19/
43.	Rounded Machine Key_2977N25		X		3		https://www.mcmaster.com/2977N25/
44.	Sensor Cover	X		Clear Polymethyl	2		
45.	Sensor Tube	X		Nylon 101	2		
46.	Short Accordion Stick	X		Nylon 101	2		
47.	slotted cheese head screw		X		4		

48.	slotted pan head screw		X		8	Unique-design components are in the “make” part category while standard components are in the “buy” part category.	
49.	M4 Socket Head Cap Screw		X		6		
50.	Solenoid Bracket	X		Polyphenylene (PPS)	1		
51.	Upper Shaft	X		6060 Alloy	1		
52.	Upper Shell	X		Polyphenylene (PPS)	1		
53.	Gear Shell	X		Acrylonitrile Butadiene Styrene (ABS)	1		
54.	Cotter pin_98350A150		X		1		https://www.mcmaster.com/2977N25/
55.	Wire Cover	X		Nylon 101	2		
56.	Countersunk flathead cross recess screw		X		16		
57.	M3x5 Socket Head Cap Screw		X		2		
58.	M6x10 Socket Head Cap Screw		X		5		
59.	M3x8 Socket Head Cap Screw		X		4		

60.	M5x10 Socket Head Cap Screw		X		4		

2.4.4 Semi-finished goods for manufacturing

No.	Part Name	Make	Buy	Material	Quantity	Make-or-Buy Explanation	Supplier Links & Comments
1.	Aluminium round bar stock		X	Aluminium 6061	3	Buy as a product of extrusion in order to process it in a lathe into each of the three types of shafts used in the product.	Metric 6060 Aluminium Round Bar (Shafting) | Metric Metal

2.5 Manufacturing Technology Selection for "Make" Parts

2.5.1 Overview

This section revolves around those mechanical components which have to be manufactured in house as they are specially designed for our product and they are not available freely in the market as standard components in the desired dimensions.

Few of other "**general**" reasons to manufacture the product components autogenously are:

1. **Availability:** The specific parts are not available in the market in a standard form which suffice the dimensions and requirements in the specific applicability. Thus, these customized components need to be manufactured autogenously.

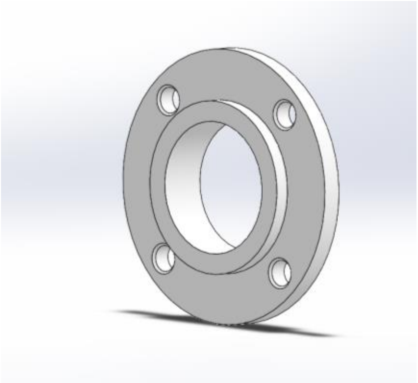
2. **Cost factor:** Sometimes getting the customized parts manufactured outside is very expensive. In such cases getting it manufactured in house is a better idea as it saves a lot of costs.

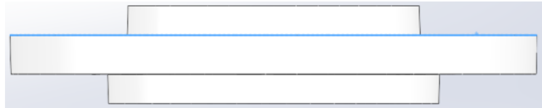
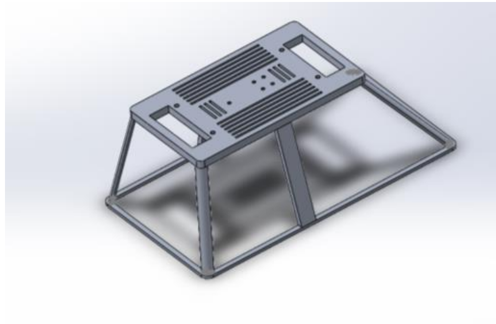
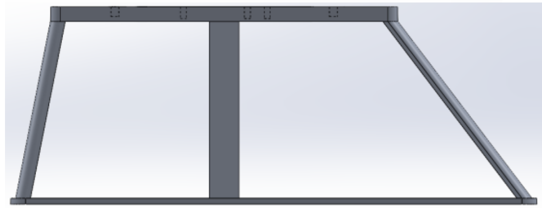
3. **Time Factor:** Obtaining the customized manufactured parts or even the standard parts from an external supplier might exceed the expected deadlines in a project. So, it seems better to get it done in house as in such a case the time can be utilized easily to get the work done on time.

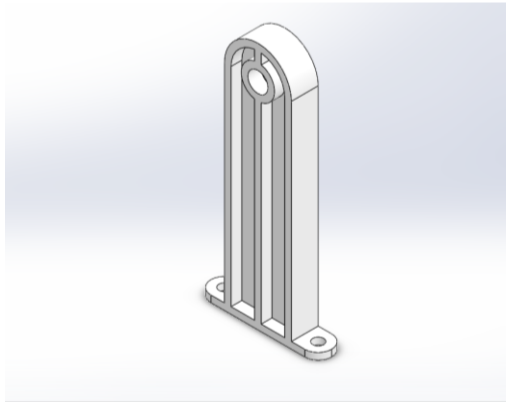
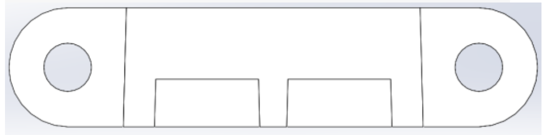
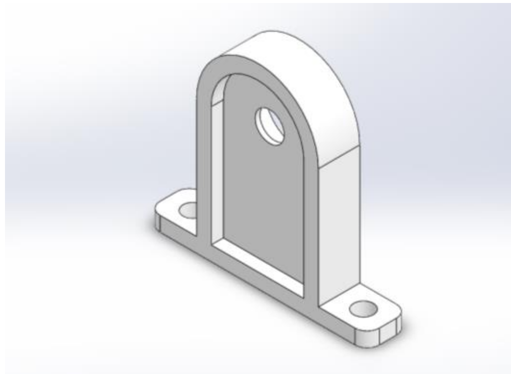
4. **Quality Control:** The newly designed customized parts for a special application which don't exist outside in the market as standard ones require special quality control and care so as to make sure it's completely safe for use. In such cases the parts are preferred to be manufactured as an in-house production.

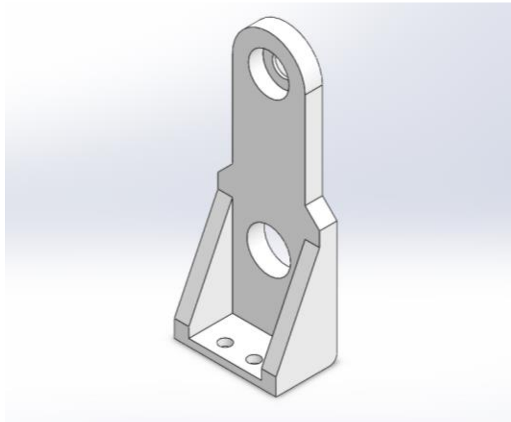
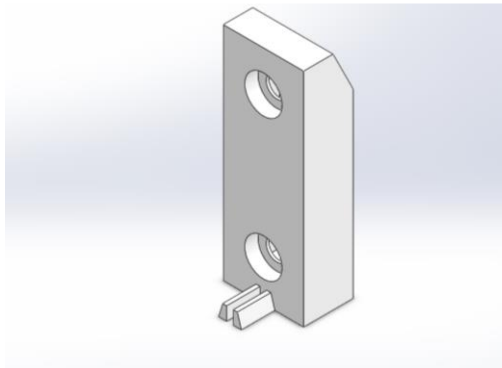
5. **Storage and Logistics:** There might be a good possibility of lack of enough storage space to store the buy parts or problems with logistics such as transportation problems or exceedingly high conveyance charges which forces the product designers to manufacture the product.

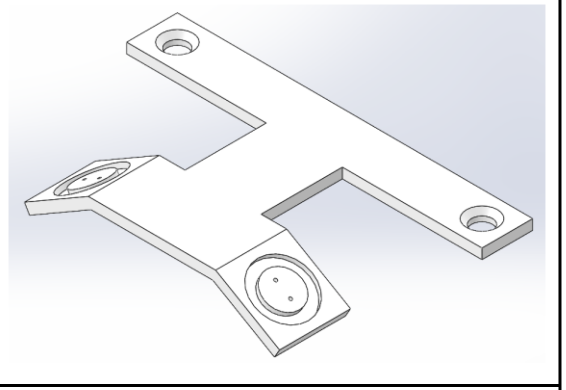
2.5.2 “Make” Parts Manufacturing Technology Selection Table

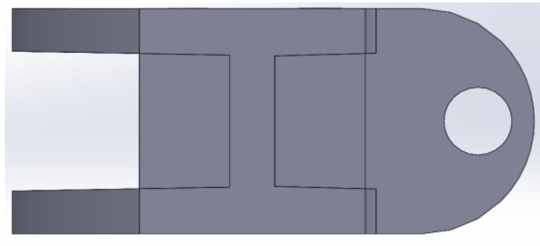
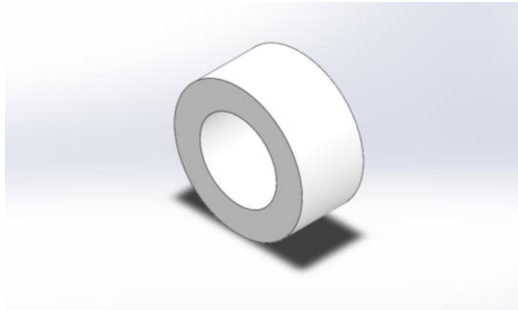
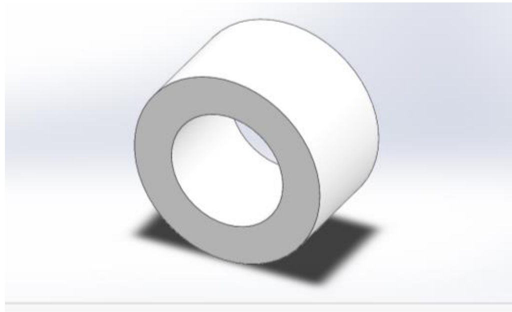
No.	Part Name	Material	Qty.	Manufacturing Technology Selected in	Manufacturing Technology Description	Component Images
1.	Accordion Stick	Nylon 101	10	-Injection moulding -3-axis milling, one clamping position	Injection moulding for primary forming. Mould separation up and down as seen in the second image, parting at the bottom face. 3-axis milling for the perforations, only one clamping position required.	 
2.	Auxiliary Bearing Holder	Polyphenylene (PPS)	1	-Injection moulding -3-axis milling	Injection moulding for primary forming. Parting direction up and down as seen in the second image, parting line on face highlighted in blue. 3-axis milling necessary to drill the central bore as it holds a bearing and may not have a draft angle. In this same mill, the 4 threaded holes must be tapped. One clamping	

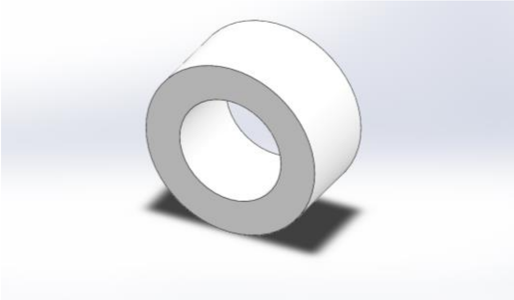
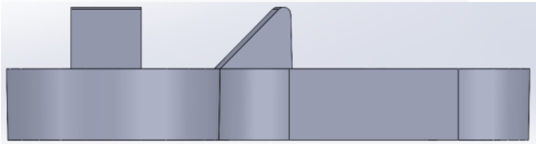
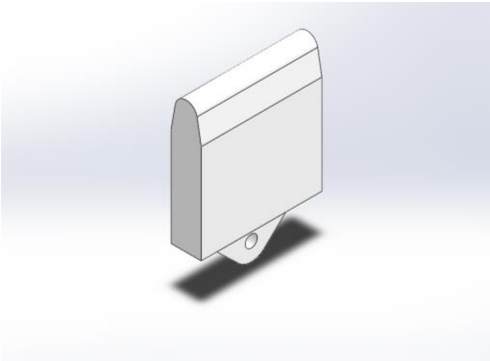
					position is enough.	
3.	Base Plate	Aluminium 6060 Alloy	1	-Die casting -3-axis milling	Die Casting for primary forming. Parting direction up and down as seen in the second image, parting at the bottom most face. All perforations on the top are to be milled in a 3-axis milling machine. In this same mill, all threaded holes can be tapped. One clamping position is enough.	 
4.	Beam	Nylon 101	1	-Profile extrusion -3-axis milling for tapping the threaded holes.	Profile extrusion for the primary forming. The threaded holes must be tapped in a 3-axis milling machine. Since there are holes on opposite sides, two clamping positions are required.	

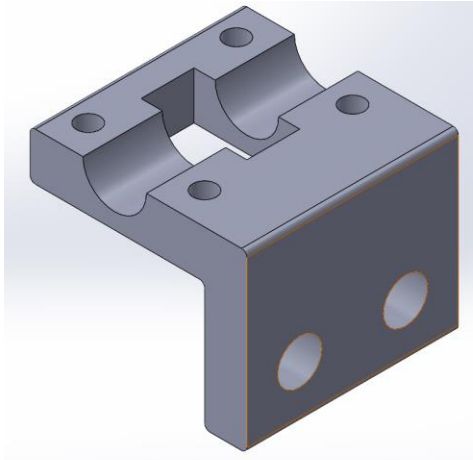
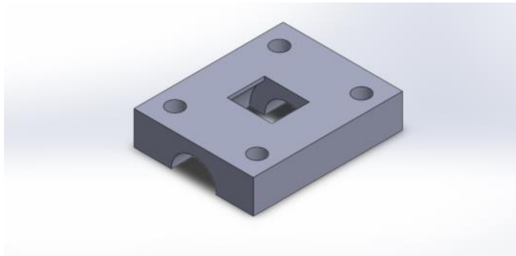
5.	Bearing Support 1	Acrylonitrile Butadiene Styrene (ABS)	1	-Injection moulding -3-axis milling	Injection moulding for primary forming. The second image is a cross-section to show the draft angles. The parting direction is up and down as shown in said image, parting at the lower face as seen. 3-axis milling to machine the holes for the screws and for the bearings since those holes cannot have draft angles. Two clamping positions are required.	 
6.	Bearing Support 2	Acrylonitrile Butadiene Styrene (ABS)	1	-Injection moulding -3-axis milling	Injection moulding for primary forming. Parting direction up and down as seen on image. Parting at the bottom face. All holes must be drilled in a 3-axis mill since drafts are not allowed for them. Two clamping positions needed.	

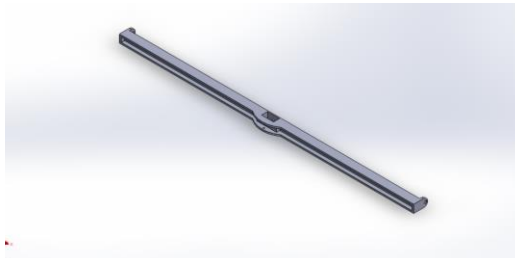
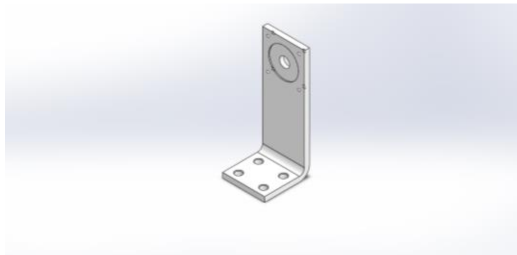
7.	Bearing Support 3	Acrylonitrile Butadiene Styrene (ABS)	1	-Injection moulding -3-axis milling	Injection moulding for primary forming. Parting direction is back and front as seen on image. All perforations must be made in a 3-axis CNC mill since those holes cannot have draft angles. Two clamping positions are needed.	
8.	Bearing Support 4	Acrylonitrile Butadiene Styrene (ABS)	1	-Injection moulding -3-axis milling	Injection moulding for primary forming. Parting direction back and front as seen on image, parting at the front face. The small protrusion at the bottom must be injected overdimmensioned and then milled down to the desired shape in the 3-axis mill. Perforations and bores must also be milled there. Two clamping positions required.	

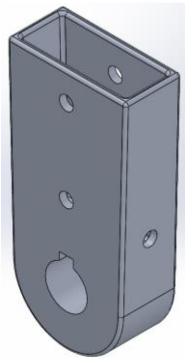
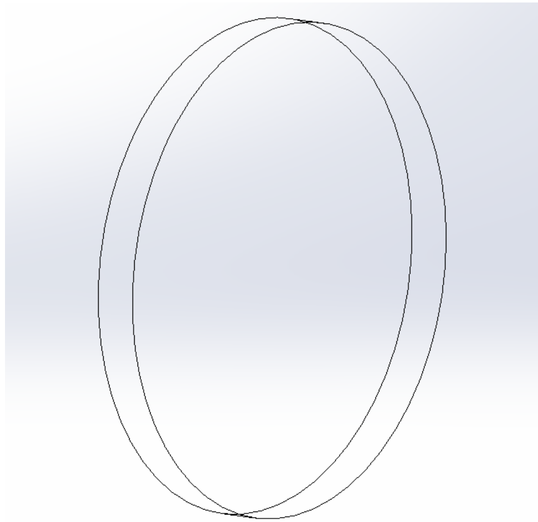
9.	Sensor Bracket	Acrylonitrile Butadiene Styrene (ABS)	1	-Injection moulding -4-axis milling	Injection moulding for primary forming. Parting direction up and down as seen in image, parting at the bottom face. 4-axis milling is needed for machining the perforations and grooves. One single clamping position will be enough using 4-axis milling.	
10.	Canvas Holder	Acrylonitrile Butadiene Styrene (ABS)	4	-Injection Moulding -CNC lathe	Injection moulding for primary forming. Parting over the round face. Tapping of threaded holes at both ends on a lathe. Since there is a hole on each end, two clamping positions are needed.	
11.	Cross Beam	Nylon 101	1	-Injection moulding -3-axis milling	Injection moulding for primary forming. Second image is a cross-section to show the drafts. Parting direction is left and right as seen in that image. 3-axis milling is required for perforations and to flatten	

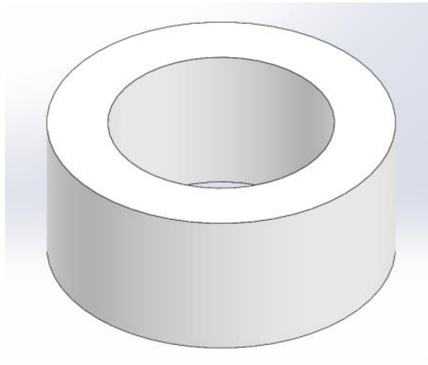
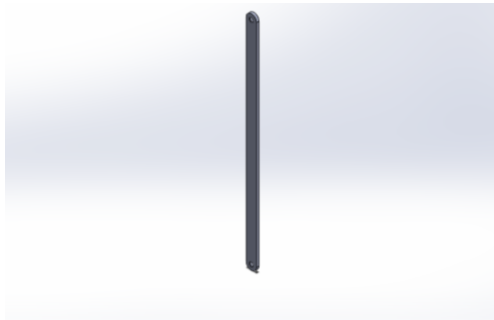
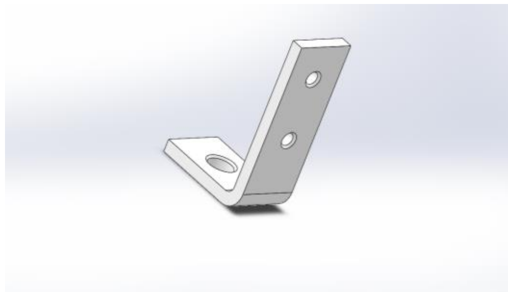
					some of the faces that are drafted to allow for nuts and bolts to be used. 3-clamping positions are needed.	
12.	Distancing Bushing 1	Acrylonitrile Butadiene Styrene (ABS)	1	-Extrusion -CNC lathe	Profile extrusion, followed by cutting in a CNC lathe to the desired length	
13.	Distancing Bushing 2	Acrylonitrile Butadiene Styrene (ABS)	1			

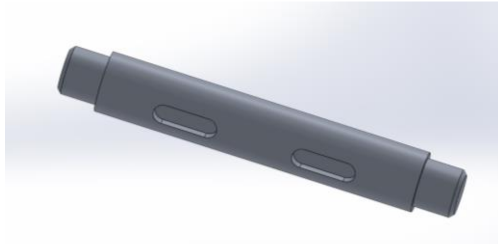
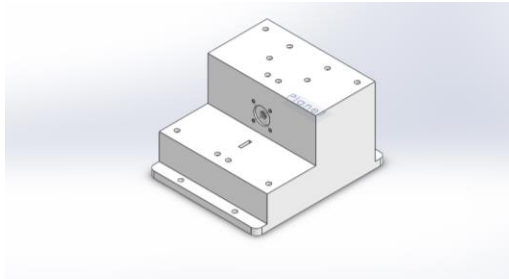
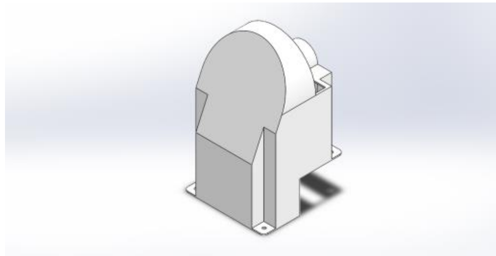
14.	Distancing Bushing 3	Acrylonitrile Butadiene Styrene (ABS)	1			
15.	Front Shade Stick	Nylon 101	2, one of each type	-Injection moulding -3-axis milling	Injection moulding for primary forming. Separation direction up and down as seen in the second image. 3-axis milling is needed for the perforations. One clamping position is enough. There are two configurations for this part, one being the mirror image of the other. For the second configuration the process is the same but mirrored.	 
16.	Locking Pin	Polyphenylene (PPS)	1	-injection moulding	Injection moulding. A slider in the mould will be needed for the small hole at the bottom of the locking pin. Other than that, the parting direction is up and down as seen in the image parting at the bottom face.	

17.	Lower Canvas Mount A	Nylon 101	1	-Extrusion -3-axis milling	Primary forming by extruding the L-shaped profile. Milling is needed for the perforations and finishing. Three Clamping positions are needed.	
18.	Lower Canvas Mount B	Nylon 101	1	-Injection moulding -3-axis milling	Injection moulding for primary forming, Parting direction up and down as seen in image, parting at the bottom face. The holes must be drilled in a 3-axis milling machine. One clamping position is enough	
19.	Lower Shaft	6060 Alloy	1	-CNC mill turning	All diameters and circular features to be made in a CNC lathe. Using a mill-turning capable lathe, the non-circular features like key seats can be machined in this same lathe.	

20.	Middle Shaft	6060 Alloy	1	-Milling capable CNC lathe	All diameters and circular features to be made in a CNC lathe. Using a mill-turning capable lathe, the non-circular features like key seats can be machined in this same lathe.	
21.	Mobile cross beam	Nylon 101	1	-Injection moulding -3-axis milling	Injection moulding process similar to part number 11. 3-axis milling in order to do perforations with three clamping positions.	
22.	Motor Mount	Polyphenylene (PPS)	1	-Profile Extrusion -3-axis milling	Extrusion of the L-shaped profile followed by 3-axis milling for perforations and finishing. Two clamping positions needed. Profile extrusion is chosen to avoid the need for draft angles in this mounting part.	

23.	Mounting Hub	6060 Alloy	1	-Die casting -3-axis milling	Die casting for primary forming. Parting direction up and down as seen in image. 3 axis milling needed for perforations, bore and keyway. 3 clamping positions needed.	
24.	Sensor Cover	Clear Polymethyl Methacrylate (PMMA)	2	-Injection moulding	After injection moulding, the part is assembled using adhesive. Adhesive details discussed at the end of table.	

25.	Sensor Tube	Nylon 101	2	-Extrusion -CNC lathe turning	Extrusion of the round profile in long lengths. This then is to be cut in a CNC lathe to the desired length for quick successive production. Attached to the assembly using adhesive. Details of adhesive are discussed at the end of the table.	
26.	Short Accordion Stick	Nylon 101	2	-Injection moulding -3-axis milling	Process exactly the same as part 1. Injection moulding parting in the same sense, followed by milling in one clamping position for the perforations.	
27.	Solenoid Bracket	Polyphenylene (PPS)	1	-Profile Extrusion -3-axis milling	Extrusion of the L-shaped profile followed by 3-axis milling for perforations and finishing. Two clamping positions needed. Profile extrusion is chosen to avoid the need for draft angles in this mounting part.	

28.	Upper Shaft	6060 Alloy	1	-Milling capable CNC lathe	All diameters and circular features to be made in a CNC lathe. Using a mill-turning capable lathe, the non-circular features like key seats can be machined in this same lathe.	
29.	Upper Shell	Polyphenylene (PPS)	1	-injection moulding -3-axis milling	Injection moulding for primary forming. Parting direction up and down as seen in image. Parting at the bottom face. 3-axis milling for all perforation. Three clamping positions needed.	
30.	Gear Shell	Acrylonitrile Butadiene Styrene (ABS)	1	-Injection moulding -3-axis milling	Injection moulding for primary forming. Parting direction up and down as seen in image. Parting at the bottom face. 3-axis milling for all perforation. One clamping position needed.	
31.	Wire Cover	Nylon 101	2	-Extrusion moulding -3-axis milling	Extrusion for the primary forming and milling for the countersunk holes. One clamping position	

2.5.3 Notes on adhesive assembly

All electronic components housed inside the shell are mounted using double sided adhesive tape, with the exception of the motor and solenoid, which are mounted with screws. The double-sided tape is used since it allows for easy and secure fastening without any special geometric features: fastening methods like screws or bolts would require tapped holes or perforations on whatever component the part is being fastened to. Using adhesive tape allows for mounting directly to the inside of the shell, which would otherwise be too thin for tapped holes or would lose its water protection for the same electrical components it's trying to protect. Double sided tape is also a very simple fastening method, and it requires no special tools or methods at all.

For the two plastic components that were mentioned to be mounted using adhesive, the adhesive used is epoxy resin-based adhesive. To be precise, the adhesive chosen for these parts is the product named “PlasticWeld” from the J-B Weld company. This is a two-part resin adhesive formulated specifically for joining plastic components. As a precaution to improve the bonding coming from this method, the two mentioned parts will have the faces that will be joined, sanded with medium-grit sandpaper by hand to add to the roughness of the surface to bond. Since these are all very lightweight and non-loaded parts, only a small amount of adhesive is required for each. This joining product is simple to use, it only requires pushing the desired amount of resin out of its tube and mixing it in a mixing tray that comes included with the product. Afterwards, the mixed resin is applied to the parts to be joined and these are left for an hour until it has fully cured.

2.6 Requirement Manual for "Buy" Parts

2.6.1 Overview

In this section all the electrical and mechanical components which need to be bought from an outside source for the product design are mentioned in detail along with their specifications and requirements. Few of the core reasons to buy these parts from external suppliers rather than manufacturing in house are:

1. **Availability:** These buy parts component lists are all standard components being used in the product development so they are readily available by any well-known supplier or distributor all over the globe.

2. **Cost factor:** Apart from other things to be considered in the product design phase, money plays a major role as a deciding factor when it comes to make-or-buy decisions as buying standard parts at fixed costs can help to pin down the total costs of the product to reach closer to the final value of the product. This way the estimates for cost calculation and production planning can be easily anticipated.

3. **Time factor:** Time is another important factor when it comes to product development. There are various deadlines to be met in the course of a project development so, to meet all the due dates the product should be ready without having any defects. In such cases, buying such standard components makes a huge benefit for the company as once the workforce is trained to deal with such types of standardized components it makes the development at a faster rate hence increasing the overall production rate.

4. **Quality Control:** The standard components bought for this project meet all the quality control standards as they are manufactured and supplied by authorized, well known producers and distributors who manufacture them for a wide range of applicability.

5. **Integrability:** Standard components are designed such that they are easily integrable in the product and have a wide scope of applicability.

6. **Resources and Expertise:** The designers are forced to buy many components of the system under design because most of the time the required resources such as raw material, machinery and skilled force to manufacture such components is missing and it takes a huge effort and money to gather all this. Buying in these cases makes more sense.

2.6.2 Electrical Components "Buy" Parts Manual

1. Microcontroller

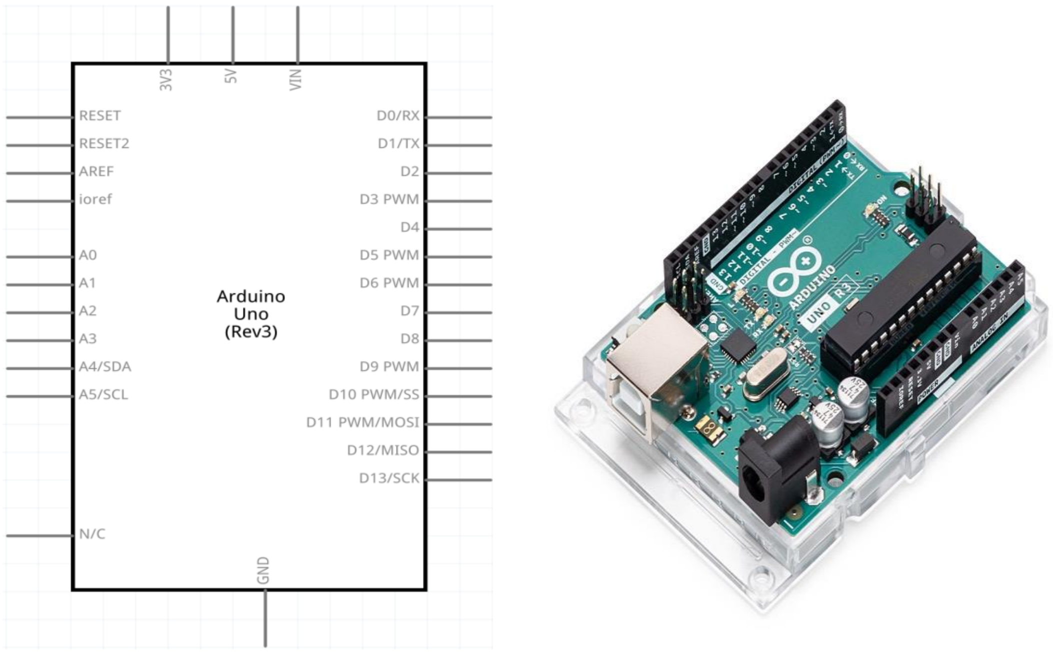


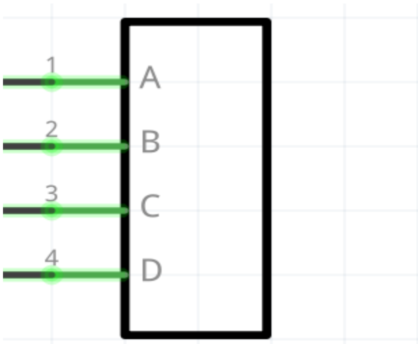
Figure 2.6.2.1: Microcontroller Schematic and component image

<u>Specifications:</u>

Microcontroller Chip	ATmega328P
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limit)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
PWM Digital I/O pins	6
Analog Input Pins	6
DC Current per I/O pin	20 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB (ATmega328P) of which 0.5 KB used by bootloader
EEPROM	1KB (ATmega328P)
Clock Speed	16 MHz

LED_BUILTIN	13
Length	68.6 mm
Width	53.4 mm
Height	12.5mm
Weight	25 g
Operating Temperature	-40C to +85 degree Celsius
Quantity	1

2. Stepper Motor



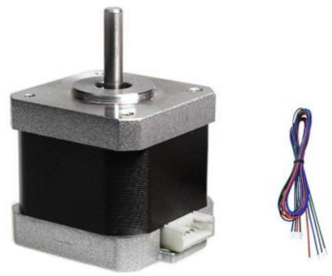


Figure 2.6.2.2: Stepper Motor Schematic and component image

Specifications:

Model	NEMA17
Motor Type	Single shaft
Step Angle	1.8° per step
Holding Torque	5.6 kg-cm
No. of Phases	2
Operating Voltage	8 - 45V DC
Supply Current	1.2 A/Phase (2.4A in total)
No. of Leads and connection	4 (4 line wires for 4 pole connections)
Rotor Inertia	54 g-cm^2
Weight	375 g
Length	42.35 mm

Width	42.35 mm
Height	40.58 mm
Detent Torque	0.28 kg-cm
Step Angle Accuracy	±5%
Shaft Type	D-Type
Shaft Diameter	5 mm
Shaft Length	20 mm
Cable Length	720 mm
Operating Temperature	up to +180 deg Celsius
Details	Bipolar stepper motor
Quantity	1

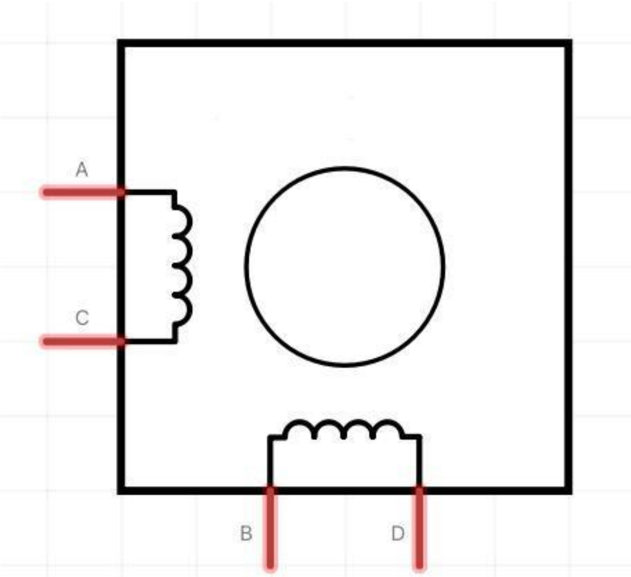


Figure 2.6.2.3: NEMA 17 bipolar stepper motor connection details. A & C connected to 2A & 2B, B & D connected to 1A & 1B

3. Stepper Motor Driver

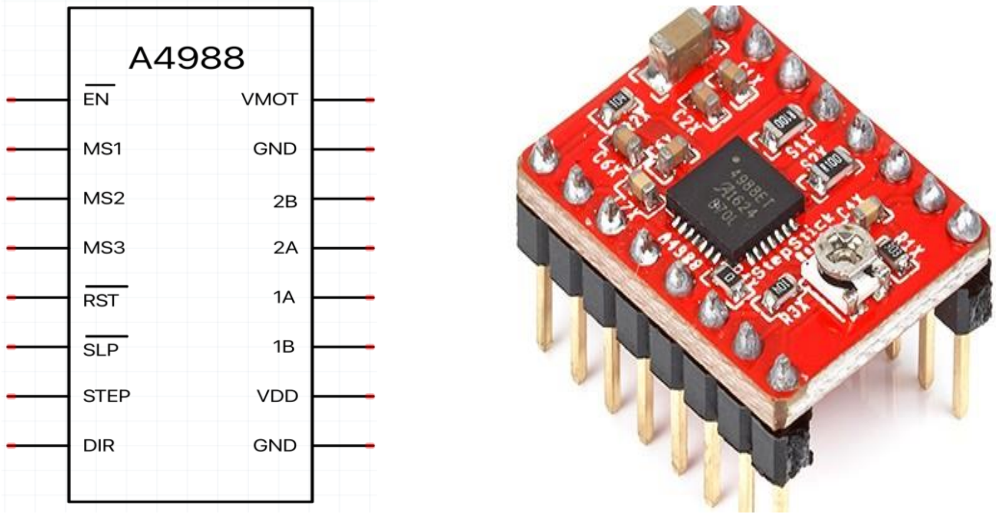


Figure 2.6.2.4: Stepper Motor Driver Schematic and component image

Specifications:

Model Name	A4988
Input Motor Load Supply Voltage	8 - 35 VDC
Operating Current	1 A (no heat-sinking), 2 A (with heat-sinking)
Logic Input	3 - 5.5V
Five Step Mode	Full, ½, ¼, ⅛, and 1/16
Weight	0.08 kg
Dimensions	50 x 50 x 40 mm
Operating Temperature	-20 to +85 deg Celsius
Storage Temperature	-55 to 150 deg Celsius
Reference Voltage	5V
Quantity	1

4. LDR Sensor

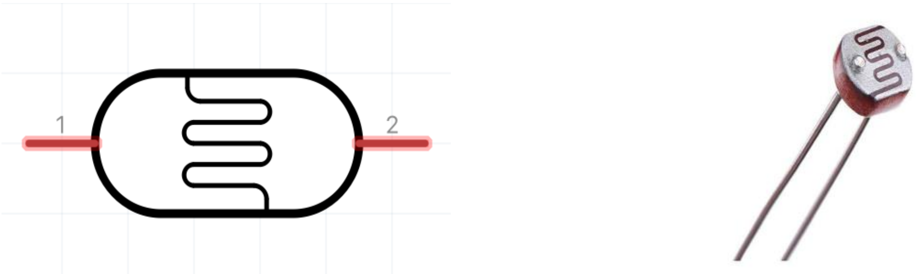


Figure 2.6.2.5: Sensor Schematic and component image

Specifications:

Brand Name, Model	EBOOT, 5539
Material	CdS
Part Number	EBOOT-RESISTOR-05
Maximum Voltage	150V DC
Spectral Peak	540 nm
Maximum Wattage	100 mw
Light Resistance (10 Lux)	50 - 100 Kohm
Dark Resistance	5 Mohm
Operating Temperature	-30 to +70 Degree Celsius
Dimensions	Given below
Quantity	2

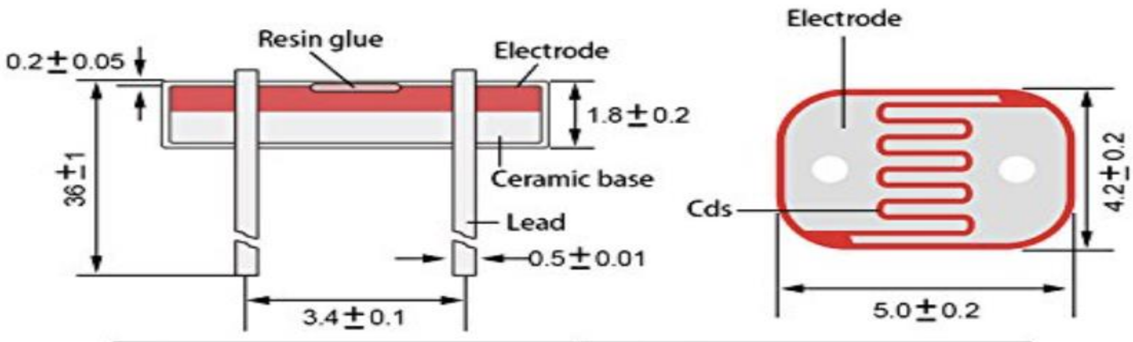
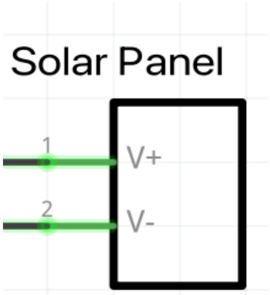


Figure 2.6.2.6: Dimensions of LED Sensor

5. Solar Panel



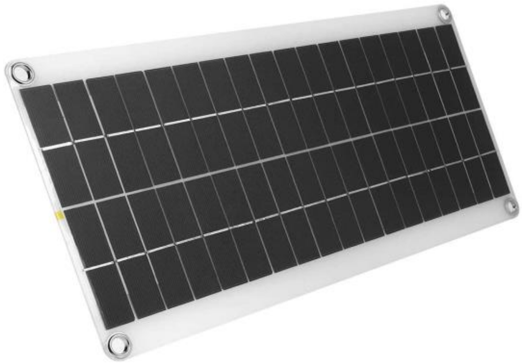


Figure 2.6.2.7: Solar Panel Schematic and component image

Specifications:

Part Number	HHC-442799
Material	Monocrystalline silicon
Output Voltage	12 - 18V DC
Power	15W
Dimensions	411 x 200 x 2.5 mm
Weight	344 g
Water Resistance class	IP65 and advanced water and dust tightness (complete protection against environmental influences)
Solar Panel Frame	Corrosion resistant lightweight anodised aluminium frame with anti-reflective tempered glass.
Quantity	1

6. Solar Charger

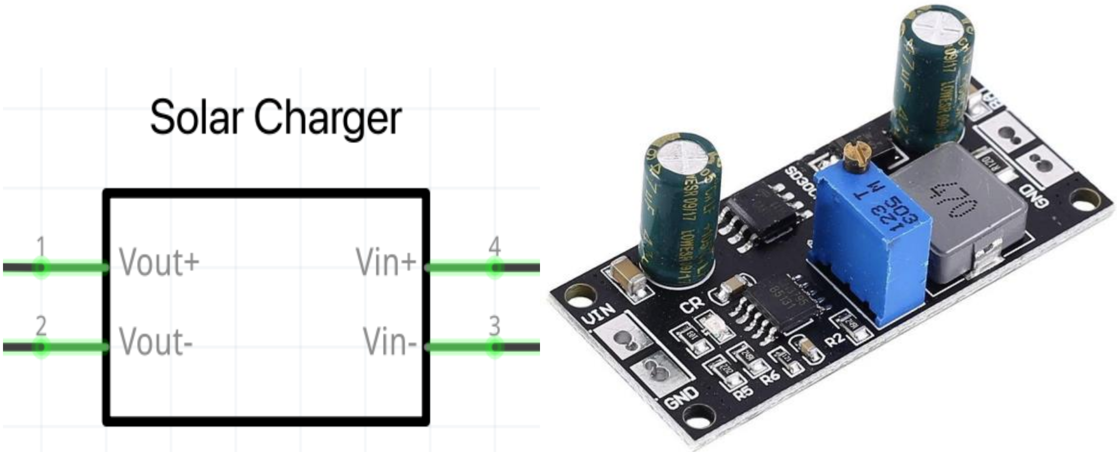


Figure 2.6.2.8: Solar Charger Schematic and component image

<u>Specifications:</u>

Part Name	MPPT Solar Controller 1A 3.2V 3.7V 3.8V 7.4V 11.1V 14.8V Lithium ion LiFePO4 Titanate Battery Charger Module SD30CRMA - 18V
Part Number/ Model	SD30CRMA - 18V
Features	Solar Charging, high efficiency, low power consumption, MPPT function. Can be used as a charger for lithium-ion batteries or a step-down power supply module.
Input DC	18 - 28V
Output DC	1.2V - 17V Adjustable (3.6V, 4.2V, 4.3V 4.35V 8.4V 12.6V 16.8V)
Output Current	1A
Operating Temperature	-20 to +85 degree Celsius
Operating Humidity	5% - 95% RH
PCB Size	45 x 20 x 15 mm
Weight	7.3gms
Connection	2 line
Quantity	1

7. DC Battery

Figure 2.6.2.9: Battery Schematic and component image

Specifications:

Battery Type	Polymer Li-ion Rechargeable Battery
Model	DTP603450
Voltage	3.70V
Capacity	1000 mAh
Connections	Positive and negative Terminals
Quantity of batteries used	5
Total output Voltage	18.5 VDC (5 individual batteries connected in series)
Dimensions	50.8 x 33.5 x 5.9 mm
Weight	22gms
Operating Temperature	Charge: 0 to +45 deg Celsius Discharge: -20 to +60 deg Celsius
Storage Temperature	-20 to +60 deg Celsius
Operation & Storage Humidity Range	65 RH

8. Switch

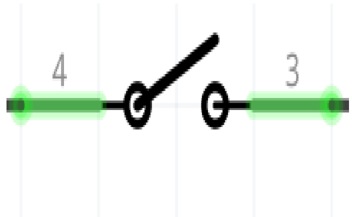


Figure 2.6.2.10: Switch Schematic and component image

Specifications:

Switch Type	Manual
Actuator Style	Rocker
Number of Positions	2
Number of Circuit Controlled	1
Switch Starting Position	1 Off (Normally Open) or 1 On (Normally Closed)
Switching Current @ Voltage	6 A @ 125 V AC 4 A @ 28 V DC
Maximum Voltage	30V DC 250V AC
Wire Connection Type	Solder Lugs
Dimensions	Given below
Mounting of the switch in the device	On the housing
Switch Action	Stays switched (Maintained)
Quantity	2

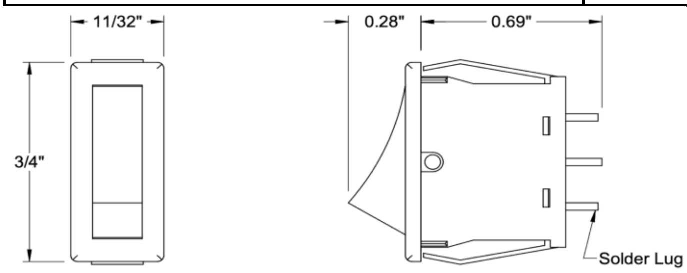


Figure 2.6.2.11: Dimensions of the switch

9. DC-DC Buck Convertor

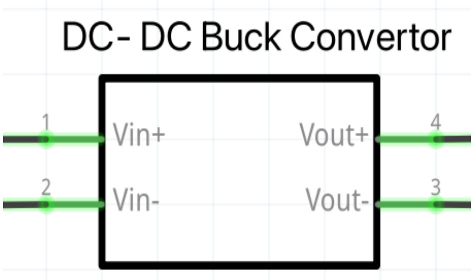


Figure 2.6.2.12: DC-DC Buck converter Schematic and component image

Specifications:

Model	LM2596 Step down adjustable DC-DC Switching Buck Convertor
Input Voltage	3 - 40V DC
Output Voltage Range	1.23 - 37V DC
Max Output Current	3A
Adjustment	25- Turn Trimpot
Efficiency	up to 93%
Switching Frequency	150 kHz
Built-in Protection	Thermal shutdown and current limit
Length	43.2 mm
Width	21 mm
Height	14 mm
Weight	11.23 g
Maximum Operating Temperature	Up to 125 deg Celsius
Quantity	1

10. Solenoid

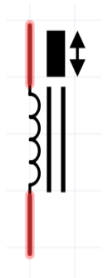


Figure 2.6.2.13: Solenoid Schematic and component image

Specifications:

Model	JF-0530B-6V
Voltage	6V DC
Current	~1600mA on 6V (only for short-term use)
Current (max for a longer time)	300mA
Power	1.8W(max continuous), 9.6W(peak, short-term)
Type	Push-Pull, linear motion, spring plunger return DC solenoid electromagnet
Force (maximum in end position)	5N
Length stroke	10 mm
Dimensions (frame)	30 x 16 x 15mm
Dimensions (pin)	6 x 58mm
Cable length	~200 mm
Quantity	1

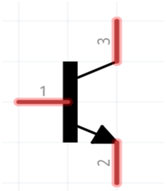
11. Resistor

Figure 2.6.2.14: Resistor Schematic and component image

<u>Specifications:</u>

Part	CFR-25JB-1K0, CFR-25JB-10K
Resistance required	1K ohm, 10K ohm
Power	0.25W
Tolerance	-5% to 5%
Composition	Carbon film
Max working voltage	250V DC
Connection	2 terminals, breadboard and Arduino compatible
Operating Temperature range	-55 to +155 deg Celsius
Quantity	3

12. NPN Transistor



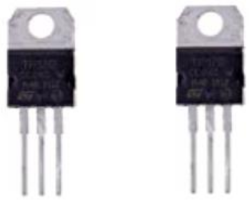
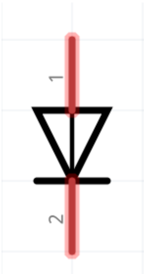


Figure 2.6.2.15: Transistor Schematic and component image

Specifications:

Model Name	TIP120 NPN Transistor
Model Number	BJ-TIP-120
Transistor polarity	NPN (Medium power Darlington transistor)
Vceo	60V
Vcbo	60V
Base current	120mA
Peak Load Current	8A
DC current gain hFE	1000
Collector DC current	5A
Power consumption	2W
Power Dissipation (Pd)	65W
Number of pins	3
Operating temperature	-65°C to +150 degree Celsius
Quantity	1

13. Diode



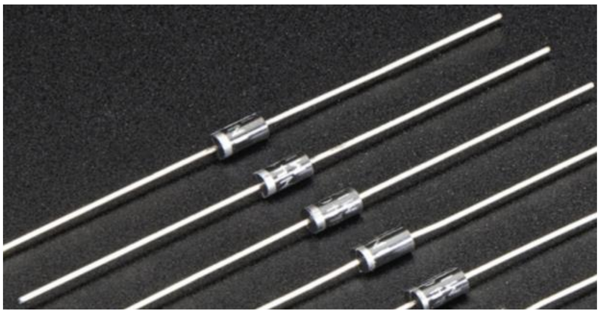


Figure 2.6.2.16: Diode Schematic and component image

Specifications:

Model	1N4001
Case	Epoxy, Moulded
Weight	0.4 g
Finish	All external surfaces corrosion resistant and terminal leads are readily solderable
Lead and Mounting Surface Temperature for Soldering purposes	260°C Max. for 10 Seconds, 1/16 in. from case
Polarity	Cathode Indicated by Polarity Band
Operating Temperature	-65 to +175 deg Celsius
Average Forward Current	1A
RMS Reverse voltage	35V
Peak Reverse Voltage	50V

Reverse Current	5uA
Max instantaneous forward voltage drop	Typical: 0.93V, Max: 1.1V
Quantity	1

14. Breadboard

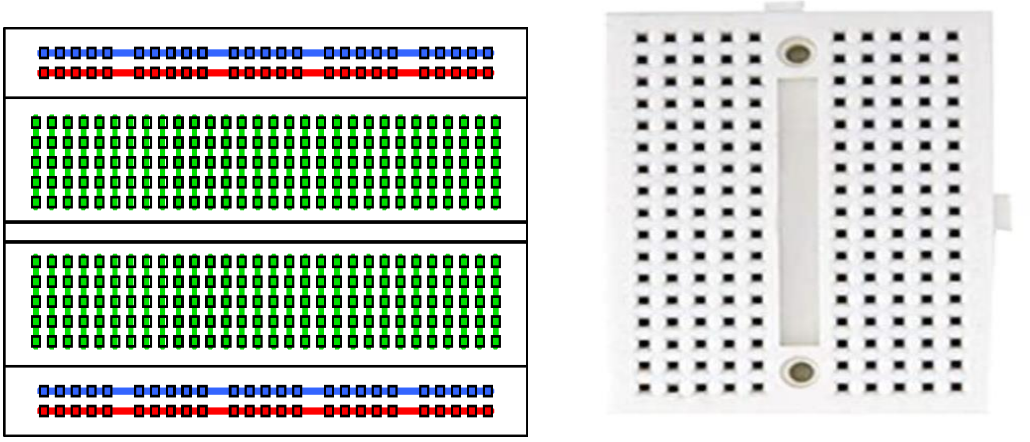


Figure 2.6.2.17: Breadboard Connection Schematic and component image

Specifications:

Connection Points	170, mini solderless breadboard
Material	ABS Plastic Board
Dimensions	47 x 35 x 8.5 mm
Hole/Pitch style	Square wire holes (2.54mm)
Connection type and compatibility	Connection via Jumper wires and suitable for Arduino projects
Insulation Resistance	500 Mohm / DC 500V
Backing	Self-adhesive double adhesive tape
Description	17 pair of rows each with 5 points
Quantity	2

15. Wires

Calculation and specifications for wires

AWG gauge	Conductor Diameter Inches	Conductor Diameter mm	Conductor cross section in mm^2	Ohms per 1000 ft.	Ohms per km	Maximum amps for chassis wiring	Maximum amps for power transmission
0000	0.46	11.684	107	0.049	0.16072	380	302
000	0.4096	10.40384	84.9	0.0618	0.202704	328	239
00	0.3648	9.26592	67.4	0.0779	0.255512	283	190
0	0.3249	8.25246	53.5	0.0983	0.322424	245	150
1	0.2893	7.34822	42.4	0.1239	0.406392	211	119
2	0.2576	6.54304	33.6	0.1563	0.512664	181	94
3	0.2294	5.82676	26.7	0.197	0.64616	158	75
4	0.2043	5.18922	21.1	0.2485	0.81508	135	60
5	0.1819	4.62026	16.8	0.3133	1.027624	118	47
6	0.162	4.1148	13.3	0.3951	1.295928	101	37
7	0.1443	3.66522	10.6	0.4982	1.634096	89	30
8	0.1285	3.2639	8.37	0.6282	2.060496	73	24
9	0.1144	2.90576	6.63	0.7921	2.598088	64	19
10	0.1019	2.58826	5.26	0.9989	3.276392	55	15
11	0.0907	2.30378	4.17	1.26	4.1328	47	12
12	0.0808	2.05232	3.31	1.588	5.20864	41	9.3
13	0.072	1.8288	2.63	2.003	6.56984	35	7.4
14	0.0641	1.62814	2.08	2.525	8.282	32	5.9
15	0.0571	1.45034	1.65	3.184	10.44352	28	4.7
16	0.0508	1.29032	1.31	4.016	13.17248	22	3.7
17	0.0453	1.15062	1.04	5.064	16.60992	19	2.9
18	0.0403	1.02362	0.823	6.385	20.9428	16	2.3
19	0.0359	0.91186	0.653	8.051	26.40728	14	1.8
20	0.032	0.8128	0.519	10.15	33.292	11	1.5
21	0.0285	0.7239	0.412	12.8	41.984	9	1.2
22	0.0253	0.64516	0.327	16.14	52.9392	7	0.92
23	0.0226	0.57404	0.259	20.36	66.7808	4.7	0.729
24	0.0201	0.51054	0.205	25.67	84.1976	3.5	0.577
25	0.0179	0.45466	0.162	32.37	106.1736	2.7	0.457
26	0.0159	0.40386	0.128	40.81	133.8568	2.2	0.361
27	0.0142	0.36068	0.102	51.47	168.8216	1.7	0.288
28	0.0126	0.32004	0.080	64.9	212.872	1.4	0.226
29	0.0113	0.28702	0.0647	81.83	268.4024	1.2	0.182
30	0.01	0.254	0.0507	103.2	338.496	0.86	0.142
31	0.0089	0.22606	0.0401	130.1	426.728	0.7	0.113
32	0.008	0.2032	0.0324	164.1	538.248	0.53	0.091

Figure 2.6.2.18: Table showing list of different wires and their specifications.

For power transmission wiring system from the battery through buck converter to stepper motor and microcontroller which needs to be powered up at 12V as well as power transmission from solar panel to the battery through solar charge converter a maximum of 4A is needed. Keeping a sufficient safety factor in mind, wire of 14 AWG was chosen for this purpose.

Rest of the low power consumption devices such as microcontroller, sensors, solenoid, stepper motor driver, passive elements in the circuit as well as breadboard connections, jumper cables are sufficient and capable of handling and serving the desired requirements.

Figure 2.6.2.19: 14 AWG wire and jumper cables

14 AWG wire specifications

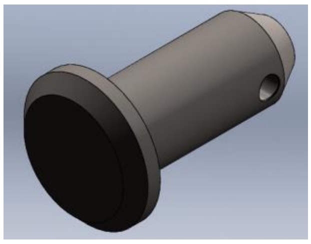
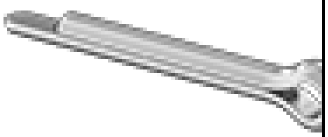
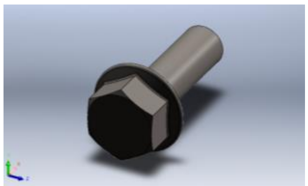
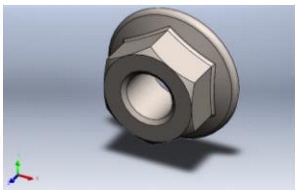
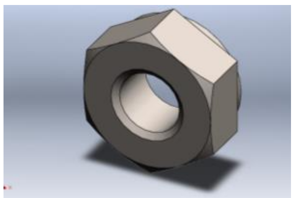
Material	Conductor tinned copper
Insulator	Silicon
Gauge	14 AWG
Operating Temperature	-65 to +200 deg Celsius
Single wire Diameter	0.08mm
Outer Diameter	3.5mm
Length	5m x Red Silicone wire 5m slack Silicone wire

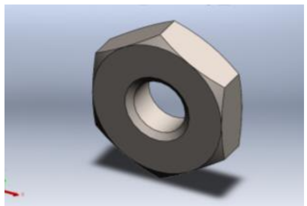
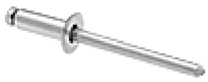
Jumper Wire Specifications

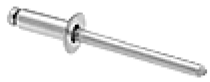
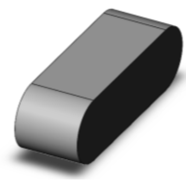
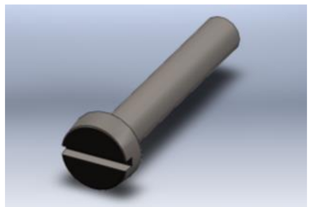
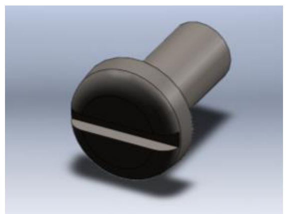
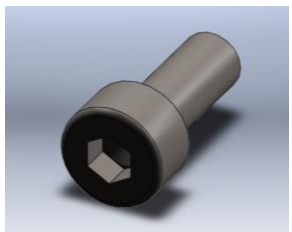
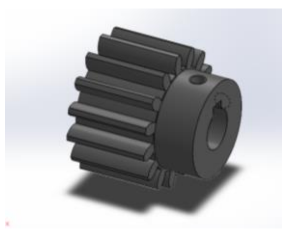
Length	5m 20P Jumper Cable
Material	Copper Wire tinned
Pitch	1.27mm
Description	Fits breadboard and friendly use for Arduino based Projects

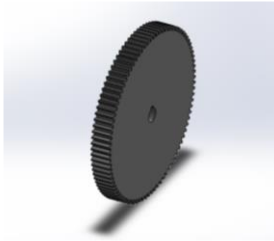
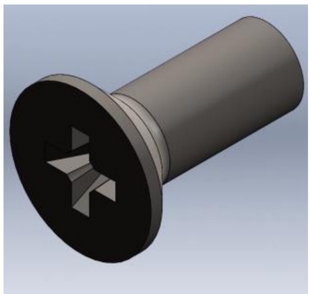
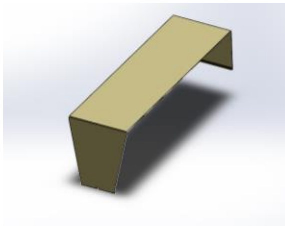
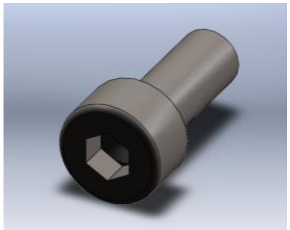
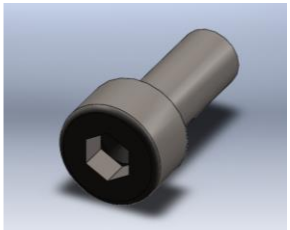
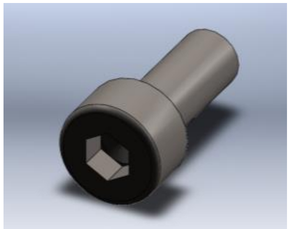
Note: The passive electrical components such as resistor, diode, transistor etc whose dimensions or weight have not been mentioned in the requirements manual doesn't really account much relevance because these components are very small in size and weight which fits easily on the breadboard. There is also enough space above the breadboard to incorporate these components on it.

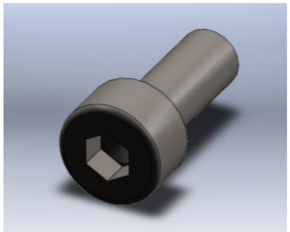
2.6.3 Mechanical Components "Buy" Parts Manual

No.	Part Name	Qty.	Dimension	Component images
1.	Black-Finish Steel External Retaining Ring_98541A118	5	DIN 471 -Diameter: 9.6mm -Inner Diameter: 9.3mm -Outer Diameter: 10mm -Width: 1.1mm	
2.	Black-Finish Steel External Retaining Ring_98541A410	2	DIN 471 -Diameter: 14.3mm -Inner Diameter: 13.8mm -Outer Diameter: 15mm -Width: 1.1mm	
3.	Clevis pin	16	DIN EN 22341 B-6x14x1.6	
4.	Cotter Pin_98350A211	16	DIN 94, ISO 1234 -Diameter: 1.6mm -Length: 10mm	
5.	Hex Flange Bolt	16	DIN 6921 M8x25x25	
6.	Hex Flange Nut	16	DIN 6923 M8	
7.	M4 Hex Nut AB	6	ISO 4032 M4-W	

8.	M2 Hex thin Nut AB	4	ISO 4035 M2	
9.	Metric Quick-release Pin_95335A512	1	-Diameter: 5mm -Length: 25mm -Material: 12L14 Carbon Steel -Finish: Zinc Plated	
10.	Plastic Ball Bearing_6455K118	2	-Inner Diameter: 8mm -Outer Diameter: 28mm -Width: 9mm -Ring and Cage material: Acetal Plastic -Ball Material: 316 Stainless Steel	
11.	Plastic Ball Bearing_6455K137	1	-Inner Diameter: 10mm -Outer Diameter: 26mm -Width: 8mm -Ring and Cage material: Acetal Plastic -Ball Material: 316 Stainless Steel	
12.	Plastic Ball Bearing_6455K138	3	-Inner Diameter: 12mm -Outer Diameter: 28mm -Width: 8mm -Ring and Cage material: Acetal Plastic -Ball Material: 316 Stainless Steel	
13.	Polycarbonate Plastic Washer_90940A117	8	-Inner Diameter: 3.3mm -Outer Diameter: 10mm -Thickness: 0.7-1mm	
14.	Rivet_97525A232	2	DIN 7337, ISO 15983 -Diameter: 14mm -Thickness: 16-21mm -Length: 25mm -Hole Size: 4.1-4.2mm	

15.	Rivet_97525A246	1	DIN 7337, ISO 15983 -Diameter: 5mm -Thickness: 15-20mm -Length: 25mm -Hole Size: 5.1-5.2mm	
16.	Rounded Machine Key_2977N19	2	DIN 6885 -Height: 4mm -Width: 4mm -Length: 20mm	
17.	Rounded Machine Key_2977N25	3	DIN 6885 -Height: 5mm -Width: 5mm -Length: 16mm	
18.	slotted cheese head screw	4	DIN EN ISO 1207 M2x12	
19.	slotted pan head screw	8	DIN EN ISO 1508 M3x6	
20.	M4 Socket Head Cap Screw	6	EN ISO 4756 M4x12	
21.	Gear PS2-15	2	-Grade: JIS N9 -Hole Diameter: 10mm -Module: 2 -Tooth count: 15 -MC901 Nylon -Face Width: 15mm	

22.	Gear PSA2-90	2	-Grade: JIS N9 -Hole Diameter: 15mm -Module: 2 Tooth Count: 90 -MC901 Nylon -Face Width: 15mm	
23.	Cotter pin_98350A150	1	DIN 94, ISO 1234 -Diameter: 2mm -Length: 12mm	
24.	Countersunk flathead cross recess screw	16	DIN EN ISO 7046-1 M2x5	
25.	Canvas Sheet	1	Cloth specification: 2oz/square yard outdoors grade nylon cloth. Please read note at the end of the section.	
26.	M3x5 Socket head cap screw	2	EN ISO 4756 M5x5	
27.	M6x10 Socket head cap screw	5	EN ISO 4756 M6x10	
28.	M3x8 Socket Head Cap Screw	4	EN ISO 4756 M3x8	

29.	M5x10 Socket Head Cap Screw	4	EN ISO 4756 M5x10	

Note on the Canvas Sheet: The canvas sheet is a custom designed part. It is a simple rectangular sheet of nylon cloth but it has a few modifications to this basic shape. First, there are some sections cut out of what would otherwise be a simple rectangular sheet. These are very simple, straight-edged cuts that could be removed from the cloth with shears or scissors. There is also the need to sew closed the loops at the two ends of the sheet in order to place the canvas holders in these loops. Despite all these customizations, it has been decided to make this a buy part rather than a make part. The reason for this is that it is considered such a different type of component to produce. Where all other parts are either metal or plastic, both rigid materials that can be processed with the machinery and tools usually found at a machinist's workshop, the same cannot be said for fabric. Hence, it has been deemed the best option to secure a partnership with a company specialized on fabric products for them to be the suppliers of this finished part. The machinery and personnel required to make this product is very different to that which would be expected for all other manufactured parts. This would make doing it inhouse very inefficient by comparison to outsourcing it. Nonetheless, since it is a custom design, a technical drawing of the sheet detailing its relevant dimensions will be provided in the next milestone of the project along with the rest of the usual manufactured parts.

2.6.4 Semi-finished goods buying manual

No.	Part Name	Qty.	Dimension
1.	Aluminium round bar stock	3	-Aluminium Alloy 6061 -Diameter: 16mm -Length can be discussed with suppliers in order to negotiate a good price, but the length of each stock unit must be greater than the length of the longest shaft: 110mm.

3.1 Fatigue assessment

This section is comprised of the calculations performed to determine the resistance to fatigue of the mechanical elements which will be under varying loads from different origins. These critical elements have been selected because they will be under variable loads either from the wind or, in the case of shafts, from the short pulses of torque they receive every ten minutes when an adjustment to the position of the shade is made by the device's motor and the subsequent forces. These fatigue assessments have been carried out following the fourth chapter of the FKM guidelines for fatigue assessment when applicable. The calculations have been largely simplified by assuming certain values for some of the key factors. These assumptions are detailed in the following table:

Factor	Assumed value
$K_{NL,E}$	1
K_V	1
K_S	1
K_F	2
N_S	1

Table 3.1.1 Assumptions for the values of stress factors

These assumptions result in the fatigue limit being calculated from the testing data from polished specimens ($\sigma_{w,zd}$) as:

$$\sigma_{BK} = \frac{1}{1+\frac{1}{2}(\frac{1}{K_R}-1)}\sigma_{w,zd}$$

Following this, the degree of utilization is calculated, considering a safety factor j_D, checking that it is less than one; that is, that the element should be able to safely handle the variable stresses on it considering a selected safety factor.

$$\alpha_{BK,\sigma} = \frac{\sigma_{a,1}}{\sigma_{BK}/j_D} \leq 1$$

Therefore, the assessment will depend on three unknowns. The first is K_R, related to the surface roughness of the component. The second is the safety factor j_D, which has been found for all parts to be 1.4:

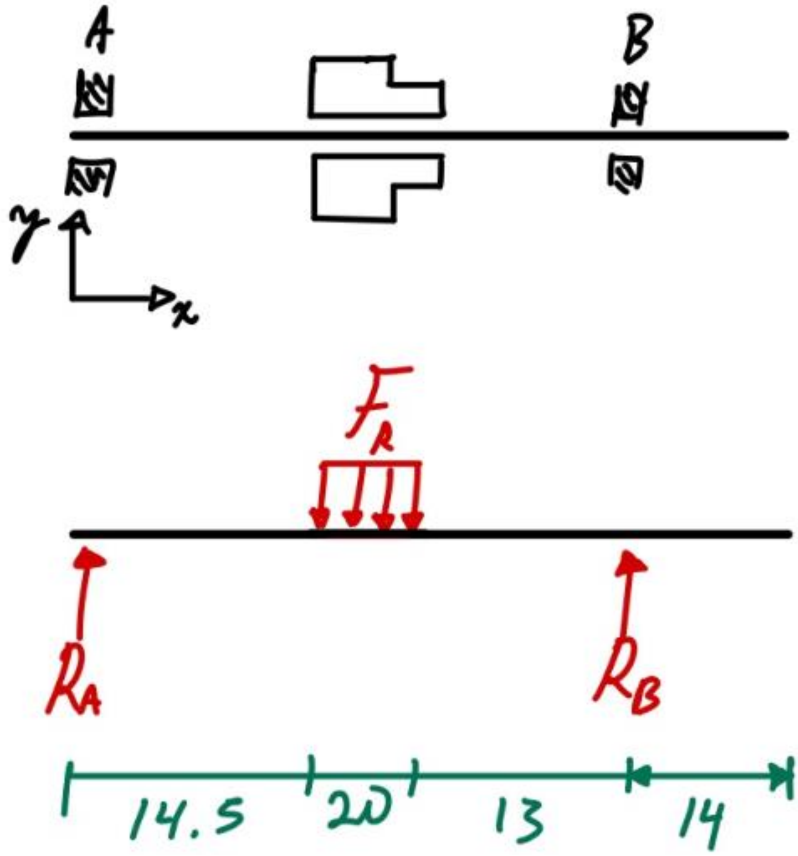
$$j_D = j_s \frac{j_F}{K_{T,D}}$$

J_S is the load factor. It is assumed to be equal to one with reliable design loads. J_F for a wrought aluminium piece like these, with mean consequences of failure and no regular inspection is 1.4 according to table 4.5.1 of the FKM guidelines. $K_{T,D}$ is a temperature factor which will be assumed as 1 since the device is never expected to exceed the "normal" temperature window according to chapter 4.2.3. Therefore, J_D and J_F have the same value: 1.4.

Because of the way the device operates, it is in rest for the vast majority of time. Every ten minutes, measurements of the sun's relative position are made and the position of the shade is adjusted by turning the shafts. Each adjustment is only of a few degrees of rotation for the shade, which means the shafts are only in movement (and under the loads coming from this movement) for a few seconds. After this, they are once again in rest for another ten minutes. This means the loading condition for the shafts is that of pulsating loads. However, since the vast majority of the time the loads are zero, the mean stress over time will be so close to zero as to be negligible. The stresses calculated for the shafts in the following sections will be the amplitude of these pulsating stresses.

3.1.1 Lower Shaft

This shaft is under torsional load between one of its ends, where it is coupled to the motor, and the location of the gear. There is also a radial force that results from the operation of this spur gear. The torque on this shaft is the motor's output torque: 0.56Nm. The diameter of this shaft is 10mm.
The radial load results in the shear and bending loads depicted in the following FBD:



The radial force from the gear F_R is calculated from the gears pitch radius and the torque transmitted.

$$F_R = \frac{T}{r}$$

$$F_R = 18.7N$$

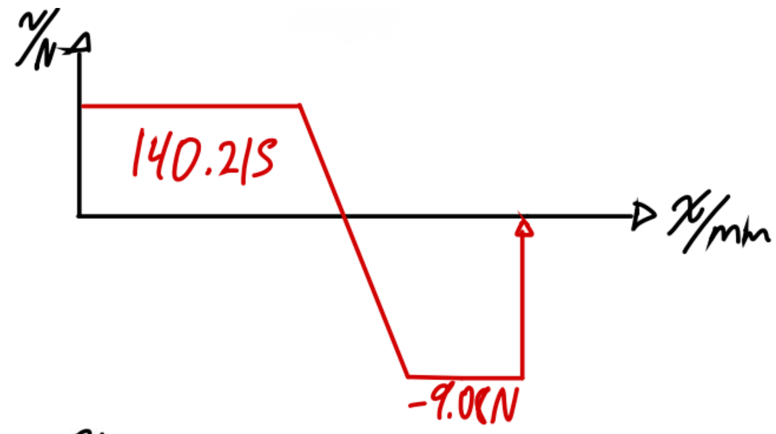
This force is represented as a distributed load since it is transmitted over the length of the gear. Finding the sum of moments around point A, the reaction force R_B is determined:

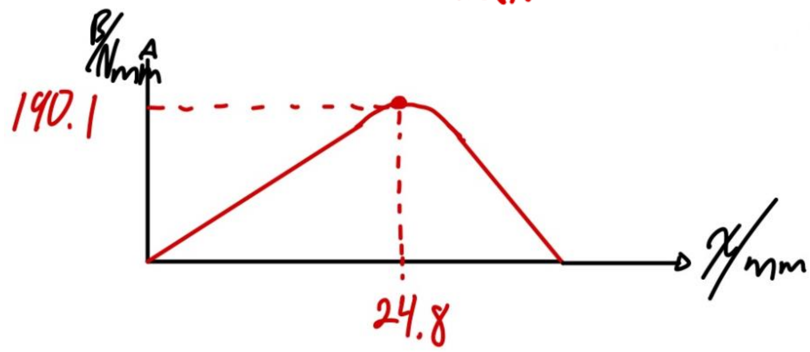
$$R_B = 9.67N$$

Finding the sum of forces in y in equilibrium, the reaction force R_A is determined:

$$R_A = -9.08N$$

The following shear force and bending moment diagrams for the shaft are created:





The bending moment diagram indicates that the maximum bending moment in this shaft is 190.1Nmm. This bending is the only source of axial stresses on the shaft, there are no axial forces. The stress due to bending is calculated based on this value.

$$\sigma_{ba} = \frac{M_{ba}}{W_b}$$

$$W_b = \frac{\pi * d^3}{32} = 9.81 * 10^{-8} m^3$$

$$\sigma_{ba} = 1.93MPa$$

The shear stress due to torsion is found as:

$$\tau_{ta} = \frac{T}{W_t}$$

$$W_t = \frac{\pi * d^3}{16} = 1.96 * 10^{-7} m^3$$

$$\tau_{ta} = 2.85MPA$$

The shear stresses due to radial force or bending are several orders of magnitude smaller than these two so they are neglected for the calculations from this point onwards. The resulting stress state in 3D can be expressed in a stress tensor which will then allow to find the principal stresses. The resulting tensor, expressing the stresses in MPA, is as follows:

$$\begin{bmatrix} 1.93 & 0 & 2.85 \\ 0 & 0 & 0 \\ 2.85 & 0 & 0 \end{bmatrix}$$

A short MATLAB function was written to find the principal stresses of this tensor by solving an eigenvalue problem.

```
function sigmas=principal_stresses(tensor)
%takes as argument a stress tensor and returns a vector containing the
%principal stresses
[D,lambda]=eigs(tensor);
sigmas=[0,0,0];
sigmas(1)=lambda(1,1);
sigmas(2)=lambda(2,2);
sigmas(3)=lambda(3,3);

end
```

The resulting principal stresses are:

$$\sigma_1 = 3.9542MPa$$

$$\sigma_2 = 0$$

$$\sigma_3 = -2.0542MPA$$

For the selected material: Aluminium alloy 6060T6 (3.3206)

$$\sigma_{w,zd} = 65MPa$$

For this CNC turned shaft, the final specified Rz is 6.3 µm. This means a K_R value of:

$$K_R = 0.96$$

$$\sigma_{BK} = 63.67MPa$$

As mentioned before, the safety factor for all shafts is 1.4. The final calculation for the degree of utilization is:

$$\alpha_{BK} = \frac{\sigma_a}{\sigma_{BK}/j_D} = 0.087 \leq 1$$

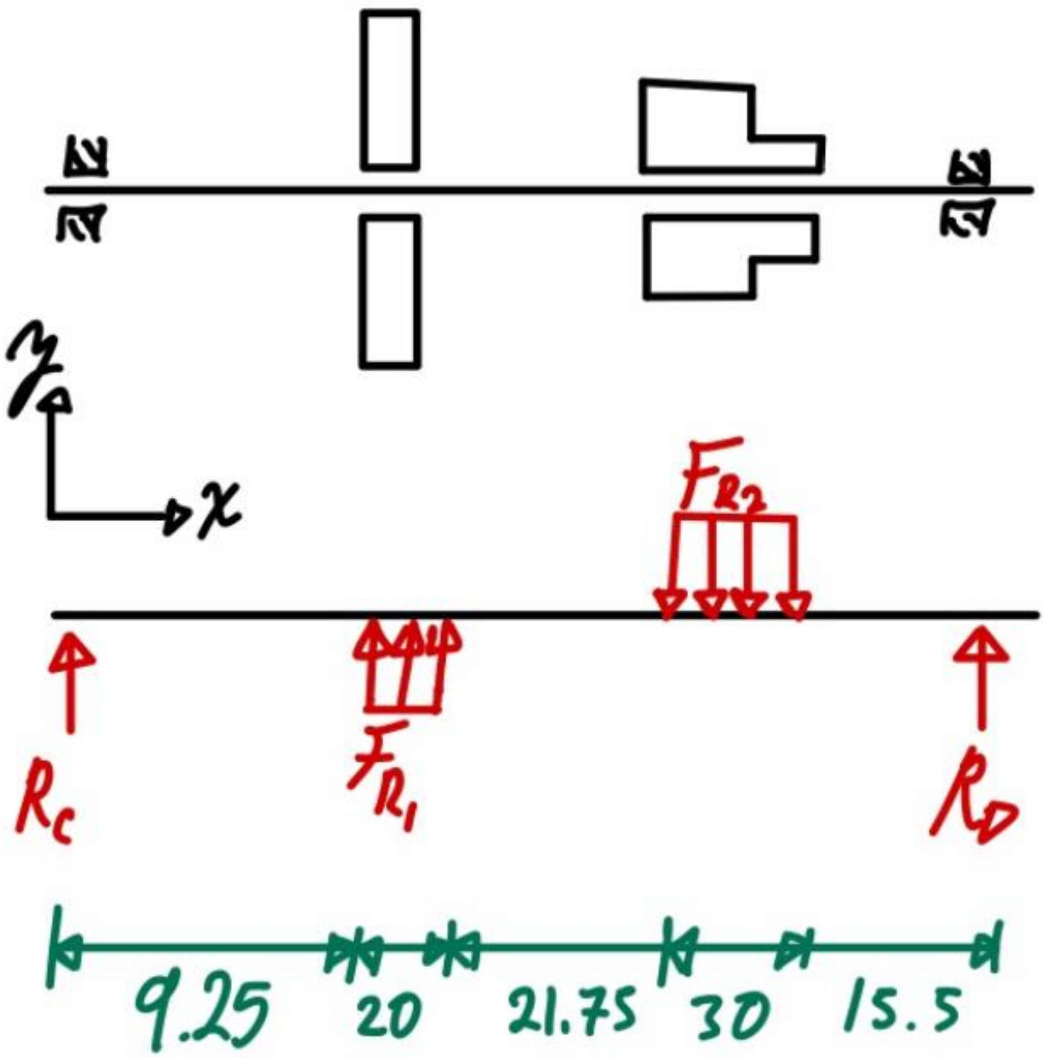
The shaft is very much safe against fatigue.

3.1.2 Middle Shaft

This same calculation process is repeated for the second shaft. Because the procedure is largely the same, the key values of this calculation will be expressed without showing each step of the calculation. This shaft has two diameters: 10mm and 15mm. The transition between these two is a taper of 20º. Because of this progressive transition notch effects of stress concentration will not be considered. Instead, the calculations will be performed as if the entire shaft had a diameter of 10mm in order to show that the smaller diameter can handle any of the loads on the shaft.

The torque transmitted by this shaft is six times greater than the torque on the previous shaft. This is equal to 3.36Nm.

From the radial forces produced by the spur gears, the following FBD arises:



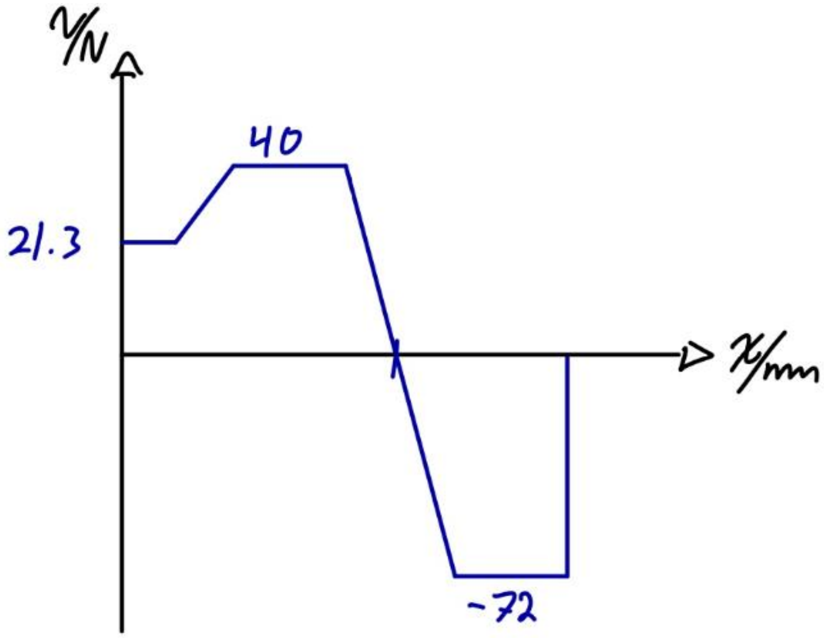
The radial forces are calculated by the dividing the torque by the pitch radius of the gear.

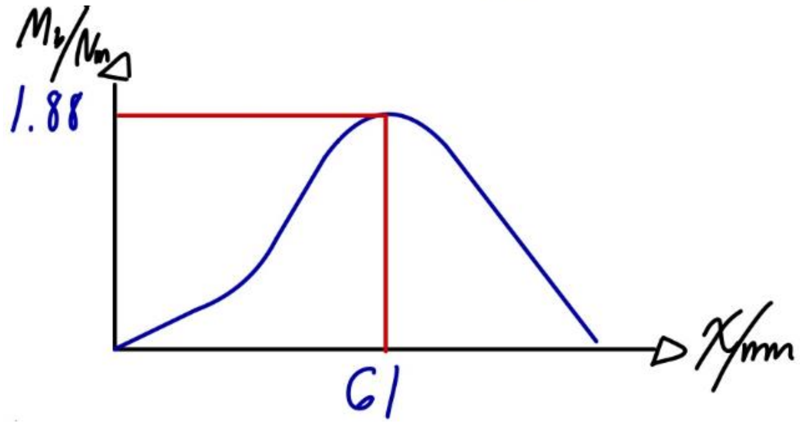
$$F_{R1} = 18.7N$$
$$F_{R2} = 112N$$

Using equations of static equilibrium, the reactions forces are found:

$$R_D = 72N$$
$$R_C = 21.3N$$

The following shear force and bending moment diagrams result:





The maximum bending moment amplitude for the shaft will be 1.88Nm. Once again, there are no axial forces in this shaft. The stress from this bending moment is:

$$\sigma_{b,a} = 19.15MPa$$

The shear stress from torsion on this shaft is:

$$\tau_{t,a} = 17.11\ MPa$$

These stresses are ordered into the following stress tensor:

$$\begin{bmatrix} 19.15 & 0 & 17.11 \\ 0 & 0 & 0 \\ 17.11 & 0 & 0 \end{bmatrix}$$

The following principal stresses were found for this tensor:

$$\sigma_1 = 29.18\ MPa$$
$$\sigma_2 = 0$$
$$\sigma_3 = -10.00\ MPa$$

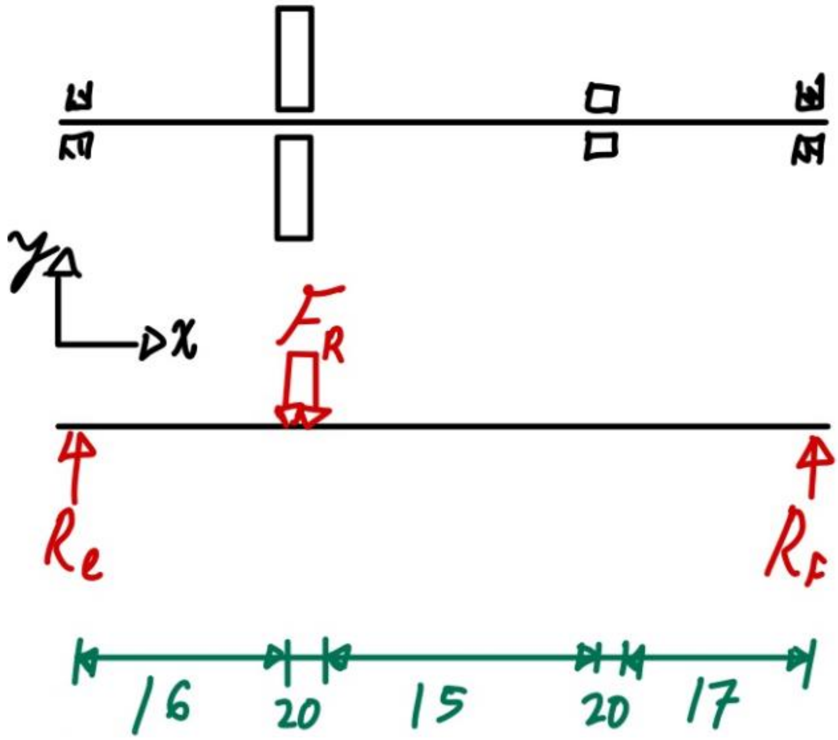
The principal stress with the largest magnitude is used to check the degree of utilization. The adjusted fatigue stress limit and the safety are the same as for the previous shaft since the material, material finish and application conditions are the same.

$$\alpha_{BK} = \frac{\sigma_a}{\sigma_{BK}/_{j_D}} = 0.64 \leq 1$$

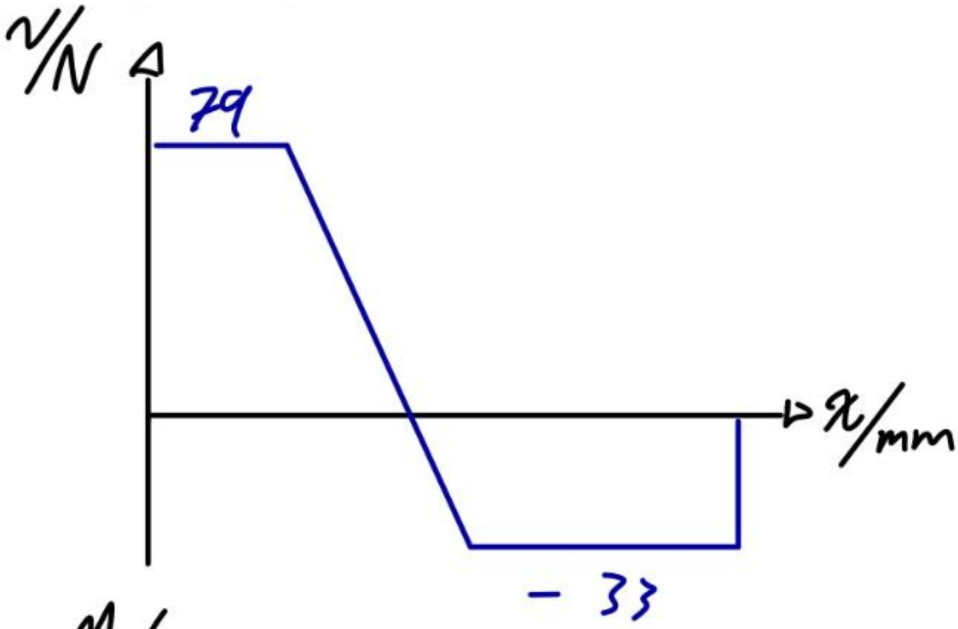
3.1.3 Top Shaft

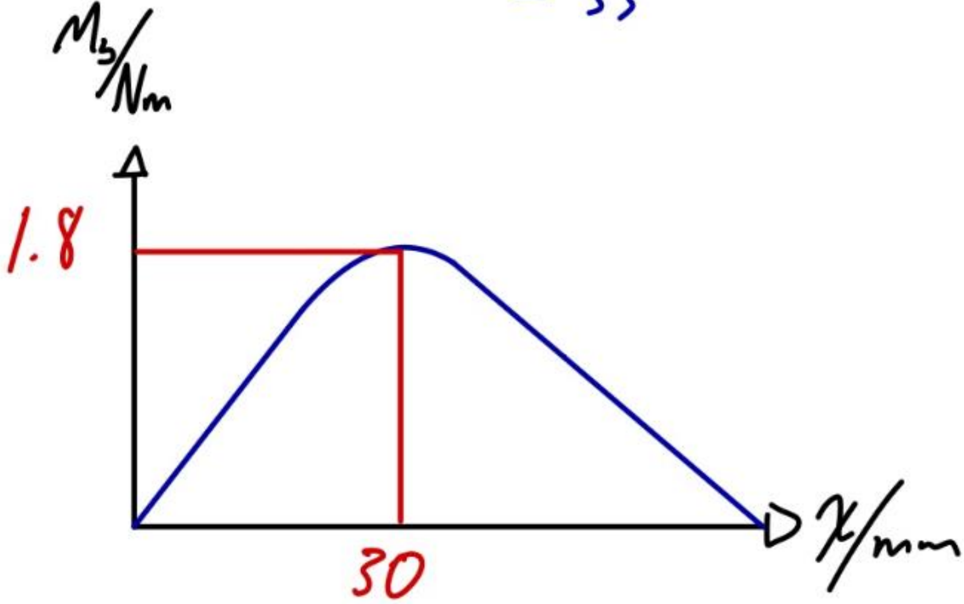
Once again there are no axial forces on this shaft. The torque transmitted in this shaft is six times bigger the torque in the previous shaft. The torque and the radial force from the spur gear are:

$$T = 20.1Nm$$
$$F_R = 112N$$



The resulting shear force and bending moment diagrams are:





The diameter of this shaft is 15mm all along its length. The maximum bending moment is 1.8Nm. The axial stress from bending moment is:

$$\sigma_{ba} = \frac{M_{ba}}{W_b} = 5.45MPa$$

$$\tau_{ta} = \frac{T_a}{W_t} = 30.30MPa$$

The resulting stress tensor is:

$$\begin{bmatrix} 5.45 & 0 & 30.3 \\ 0 & 0 & 0 \\ 30.3 & 0 & 0 \end{bmatrix}$$

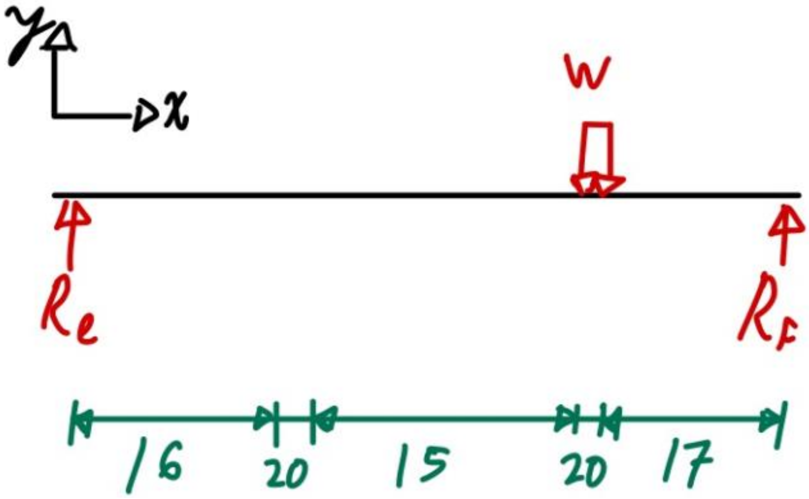
The principal stresses found for this tensor are:

$$\sigma_1 = 33.15\ MPa$$

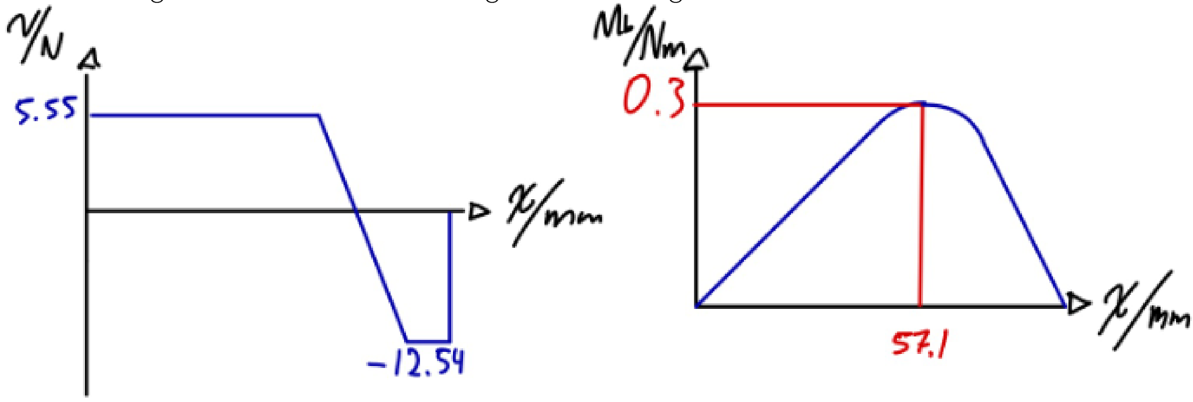
$$\sigma_2 = 0$$

$$\sigma_3 = -27.70\ MPa$$

Before checking the degree of utilization, the effects of a non-zero mean stress must be considered. This shaft is under a permanent radial load from the weight of the shade that rests on it. The mass of this shade is 1.841kg which results in a weight of 18.1 N.



The resulting shear force and bending moment diagrams are:



The maximum bending stress is 0.3Nm. The resulting stress from bending is:

$$\sigma_b = \frac{M_b}{W_b} = 0.9MPa$$

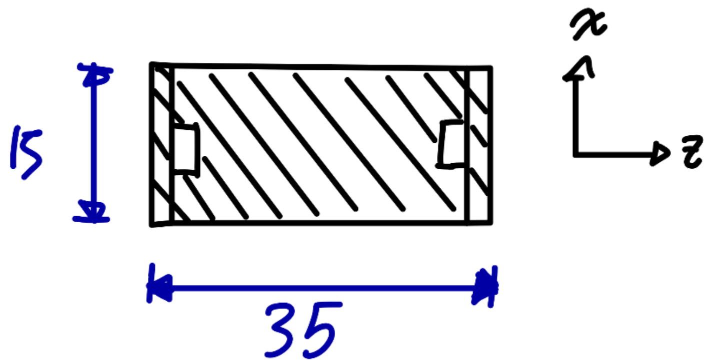
This stress is so small, especially when compared to the magnitude of the principal stresses previously calculated. Therefore, the effects it may have on the fatigue limit of the component will be neglected. The degree of utilization is calculated:

$$\alpha_{BK} = \frac{\sigma_a}{\sigma_{BK}/j_D} = 0.73 \leq 1$$

Once more, this shaft is safe against fatigue.

3.1.4 Vertical Beam – Case 1

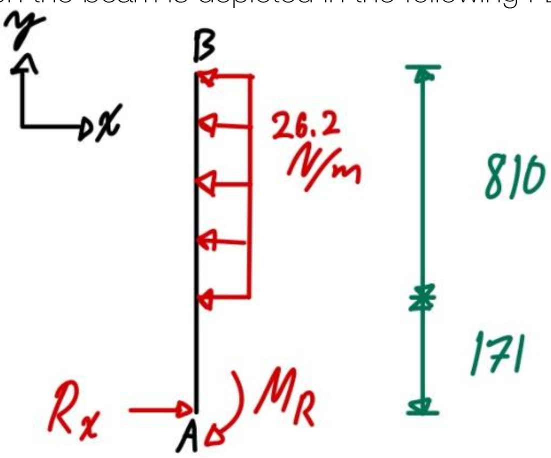
The vertical beam that holds up the shade will be under loads originating from the impact of the wind on the large area of the shade itself. These loads will change as the wind changes. Therefore, they will be idealized as fully reversing alternating loads. The loads created by the wind will depend on what direction the wind impacts against the shade from. An impact from the front or back will result in one type of loading. Impact from the side of the upright shade will result in a negligible load since the projected area of the shade from its sides is minimal. However, if the shade is inclined, the projected area which would be impacted by a sideways wind will be significant, so the loading situation for this event will be considered as its own separate loading case. All of this is discussed in greater detail in the previous "strength assessment" section of this report. The shape and area of the shade has not been changed at all since the strength assessment was performed. Therefore, the loads from the wind under Beaufort 4 conditions will not be calculated once again. They will simply be taken from that earlier section and used to find the magnitude of those alternating loads.
The first case will be that in which the wind strikes on the front of the shade.
The cross-sectional area of the beam is as follows:



The area moment of inertia around z is:

$$\frac{0.015^3 * 0.035}{12} - 2 * \frac{0.005^3 * 0.003}{12} = 9.78 * 10^{-9} m^4$$

The force of the wind on the beam is depicted in the following FBD:



Using the equations of static equilibrium, the reaction force and moment are found to be:

$$R_x = 21.22N$$
$$M_R = 12.22Nm$$

It is clear from the FBD that the largest bending moment magnitude on beam will be at point A, the bottom mounting point. The magnitude of this will be the same as the magnitude of M_R. This bending moment is used to find the amplitude of the variable bending stresses on the beam:

$$\sigma_{b,a} = \frac{M_{b,a} * x_{max}}{I_z} = 9.36\ MPa$$

This is the only variable load on this beam in this case. Because this beam is made out of nylon plastic, and because plastics act differently under variable stresses than ductile metals, the calculations according to the FKM guidelines are not applicable. Instead, the amplitude of the variable stress will be compared directly to the fatigue limit of material. For this comparison:

$$\sigma_{BK} = 36MPa$$

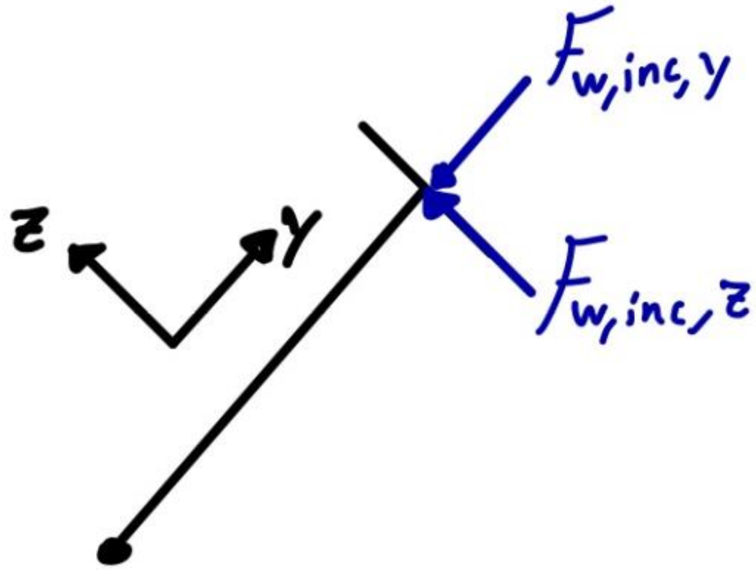
$$\alpha_{BK} = \frac{\sigma_{b,a}}{\sigma_{BK}} = 0.26$$

The beam is safe to fatigue in this loading case.

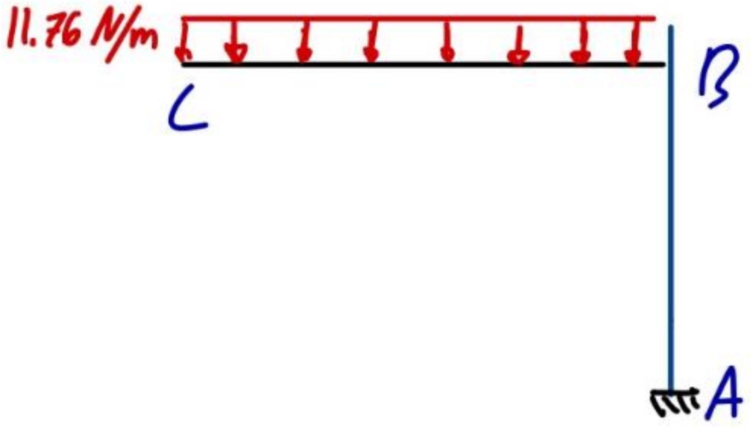
3.1.5 Vertical Beam – Case 2

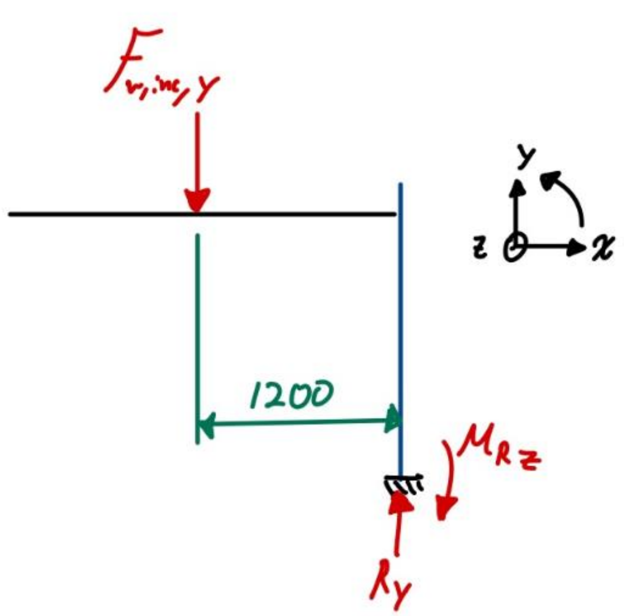
When the shade is tilted, the force produced by the wind can be separated into two components that coincide with a coordinate system mounted on the shade. This will make it easy to evaluate the different types of stresses as they act on the beam. From the strength Assessment the wind forces are obtained as:

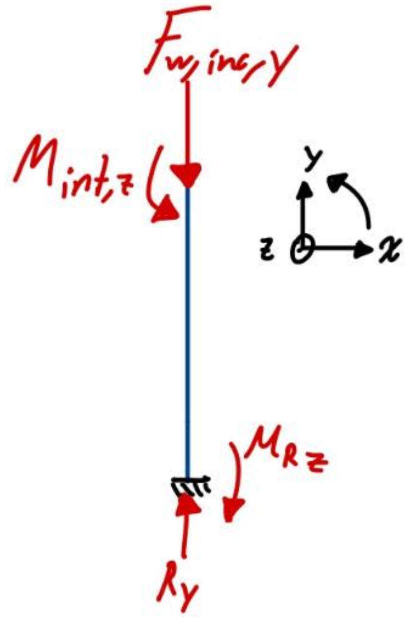
$$|F_{w,inc,y}| = |F_{w,inc,z}| = 28.23N$$



This results in multiaxial stressing on the beam which will be analysed with more than one FBD. The first of this is:



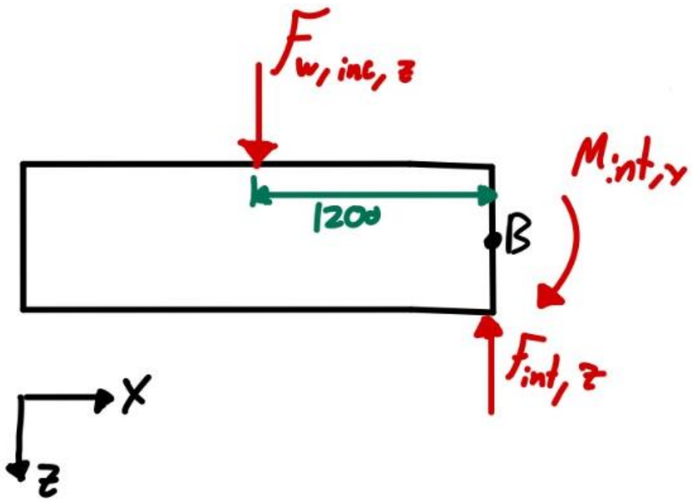




From this perspective, the beam will be under direct compressive force but also under pure bending, since it is bent by couple moments and not shear forces. This also means the bending moment along the whole beam is constant. The value of this is:

$$M_{int,z} = M_{RZ} = 33.876Nm$$

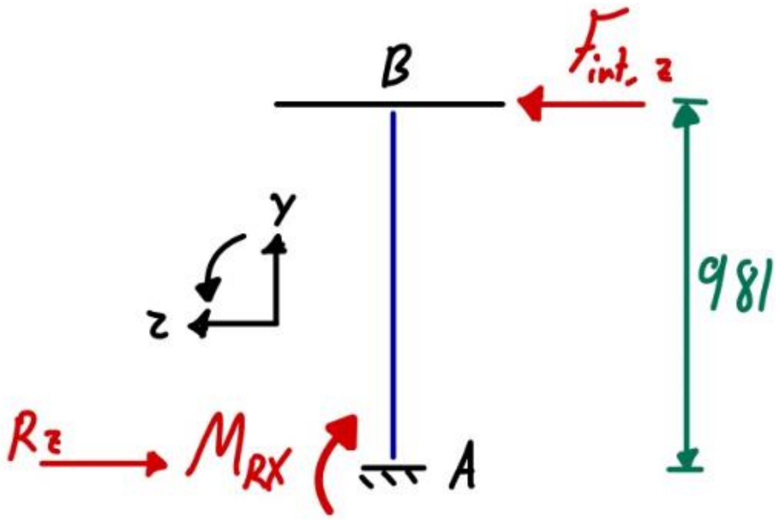
There will also be a sideways force on the shade which will result in a torsion to the beam.



The resulting twisting moment is calculated as:

$$M_{int,z} = 33.876Nm$$

Finally, there will be another bending moment around the x axis from the lateral force:



In this case, the maximum bending moment will occur at the bottom where the beam is held and it will be equal in magnitude to the reaction force.

$$M_{RX} = 27.7Nm$$

The two bending moments result in axial stresses which must be combined. There will also be a torsional shear stress from the twisting moment. After calculating these stresses, they are expressed in the following stress tensor:

$$\begin{bmatrix} 32.3 & 0 & 8.5 \\ 0 & 0 & 0 \\ 8.5 & 0 & 0 \end{bmatrix}$$

The resulting principal stresses are:

$$\sigma_1 = 34.40\ MPa$$
$$\sigma_2 = 0$$
$$\sigma_3 = -2.1\ MPa$$

Once more, because this is plastic, the degree of utilization is calculated simply by comparing the largest of the principal stresses and the fatigue limit of the material:

$$\alpha_{BK} = \frac{\sigma_1}{\sigma_{BK}} = 0.95$$

Since this is less than 1, it could be considered safe. Nonetheless, it is safe by a very small margin, and a revision to the design or the material choice could be a sensible safeguard.

3.2 Pseudo-Code

3.2.1 Overview

Pseudocode is a term used in computer science, which basically describes a series of execution of steps with the assistance of plain language or English text at a semantic level. It is always written such that it is independent of any programming language platform and the basic idea of pseudo code is to describe the processes which a computer follows while executing a program in any programming language. This is the reason that the pseudo code does not have any defined syntax in itself as they are more intended for human reading and comprehension describing the key principles of the algorithm rather than machine reading. But they do follow some of the fundamentals of programming language such as proper indentation of control structures which defines in the way the whole algorithm is structured. These types of codes help one coder to explain his idea to another programmer who can easily understand it and then develop the actual conventional code on any programming platform.

The smart sun shade has a sun tracking system which works on the principle of the light differential produced between two light dependent resistors and a stepper motor. The difference in amount of light produced is checked to see whether the left or the right sensor is receiving more light (outside the calculated tolerances), and accordingly the motor turns the sun shade clockwise or counter clockwise until both the sensors receive the same amount of sunlight i.e.: the light differential becomes zero or the differential is within the desired tolerance limit. Due to the slow motion of the sun, and to save power drainage through the battery by the motor, the sun shade system only moves the motor once in every 10 minutes. The remaining period, the motor remains in shutdown mode. Only when the rest mode period is over, the motor powers up to perform its normal function.

Important points to be considered for the pseudo code:

- The code is explained very well itself with sufficient comments shown in grey.
- The indentation for control structures have been displayed appropriately to let the reader know about the start and end of these structures.
- Additionally, numbering of the codelines as well as writing them down in a landscape mode is intended to enhance the readability of the code itself.
- The variables initialized with an asterisk (*) means that an exact value is not known yet and would be determined during the exact calculations and simulation of the device in real time while the actual code is under development.
- The pseudo code has been made keeping in mind the logic developed in the mechanical and sensor activity diagrams. The code is structured in a way that it follows the UML diagrams with no exact formulas/calculations mentioned as they are supposed to be developed during the actual code development.
- There is a time tracking system which has been used in the following code to check for the rest mode of the system which would help save power from the battery instead of using any delay function keeping in mind that the latter causes a lot of errors and is prone to sudden program crash.
- There is no function which has been deployed to aid the pseudo code because that all depends on the choice of the programmer who develops the code on an actual programming language platform (he/she is the one who decides if a

function is required or not). Additionally, the variable data types defined in the pseudo code may be subject to change (if required) during the actual coding of the sun shade.

- Names of the variables might even change during the actual programming. In this code, intuitive names have been assigned to enhance the comprehensibility of the overall pseudo code.
- Calculations to be done (to calculate the exact number of steps needed to as to compensate the shade in the best precise and accurate manner) during the device simulation keeping in mind the following points:
    a. The angle swept by the sun in 10minutes. The calculations have been already provided in the previous milestone under the electrical circuit diagram section.
    b. The differential between the two sensors.
    c. The shade boundary limits as well as the current shade position.
    d. The tolerance is also defined in real time during simulation as to how much difference in voltages is being produced by the two sensors and accordingly the tolerance limit is defined to make the code as accurate and precise as possible.
    e. The overall gear ratio, angle between the individual gear teeth, total number of teeth would also be considered during the calculations to find an exact formula which would determine how many steps (in which direction and speed) does the motor has to rotate in order to compensate the shade and to keep the sun chair under its cover all times.
    f. The measurement error of the individual electrical component and their error tolerance limits also play a crucial role in calculating the exact formula which as a fact is also to be considered.

3.2.2 Pseudo-Code

```
Control “LeftLDR” by the microcontroller                    ▷These statements basically mean that while designing the actual code, all the
Control “RightLDR” by the microcontroller                     pins connected and controlled by the microcontroller would be defined and
Control “Solenoid” by the microcontroller                     configured
Control “Enable” pin of the motor driver by the microcontroller
Control “step” pin of the motor driver through microcontroller
Control “dir” pin of the motor driver by the microcontroller
int LeftSensorValue ← 0                        ▷ADC value stored from the left sensor
int RightSensorValue ← 0                       ▷ADC value stored from the right sensor
boolean MotorMode ← true                       ▷Basically orders the motor to power up or shut down
int ShadePosition ← 0                          ▷Shade set vertically initially as a reference position (in degrees)
const int minLimit ← *                         ▷Lower boundary limit for shade position. The value is in degrees
const int maxLimit ← *                         ▷Upper boundary limit for shade position. The value is in degrees
long initialTime ← Read time from computer     ▷They are meant for time tracking so that the rest mode can be defined
long presentTime ← 0                            appropriately by reading time from the computer
const int tolerance ← *                        ▷Basically defines the level of accuracy under which the sensors work
const int MotorRotationalSpeed ← *             ▷Defines the speed of rotation of the stepper motor
const int Step ← *                             ▷Defines the no. of steps the motor should rotate in every single revolution of the motor
Solenoid ← Set the solenoid output low         ▷Initially solenoid locks the system for security; to keep shade in position
int dir ← *                                    ▷Defines the direction of rotation of the motor according to the control structure evaluation
```

▷At the device start-up, the solenoid is set to low as well as the motor is turned on in order to be completely sure that the shade remains fixed & locked in its position with the desired amount of holding torque needed from the motor as well as keeping it still mechanically.

```
while true do                                                   ▷Forever Loop; runs as soon as system switched on & powered
LeftSensorValue ← LeftLDR                                       ▷Microcontroller reads & stores ADC value from left sensor
RightSensorValue ← RightLDR                                     ▷ Microcontroller reads & stores ADC value from right sensor
MotorMode ← false
Enable ← MotorMode                                              ▷Motor disabled/shutdown to save power
presentTime ← Read time from computer every iteration           ▷Reading current time to check further for rest mode
    if (presentTime – initialTime < 10 minutes) then            ▷Check for rest mode
        Solenoid ← Set the solenoid output low                  ▷Locks system with solenoid; shade fixed in position
    else
        MotorMode ← true
        Enable ← MotorMode                                      ▷Motor enabled/powered up
Label: A                                                        ▷A label to redirect the code for reiteration according to the need
LeftSensorValue ← LeftLDR                                       ▷Microcontroller reads & stores ADC value from left sensor
RightSensorValue ← RightLDR                                     ▷Microcontroller reads & stores ADC value from right sensor
            if (ShadePosition > minLimit && ShadePosition < maxLimit)   then   ▷Condition to check for physical shade position
                if (LeftSensorValue > (RightSensorValue + tolerance))  then    ▷Condition;Check for difference b/w the photodiode values
                    Solenoid ← Set the solenoid output high     ▷Unlocking system via solenoid
                    Rotate motor clockwise with defined speed and steps   ▷Motor rotation for shade compensation
                    Solenoid ← Set the solenoid output low      ▷Locking the system via solenoid
                    Shade position calculated* and updated to the “ShadePosition” variable
                    Go to Label: A                              ▷To check until the shade has been compensated
                else if (RightSensorValue > (LeftSensorValue + tolerance)) then
                    Solenoid ← Set the solenoid output high     ▷Unlocking system via solenoid
                    Rotate motor counter clockwise with defined speed and steps   ▷Motor rotation for shade compensation
                    Solenoid ← Set the solenoid output low      ▷Locking the system via solenoid
                    Shade position calculated* and updated to the “ShadePosition” variable
                    Go to Label: A                              ▷To check until the shade has been compensated
                else if ((LeftSensorValue – RightSensorValue) <= tolerance or equal to zero) then
                    MotorMode ← false
```

```
48:                 Enable ← MotorMode                                  ▷Motor disabled/shutdown
49:                 Solenoid ← Set the solenoid output low              ▷Locking the system via solenoid
50:             else                                                    ▷For line no. 34
51:             end if                                                  ▷For line no. 34
52:           else                                                      ▷For line no. 33
53:               Solenoid ← Set the solenoid output low                ▷Locking the system via solenoid
54:               MotorMode ← false
55:               Enable ← MotorMode                                    ▷Motor disabled/shutdown
56:          end if                                                     ▷For line no. 33
57: initialTime ← Read time from the computer every iteration of the loop   ▷Initial time updated for the next execution of the loop
58:     end if                                                          ▷For line no. 25
59: end while                                                           ▷For line no. 19
```

3.3 Bill of Materials

3.3.1 Electrical Components: Bill of Materials

Important points to be considered for the electrical components: Bill of Materials.

- Currency conversion rates used in the bill for the products bought from outside Europe (currency rates dated on: 18 June, 2021):

1 EUR = 87.91 INR (Approximated to 88 INR for calculation purposes)
1 USD = 0.84 EUR

- As most of the websites documented the prices of the product inclusive of VAT, considering VAT as 19% for Germany the actual prices of every single component written in the table are without the taxes and ultimately VAT has been included at the end for the whole of the bill.

- The table consists of components which have been bought from the given list of suppliers but there are even components bought from other sources as well. The reason behind is simple because during the design phase of the product in the second milestone, when the electrical components were selected, correspondingly the CAD model was developed following the given dimensions so the requirements have been fixed. The exact components were not found on these websites matching the dimensions so the designers of this project were forced to stick to the other websites for component selection.

- In case there are readability issues regarding the BOM, the excel file has been uploaded on Sciebo for reference.

- The links for each component have been mentioned in the references section.

- Some cells in the BOM have been left empty simply due the reason that the corresponding information was not found on the websites.

Group no.		02				Project	B-Matic Shade SoSe 2021		
Date		6/16/2021				Team members	Singh Anmol, Abdelrazak Ismail Ali Youssef, Cabrera Gerardo, Arbhabirom Ariya		
No.	**Qty.**	**Manufacturer**	**Component**	**Ordering Code (manufacturer)**	**Vendor**	**Ordering Code (vendor)**	**Price per unit €***	**Price €***	**Link**
1	1	Seeed Studio	Microcontroller Arduino UNO	102990189	Mouser	713-102990189	18.83	18.83	https://www.mouser.de/ProductDetail/Seeed-Studio/102990189?qs=W0yvOO0ixfEl8v9TJdk2SA%3D%3D
2	1	NEMA	Stepper Motor	-	Other	SKU: 75439	7.18	7.18	https://robu.in/product/nema17-4-8-kgcm-stepper-motor-with-detachable-72-cm-cable/
3	1	-	Stepper Motor Driver	-	Other	SKU: 6722	1.34	1.34	https://robu.in/product/a4988-driver-stepper-motor-driver/
4	2	LUNA Optoelectronics	LDR Sensor	PDV-P8104	Conrad	1762911-62	0.52	1.04	https://www.conrad.de/de/p/luna-optoelectronics-pdv-p8104-fotowiderstand-ldr-tht-1-st-150-v-max-l-x-b-x-h-4-29-x-5-08-x-2-mm-1762911.html
5	1	-	Solenoid	JF- 0530B-6V	Other	SKU: 001926	3.31	3.31	https://www.tinytronics.nl/shop/en/robotics/accessories/solenoid-push-pull-6v-300ma-jf-0530b
6	5	SparkFun Electronics	Li-ion Rechargeable Battery	PRT - 13813	Other	1568 - 1492 - ND	7.02	35.12	https://www.digikey.com/en/products/detail/sparkfun-electronics/PRT-13813/6605198

7	1	Haihuic	Solar Panel	-	Other	ASIN: B07RWJVPRL Reference: HHC-442799	17.40	17.40	https://www.amazon.de/Haihuic-Solarmodul-Photovoltaik-Polykristalline-Marine-Boot/dp/B07RWJVPRL
8	1	-	Solar Charger	-	Other	ID: 1625268	7.60	7.60	https://www.banggood.com/de/MPPT-Solar-Controller-1A-3_2V-3_7V-3_8V-7_4V-11_1V-14_8V-Lithium-ion-LiFePO4-Titanate-Battery-Charger-Module-SD30CRMA-p-1625268.html?utm_source=googleshopping&utm_medium=cpc_organic&gmcCountry=DE&utm_content=minha&utm_campaign=minha-de-de-pc&currency=EUR&cur_warehouse=CN&createTmp=1&ID=510351&utm_source=googleshopping&utm_medium=cpc_bgs&utm_content=sxxx&utm_campaign=sxxx-ssc-de-all-0623&ad_id=443948616171&gclid=CjwKCAjwq7aGBhADEiwA6uGZp0jw7FTMNI4TpRh3gyXYmH3yRr3Ec5wk0LEp2ePt447kKweMpIw0YxoCLbAQAvD_BwE
9	1	Developer Boards	DC-DC Buck Convertor	ME085	Reichelt	DEBO DCDC DOWN2	2.86	2.86	https://www.reichelt.de/entwicklerboards-spannungsregler-dc-dc-wandler-lm2596-debo-dcdc-down-2-p282579.html?&nbc=1&trstct=lsbght_sldr::282576
10	2	SparkFun Electronics	Mini Breadboard	PRT-12045	Mouser	474-PRT-12045	2.82	5.63	https://www.mouser.de/ProductDetail/SparkFun/PRT-

									12045?qs=WyAARYrbSnbDbZAvnukotA%3D%3D
11	1	Diotec	Diode	1N4001	Conrad	162213-62	0.14	0.14	https://www.conrad.de/de/p/diotec-si-gleichrichterdiode-1n4001-do-204al-50-v-1-a-162213.html
12	1	STMicroelectronics	NPN Transistor	TIP120	Conrad	150872-62	0.56	0.56	https://www.conrad.de/de/p/stmicroelectronics-transistor-bjt-diskret-tip120-to-220ab-anzahl-kanaele-1-npn-darlington-150872.html
13	2	-	Rocker Switch	-	Other	7395K35	3.80	7.60	https://www.mcmaster.com/7395K35/
14	1	Yageo	Resistor 1k ohm	CFR-25JT-52-1K	Reichelt	1/4W 1,0K	0.08	0.08	https://www.reichelt.de/widerstand-kohleschicht-1-0-kohm-0207-250-mw-5--1-4w-1-0k-p1315.html?&trstct=pos_0&nbc=1
15	2	Yageo	Resistor 10k ohm	CFR25J10KH	Conrad	1417697-62	0.06	0.12	https://www.conrad.de/de/p/yageo-cfr-25jt-52-10k-kohleschicht-widerstand-10-k-axial-bedrahtet-0207-0-25-w-5-1-st-1417697.html
16	1 roll (5m)	Geekcreit	Wires: Jumper Cables	-	Other	ID: 959792	5.54	5.54	https://www.banggood.com/de/Geekcreit-5M-1_27mm-20P-Jumper-Cable-DuPont-Wire-Rainbow-Flat-Wire-Support-Wire-Soldered-p-959792.html?utm_source=googleshopping&utm_medium=cpc_organic&gmcCountry=DE&utm_content=minha&utm_campaign=minha-de-de-pc&currency=EUR&cur_warehouse=CN&createTmp=1&utm_source=googleshopping&utm_medium=cpc_bgs&utm_content=frank&utm_campaign=frank-ssc-de-all-

									0408&ad_id=512680164432&gclid=Cj0KCQjw78yFBhCZARIsAOxgSx0jeVsxgiX1zCVNuFn9xaJVTpts-o6FhmmNwVaU8jCY3W7YKE-EoOkaAqP7EALw_wcB
17	1 roll (5m)	AIKELEYISI Store	Wires: Power Transmission	14AWG	Other	-	8.50	8.50	https://de.aliexpress.com/item/4000342576447.html?spm=a2g0o.search0302.0.0.69bbb563xozgcD&algo_pvid=null&algo_expid=null&btsid=0bb0624016223873013977050e8ca9&ws_ab_test=searchweb0_0,searchweb201602_,searchweb201603_
						total price*		122.85	
List of suitable vendors:						value added tax (VAT)		23.34	
shop		**language**	**homepage**			total price inclusive VAT:		146.19	
HSRW		en	https://ee.hsrw.org/						
Mouser		en/de	https://www.mouser.de/						
Reichelt		en/de	https://www.reichelt.de/				*without value added tax (VAT)		
Conrad		en/de	https://www.conrad.biz/						
Other			only when absolutely necessary						

3.3.2 Mechanical Components: Bill of Materials

The mechanical bill of materials has been included as the first part of appendix C of this report. This was decided because the bill of materials is exported directly from solidworks as a PDF file. Likewise, the standalone pdf for this drawing has been uploaded to Sciebo.

3.4 Production Planning

In this section, several terms will be mentioned and calculated such as shift model, process time, necessary machines, overall equipment effectiveness (OEE), and lot-size definition. All of the mentioned terms will be determined based on decided sales volume in the first milestone and make-or-buy decision in the second milestone.

3.4.1 Shift model and available production time

According to German standards, the total workday per year is 255 days. Thus, this number will be considered as the total workday for our company. Furthermore, in this project, one shift model will be used. One shift model means that workers work one shift per day or equivalent to 8 hours per day including lunch break of one hour. This means that there are 7 hours of production time per working-day. In total, we can say that the total working-hour per year is

255 days x 7 hours = 1785 hours per year.

According to the decision in the part 'marketing decision' in the first milestone, we have decided the expected sales volume to be 50,000 products per year. Thus, the total number products that should be produced per day is

50,000 units ÷ 255 days = 197 products per day

Furthermore, with the number of total workdays, shift model and the desired production volume, Takt Time can be calculated:

Takt time = available production time / target production volume

To calculate:

(255 days x 7 hours) / 50,000 units = 0.357 hour per unit
(0.357 hour per unit x 60 seconds) / 1 minutes = 22 minutes per unit

Thus, Takt time is 22 minutes per unit.

3.4.2 Process time

As we have mentioned in the third milestone report, there are 31 components that are decided to be manufactured by our company including both mechanical 'make' parts and semi-finished products. The total process time of all the make-parts will be calculated based on machinery used in each manufacturing step including set-up time which is required when a machine produces components in batch. In order to calculate a total process time for each component, overall equipment effectiveness or so-called OEE for each type of machine will also be considered

Table 3.4.2.1: Manufacturing steps for each ‘make’ part

Part	Machine 1	Machine 2
Accordion Stick	Injection moulding	3-axis milling machine
Auxiliary Bearing Holder	Injection moulding	3-axis milling machine
Bearing Support 1	Injection moulding	3-axis milling machine
Bearing Support 2	Injection moulding	3-axis milling machine
Bearing Support 3	Injection moulding	3-axis milling machine
Bearing Support 4	Injection moulding	3-axis milling machine
Cross Beam	Injection moulding	3-axis milling machine
Front Shade Stick	Injection moulding	3-axis milling machine
Lower Canvas Mount B	Injection moulding	3-axis milling machine
Gear Shell	Injection moulding	3-axis milling machine
Upper Shell	Injection moulding	3-axis milling machine
Short Accordion Stick	Injection moulding	3-axis milling machine

Mobile cross beam	Injection moulding	3-axis milling machine
Sensor Bracket	Injection moulding	4-axis milling machine
Canvas Holder	Injection moulding	CNC lathe
Locking Pin	Injection moulding	-
Sensor Cover	Injection moulding	-
Base Plate	Die casting	3-axis milling machine
Mounting Hub	Die casting	3-axis milling machine
Beam	Profile extrusion	3-axis milling machine
Lower Canvas Mount A	Profile extrusion	3-axis milling machine
Solenoid Bracket	Profile extrusion	3-axis milling machine
Motor Mount	Profile extrusion	3-axis milling machine
Distancing Bushing 1	Profile extrusion	CNC lathe
Distancing Bushing 2	Profile extrusion	CNC lathe
Distancing Bushing 3	Profile extrusion	CNC lathe

Sensor Tube	Profile extrusion	CNC lathe
Lower Shaft	CNC mill turning	-
Upper Shaft	CNC mill turning	-
Middle Shaft	CNC mill turning	-
Wire Cover	Extrusion moulding	4-axis milling machine

In addition, assembly steps and time are also determined. For assembling, electrical and mechanical buy-parts will also be included along with all of the make-parts.

Table 3.4.2.2: Assembly time an. Note: Assembly Station No.3 is the only station that assembles assemblies (Shade, Base).

No.	Assembly Station	Components	Assembly time / [s]	Assembly time / [m]
1.	Shade	Components that are placed higher than the base housing will be assembled in this station including sensor which is an electrical part	1,800	30
2.	Base	The base including the base housing and all of the electrical parts inside will be assembled in this station	1,800	30
3.	Final	-Shade (Assembly) -Base (Assembly) -Packaging	1,200	20

The assembly time is based on YouTube video on part assembling and is adjusted accordingly to the number of components assembled and the difficulty of the process.

As mentioned earlier, the time used in the process of manufacturing the 'make' part will be calculated in this section. In order to do so, there are three variables used in calculating actual time per batch. The variables are OEE, lot size, time per piece. If the calculation is done without considering OEE, the result can easily mislead how the actual time taken and also can lead to wrong assumptions in the number of necessary machines. Thus, the calculation should involve OEE or Overall Equipment Effectiveness which can indicate the general effectiveness of each machine which can be calculated by:

$$\text{OEE} = \text{Availability} \times \text{Performance} \times \text{Quality}$$

However, in this section, the numbers of OEE used in calculation are found in several machine catalogues instead which in the catalogue also provides time per piece used in each machine. Nevertheless, some assumptions are also made. We assume that the setup time for all kinds of CNC machines will be the same. Thus, in the table 4.2.3, the set-up time for CNC milling, CNC mill turning, and CNC lathe are equal. We also assume that similar manufacturing processes will have similar throughput time such as injection moulding and extrusion moulding, CNC lathe and CNC mill turn which CNC lathe might take slightly more time due to having more features. Lastly, for profile extrusion, we assume that all types of plastic will behave in the similar way, thus, we use the speed 0.001kg/s which is the speed for extruding plastic to calculate the time used in the process of profile extrusion.

To finally find the actual time per batch, the formula used in calculation is

$$\text{Actual Time per Batch} = \text{OEE} \times \text{Lot Size} \times \text{Time per Piece}$$

According to the formula above, it can be seen that the setup time is not involved in the calculation. The reason is that the setup time will only be considered if a machine produces each component in batch. If a machine only produces one type of component, then it does not have to change the setup before the component is manufactured.

Table 3.4.2.3: Calculation of the time per batch

Component	Machine	OEE [%]	Lot size [pcs]	Time / piece [s]	Time / batch [s]	Actual Time per batch [s]
Accordion Stick	Injection moulding	88	1970	12	23,640	26,864
	3-axis milling machine	74	1970	30	59,100	79,865
Auxiliary Bearing Holder	Injection moulding	88	197	12	2,364	2,686
	3-axis milling machine	74	197	30	5,910	7,986
Bearing Support 1	Injection moulding	88	197	12	2,364	2,686
	3-axis milling machine	74	197	30	5,910	7,986
Bearing Support 2	Injection moulding	88	197	12	2,364	2,686
	3-axis milling machine	74	197	30	5,910	7,986
Bearing Support 3	Injection moulding	88	197	12	2,364	2,686
	3-axis milling machine	74	197	30	5,910	7,986
Bearing Support 4	Injection moulding	88	197	12	2,364	2,686

Bearing Support 4	3-axis milling machine	74	197	30	5,910	7,986
Cross Beam	Injection moulding	88	197	12	2,364	2,686
	3-axis milling machine	74	197	30	5,910	7,986
Front Shade Stick type 1	Injection moulding	88	394	12	4,728	5,373
	3-axis milling machine	74	394	30	11,820	15,973
Front Shade Stick type 2	Injection moulding	88	394	12	4,728	5,373
	3-axis milling machine	74	394	30	11,820	15,973
Lower Canvas Mount B	Injection moulding	88	197	12	2,364	2,686
	3-axis milling machine	74	197	30	5,910	7,986
Gear Shell	Injection moulding	88	197	12	2,364	2,686
	3-axis milling machine	74	197	30	5,910	7,986
Upper Shell	Injection moulding	88	197	12	2,364	2,686
	3-axis milling machine	74	197	30	5,910	7,986
Short Accordion Stick	Injection moulding	88	394	12	4,728	5,373

Short Accordion Stick	3-axis milling machine	74	394	30	11,820	15,973
Mobile cross beam	Injection moulding	88	197	12	2,364	2,686
	3-axis milling machine	74	197	30	5,910	7,986
Sensor Bracket	Injection moulding	88	197	12	2,364	2,686
	3-axis milling machine	74	197	30	5,910	7,986
Canvas Holder	Injection moulding	88	958	12	11,496	13,064
	3-axis milling machine	74	958	30	28,740	38,838
Locking Pin	Injection moulding	88	197	12	2,364	2,686
Sensor Cover	Injection moulding	88	394	12	4,728	5,373
Base Plate	Die casting	80	197	18	3,546	4,433
	3-axis milling machine	74	197	30	5,910	7,986
Mounting Hub	Die casting	80	197	18	3,546	4,433
	3-axis milling machine	74	197	30	5,910	7,986
Beam	Profile extrusion	65.47	197	485	95,545	145,937

nylon	3-axis milling machine	74	197	30	5,910	7,986
Lower Canvas Mount A nylon	Profile extrusion	65.47	197	7	1,379	2,106
	3-axis milling machine	74	197	30	5,910	7,986
Solenoid Bracket	Profile extrusion	65.47	197	9	1,773	2,708
Solenoid Bracket	3-axis milling machine	74	197	30	5,910	7,986
Motor Mount PPS	Profile extrusion	65.47	197	65	12,805	19,559
	3-axis milling machine	74	197	30	5,910	7,986
Distancing Bushing 1 ABS	Profile extrusion	65.47	197	9	1,773	2,708
	CNC lathe	79.31	197	45	8,865	11,178
Distancing Bushing 2	Profile extrusion	65.47	197	10	1,970	3,009
	CNC lathe	79.31	197	45	8,865	11,178
Distancing Bushing 3	Profile extrusion	65.47	197	9	1,773	2,708
	CNC lathe	79.31	197	45	8,865	11,178

Sensor Tube	Profile extrusion	65.47	197	6	1,182	1,805
	CNC lathe	79.31	197	45	8,865	11,178
Lower Shaft	CNC mill turning	74	197	45	8,865	11,980
Upper Shaft	CNC mill turning	74	197	45	8,865	11,980
Middle Shaft	CNC mill turning	74	197	45	8,865	11,980
Wire Cover	Extrusion moulding	73	394	8	3,152	4,318
	4-axis milling machine	74	394	30	11,820	15,973

3.4.3 Numbers of Necessary Machines and Lot size definition

In order to calculate the necessary amount of each type of machine, the maximum working hour per day has to be considered. As mentioned in section 4.1, the total working hour per day is 7 hours or 420 minutes which is also the maximum working time for each machine. If the time usage for producing a component per day exceeds maximum working hour or 420 minutes, then one of the machines will only be used for producing one component, while the excessive amount will be produced by another machine along with other components. In case that one machine has to produce more than one type of components, then the setup has to be considered in the calculation.

(no. of component x setup time) + total time per batch for all components ≤ 420 minutes

Injection moulding has a set up time of 35 minutes. Thus, for the calculation, additional 35 minutes must be added for each component when produced in batch. The total summation for each machine should be less than or equal 420 minutes.

Table 3.4.3.1: Injection moulding times

Injection Moulding			
Number of Machine	**Components**	**Time / batch [s]**	**Time / batch [m]**
Machine No. 1	Auxiliary Bearing Holder	2,159	45
	Bearing Support 1	2,159	45
	Bearing Support 2	2,159	45
	Bearing Support 3	2,159	45
	Bearing Support 4	2,159	45
Machine No. 2	Cross Beam	2,159	45
	Lower Canvas Mount B	2,159	45
	Gear Shell	2,159	45
	Upper Shell	2,159	45
	Mobile cross beam	2,159	45
Machine No. 3	Front Shade Stick type 1	5,373	90

Machine No.3	Front Shade Stick type 2	5,373	90
	Short Accordion Stick	4,318	90
Machine No. 4	Sensor Bracket	2,159	45
	Locking Pin	2,159	45
	Sensor Cover	4,318	90
Machine No. 5	Accordion Stick	25,200	420
Machine No. 6	Accordion Stick	1680	28
	Canvas Holder	13,064	218

3-axis milling machine has a set up time of 30 minutes. Thus, for the calculation, additional 30 minutes must be added for each component when produced in batch. The total summation for each machine should be less than or equal 420 minutes. For machines that only produce one component, the setup time is not considered.

Table 3.4.3.2: Milling times

3-axis milling machine			
Number of Machine	Components	Time Usage [s]	Time Usage [m]
Machine No. 1	Auxiliary Bearing Holder	10,418	174
	Bearing Support 1	10,418	174
Machine No. 2	Bearing Support 2	10,418	174
	Bearing Support 3	10,418	174
Machine No. 3	Bearing Support 4	10,418	174
	Cross Beam	10,418	174
Machine No. 4	Lower Canvas Mount B	10,418	174
	Gear Shell	10,418	174
Machine No. 5	Upper Shell	10,418	174
	Mobile cross beam	10,418	174
Machine No. 6	Sensor Bracket	10,418	174

Machine No. 6	Base Plate	10,418	174
Machine No. 7	Mounting Hub	10,418	174
	Beam	10,418	174
Machine No. 8	Lower Canvas Mount A	10,418	174
	Solenoid Bracket	10,418	174
Machine No. 9	Motor Mount	10,418	174
	Accordion Stick	6,720	112
Machine No. 10-12	Accordion Stick	25,200 x 3 = 75,600	420 x 3 = 720
Machine No. 13	Front Shade Stick type 1	18,405	307
Machine No. 14	Front Shade Stick type 2	18,405	307
Machine No. 15	Short Accordion Stick	18,405	307
Machine No. 16	Canvas Holder	25,200	420
Machine No. 17	Canvas Holder	16,080	268

Profile Extrusion has a set up time of 150 minutes. Thus, for the calculation, additional 150 minutes must be added for each component when produced in batch. The total summation for each machine should be less than or equal 420 minutes. For machines that only produce one component, the setup time is not considered.

Table 3.4.3.3:

Profile Extrusion			
Number of Machine	Components	Time Usage [s]	Time Usage [m]
Machine No. 1	Lower Canvas Mount A	2,106	36
	Solenoid Bracket	2,708	46
Machine No. 2	Distancing Bushing 1	2,708	46
	Distancing Bushing 2	3,009	51
Machine No. 3	Sensor Tube	1,805	31
	Distancing Bushing 3	2,708	46
Machine No. 4-9	Beam	145,937	420 x 5 + 333
Machine No. 10	Motor Mount	19,559	326

CNC Lathe has a set up time of 30 minutes. Thus, for the calculation, additional 30 minutes must be added for each component when produced in batch. The total summation for each machine should be less than or equal 420 minutes.

Table 3.4.3.4: CNC lathe times

CNC Lathe			
Number of Machine	Components	Time Usage [s]	Time Usage [m]
Machine No. 1	Distancing Bushing 1	11,178	187
	Distancing Bushing 2	10,380	173
Machine No. 2	Distancing Bushing 3	11,178	187
	Sensor Tube	10,380	173
Machine No. 3	Distancing Bushing 2	840	14
	Sensor Tube	840	14

CNC mill turning machine has a set up time of 30 minutes. Thus, for the calculation, additional 30 minutes must be added for each component when produced in batch. The total summation for each machine should be less than or equal 420 minutes.

Table 4.3.5: CNC milling times

CNC Mill turning			
Number of Machine	**Components**	**Time Usage [s]**	**Time Usage [m]**
Machine No. 1	Lower Shaft	11,980	200
	Upper Shaft	9,600	160
Machine No. 2	Middle Shaft	11,980	200
Number of Machine	**Components**	**Time Usage [s]**	**Time Usage [m]**
	Upper Shaft	2,400	40

Die Casting has a set up time of 6-10 weeks. Thus, every component has its own machine.

Table 3.4.3.6: Die Casting times

Die Casting			
Number of Machine	**Components**	**Time Usage [s]**	**Time Usage [m]**
Machine No. 1	Base Plate	4,433	74
Machine No. 2	Mounting Hub	4,433	160

Wire cover is the only component that uses extrusion moulding.

Table 3.4.3.7: Extrusion moulding times

Extrusion Moulding			
Number of Machine	Components	Time Usage [s]	Time Usage [m]
Machine No. 1	Wire Cover	14,318	72

Wire Cover is the only component that uses a 4-axis milling machine.

Table 3.4.3.8: 4-Axis milling times

4-axis milling machine			
Number of Machine	Components	Time Usage [s]	Time Usage [m]
Machine No. 1	Wire Cover	15,973	267

In conclusion, the number of each machine are as follows:

Machine	Number of machines [pcs]
Injection moulding	6
3-axis milling machine	17
Profile extrusion	10

CNC lathe	3
CNC mill turning	2
Die Casting	2
Extrusion moulding	1
4-axis milling machine	1
Total	42

3.4.4 Number of Employee

In this section, job positions and the number of employees in each position are determined. However, the positions that are mentioned here are the ones that have a direct impact on the product and are considered as a direct cost. The roles that have an indirect impact on the product such as human resource, accountant, etc., are not considered. The table includes necessary job position, quantity, and the reason for the decision made.

Table 3.4.4.1: Employee positions

Position	Qty	Reason
Mechanical Engineer	2	Control mechanical ‘make’ part manufacturing process and in charge mechanical ‘buy’ parts in terms of specification and quality.
Electrical Engineer	1	In charge of electrical ‘buy’ parts in terms of specification and quality.
Machine Operator	42	Operate each machine in the production process. One operator is assigned to work with one machine for setting up and changing workpieces along the entire process.
Assembly workers	40	In order to reach the goal of producing 197 units per day, each station requires a certain number of workers that can finish the assembling step on time within the working hour. Thus, $(197 \times \text{assembly time}) \div \text{no. of worker} \leq 420$ To conclude, assembly station 1 and assembly station 2 required 15 workers each, while assembly station required 10 workers.

3.5 Cost Calculation

In cost calculation, the cost will be classified into two categories which are variable cost and fixed cost. Variable costs are costs that vary depending on the amount of manufactured volume, while fixed costs are always fixed regardless of the amount of manufactured volume. For determining total variable cost, three types of costs will be considered, which are salary, procurement expenditure, and raw material usage. On the other hand, depreciation of machines will be considered for fixed cost.

3.5.1 Salary Calculation

The role and quantity are mentioned in section 3.4.4, while the salary of each role is assumed based on research of the average salary earned by each position in Germany.

Table 3.5.1.1: Labour costs

Position	Qty	**Annual salary / Person (€)**	**Total Annual Salary (€)**	**Salary / piece (€)**
Mechanical Engineer	2	50,000	100,000	2
Electrical Engineer	1	50,000	50,000	1
Machine Operator	42	30,000	1,260,000	25.2
Assembly workers	40	28,000	1,120,000	22.4
Total wage cost / piece				50.6

3.5.2 Procurement Expenditure

The list includes electrical and mechanical 'buy' parts and price from trustworthy suppliers. In case that the sales price is not in Euro currency, the price has been converted according to the currency value on 22nd of June 2021.

Table 3.5.2.1: Procurement costs

Component	Qty	**Price / unit (€)**	Total Price
Microcontroller - Arduino UNO	1	22.4077	22.4077
Stepper Motor	1	8.5442	8.5442
Stepper Motor Driver	1	1.5946	1.5946
LDR Sensor	2	0.6188	1.2376
Push/Pull Solenoid	1	3.9389	3.9389
Lithium-ion Rechargeable Battery	5	8.3538	41.7928
Solar Panel	1	20.706	20.706
Solar Charger	1	9.044	9.044
DC Buck Convertor	1	3.4034	3.4034
Mini Breadboard	2	3.34985	6.6997
Diode	1	0.1666	0.1666
NPN Power Transistor	1	0.6664	0.6664

Rocker Switch	2	4.522	9.044
Resistor 1k	1	0.0952	0.0952
Resistor 10k	2	0.0714	0.1428
Wires: Jumper Cables	25: 4wires 1.5m each and the rest 0.5m each.	6.5926	6.5926
Wires: Power Transmission	1 roll (5m)	10.115	10.115
Aluminium round bar stock	3	7.52	22.56
Black-Finish Steel External Retaining Ring_98541A118	5	0.0749	0.3745
Black-Finish Steel External Retaining Ring_98541A410	2	0.1036	0.2072
Clevis pin	16	0.145	2.32
Cotter Pin_98350A211	16	0.0781	1.2496
Hex Flange Bolt	16	2.26	36.16
Hex Flange Nut	16	3	48
M4 Hex Nut AB	6	0.0454	0.2724
M2 Hex thin Nut AB	4	0.02204	0.08816
Metric Quick-release Pin_95335A512	1	2.8	2.8
Plastic Ball Bearing_6455K118	2	8.18	16.36

Plastic Ball Bearing_6455K137	1	7.75	7.75
Plastic Ball Bearing_6455K138	3	8.18	24.54
Polycarbonate Plastic Washer_90940A117	8	0.195	1.56
Rivet_97525A232	2	1	2
Rivet_97525A246	1	1.143	1.143
Rounded Machine Key_2977N19	2	1.962	3.924
Rounded Machine Key_2977N25	3	2.012	6.036
slotted cheese head screw	4	2.1	8.4
slotted pan head screw	8	0.11	0.88
M4 Socket Head Cap Screw	6	0.17	1.02
Gear PS2-15	2	15.87	31.74
Gear PSA2-90	2	119.1	238.2
Cotter pin_98350A150	1	0.0792	0.0792
Countersunk flathead cross recess screw	16	0.023	0.368
Canvas Sheet	1	0.62	0.62
M3x5 Socket head cap screw	2	351.1	702.2

M6x10 Socket head cap screw	5	0.29	1.45
M3x8 Socket Head Cap Screw	4	1.42	5.68
M5x10 Socket Head Cap Screw	4	0.3225	1.29
Total price per unit			613.9

3.5.3 Raw Materials Usages

The list includes material used in each component and the price from trustworthy suppliers. In case that the sales price is not in Euro currency, the price has been converted according to the currency value on 22nd of June 2021.

Table 3.5.3.1: Raw material costs

Component	Material type	Qty (kg)	**Price (€)**	Usage /unit (kg)	**Price/piece (€)**
Accordion Stick	Nylon 101	0.44	4.57	0.093	0.97
Auxiliary Bearing Holder	Polyphenylene (PPS)	1	2	0.013	0.03
Base Plate	Aluminium 6060 Alloy	1	1.92	2.8	5.38
Beam	Nylon 101	0.44	4.57	0.48	4.99
Bearing Support 1	Acrylonitrile Butadiene Styrene (ABS)	1	0.57	0.135	0.08

Bearing Support 2	Acrylonitrile Butadiene Styrene (ABS)	1	0.57	0.058	0.03
Bearing Support 3	Acrylonitrile Butadiene Styrene (ABS)	1	0.57	0.151	0.09
Bearing Support 4	Acrylonitrile Butadiene Styrene (ABS)	1	0.57	0.159	0.09
Sensor Bracket	Acrylonitrile Butadiene Styrene (ABS)	1	0.57	0.004	0.00
Canvas Holder	Acrylonitrile Butadiene Styrene (ABS)	1	0.57	0.021	0.01
Cross Beam	Nylon 101	0.44	4.57	0.188	1.95
Distancing Bushing 1	Acrylonitrile Butadiene Styrene (ABS)	1	0.57	0.004	0.00
Distancing Bushing 2	Acrylonitrile Butadiene Styrene (ABS)	1	0.57	0.005	0.00
Distancing Bushing 3	Acrylonitrile Butadiene Styrene (ABS)	1	0.57	0.004	0.00

Front Shade Stick	Nylon 101	0.44	4.57	0.035	0.36
Locking Pin	Polyphenylene (PPS)	1	2	0.003	0.01
Lower Canvas Mount A	Nylon 101	0.44	4.57	0.003	0.03
Lower Canvas Mount B	Nylon 101	0.44	4.57	0.002	0.02
Lower Shaft	6060 Alloy	1	1.92	0.07	0.13
Middle Shaft	6060 Alloy	1	1.92	0.11	0.21
Mobile cross beam	Nylon 101	0.44	4.57	0.183	1.90
Motor Mount	Polyphenylene (PPS)	1	2	0.06	0.12
Mounting Hub	6060 Alloy	1	1.92	0.087	0.17
Sensor Cover	Clear Polymethyl Methacrylate (PMMA)	1	0.56	0.001	0.00
Sensor Tube	Nylon 101	0.44	4.57	0.0001	0.00
Short Accordion Stick	Nylon 101	0.44	4.57	0.0003	0.00
Solenoid Bracket	Polyphenylene (PPS)	1	2	0.004	0.01
Upper Shaft	6060 Alloy	1	1.92	0.1	0.19
Upper Shell	Polyphenylene (PPS)	1	2	1.208	2.42
Gear Shell	Acrylonitrile Butadiene Styrene (ABS)	1	0.57	0.624	0.36

Wire Cover	Nylon 101	0.44	4.57	0.042	0.44
Total Raw Material Cost					19.98

3.5.4 Variable Cost

The total variable cost is the summation of salary, procurement expenditure, and raw material usage.

Table 3.5.4.1: Production variable costs

salary calculation (€)	50.6
Procurement Expenditure (€)	613.9
Raw Material Usages (€)	19.98
Variable Cost (€)	684.48

3.5.5 Fixed Cost

In section 3.4.3, the necessary number of each type of machine has been determined. All of the necessary machines are machines that can be used for a long term; thus, total depreciation time is decided to be five years until the value of the machine will be considered as no value.

In order to calculate production over depreciation time, the used formula is as follow:

Production volume over depreciation time = Depreciation Time x Working days in a year x Daily Volume

Production Volume over depreciation time is calculated by using the mentioned formula which working days in a year has been decided in section 3.4.1 and daily volume has been calculated in section 3.4.1.

Table 3.5.5.1: Production Volume over depreciation time

Depreciation Time	5	years
Working days in a year	255	days
Daily Volume	197	pieces
Production Volume over depreciation time	251,175	pieces

Price per piece = Total machine price ÷ Production Volume over depreciation time

Table 3.5.5.2: Total Fixed cost per piece

Machine	Qty	Price / machine	**Total Price (€)**	**Price/pcs (€)**
Injection Moulding	6	46,000	96000	0.38
3-axis milling machine	17	50,000	850000	3.38
Profile extrusion	10	24,000	240000	0.96
CNC lathe	3	50,000	150000	0.60
CNC mill turning	2	50,000	100000	0.40
Die Casting	2	70,000	140000	0.56
Extrusion moulding	1	59,000	59000	0.23
4-axis milling machine	1	50,000	50000	0.20

Total fixed cost (€)	6.71

3.5.6 Total Cost

Total cost per unit = Variable Cost + Fixed Cost

Table 3.5.6.1: Total cost per unit

Variable Cost (€)	684.48
Fixed Cost (€)	6.71
Total Cost per unit (€)	691.19

The total cost per unit is €691.19 which exceeds the determined price of €250 that has been decided in milestone 1. Even though the total cost is outside the range of determined sale price, it is still sensible in a way that the product is originally aimed for upper and upper middle-class people.

In addition, the products will be sold directly to the customer which in this case are other business (B2B) such as hotel, sport clubs, beach resorts etc., thus, the price can be negotiable case by case.

3.6 Technical Drawing

The technical drawing for this device has been included as the second part of appendix C of this report. This was decided due to the different page size used for this drawing. Likewise, the standalone pdf for this drawing has been uploaded to Sciebo and the pack&go zip file.

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5 Appendixes

Appendix A: Notes on updated calculation of required torque

With the now complete CAD model, the final weight of the rotating mass is known. This mass is 2.18Kg. The position of the centre of mass has not changed substantially. This means that the calculations for the required torque must have their weight numbers corrected. Since the equations remain the same, they will not be repeated here. Suffice it to say, the mass is now 2.18 kg, the weight is 21.4N, and the static torque generated by when inclined is now 16.5 Nm. Because of this increase, we decided to change from a 1:3 gear ratio to a 1:36 gear ratio. This was accomplished using two pairs of gears with gear ratios of 1:6 each. Once the torque of 16.5Nm has been reduced through these gears, the final torque required from the motor is of 0.458Nm. This is a very substantial reduction from the prior motor torque specification, but was done considering that a smaller motor not only will weigh less and occupy less space, but will also use up less energy and hence require less batteries and a smaller charging solution (solar panel). This 0.458Nm torque will also be the one endured by the locking pin. Since this is a fraction of the torque it was enduring before, the calculations for it have not been repeated.

Appendix B: Uploaded files on Sciebo Cloud

Folder Name and path on Sciebo: Group2 --> Milestone 3

Names of uploaded files:

1. Mechanical BOM.pdf
2. 2021_project_team_02_drawing.zip
3. Complete Model.pdf
4. BOM Electrical components SunShade.xlsx
5. Group02_Milestone2_SS2021.docx
6. Group02_Milestone2_SS2021.pdf
7. Sun Shade Electrical Circuit Diagram.fzz
8. Sun Shade Circuit Schematic.pdf
9. Sensor Activity UML Diagram.pdf
10. Mechanical Activity UML Diagram.pdf
11. Team-02-Milestone1 Report.pdf
12. Team-02-First Milestone.docx
13. D-FMEA Sun Shade.xlsx
14. Gantt-chart_L.xslx

Appendix C: Mechanical BOM and technical drawing

item	qty.	description	specification	drawing no.	rev.	material
42	4	Socket Head Screw M5X10	EN ISO 4762 M5X10 - 10N			
41	12	Hex Flange Nut	DIN 6923 - M8 -N			
40	2	Socket Head screw M3X5	EN ISO 4762 M3X5 - 5N			
39	5	Socket Head Screw M6X10	EN ISO 4762 M6X10 - 10N			
38	4	Socket Head Screw M3X8	EN ISO 4762 M3X8 - 8N			
37	12	Hex Flange Bolt Long	DIN 6921 - M8X25X25- N			
36	4	Hex Flage Bolt Short	DIN 6921 - M8X16X16- N			
35	1	Distancing Bushing 1		210330-01-035	-00	ABS
34	1	Distancing Bushing 2		210330-01-034	-00	ABS
33	1	Distancing Bushing 3		210330-01-033	-00	ABS
32	1	Mounting Hub		210330-01-032	-00	6060T6 Alloy
31	1	Upper Shaft		210330-01-031	-00	6060T6 Alloy
30	2	Retaining Ring 98541A410	DIN 471 D 14.3			
29	2	Larger Gear	KHK gears code PSA2-90			
28	3	Plastic Bearing 6455K138	ID 12 OD 28 W 8			
27	3	Rounded Key 2977N25	DIN 6885 5X5X20			
26	1	Middle Shaft		210330-01-026	-00	6060T6 Alloy
25	2	Plastic Bearing 6455K118	ID 8 OD 28 W 9		-00	
24	2	Smaller Gear	KHK gears code PS2-15		-00	
23	2	Rounded Key 2977N19	DIN 6885 4X4X20		-00	
22	5	Retaining Ring 98541A118	DIN 471 D 9.6		-00	
21	1	Plastic Bearing 6455K137	ID 10 OD 26 W 8		-00	
20	1	Lower Shaft		210330-01-020	-00	6060T6 Alloy
19	1	Bearing Support 1		210330-01-019	-00	ABS
18	1	Bearing Support 2		210330-01-018	-00	ABS
17	1	Bearing Support 3		210330-01-017	-00	ABS
16	1	Bearing Support 4		210330-01-016	-00	ABS
15	1	Solar Charger Controller				
14	1	Convertor				
13	2	Breadboard				
12	1	Arduino				
11	2	Rocker Switch				
10	5	Battery				
9	1	Locking Pin		210330-01-009	-00	PPS
8	1	Solenoid Bracket				
7	1	Motor Mount				
6	1	Solenoid Bracket		210330-01-006	-00	PPS
5	1	Motor Mount		210330-01-005	-00	PPS
4	1	Auxiliary Bearing Holder		210330-01-004	-00	PPS
3	1	Gear Shell		210330-01-003	-00	ABS
2	1	Upper Shell	flat bar 30x10 x400	210330-01-002	-00	PPS
1	1	Base Plate		210330-01-001	-00	6060T6 Alloy

faculty or department	technical reference	drawn by (last saved by)	drawing date	released by
Technology & Bionics	26244	26244	18/06/2021	

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title, additional title
B-matic Shade

projection method | scale

drawing no. prefix: 26244-ME.5.2015.02
type of document: bill of material
drawing no.: 210330-01
rev.: 00
date of issue: 18/06/2021
sheet: 1 /2

item	qty.	description	specification	drawing no.	rev.	material
73	6	M4 Hex Nut	ISO 4032-M4-W-N			
72	2	Sensor Cover		210330-01-072	-00	PMMA
71	2	Sensor Tube		210330-01-071	-00	Nylon 101
70	1	Sensor Bracket		210330-01-070	-00	ABS
69	2	Light Sensor				
68	6	M4 Socket head cap screw	EN ISO 4762 M4X12-12N			
67	1	Solar Panel				
66	1	Canvas Sheet				
65	1	Front Shade Stick	Right Variant	210330-01-065	-00	Nylon 101
64	1	Front Shade Stick	Left Variant	210330-01-064	-00	Nylon 101
63	8	Slotted Pan head Screw	DIN EN ISO 1580-M3X6-6N			
62	8	Plastic Washer 90940A117	ID 3.3 OD 10 T 0.7			
61	16	Cotter Pin 98350A211	DIN 94 1.6X10			
60	16	Clevis Pin	DIN EN 22341-B-6X14X1.6-St			
59	2	Short Accordion Stick		210330-01-059	-00	Nylon 101
58	10	Accordion Stick		210330-01-058	-00	Nylon 101
57	3	Rivet 97525A246	DIN 7337 diameter 5			
59	1	Quick release pin 95335A512	D 5 L 25			
55	2	Rivet 97525A232				
54	4	M2 Hex Nut				
53	4	Slotted cheesehead screw				
52	1	Lower Canvas Mount B		210330-01-052	-00	Nylon 101
51	1	Canvas Holder	Lower Variant	210330-01-051	-00	ABS
50	1	Lower Canvas Mount A		210330-01-050	-00	Nylon 101
49	3	Canvas Holder	Upper Variant	210330-01-049	-00	ABS
48	1	Mobile Crossbeam		210330-01-048	-00	Nylon 101
47	1	Cross Beam		210330-01-047	-00	Nylon 101
46	16	Countersunk screw	DIN EN ISO 7046-1 M2X5	210330-01-046	-00	
45	2	Wire Cover		210330-01-045	-00	Nylon 101
44	1	Beam		210330-01-044	-00	Nylon 101
43	1	Cotter Pin 98350A150	DIN 94 2X12			

faculty or department	technical reference	drawn by (last saved by)	drawing date	released by
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projection method

scale

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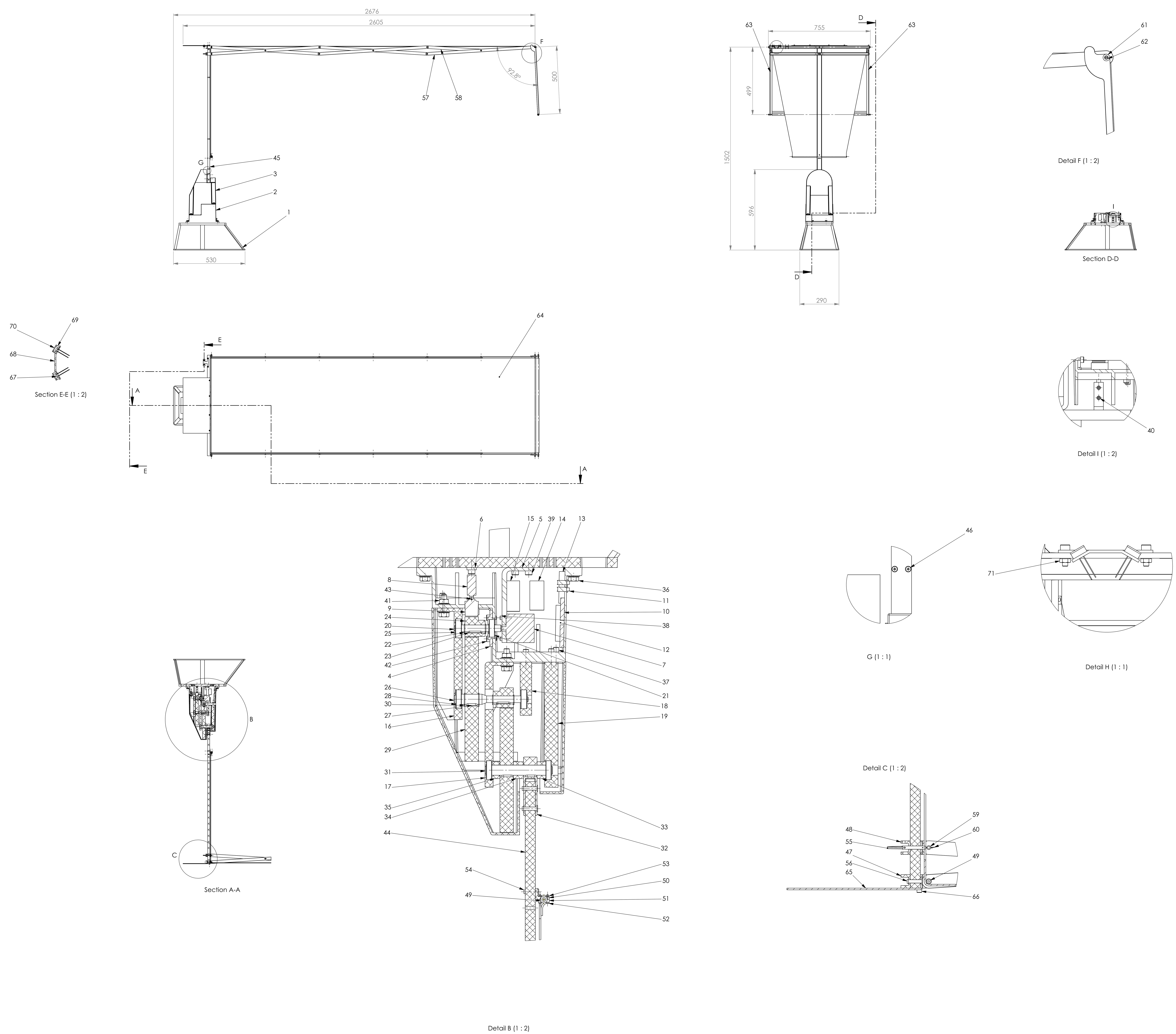
type of document: bill of material

drawing no.	rev.	date of issue	sheet
210330-01	00	18/06/2021	2 /2



Item	qty.	Description	specification	Drawing No.	rev.	Material
73	6	M4 Hex Nut	Hexagon Nut ISO 4032 - M4 - W - N			
72	2	Sensor Cover		210330-01-072	-00	PMMA
71	2	Sensor Tube		210330-01-071	-00	Nylon 101
70	1	Sensor Bracket		210330-01-070	-00	ABS
69	2	Light Sensor				
68	6	M4 socket head cap screw	EN ISO 4762 M4 x 12 - 12N			
67	1	Solar Panel				
66	1	Canvas Sheet				
65	1	Front Shade Stick	Right Variant	210330-01-065	-00	Nylon 101
64	1	Front Shade Stick	Left variant	210330-01-064	-00	Nylon 101
63	8	Slotted Pan head Screw	DIN EN ISO 1580 - M3 x 6 - 6N			
62	8	Plastic washer 90940A117	ID 3.3 OD10 T 0.7			
61	16	Cotter Pin 98350A211	DIN 94 1.6X10			
60	16	Clevis Pin	DIN EN 22341 - B - 6 x 14 x 1.6 - St			
59	2	Short Accordion Stick		210330-01-059	-00	Nylon 101
58	10	Accordion Stick		210330-01-058	-00	Nylon 101
57	3	Rivet 97525A246	DIN 7337 diameter 5			
56	1	Quick release pin 95335A512	D 5 L 25			
55	2	Rivet 97525A232	DIN 7337 diameter 14			
54	4	M2 hex nut	Hexagon Thin Nut ISO 4035 - M2 - N			
53	4	Slotted cheesehead screw	DIN EN ISO 1207 - M2 x 12 - 12N			
52	1	Lower Canvas Mount B		210330-01-052	-00	Nylon 101
51	1	Canvas Holder	Lower Variant	210330-01-051	-00	ABS
50	1	Lower Canvas Mount A		210330-01-050	-00	Nylon 101
49	3	Canvas Holder	Upper Variant	210330-01-049	-00	ABS
48	1	Mobile Crossbeam		210330-01-048	-00	Nylon 101
47	1	Cross Beam		210330-01-047	-00	Nylon 101
46	16	countersunk flat head cross recess screw	DIN EN ISO 7046-1 M2X5			
45	2	Wire Cover		210330-01-045	-00	Nylon 101
44	1	Beam		210330-01-044	-00	Nylon 101
43	1	CotterPin 98350A150	DIN 94 2X12			
42	4	Socket Head Cap Screw M5X10	EN ISO 4762 M5 X 10 - 10N			
41	12	Hex Flange Nut	Hexagon Flange Nut DIN 6923 - M8 - N			
40	2	Socket Head Cap Screw M3X5	EN ISO 4762 M3 x 5 - 5N			
39	5	Socket Head Cap Screw M6X10	EN ISO 4762 M6 x 10 - 10N			
38	4	Socket Head Cap Screw M3X8	EN ISO 4762 M3 x 8 - 8N			
37	12	Hex Flange Bolt long	DIN 6921 - M8 x 25 x 25-N			
36	4	Hex Flange Bolt short	DIN 6921 - M8 x 16 x 16-N			
35	1	Distancing Bushing 1		210330-01-035	-00	ABS
34	1	Distancing Bushing 2		210330-01-034	-00	ABS
33	1	Distancing Bushing 3		210330-01-033	-00	ABS
32	1	Mounting Hub		210330-01-032	-00	6060T6 Aluminium
31	1	Upper Shaft		210330-01-031	-00	6060T6 Aluminium
30	2	Retaining Ring 98541A410	DIN 471 D 14.3			
29	2	Larger Gear	KHK gears code PSA2 - 90			
28	3	Plastic Ball Bearing 6455K138	ID 12 OD 28 W 8			
27	3	Rounded Machine Key 2977N25	DIN 6885 5X5X20			
26	1	Middle Shaft		210330-01-026	-00	6060T6 Aluminium
25	2	Plastic Ball Bearing 6455K118	ID 8 OD 28 W 9			
24	2	Smaller Gear	KHK gears code PS2-15			
23	2	Rounded machine key 2977N19	DIN 6885 4X4X20			
22	5	Retaining ring 98541A118	DIN 471 D 9.6			
21	1	Plastic Bearing 6455K137	ID 10 OD 26 W8			
20	1	Lower Shaft		210330-01-020	-00	6060T6 Aluminium
19	1	Bearing Support 1		210330-01-019	-00	ABS
18	1	Bearing Support 2		210330-01-018	-00	ABS
17	1	Bearing Support 3		210330-01-017	-00	ABS
16	1	Bearing Support 4		210330-01-016	-00	ABS
15	1	Solar Charger Controller				
14	1	Convertor				
13	2	Breadboard				
12	1	Arduino				
11	2	Rocker Switch				
10	5	Battery				
9	1	Locking Pin		210330-01-009	-00	PPS
8	1	Solenoid				
7	1	Motor				
6	1	Solenoid Bracket		210330-01-006	-00	PPS
5	1	Motor Mount		210330-01-005	-00	PPS
4	1	Auxilary Bearing Holder		210330-01-004	-00	PPS
3	1	Gear Shell		210330-01-003	-00	ABS
2	1	Upper Shell		210330-01-002	-00	PPS
1	1	Base Plate		210330-01-001	-00	6060T6 Aluminium

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Document type	Document status
Assembly Drawing	Finished

Title, Additional title	Drawing number
B-matic Shade	26244-ME.5.2015.02 210330-01

Material	Weight	Scale	Creation date	Proj.
	10 kg	1:10	18/06/2021	