SUNO
The Self-Oriented Solar Mirror

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Spring semester 2017

Instituto Superior de Engenharia do Porto

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Report

SUNO - The Self-Oriented Solar Mirror

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Acknowledgement

The team would like to start by thanking the teachers first of all for giving us the opportunity to participate in this project, but also for helping us with it.

Glossary

Table 1: Glossary

Abbreviation	Description
AC	Alternating Current
DC	Direct Current
EMC	Electromagnetic Compatibility
EPS	European Project Semester
EU	European Union
ISEP	Instituto Superior de Engenharia do Porto
LCA	Life Cycle Assessment
LVD	Low Voltage Directive
MDF	Medium Density Fibreboard
NREL	National Renewable Energy Laboratory
PVC	Polyvinyl Chloride
RACI	Responsible, Accountable, Consulted and Informed
RAM	Responsibility Assignment Matrix
ROHS	Restriction of Hazardous Substances in Electrical and Electronic Equipment
SA	Société Anonyme/Sociedad Anónima
SMART	Specific, Measurable, Achievable, Realistic and Timed
SOSM	Self-Oriented Solar Mirror
SWOT	Strengths, Weaknesses, Opportunities and Threats
US	United States
USB	Universal Serial Bus
WBS	Work Breakdown Structure

1. Introduction

1.1 Presentation

Within the *European Project Semester* (EPS), the authors are Team 3 (see **Fig.** 1), or better known as Team Tree. The motto of the team is planting a tree, the team plans to “plant a tree”, build a project, and make it grow. Eventually, the team hopes to profit from the fruit, taking the knowledge and experience gained to apply it in the future. The team consists of Margot Gutscoven (Civil Engineering Technology) of Belgium, Jan Latko (Computer Science) of Poland, Raymond Quinn (Electrical Power Engineering) of Scotland, José Hugo Valiente Saltos (Mechanical Engineering) of Spain and Anna Simons (Industrial Management) of Finland as detailed in **Table** 2 . The team will draw on this diverse range of knowledge and experience to try and deliver a successful project. The aim of this report is to provide information on the all of the different challenges and considerations related to the project and to show how the team has tackled these issues.

Figure 1: Team photo

Table 2: Team Members

Name	**Country**	**Specialization**
Anna Simons	Finland	Industrial Management
Jan Latko	Poland	Computer Science
José Hugo Valiente Saltos	Spain	Mechanical Engineering
Margot Guscoven	Belgium	Civil Engineering Technology
Raymond Quinn	Scotland	Electrical Power Engineering

1.2 Motivation

The solar mirror is a simple way to harness solar energy and to transform it into energy that can be used daily. Raw materials are overused and new sources of energy are needed. This is why the team were drawn to the solar mirror project, this way the team can contribute to a better and greener Earth. People are thinking more and more in an environmental way and it is necessary as engineers to facilitate this.

The team hope the EPS program will help them to become better engineers and give them experience of working in a multidisciplinary international team. The team hopes to develop English skills but also learn something about different fields of engineering. The members can apply their own knowledge but also learn from the others. It will also be possible to learn about different cultures, how to interact with people who are from different parts of Europe and see how they differ, but also see the similarities.

1.3 Problem

The goal of this project is to develop a *Self-Oriented Solar Mirror* (SOSM). The purpose of the mirror has not been defined. The mirror must track the movement of the Sun and reflect the sunlight onto a predefined area. Without knowing the purpose, it is difficult to know the target market and how to go about the project. The creation of the sun tracking system will be one of the main challenges for the team.

1.4 Objectives

The SOSM has to detect the Sun by itself with the aid of sensors or with software that knows the path of the Sun. The team can contribute to a greener planet through the development of this product. Another objective is to cooperate well in a team and learn to work in a multicultural environment.

1.5 Requirements

This project is part of the EPS at *Instituto Superior de Engenharia do Porto* (ISEP) 2017. The EPS is a program that brings students together from all over Europe. The program was designed for engineering students, but others can participate as well. The students are divided into small groups of 5 students preferably from different countries and with different fields of study. Every group has to choose a different project to work on during the semester. The students must attend support classes on ethics, sustainability, marketing and engineering. The students are supported by an EPS-team that consists of teachers from various fields. There are certain requirements that the project should fulfil.

These requirements are:

- Use low cost hardware solutions.
- Use open source software.
- Adopt the international system of units (NIST).
- Comply with the 2006/42/CE 2006-05-17; 2004/108/EC 2004-12-15, 2014/35/EU 2016-04-20, 2014/53/EU 2014-04-16 and ROHS EU Directives.
- Stay under the budget of 100.00 €.

1.6 Functional Tests

In order to evaluate the project, certain functional tests have to be done. This way the product can be improved where necessary. Some functional tests may be:

- Test if the solar mirror tracks the Sun correctly.
- Test if the sunlight is reflected at the correct angle.
- Test if the materials used can withstand heat.
- Test if the area that needs to be heated/illuminated, is heated/illuminated.

1.7 Project Planning

Table 3 contains the different tasks to perform, as well as the person responsible for it.

Table 3: Task identification and allocation

Task	Responsible
Initial Planning	
Task Identification and Allocation	Margot
Gant Chartt	José
Technical Research	Jan
Market Research	Anna
Initial Budget Planning	Raymond
Purpose Definition	All
Specific Planning	
System Diagrams	Jan and Raymond
Structural Drafts	José
Design	José
List of Materials and Budget Re-planning	Raymond
Interim	
Project Management	Anna
Eco-efficiencey Measures for Sustainability	José
Ethical and Deontological Concerns	Jan
Upload Interim Report and Presentation	Anna and Margot
Interim presentation	Anna and Margot
Upload Refined Interim Report	Anna and Margot
Complete List of Materials	Raymond
Construction	
Construction Hardware	José and Raymond
Construction Software	Jan
Testing	
Product Testing and Corrections	Jan, José and Raymond
Upload Functional Test Results	Jan, José and Raymond
Final	
Upload the Final Report and Presentation	Anna
Upload the Movie, Poster, Manual and Leaflet	Margot
Final Presentation, Individual Discussion and Assessment	Jan, José, Margot and Raymond
Upload the Wiki with all Correction Suggestions	Anna
Hand in a CD with all the Corrected Deliverables	Margot
Hand in one Printed Exemplar of the Corrected Report	Anna
Hand in the Prototype and User Manual to the Client	Margot

1.8 Report Structure

The report is divided into eight chapters, which include different subsections. The different chapters are detailed at **Table** 4.

Table 4: Report structure

Chapter	Task	Description
1	Introduction	Short description of what the project is about, the objectives and requirements
2	State of art	Technological and market research. How the mirror has to be built, which materials are best to use, how software will be used etc.
3	Project management	The task and time allocation. How the tasks are divided and when they must be completed to be able to finish the task in time.
4	Marketing plan	Who is going to buy the product.
5	Eco-efficiency measures for sustainability	What the team have done to make the project eco-efficient and the measures the team have taken to make it sustainable.
6	Ethical and deontological concerns	The ethical concerns regarding the solar mirror.
7	Project development	How the project developed, the problems encountered and how they have been tackled.
8	Conclusions	A brief summation of the main conclusions of the project.

2. State of the Art

2.1 Introduction

In the State of the art, the technologies that are already on the market are going to be discussed, it refers to the highest level of general development, as of a device, technique, or scientific field achieved at a particular time. This is done to get ideas and maybe add them to our product. Especially the different purposes of the solar mirror are going to be discussed. This was done to find first of all, the purpose of these mirror, see where there is a gap in the market and which ideas are not made into reality yet.

A solar mirror is a substrate covert with a reflective coating, this way it can reflect the sunlight to a certain point. The substrate can be flat, but can also have a parabolical form. The goal of the SOSM is to reflect the sunlight and to achieve a significantly higher concentrated reflector factor.

2.2 Solar Mirrors' Purpose

A solar mirror can be used for lots of purposes. Mainly it is used to heat things. The heat can be used directly in homes for warm water, but can also be transformed into electrical energy. Another way to use the solar mirror is to use it for light. You could put the solar mirror in a garden and point it at your window to bring more light into the room. In this chapter, the different purposes of the solar mirror are going to be explained.

2.2.1 Heliostat

2.2.1.1 Purpose

The heliostat is a mirror targeted mainly at small scale or personal use. It can light up rooms, work areas, desks, small gardens etc. depending on the size of the mirror. The mirror would be universal, not task specific, but focused on providing light rather than heat or electrical energy.[1] **Fig.** 2 shows a room before and after reflecting sunlight with a mirror. It shows that such a device could make a room significantly brighter.

Figure 2: Room without and with light from heliostat [2]

2.2.1.2 Technology

- **Sensors**

In this case, the position of the Sun and of the centre of focus is needed. The position of the centre of focus could be either set mechanically with a pointer or input digitally, for this it is necessary two angles and optionally a distance. Some kind of positioning device could also be used as a target for the mirror.

For the position of Sun two approaches could be considered. First is setting a date, time and geographical location and calculating the Sun position from that data. The advantage of this approach is that it does not require any additional sensors. The disadvantage is that it works only with sunlight and does not take into account light reflections, artificial sources of light nor objects that can eclipse the Sun, like trees and buildings.

The second approach needs several light sensors. What makes the case even more complex is that the mirror has to reflect the light in a specific direction rather than just turn itself towards the Sun. One way to achieve this would be not to place a Sun tracking sensor together with the mirror, but move them separately with the mirror position depending on the position of Sun tracker, the mirror's normal should be the bisector of the angle between the Sun tracker and the focus direction. This solution involves much more complicated mechanics, but simplifies electronics and computation and involves components that might be easier to find.

Another way is to build a sensor that would tell exactly where the light is. There are different ways to do this. First of all, several light intensity sensors could be used to approximate where the light intensity is at its strongest. An alternative option is using a box with a hole and detecting where the Sun spot is on the bottom of the box (shown in **Fig.** 3).[3] There might be some sensors that would provide this functionality out of the box, which would be a perfect solution, nevertheless these are not easily available and may be more expensive.

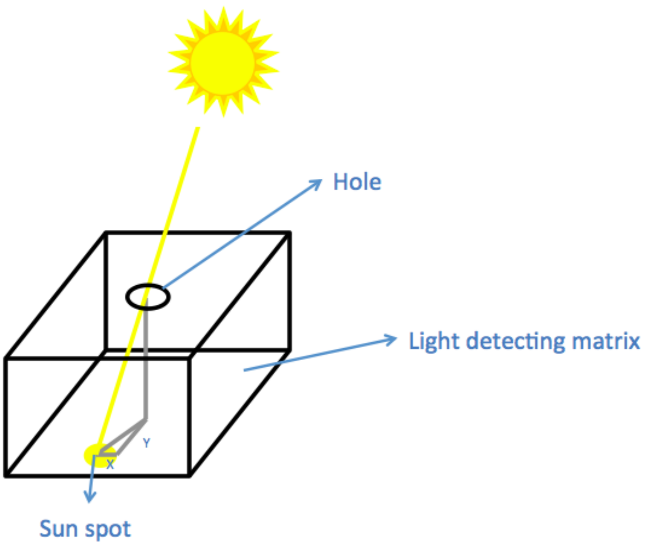

Figure 3: Box with holes

- **Controller:** Unless a movable sensor with some mechanical way of moving a mirror and setting the target is present, the controller is necessary for the angles calculation.
- **Actuators:** The mirror needs to be rotated in two axes, therefore two motors, some construction and most probably some angle monitoring are needed.

2.2.1.3 Budget

An Arduino controller costs about 20.00-25.00 € and some alternatives can be found for 10.00-15.00 €. Simple photocells can be bought for about 1.00 €. Quad photodiodes cost about 5.00-6.00 €. *Direct Current* (DC) motors can be bought from 2.00 € (depending on size). A Display can be found for about 10.00 € or less and a 4-digit display costs 2.00 €. The device's cost depends mostly on the price of light sensors and mechanical components and materials.[4]

2.2.1.4 Market research

Figure 4: Sunflower (heliostat) [5]

Sunflower is a heliostat for home use.[6] It costs 299.00 $, but it is not available for the moment, because it is sold out. Its price could be considered affordable. Other heliostats on the market are larger and significantly more expensive, they cost around 2 000.00 $.[7] There are not so many heliostats easily available on the market, H1 Heliostat[8] that costs 2 200.00 $ is the only one that can be easily found on the internet. That means that with good marketing there is a possibility to replace currently unavailable Sunflower and create an affordable heliostat for home use. Price of the device should therefore be less than 300.00 $ for a small size mirror or more for a larger one.

2.2.2 Cooking Mirror

2.2.2.1 Purpose

A solar cooker could be used for outdoor cooking and possibly grilling. Such a device could also be used to heat something up or keep it warm. As such a function does not exactly need a solar tracking system it might be good to add some functionality such as temperature monitoring or a timer. On the other hand, if the cooking or heating takes a long time, self-control would be a useful feature.

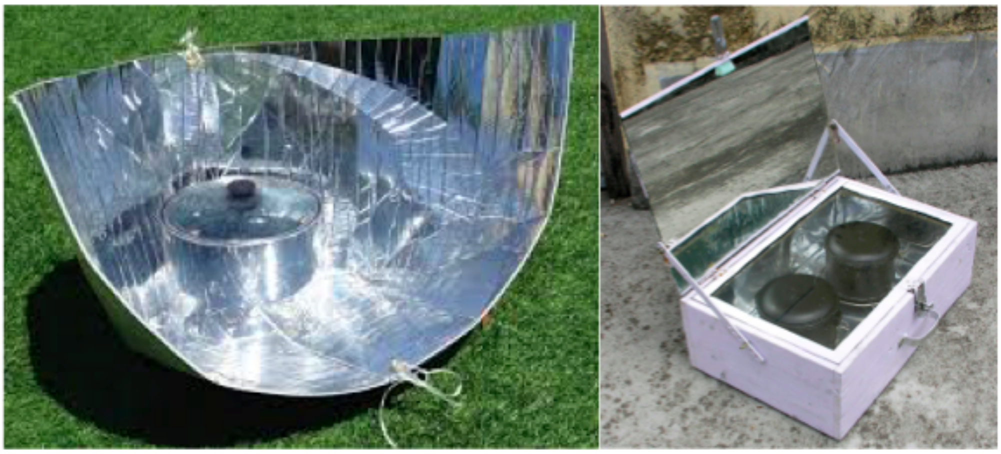

Figure 5: Solar cookers [9][10]

2.2.2.2 Technology

There are three possible shapes of the mirror: panels connected together, parabolic or solar box. Unless it is a solar box oven, it would also need a black pot or pan. A windscreen could also be useful. As it only needs to rotate towards the Sun the control system would not be complicated. A one or two axis construction and a pair of sensors for each axis would be enough. Motors are triggered when there is a difference between the intensity of light received by sensors of a pair. Then the mirror should be rotated towards the brighter Sun. Additional functions might involve a controller and additional sensors for temperature monitoring (a thermometer) and time measuring.[11]

2.2.2.3 Budget

A sensor might be based on 2 to 4 light sensors for 1.00 € or one quad photodiode for 6.00 € and the device needs 1 or 2 motors (depending on the size 2.00-10.00 €). A controller costs around 10.00-25.00 €. Nevertheless, a cooker might involve more expensive materials as it needs to handle high temperatures.

2.2.2.4 Market Research

The solar cooker could be a suitable device for garden parties or barbecues and would suit a recent trend off “being ecologic”. Such a device has to be rather big, so its mobility would be limited. Nevertheless, it could be easily transported with a car. There are several examples of solar cookers and ovens on the market, as you can see in section 2.2.2.1. None of them are self-oriented nor have any additional digital functions. Therefore, there is a possibility to build a device that would be more convenient to use, because of the automation and possibility to add some helper functions. The prices of the existing ones vary from 50 dollars for a rather simple and small version of solar cooker to 300.00-400.00 dollars for bigger and more advanced solar ovens.[12] The first price is low, but the cooker is also very simple, therefore our device could be much more expensive. Its price could even be higher, as it would provide much more functionality.

2.2.3 Agricultural Solar Mirror

2.2.3.1 Purpose

Agricultural solar mirrors are used for growing plants, vegetables, tomatoes and so on. They can also be used to make plants grow larger, longer and more plentiful and better.[13] **Fig.** 6 shows an example of a solar mirror that is placed under a tree. This way the tree leaves that are normally always in the shadow, because there covered by the upper leaves, can last longer. This have been done with and without a rotating disk.[14]

Figure 6: Solar mirror for under tree [15]

Another application of the solar mirror is to dry fruits and vegetables. It is very important to dehydrate fruit and vegetables, this ensures that they can be preserved longer and add value to the products by controlling the moisturising.[16]

2.2.3.2 Market Research

There is a Farm in the South Australian desert where they grow tomatoes by using just sunlight and seawater. They turn seawater and sunlight into energy and water, and use sustainability sourced carbon dioxide and nutrients to maximize the growth. After the seawater arrives at the farm, it is desalinated at an on-site, solar-powered plant that turns it into fresh, plant-ready water by 'scrubbing' the salt out of it. They have a field of mirrors that focus the Sun´s rays onto a fixed tower, where it powers a generator to create electricity. In this case, there is 180 000 tomato plants and 23 000 mirrors, and it cost $200x10^9$ US $ to build. So in this case you can use the mirror to both desalinate the water for the plants and to make the plants grow.[17]

2.2.4 Desalination

2.2.4.1 Purpose

Desalination signifies the removal of salt and other minerals from a substance. These minerals can be bad for human consumption, but also for agricultural purposes it is best to remove them. In dryer countries desalination is particularly relevant. It is a fact that regions where the clean water source is scarce, have plenty of solar radiation. This is why it would be very advantageous to use solar radiation for the desalination of water; Nevertheless, this requires large amounts of energy. Using solar radiation would be a way to produce emission free renewable energy. The solar radiation can be converted into electrical energy and used for the condensation of the water or it can be used directly to condensate water.

2.2.4.2 Technology

There are a lot of methods to remove salts and minerals from water, for more information, you can read the article “Water Desalination” of *Tom Parise* [18]. Most of them involve the evaporation of water and after condensing the vapour back to its liquid state. Commonly vacuum distillation is used, where the pressure is lowered so a lower temperature is needed to evaporate the water.

2.2.4.3 Market Research

The demand for water desalination products increases by 9.30 % per year. The worldwide water distillation industry is worth about $8.6x10^9$ $. Veolia environment S.A., Acciona S.A. and General Electric Co. are some of the key players in the water market with a focus on the distillation industry. They cover Saudi Arabia, the United Arab Emirates and the United States of America [19].

The desalination of seawater is in generally more costly than the desalination water from rivers or ground water. Currently, 1 % of the population depends on the desalination of water. Water is the major necessity of life, a lack of it can affect agriculture and lead to thirst and famine. Nevertheless, this seems like a suitable solution, economically and environmental it has appeared to be not. Although it is beneficial for solving the drought problems, it is recommended to find other solutions to protect the economy and the ocean life.

How would this affect the economy? For example, for the last decade people are suffering from drought in California affection around about 64 000 000 people, due to changes in the rainfall patterns. Because of the drought, agriculture has been seriously affected. Which has led to a weaker economy, as agriculture is the main source of revenue. Desalination could be a solution, nevertheless there are flaws. Building the desalination installation will cost up to $1x10^9$ or $0.9x10^9$ €, which is too high for a community [20].

In this project, a small destination for home use would be produced. The market target will be third world countries, where they do not have clean water coming out of the tap, or just can go the store to buy some. The people who need the water distiller are naturally not capable of buying the distiller themselves, that is why first of all charity organizations are the main target group. Charities such as WaterAid, WellFound, WorldVision, Water.org would be perfect targets for this project (**Fig.** 7) [21].

Figure 7: Possible clients [22]

2.2.5 Water Heating

2.2.5.1 Purpose

One solution could be to use the mirror for water heating. A lot of houses already have a solar water heater on their roof. The mirror could help to heat it even more and gain even more energy to heat the water. A solar water system includes solar collectors and storage tanks. When adding the mirror more solar collectors should be added because the light will come from another point. **Fig.** 6 shown a picture of a solar water heater.

Figure 8: Solar water heater [23]

2.2.5.2 Technology

There are two kinds of solar water heaters, the active kind and the passive kind. The active kind has circulation pumps and controls and the passive kind does not. They both have two possibilities. In the first case normal water can be pumped around, this can only be used in climates where it does not freeze that much, otherwise the water is going to freeze and the system will be blocked. In the second case the pump circulates a non-freezing fluid through the system, this case is more expensive, but certainly necessary in cold climates [24].

The water in the solar collectors is heated and afterwards sent to the storage. The heat can be stored in a tank or in the masonry mass of a radiant slab system. The role of the mirror will be to heat the collectors more than they heat with only the Sun.

2.2.5.3 Market Research

This would be brand new and there would be no competition as currently there are no such products. The challenge here, is to make the water heater as efficient as possible so that people will save more money than they will use in paying for the energy. This also means that the product will have to be sustainable, it has to have a long lifespan, so it will live long enough to make profit out of it.

2.2.6 Solar Energy Production

2.2.6.1 Purpose

The purpose of using solar mirrors in electricity production is to harness the power of the Sun. Most concentrated solar power plants use a vast field of hundreds to thousands of heliostats which reflect the sunlight up to a tower situated in the centre of the field. A heliostat is a mirror which tracks the Sun throughout the day. The mirrors focus the sunlight on one area of the tower and this focused light is many times more intense than regular sunlight (see **Fig.** 9). One plant in California can power over 100 000 homes.

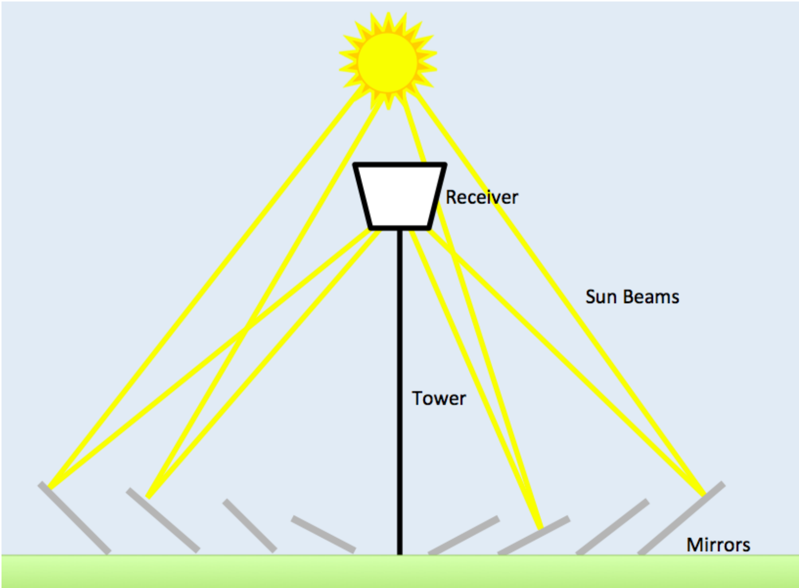

Figure 9: Reflection sun on solar mirror

2.2.6.2 Technology

Some power plants use heliostats with light and heat sensors which can track where the Sun is in the sky in order to be in the optimal position to reflect the sunlight to the desired area. Other plants use a timed system where pre-recorded data about the Sun's position in the sky is used to position the mirrors, however the mirror's position can be adjusted by an engineer from a central control room in order to get as much energy from the Sun as possible.

At the top of the tower are tanks containing oil. This oil is heated by the reflected sunlight and can reach 500 °C and more. This heated oil is used to turn water into steam which drives a steam turbine to produce electricity much in the same way as a conventional power plant using a non renewable fuel source. There are also other methods such as storing the heat energy in molten salt which allows the plant to produce electricity even during hours where the Sun has set meaning the plant is operational 24 hours a day. The energy stored in the salt can drive a turbine for up to 15 hours.

2.2.6.3 Environmental Concerns

There are a great many environmental concerns when it comes to concentrated solar power plants. Wildlife may need to be displaced in order to build the plant. There are also a great many avian deaths every year. When birds fly into the path of the concentrated light they can be burned and killed. Some plants are also not entirely powered by the sunlight. Many require natural gas to be burned each morning to get the plant started up.

2.2.6.4 Budget and Market Research

Such systems for creating electricity from sunlight are very expensive. The Planta Solar 10 in Spain cost 35 000 000 € to build and can power 6 000 homes.[25]. The Ivanpah plant in the Mojave Desert cost 2.20×10^9 $. Building such a system on a small scale does not make sense financially. In terms of competitors there are many – commercial power plants already in operation as well as many more planned developments. It is possible that a smaller scale plant would be viable way to meet the energy needs of a small town in a more environmentally friendly way.

2.3 Conclusion

The advantages and disadvantages of using one of the different purposes for our project are summed up in **Table** 5.

Table 5: Purposes comparison

Purpose	**Advantages**	**Disadvantage**
Heliostat	It will be possible to make it cheaper than the ones that are already on the market	The difficulty is here to reflect the sun always to the same point
Cooking Mirror	It will be possible to make a product that is not on them market yet	The things that need to be cooked, also the things where there need to be cooked in (the pans and pots), are expensive
Agricultural Solar mirror	Easy to build	Difficult to make within budget, there need to be vegetables
		It is not really useful for small-scale projects like this one
		There are already a lot of them on the market
Desalination	It is something new on the market, there are no self-oriented desalination devices	It will be difficult to build the device that desalinate the water
		It is expensive to build the part to desalinate water
Water heating	Easy to build	It will be difficult to build the device that heats the water
		It makes the project more expensive
		There are already a lot of them on the market
Solar energy production	Easy to build	It will be difficult to build the device that conserves the energy
		It makes the project more expensive
		There are already a lot of them on the market

Building a solar cooker or a water distiller would take a lot of time and it would be very challenging technically. Therefore, it has been decided to focus on the mirror itself, not the object heated/lighted up as creating a Sun tracking system is a challenge on its own and there is not either time or budget to focus on the additional features. The mirror will be for home-use. Whether to use it to bring more light to a room or garden or to heat something is the customer's choice. The mirror can be used in several ways. The challenge will be to follow the Sun and reflect the radiation to one point.

3. Project Management

3.1 Introduction

Project management is the application of knowledge, skills, tools and techniques to project activities to meet project requirements. Project management is accomplished through the use of the processes such as: initiating, planning, executing, controlling, and closing.[26] The project team manages the work of the projects, and the work typically involves:

- Competing demands for: scope, time, cost, risk, and quality.
- Stakeholders with differing needs and expectations.
- Identified requirements.

3.2 Scope

Project Scope Management includes the processes required to ensure that the project includes all the work required, and only the work required, to complete the project successfully. Scope's Definition involves subdividing the major project deliverables into smaller components to:[27]

- Improve the accuracy of cost, duration, and resource estimates.
- Define a baseline for performance measurement and control.
- Facilitate clear responsibility assignments.

A precise scope definition determines the success of project. Otherwise, the final project costs may increase, due to the project changes, which involves rework and increase project time. A fundamental tool used for Scope Definition is the *Work breakdown structure* (WBS). A WBS is a deliverable-oriented grouping of project components that organizes and defines the total scope of the project. Its hierarchical form allows an easy identification of the final elements, also called work packages.[28]

For this Self-Oriented Solar Mirror Project, the WBS is shown in **Fig.** 10.

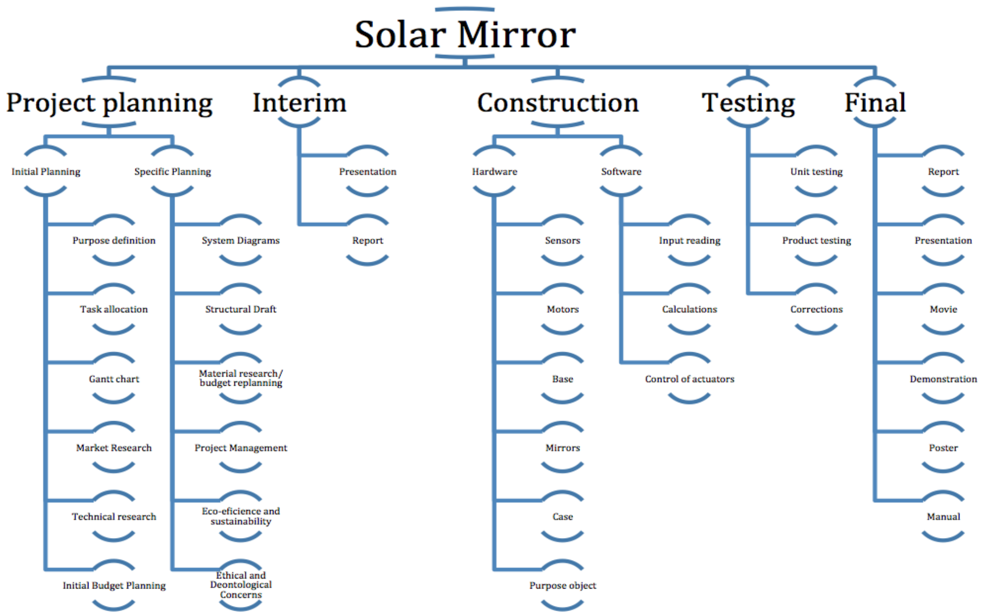

Figure 10: WBS

3.3 Time

Project Time Management include the processes required to ensure timely completion of the project.[29] These processes are described below:

- **Activity definition**: This involves identifying and documenting the differents activities to be carried out. In this way, it will be possible to produce the differents deliverables identified in the WBS.
- **Activity sequencing**: This involves identifying and documenting interactivity logical relationships. The mandatory dependences are the most important; identify which activities are not possible to start unless another ones have finished, and vice versa.
- **Activity duration estimating**: This involves taking information on project scope and resources and then developing durations for input to schedules. At the beginning of the project, this may be a difficult task, unless the customer sets some deadlines for some of the work packages.
- **Schedule development**:This means determining starts and finish dates for projects activities. This is directly related to the activity duration estimating.This means determining starts and finish dates for projects activities. This is directly related to the activity duration estimating.
- **Schedule control**: This involves the detection of changes in the schedule and the management of the same, in order to ensure that changes are agreed with the contractor.

In order to have this information in a simple and effective way, nowadays a tool called Gantt Chart is used. Of all the information that can be obtained, stands out:

- The duration of a given project, and each of the work packages.
- Know exactly the stage in which this one is located.
- Identify possible delays in lead times.
- The existing connections between the different activities.
- The different expected deadlines.

The Gantt Chart of the project described in this report is shown in **Fig.** 11 and **Fig.** 12. As you can see, the duration of the whole project is between 02.03.17 to 29.06.17 .

ID		Task Mode	Name	Duration	Start	Finish	Successors
1			**Self-Oriented Solar mirror**	**86 days**	**Thu 02/03/17**	**Thu 29/06/17**	
2			**Initial planning**	**3 days**	**Thu 02/03/17**	**Mon 06/03/17**	
3			Task identification and allocation	1 day	Thu 02/03/17	Thu 02/03/17	4
4			Gantt Chart	1 day	Fri 03/03/17	Fri 03/03/17	
5			Technical research	3 days	Thu 02/03/17	Mon 06/03/17	
6			Market research	3 days	Thu 02/03/17	Mon 06/03/17	
7			Initial budget planning	3 days	Thu 02/03/17	Mon 06/03/17	
8			Purpose definition	3 days	Thu 02/03/17	Mon 06/03/17	10;11
9			**Specific planning**	**20 days**	**Tue 07/03/17**	**Mon 03/04/17**	
10			System diagrams	5 days	Tue 07/03/17	Mon 13/03/17	12;11SS
11			Structural drafts	5 days	Tue 07/03/17	Mon 13/03/17	12
12			Design	10 days	Tue 14/03/17	Mon 27/03/17	13
13			List of materials and budget replanning	5 days	Tue 28/03/17	Mon 03/04/17	
14			**Interim**	**26 days**	**Tue 28/03/17**	**Tue 02/05/17**	**22**
15			Project management	9 days	Tue 28/03/17	Fri 07/04/17	18FF
16			Eco-effience measures for sustainability	9 days	Tue 28/03/17	Fri 07/04/17	18FF
17			Ethical and deontological concerns	9 days	Tue 28/03/17	Fri 07/04/17	18FF
18			Upload interim report and presentation	9 days	Tue 28/03/17	Fri 07/04/17	19
19			Interim presentation	9 days	Mon 10/04/17	Thu 20/04/17	20;21
20			Upload refined interim report	8 days	Fri 21/04/17	Tue 02/05/17	
21			Complete list of materials	2 days	Fri 21/04/17	Mon 24/04/17	
22			**Construction**	**16 days**	**Wed 03/05/17**	**Wed 24/05/17**	**25**
23			Construction hardware	16 days	Wed 03/05/17	Wed 24/05/17	24SS
24			Construction software	16 days	Wed 03/05/17	Wed 24/05/17	
25			**Testing**	**8 days**	**Thu 25/05/17**	**Mon 05/06/17**	**28**
26			Product testing and corrections	7 days	Thu 25/05/17	Fri 02/06/17	27
27			Upload funcional tests' results	1 day	Mon 05/06/17	Mon 05/06/17	
28			**Final**	**18 days**	**Tue 06/06/17**	**Thu 29/06/17**	
29			Upload the final report and presentation	9 days	Tue 06/06/17	Fri 16/06/17	31;30SS;32;33
30			Upload the movie, poster, manual and leaflet	9 days	Tue 06/06/17	Fri 16/06/17	31;33
31			Final presentation, individual discussion and assesment	4 days	Mon 19/06/17	Thu 22/06/17	33
32			Upload the Wiki with all correction suggestions	5 days	Mon 19/06/17	Fri 23/06/17	34
33			Hand in a CD with the corrected delirevables	1 day	Mon 26/06/17	Mon 26/06/17	
34			Hand in one printed exemplar of the corrected report	1 day	Mon 26/06/17	Mon 26/06/17	
35			Hand in the prototype and user manual to the client	1 day	Thu 29/06/17	Thu 29/06/17	

Figure 11: Gantt Chart

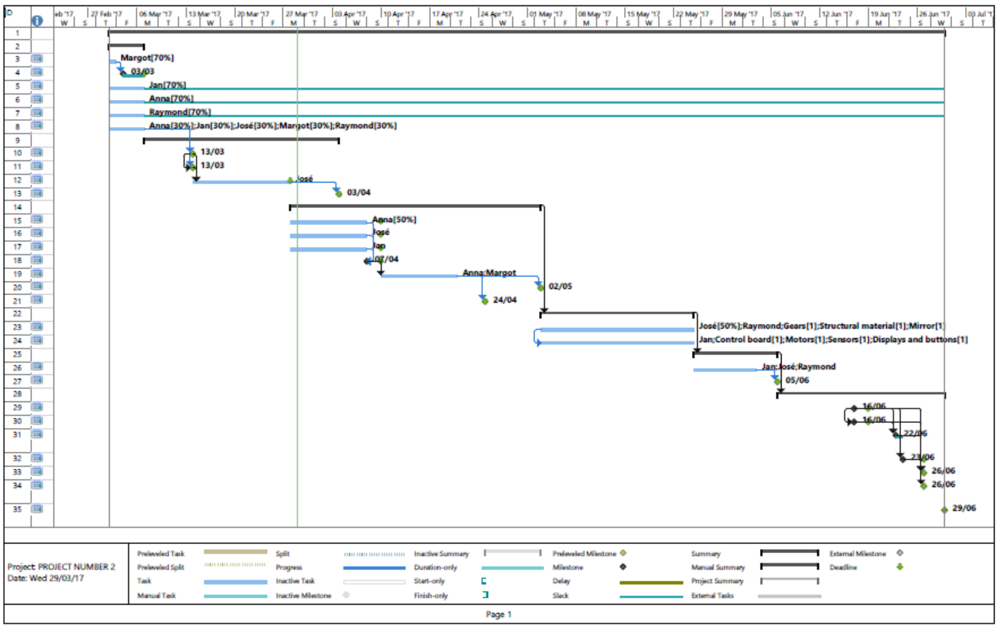

Figure 12: Gantt Chart

3.4 Cost

Project Cost Management includes the processes required to ensure that the project is completed within the approved budget. These processes are described below[30]:

- **Resources planning**: It involves determining what resources are required, and what quantity of each one, to get done all the project activities. There are three main types of resources [31]:
  1. **Human resources**: It is important to determine the different human resources available and the assigned workload for each one. This assignment should be done base on the different work packages, and also the strengths and weaknesses of each of the human resources.
  2. **Capital**: The capital is essential to be able to carry out each of the different phases of the project. The same will be used to cover the salary of the different human resources, to launch the product to the market, and for the different contingencies that may arise on the fly.
  3. **Material goods**: Those assets, whether tangible or intangible, necessary for the achievement of the project.
- **Cost estimating**: Cost estimates are quantitative assessments of the costs for each resource needed to perform the project activities.
- **Cost budgeting**: This involves allocating the overall cost estimates to individual activities or work packages to establish a cost baseline. This cost baseline will be used to measure and control cost performance on the project.
- **Cost control**: The cost control is important to detect the variances of the cost relative the cost baseline. Only then, it is possible to correct or approved changes not included in the same.

Regarding the commented above, **Fig.** 13 shows the different human resources available, as well as the total work hours and the baseline cost of the same ones. Besides, **Fig.** 14 shows the total cost of these resources, as well as the baseline cost. These estimates have been taken assuming a work resource price of 10.00 €/h.

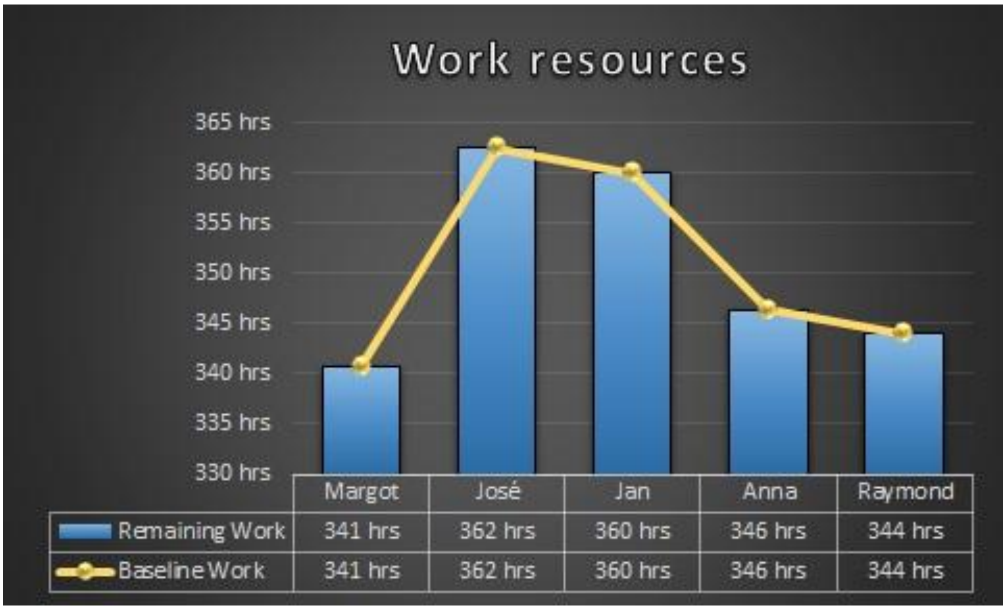

Figure 13: Work resources

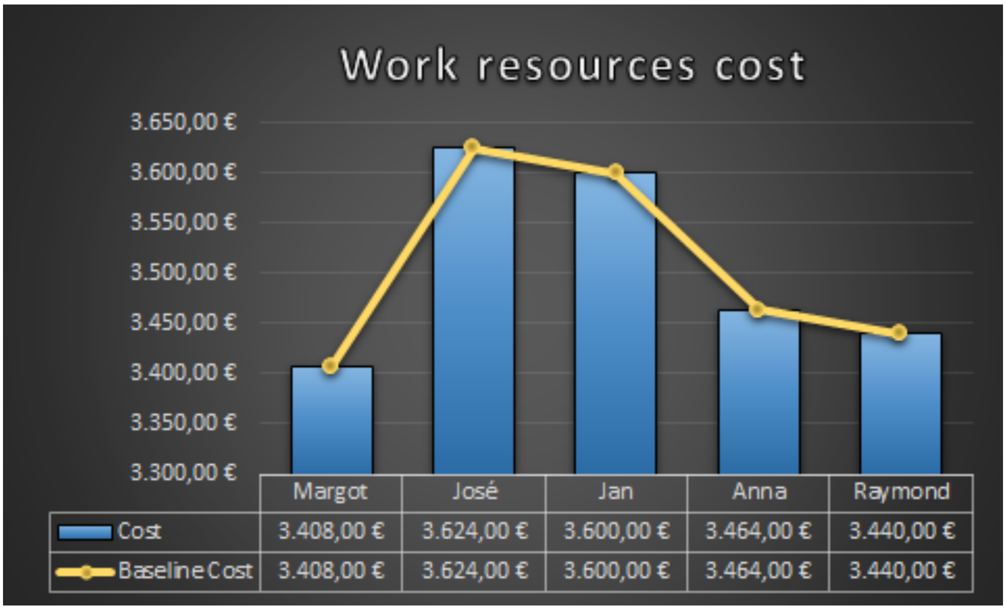

Figure 14: Work resources cost

A first approach, as shown in **Fig.** 15, has been made to the material resources needed for performance of the project, since it is not known yet exactly what and how many of these are to be used. In this way, the cost baseline estimate can be made.

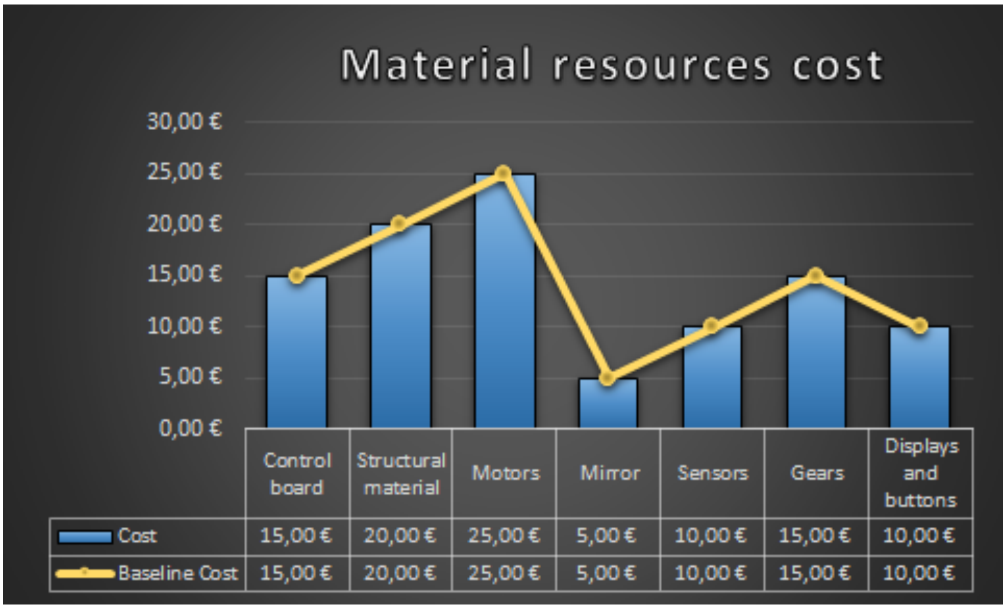

Figure 15: Material resources cost

As mentioned in section 1.5, it is mandatory to stay under the budget of 100.00 €, at least as far as the prototype manufacture is concerned. Nevertheless, looking for the best quality-price relation, the final product may be a bit more expensive.

3.5 Quality

Quality means, at its most basic level, meeting the needs of customers. Project Quality Management includes the processes required to ensure that the project will satisfy the needs for which it was undertaken. There are three key quality management concepts to consider during the project execution [32]:

- **Customer satisfaction**: It is important that the customer feels the product or service meet their needs, as well as does it with the right quality. Otherwise, the customer will be unsatisfied. In order to avoid this inconvenience, is necessary to consider the following two aspects:
    1. **Product quality**: The product must be made of good quality materials, must be pleasing to the eye, and easy to assemble, disassemble and transport.
    2. **Service quality**: Once the product has been sold, the consumer must be provided with all the necessary documentation to start the product. In addition, it will be necessary to provide an efficient after-sales service in case of operating problems.
- **Prevention over inspection**: The Cost of Quality includes money spent during the project to avoid failures, and the money spent after the project because of failures as well. This type of costs are shown in **Fig.** 16.

Cost of Conformance	Cost of Nonconformance
Prevention Costs • Training • Document Processes • Equipment • Time To Do It Right	**Internal Failure Costs** • Rework • Scrap
Appraisal Costs • Testing • Destructive Testing Loss • Inspections	**External Failure Costs** • Liabilities • Warranty Work • Lost Business

Figure 16: Cost of Quality's types [33]

- **Continuous improvement**: Continuous improvement is the ongoing effort to improve the product, in order to deliver the one deemed most convenient.

Those processes required to ensure the meeting of this quality need, are described below[34]:

- **Quality planning**: This involves identifying which quality standards are relevant to the project and how to satisfy them.
- **Quality assurance**: Evaluating overall project performance on a regular basis to provide confidence that the project will satisfy the relevant quality standards.
- **Quality control**: This involves monitoring specific project results to determine if they comply with relevant quality standards, and identifying ways to eliminate causes of unsatisfactory results. For that, the supervisors' reviews and the testing explained section 7.6 are needed.

3.6 Human Resources

Project human resource management includes the processes required to make the most effective use of the people involved with the project. These processes are described below[35]:

- **Organizational planning**: This involves identifying, documenting, and assigning project roles (who does what) and responsibilities (who decides what). In order to assign both, a *Responsibility Assignment Matrix* (RAM) is widely used. The most typically used is called *Responsible, Accountable, Consulted and Informed* (RACI) matrix. The description of each of the roles is as follows:
    1. **Responsible (R)**: Individual(s) who actually complete the task.
    2. **Accountable (A)**: Individual who is ultimately answerable for the activity or decision. Only one "A" can be assigned to an action.
    3. **Consulted (C)**: Individual(s), typically subject matter experts, to be consulted prior to a final decision or action.
    4. **Informed (I)**: Individual(s) who need to be informed after a decision or action is taken.
    5. **Tester (T)**: Individual(s) testing the project, if everything is done right

Table 6 displays the RACI matrix for this project.

Table 6: RACI matrix

Delivery	Anna	Jan	José	Margot	Raymond	Coordinator	Teacher	Supervisors
Gantt Chart			R		A	I	I	I
System diagrams		A	R		A	I	I	C
Structural drafts			R		A	I	I	C
System schematics		R	A			I	I	C
Structural drawings		R	A			I	I	C
Cardboard scale model			A		R	I	I	I
List of materials		A			R	I	I	C
Interim report	A			R		I	I	I
Interim presentation	R			A		I	I	I
Structural building		A	R		R	I	I	C
Software building		R	A		A	I	I	C
Testing and performance	T	R/T	T	T	T	I	I	C
Video		A			R	I	I	I
Paper	R			A		I	I	I
Poster	A			R		I	I	I
Manual	R			A		I	I	I
Leaflet	A			R		I	I	I
Final report	R	A	A	A	A	I	I	I
Final presentation	A	A	A	R	A	I	I	I

- **Acquire project team**: Processes of obtaining the human resources needed for completing the project.

Due to the high number of participants in this project, the ISEP management team was responsible for selecting team members. For this, three factors were considered:

- Nationality.
- The field of specialty.
- The role of each member.

To determine this last one, The test called **Belbin team roles** was performed. This test goal is to bring the right people together, so that the teams are more likely to succeed and achieve their goals.[36] In total, there are nine different team roles, which descriptions is shown in **Fig.** 17.

Team Role	Contribution	Allowable Weaknesses
Plant	Creative, imaginative, free-thinking. Generates ideas and solves difficult problems.	Ignores incidentals. Too preoccupied to communicate effectively.
Resource Investigator	Outgoing, enthusiastic, communicative. Explores opportunities and develops contacts.	Over-optimistic. Loses interest once initial enthusiasm has passed.
Co-ordinator	Mature, confident, identifies talent. Clarifies goals. Delegates effectively.	Can be seen as manipulative. Offloads own share of the work.
Shaper	Challenging, dynamic, thrives on pressure. Has the drive and courage to overcome obstacles.	Prone to provocation. Offends peoples feelings.
Monitor Evaluator	Sober, strategic and discerning. Sees all options and judges accurately.	Lacks drive and ability to inspire others. Can be overly critical.
Teamworker	Co-operative, perceptive and diplomatic. Listens and averts friction.	Indecisive in crunch situations. Avoids confrontation.
Implementer	Practical, reliable, efficient. Turns ideas into actions and organises work that needs to be done.	Somewhat inflexible. Slow to respond to new possibilities.
Completer Finisher	Painstaking, conscientious, anxious. Searches out errors. Polishes and perfects.	Inclined to worry unduly. Reluctant to delegate.
Specialist	Single-minded, self-starting, dedicated. Provides knowledge and skills in rare supply.	Contributes only on a narrow front. Dwells on technicalities.

Figure 17: Belbin team roles description [37]

Table 7 displays the results for each member of this group.

Table 7: Belbin team roles results

Team member	Team role assigned	
Anna	Shaper	Team Worker
Jan	Plant	Team Worker
José	Completer finisher	
Margot	Plant	Team Worker
Raymond	Completer finisher	Team Worker

- **Team development**: This includes both enhancing the ability of stakeholders to contribute as individuals as well as enhancing the ability of the team to function as a team. In order to enhance and promote this team development, different activities are carried out:
  1. **Team-building activities**: During the first two weeks of the project, different team-building activities were done, such as trust games, a mascot's building, etc. They were carried out to promote the members to know each order and gain confidence. For instance, the result of this mascot building activity is shown in **Fig.** 18.

Figure 18: Team 3 mascot

1. **Weekly supervisor's meeting**: Every Thursday, a meeting with the EPS supervisors is scheduled. Thereby, different concerns about project development and teamwork can be consulted.

3.7 Communication

The main objective of communication management is to ensure that the communication between two people or a group goes smoothly [38].

The difficulty in the group is that every team member speaks another native language and everyone was raised in slightly different cultures. Also, the team members did not know each other before the beginning of the project, they have therefore never worked together and so do not know the other's strengths or weaknesses. A third problem or maybe an advantage can be that they have different backgrounds of education, so they might know a lot about some subjects but also some subjects can be totally new for them, when other team members take it for granted.

Taken these flaws and strengths into account, it is important the team members meet at a regularly base. Besides:

- The team members see each other every weekday at school and work at their part of the project.
- If they need help, they can always ask another team member to help them.
- They use a group conversation on WhatsApp to arrange those meetings.
- For bigger discussion, there is also a group made on Facebook to help them.
- The sharing of necessary documents is done through Google Drive, a file storage and synchronization service developed by Google.

If the problem cannot be solved within the group, the team members can always turn to their coordinator, Fernando Ferreira, this can be done by mail. Furthermore, there are also weekly meetings between the team members and all the supervisors of the EPS program. All questions can be asked here and also the project will be evaluated.

The things the team needs to communicate are shown in **Table** 8.

Table 8: Communication matrix

What?	Why?	Who?	When?	To whom?
Deliverables	Achieve the goal of the project	The team members	On the deadlines	The supervisors, teachers and the other team members
Team meetings	Plan how to deliver the deliverables	The team members	Few times a week	The team members

Meeting with coordinator	Get feedback on the project	The team members and the coordinator, Fernando Ferreira	Every two/three weeks	the team members and the coordinator
Meeting with supervisors	Get feedback on the project and discuss our ideas	The team members and the supervisors	Every Thursday morning	The team members and the supervisors

3.8 Risk

Table 9 shows some of the risks to the project's success. The team has discussed each risk and the action to be taken should one of the risks occur. The risks are ranked by assessing the impact on the project as well as the probability of the risk occurring.

Table 9: Project Risk Assessment

Description	Cause	Effect	Trigger	Response	Impact	Probability	Rank
Materials - Late/Unavailable	Supplier/Bureaucracy	Delay in Work Commencing	Information from Supplier/ISEP	Provide List of Materials Early	High	High	1
Design Error	Lack of Knowledge/Human Error	Product may not Work	Noticing the Error	Repair Error/Find Alternative Solution	High	Medium	2
Going Overbudget	Delivery Costs/Unexpected Costs/Poor Budgeting	Being Unable to Purchase all Required Materials/ Justification of Additional Costs	Having Spent a lot of Money	Minimising Costs/Contingency Fund/Presenting Justification for Additional Costs	High	Medium	2
Missing Deadlines	Poor Project Management/Unforeseen Circumstances	Project Failure	Not Having the Work Done Close to the Deadline	Monitoring Deadlines/Setting our own Earlier Deadlines	High	Medium	2
Illness	Bacteria/Virus	Reduction in Working Hours	Beginning to Feel Ill	Living Healthily/Visiting a Doctor	Medium	Medium	3
Lateness	Public Transport/Other	Delay in Work Commencing	Looking at Watch/Travel Updates	Updating the Team	Low	High	4
Resources - Lab Unavailability/Tool Failure	Scheduling/Maintenance	Rescheduling Required	Information from ISEP	Good Organisation/Alternative use of Time	Medium	Low	5

3.9 Procurement

Procurement is the act of obtaining or buying goods or services. It contains also the management of this process, so the preparation and the processing of these goods and services [39].

In this project there is a budget of 100.00 €, the main goal is to stay under it. Regarding the actions that can be carried out for this purpose, are:

- Look at the different suppliers and at their quality-price ratio.
- Try to work as much as possible with the materials that are already at their disposal.
- Communicate with the other EPS teams, see witch materials they need. Often it is cheaper to buy materials in large quantities, if they work together well and chose for the same materials, it could have an effect on the final price.
- To reduce costs there will be mainly looked at the local suppliers; this is done to minimalize the shipping costs.

3.10 Stakeholder Management

Within stakeholders' management, the team members are going to try to analyse, plan and execute the actions to engage with stakeholders [40].

First of all, it is necessary have to identify the stakeholders. Stakeholders are individuals or companies that are interested in this project, they are directly or indirectly involved in this project. Second of all their interests and influences are going to be assessed. Departing from this a communication management plan has to be developed (see section 3.7). At last it is the intention to engage and influence the stakeholders.

Table 10 shown the stakeholders for this project:

Table 10: Stakeholders

Stakeholders	**Role**	**Expectation**	**Power**	**Interest**
Team Members	Execute the project	Develop the project, expand knowledge	High	High
Team Supervisor	Supervise the project	Help succeeding the project	High	High
EPS coordinators	Evaluating project and helping	Help succeeding the project	High	High
Teachers	Expand the team member's knowledge and evaluate project	Help succeeding the project and expanding our knowledge	High	High
Suppliers	Providing materials	Selling materials	High	Low
ISEP	Sponsor	Developing interesting projects	High	Low

3.11 Conclusion

As can be seen, project management not only focuses on time control as long as the project is completed within the established time frame. In addition, it is important to:

- Define accurately the resources, whether human or material, necessary to carry out the project.
- To carry out an exhaustive control of the expenses that derive from the project, in order to avoid concurring in unnecessary expenses.
- Have well defined the quality requirements that the product must meet.
- Identify all those situations that pose a risk to the successful completion of the project.

Taking into account all these aspects, and implementing the tools available for this, it can be ensured that the project can be carried out with the maximum rigor and minimum risks.

4. Marketing Plan

4.1 Introduction

Many organisations are becoming more and more customer-centric. For most marketing teams the experiences of the customers are a priority. The goal of marketing is to improve the performance of an organisation by responding to the needs of these customers or let the customers think they need the things that the organisation is selling. The marketing plan consists of a Market analysis including the micro- and macro-environment; a SWOT analysis; the Strategic objectives including the SMART principal; Market Segmentations; Positioning strategy; Adapted Marketing-mix as an 4P model; a Budget and a Strategy control.

4.2 Market Analysis

Every business organisation is a part of the business environment, within which it operates. No entity can function in isolation because there are many factors that closely or distantly surround the business. It is broadly classified into two categories (see **Fig.** 19:[41]

- **Micro environment**: Affects the working of a particular business only, to which they relate to, It has a direct impact on the business activities.
- **Macro environment**: Affects the functioning of all the business entities, operating in the economy. Is a general business environment, which influences all business groups.

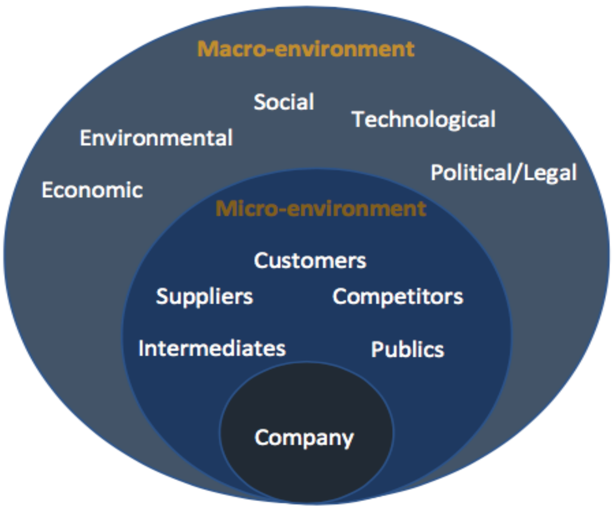

Figure 19: Micro and macro environment

4.2.1 Micro Environment

Micro environment refers to the environment which is in direct contact with the business organization and can affect the business straight away.[42] It is a collection of all the forces that are close to the firm. They can influence the performance and day to day operations of the company, but for a short term only. Its elements include suppliers, competitors, intermediaries, customers and publics. The firm itself is an aggregate of a number of elements like owners, shareholders or investors, employees and the board of directors.

- **Suppliers**: Suppliers are defined as the ones who provide inputs to the business like raw material, equipment and so on. Can control the success of your business when they hold the power. For example if you need some materials and there is only one supplier for the specific material and you need the material to finish your product.[43]

- **Competitors**: Competitors are defined as the rivals, which compete with the firm in the market and resources. The competitors are those who sell the same or similar products and services as your company, and the way they sell their product needs to be taken into account. You have to come up with a new idea so you can get ahead of your competitors.[44]
- **Intermediaries**: Marketing intermediaries may include wholesalers, distributors, and retailers are defined as those that make a link between the firm and the customers.[45]
- **Customers**: Customers / Consumers are defined as the ones who purchase the goods for their own consumption. They are considered as the king of business. The customers depend on if the business relations are Business-to-Business (B2B) or Business to Consumer (B2C) and what their reasons for buying the product are. Depending on the business relation and the reason, you have to change how you approach the marketing of your products and services to them.[46]
- **Publics**: Your Company has a duty to satisfy the public and all your actions must be considered from the angle of the public and how they are affected. The public can either help you reach your goals or prevent you from achieving them.[47]

4.2.2 Macro Environment

The definition of a Macro environment is the environment within the economy that influences the working, performance, decision-making and strategy of all business groups at the same time. It constitutes forces that are not under the control of the company but have a powerful impact on it. The study of Macro environment is known as *Political, Economic, Social, Technological, Legal and Environmental* (PESTLE) Analysis.[48][49]

- **Political/ Legal**: It depends on the stability of the political environment and the attitudes of political parties or movements, government influence on tax policies or involvement in trading agreements. The political factors go hand in hand with the legal factors such as national employment laws, international trade regulations and restrictions, monopolies and mergers´rules, and consumer protection. The difference between these two are that the political factors refers to attitudes and approaches whereas the legal factors are those which have become law and regulations and needs to be complied.[50]

- **Economic factors**: The economic environment can impact both the organisation's production and the consumer's decision-making process. It varies from one country to another and that may include economic growth rates, levels of employment and unemployment, costs of raw materials such as energy, petrol and steel, interest rates and monetary policies, exchange rates and inflation rates.[51][52]

- **Social**: How your product impact the society must be considered, any elements that are harmful to society should be eliminated to show that your company is taking social responsibility. But the social factors also represent the culture of the society, that may include demographics, age distribution, population growth rates, level of education, distribution of wealth and social classes, living conditions and lifestyle.[53][54]

- **Technological factors**: You have to consider skills and knowledge applied to the production and the technology such as new inventions and development, changes in information and mobile technology changes in Internet and e-commerce or even mobile commerce, and government spending on research. The technological environment should also include materials needed for production of products and services, materials development and new methods of manufacture, distribution and logistics.[55][56]

- **Environmental**: Country, age, ethnicity, education level, culture and so on has a huge impact on the environmental issues but also the Earth's renewal of its natural resources and the natural non-renewable resources. It can also include issues such as limited natural resources, waste disposal and recycling procedures.[57][58]

4.3 SWOT Analysis

Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis is an enterprise financial planning tool which attempts to find strengths, weaknesses, opportunities and threats in a strategic review. SWOT analysis maps the external and internal factors relating to the situation being analysed and whether or not the properties are good or harmful (see **Fig.** 20).

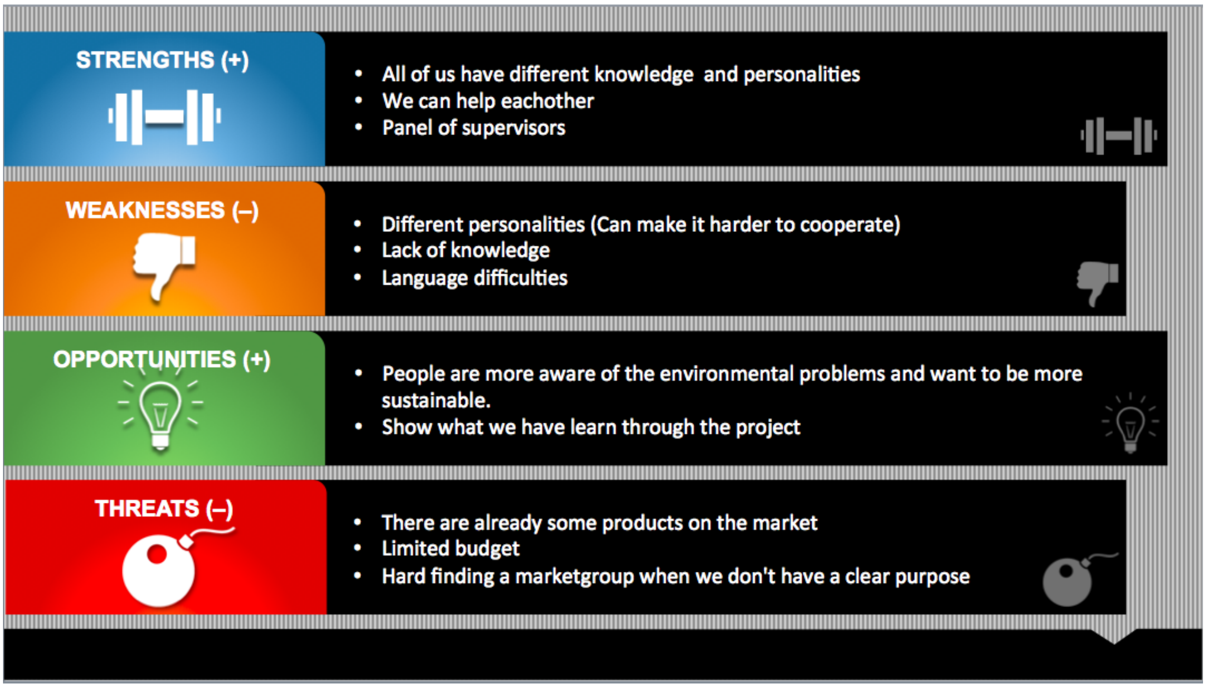

Figure 20: SWOT analysis

4.4 Strategic Objectives

When starting a company, it is first of all very important to know where you want to go, to have a goal. These goals are mostly based on the SMART principal, the goal has to be **S**pecific, **M**easurable, **A**ttainable, **R**elevant and **T**ime based.[59]

For SUNO, next goals could be taken:

- Decrease dispenses over the next 5 years by a certain percentage.
- Develop and use a customer database.
- Find cheaper and more sustainable resources.
- Ameliorate the solar mirror: make it more robust and more effective.
- Introduce the product outside of Europe.

4.5 Segmentation

To get a clear image of the market of this project, the market is going to be divided into segments, these are homogenous groups. There are four market segmentation bases, the geographic, demographic, psychographic and behavioural segment. Each of those segments have to conclude the points that are shown in **Fig.** 21.

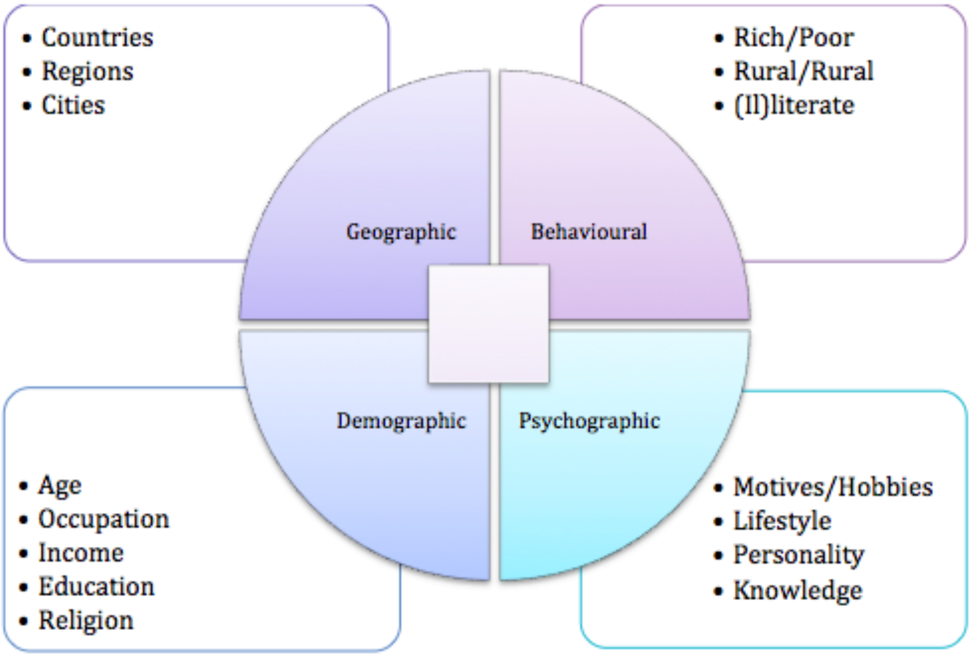

Figure 21: Market Segmentation

- **Geographic Segmentation**: Because SUNO is just starting, the geographic market target will be Portugal. After it grows bigger, SUNO could start expanding first to Spain, then to the rest of Europe and even outside. As it provides more solar energy, there are no countries where SUNO could not expand too. Third world countries could use it easily to cook or heat water, probably charity organisations will be here the main target those countries.
- **Demographic Segmentation**: For the demographic segmentation, the target group will be people who are getting out of their parents' house and they are maybe starting with a family of their own. Also, people who have already their homes for a long time and that are looking for a greener lifestyle or also just searching to save money. People with low income will probably not be able to buy it. The SOSM has as goal to provide more energy for people that already have solar cells, so people with lower income will probably try to lower their energy consumption before buying this product. The market target will have the next characteristics:
  - Age: 30-70.
  - Income: medium to high.
  - Education: higher educated persons.
  - Religion/Nationality: All.
- **Psychographic Segmentation**: For the psychographic segmentation, the main target is people who care about the environment, but also people who want to save money on energy. People with a green or economical lifestyle will be the main target. A higher social class, so people who have had a better education and have higher income, like already said in the demographic segmentation, will be more likely buying this product.
- **Behavioural Segmentation**: As last, there is the behavioural segmentation, how people behaviour will influence buying this product. The SOSM is an expensive device and not much people will buy it out of impulse. They will probably discuss it before buying it with their partner.

4.6 Strategy/Positioning

There are three steps **Fig.** 22 that you have to consider when you are choosing a positioning strategy:[60]

Figure 22: Positioning Strategy

The team have a few different competitors, companies that are making solar mirrors and companies that are making light bulbs. Compared to the competitors on solar mirrors the team is going to focus on making our product cheaper but also on making it for a more general purpose. If the team look at the light-bulb industry the team will focus on that you only have to buy our product once and that it will pay for itself and provide long-term savings on energy.

The team have some options on places where the team can sell the product, one of them is online and there is also where the competitors on the SOSM are selling their product, but it can also been sold in electronic stores or garden stores.

4.7 Adapted Marketing-Mix

In **Fig.** 23 you can see the adapted marketing mix as a 4P model:

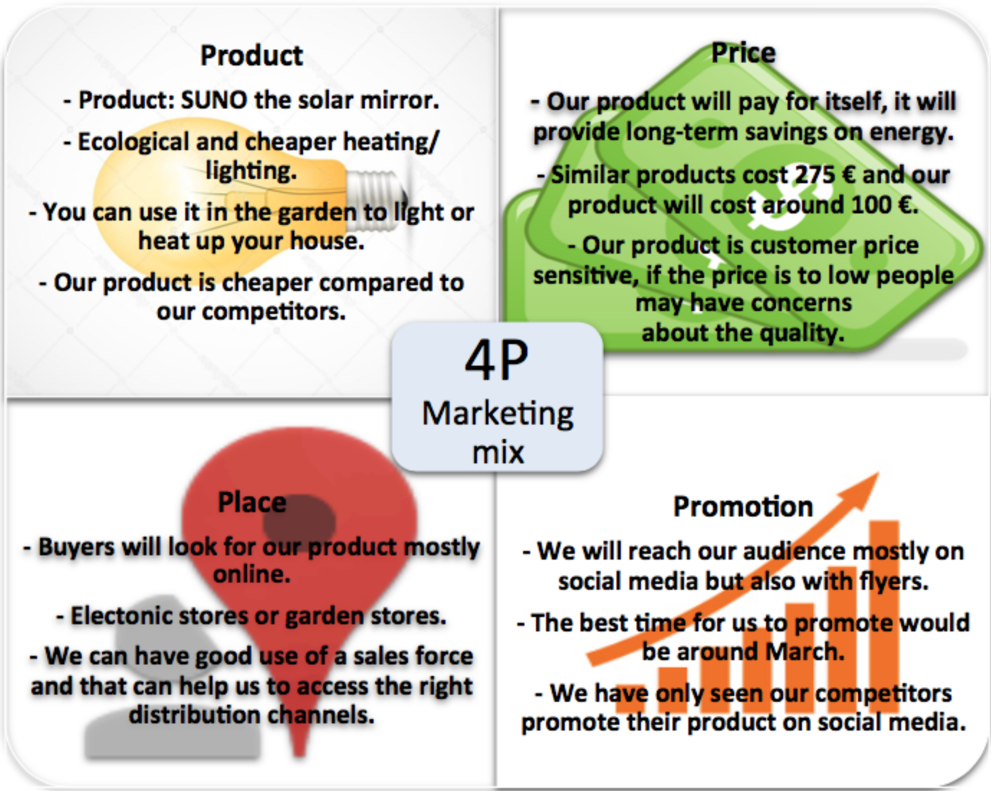

Figure 23: 4P Marketing mix

4.7.1 Product

Figure 24: Logo

The product is a SOSM, and its name is SUNO (**Fig.** 24), which means Sun on Esperanto. The SOSM will help you to get a more ecological and cheaper heating/ lighting so you can save both energy and unnecessary costs. You can use the product in the garden to light up or heat up your house.

There are already some solar mirrors established in the market, nevertheless most of them are very expensive, and the team is going to ensure to make the product cheaper.

4.7.2 Price

Before the team set a price on our product the team need to check prices on existing market and compare them. The team can see that similar products cost around 275.00 €, and this product will cost around 100.00 €, but it is necessary to be careful because the product is very customer price sensitive, if the price is too low people may have concerns about the quality. The product will pay for itself and it will provide long-term savings on energy.

4.7.3 Place

Before the team begin the selling, the team have to think about to whom they want to sell their product, the team have two main options, business to business (B2B) or business to consumer (B2C). If the team decide to sell their product directly to the consumers their main business market will be online, and there is where the costumers will look for their product. But the team can also decide to sell the SOSM directly to a business for example an electronic store or a garden store.

The team can have a good use of a sales force and that can help them to access the right distribution channels.

4.7.4 Promotion

The cheapest way for the team to promote their product is on social media but the team also think that social media is a good way to reach customers at all ages. Another good way to reach customers is by handing out flyers. The team have only seen their competitors promote their product on social media.

The best time for the team to start promoting their product would be around March.

4.8 Budget

It is important to set a budget on the side for marketing. People have to know that our product exists. SUNO has a budget of 5000.00 €, and want to put the most of this in online advertising. SUNO has to have a good website, that appeals to the persons, for this a budget of 1200.00 € is foreseen. The link to this website, SUNO wants to share on Google and Facebook. At social events SUNO wants to hang posters and distribute leaflets to people. The budget allocation is shown in **Table** 11.

Table 11: Budget allocation

Action	Budget
Website	1200.00 €
Advertisements on Google	1000.00 €
Advertisement on Facebook	1000.00 €
Advertising in Newspapers	800.00 €
Poster	500.00 €
Leaflets	500.00 €
Total	5000.00 €

4.9 Strategy Control

When executing a marketing plan, it is important to have a controlling unit. Marketing control is the process of monitoring the marketing plan and adjusting them where necessary. If the marketing plan is being adjusted, an investigation must be done to establish why this difference occurred. To perform a marketing control the steps in **Fig.** 25 have to be taken [61].

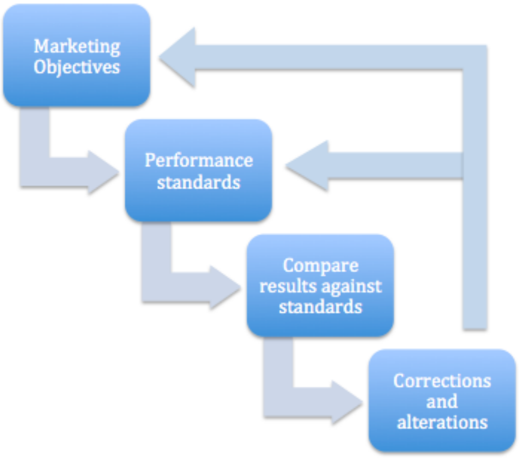

Figure 25: Process marketing control

4.10 Conclusion

The team have now explained the differences between micro and macro marketing and made a SWOT analysis where they set the company strengths, weaknesses, opportunities and threats. The team have set the SMART goals for their product and one of the team goals is to decrease dispenses over the next 5 years by a certain percentage. The team have adapted an marketing mix, 4P model, where they explained the product, price, place and promotion of their company and our team have decided that the smartest way for them to promote their product is on social media.

5. Eco-efficiency Measures for Sustainability

5.1 Introduction

Life on earth will be wiped out eventually, but how long will it take. It is human's task to cherish nature and be economic with all the raw materials the earth provides us, but we have taken it too far. Over the past century global warming has increased by 0.60 °C, and an even bigger increase is predicted.[62]. Interest in "Eco-efficiency measurements and Sustainability" are starting to grow. They will to create a world where we can meet the needs of the present without compromising the ability of the future [63].

There are three main goals in sustainability, called the "Triple P" or the "Triple Bottom-line". The three P's stand for:

- **People**, the social development, this contains the well-being, health, safety, freedom of choice, … of a person.
- **Planet**, the environmental development, the conservation of the world, energy, water, materials, …
- **Profit**, the economic development, this includes prosperity, the gain, affordability and honesty.
- Some add a forth P, **Politics**.

These 3 points are shown in **Fig.** 26.

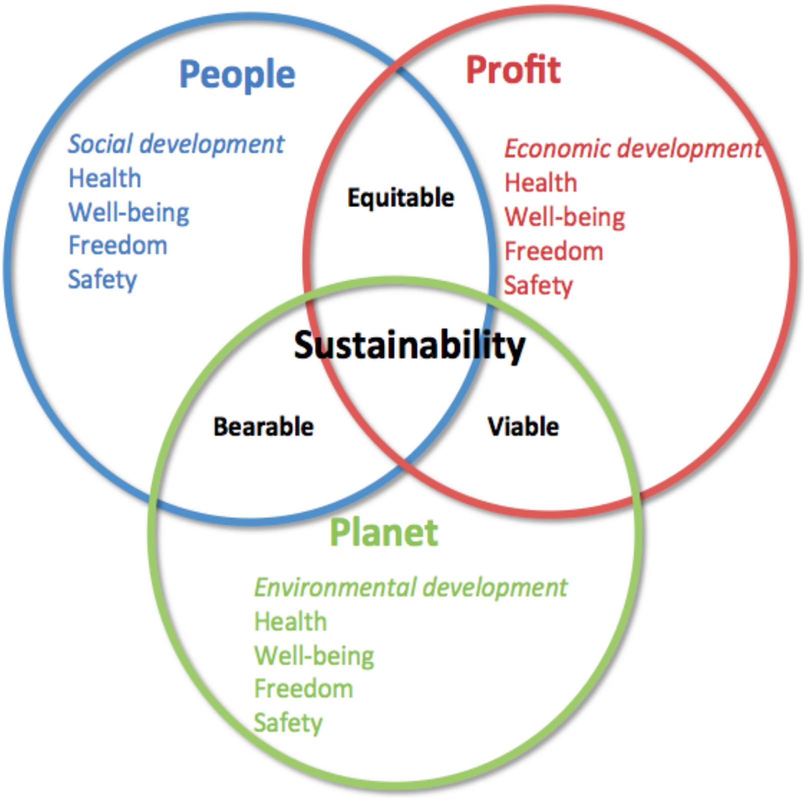

Figure 26: Triple P

5.2 Environmental

The environmental impact is maybe one of the most disputed factors in the society. This is probably one of the main reasons that when people think about sustainability, they immediately think in the environment. The environmental development, mentioned here, contains the right use of materials. The goal is, like already mentioned, to meet the needs of the people without harming the ability of the future. To make a product environmental sustainable, three things have to be done:

- The rate of intake of renewable resources should be lower than the rate of reproduction.
- The rate of pollution should be lower than the assimilative capacity that the environment (the ability of the environment to clean itself).
- The reduction of non-renewable resources requires a comparable development of renewable substitutes.

5.2.1 Choice of Materials

When materials are being chosen, there has to be taken into account the environmental development. Materials have to be renewable at a certain rate; non-renewable resources have to be avoided at all time.

The materials that are going to be use are:

- **Polyvinyl Chloride (PVC)**.
- **Medium Density Fireboard (MDF)**.
- **Steel**.
- **Aluminium**.
- **Pine tree**.

PVC was considered for this project. PVC is a synthetic derived material derived from oil and salt, which are not really good substances for the environment. Actually, people really should stop using oil for everything, our resources are getting extinct. Also, PVC is not really biodegradable, also recycling is not always easy because most of the time additives are added. Besides, a lot of hazardous organochlorine by-products are formed with the production of chlorine gas.[64] Although PVC has disadvantages his ecological footprint is far less than other substances like steel and glass used for the same application. Because PVC is made out of 57% of Chloride, which is derived of salt, of which we have plenty of. In this way, PVC contributes to oil and gas savings, because a lot of materials depend entirely on oil and gas. See the graphics in **Fig.** 27. [65] PVC has also a longer lifespan than most other plastics.

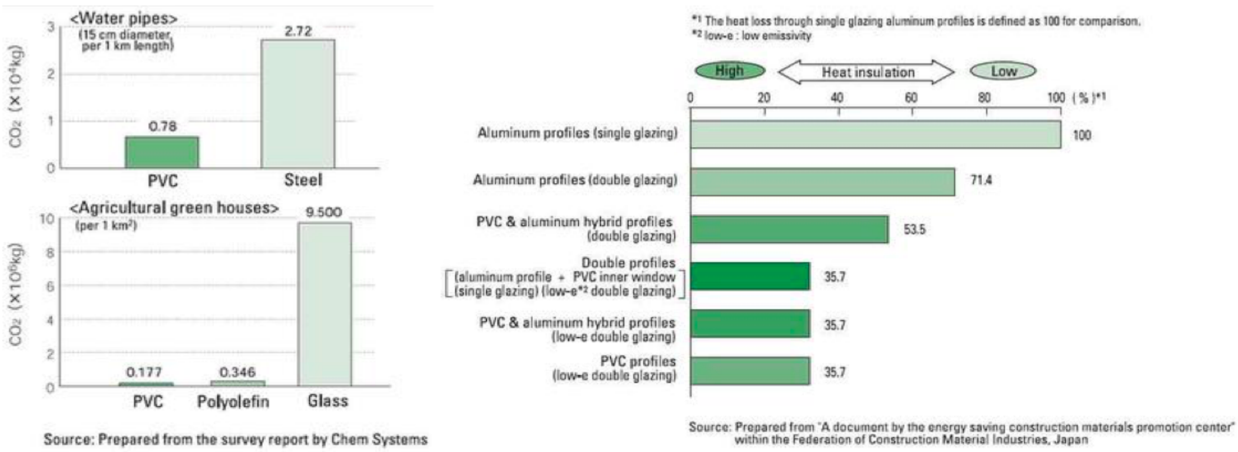

Figure 27: Ecological footprint PVC, steel, glass, aluminium [66]

MDF is a wood panel product made up of wood fibres (mostly from a pine tree) that have been bound together by heat, pressure and resin binders. The binders are often made from formaldehyde, a known carcinogen. Although they recently found out that lignin (a naturally occurring substance found in plants) can be used as a binder), most companies still use formaldehyde. MDF is completely recyclable, although the recycling process is new and the recycling locations are not always close by.[67]

Next, there has been chosen to use **Steel**. One of the major advantages of this one is that it can be used infinitely. Steel is a material that people use, not consume. It will never lose value, never lose its properties. Therefore, steel is the most recycled material on earth. There could be said that the non-renewable resources used to produce steel are not totally lost, because this one can be used forever and should not be made again.[68] Although this may seem like an ecological solution, timber still stays the best solution. It is a renewable resource and it is bio-degradable. The carbon footprint of those two materials are shown in **Fig.** 28

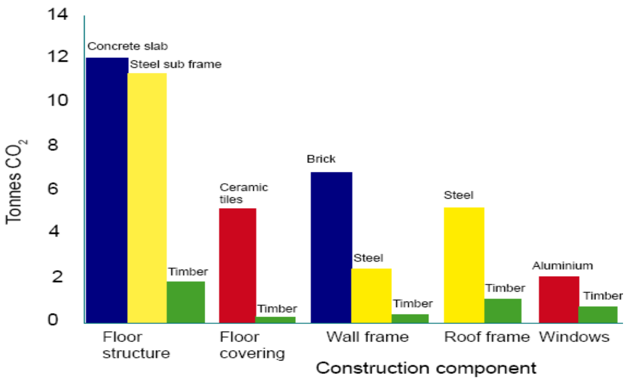

Figure 28: Carbon footprint steel in comparison with substitutes [69]

The SOSM is also going to consist of **aluminium**. Aluminium has similar properties as steel, as it can be used and recycled infinitely. Aluminium has one problem too, when it is produced with virgin sources it has an enormous ecological footprint. Nevertheless, when recycled sources are used the impact is far less, like shown on **Fig.** 29.

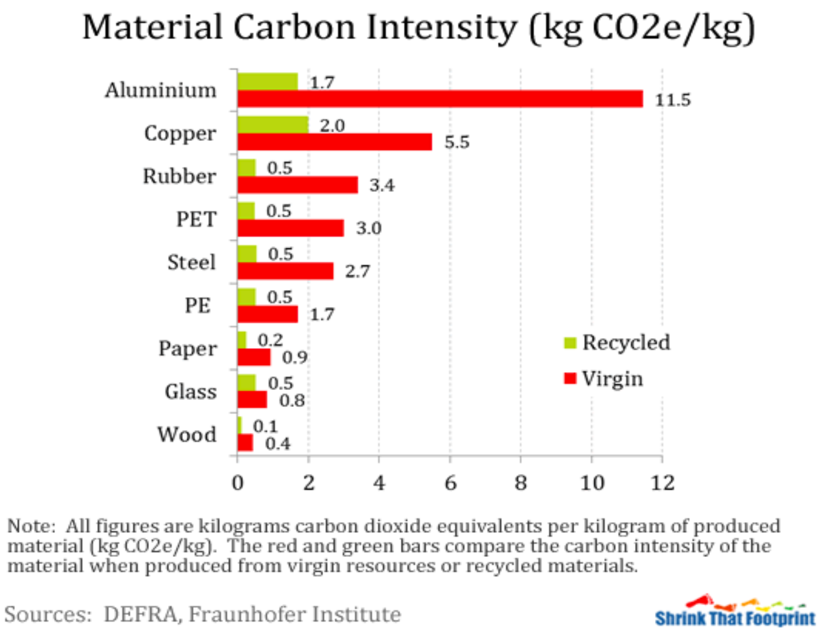

Figure 29: Virgin and recycled carbon footprint Aluminium in comparison with substitutes [70]

As shown above, wood is far the most sustainable substitute. So it is going to be used for many structural parts. Because it is an electrical device and the device will be outside, so it must be robust against the weather changes, not everything can be made out of wood unfortunately. There will also be searched for PVC without any additives and the greenest enterprises.

5.2.2 Pollution Control

As there has to be worked with a little budget, it is not possible to work with solar cells, therefore is necessary to connect it to the mains. Though whether the SOSM can be manufactured on a larger scale, is possible to make it run on solar energy. Because the device will always follow the Sun, which will lead to a higher energy gain. Also, when there is no Sun, the solar mirror has no use, this means that there will not be needed any energy storage. Also in the manufacturing, it could be best to use as much as green energy as possible.

5.3 Economical

For the economic development strategies will be made to optimize the use of existing resources. Everyone knows that sustainable business practices are necessary these days. Even people, whose main concern is business, are aware that the business depends on resources of healthy ecosystems. The main reason is that a higher impact on the planet does not lead to a higher cost for the clients. Luckily in most countries companies that or a bigger polluter, have to pay more taxes, to decrease this problem.[71]

For the ecological footprint of the SOSM, it is important to:

- Use materials that are as ecological, recyclable, long lasting, qualitative and efficient as possible at a reasonable price.
- Reduce the electricity consumes during the system construction.
- Manufacture the product with production methods and technologies focusing on sustainable production.
- Transport the system in only one box to reduce the space needed, so send the product unassembled.

5.4 Social

Social sustainability can be defined as follows:[72]

- “Social sustainability is a quality of societies. It signifies the nature-society relationships, mediated by work, as well as relationships within the society. Social sustainability is given, if work within a society and the related institutional arrangements:
  - Satisfy an extended set of human needs.
  - Are shaped in a way that nature and its reproductive capabilities are preserved over a long period of time and the normative claims of social justice, human dignity and participation are fulfilled. “

As the product will be send unassembled, there will need to be a user manual, explaining how to assemble the SOSM, and how to point it to the place the customer want to heat/light up. It must be as easy as possible, so that everyone can be able to build it, not only engineers.

The SOSM will be presented as an ecological device, because it will be using solar energy and also help to use solar energy. This way more people will be tempted to buy the product. The product will also be presented as something you can earn money with. In the long-term you will spend less money on the device than you would have paid for the energy the device has earned.

5.5 Life Cycle Assessment

It is essential for the company's development to take into account the life cycle of the product. For this is necessary to determine the next steps shown in **Fig.** 30.

Figure 30: Life cycle analysis [73]

Supposing that SUNO is a large company making the SOSM on a large scale, the *Life Cycle Assessment* (LCA) will look as follows:

5.5.1 Raw Material Extraction

The materials that were chosen and its ecological impact were already described in section 5.2.1. These where chosen in a way that they would harm the environment as less as possible, but also considering that product has to be robust and can withstand the high temperatures of the sun and also the changes of the weather. SUNO will try to find the materials as close to the manufactory as possible, so the least amount of transport is needed.

5.5.2 Product Manufacturing

During the manufacturing, the construction will be performed by machines controlled with human labour. The electrical part will be assembled in the manufacture.

5.5.3 Product Packaging and Distribution

After manufacturing the product will be packaged. For packaging, like mentioned in section 5.4, the product will be send unassembled. This way less packaging is needed, because all the pieces can be positioned close to each other.

5.5.4 Product Use

The product is for home use. It can be used in the garden or on rooftops, in different ways:

- To light up or warm up a room.
- To point on a solar cell to gain more energy.

The product will be send unassembled, so there will be a leaflet explaining how to assemble the product. After the solar mirror would have to be pointed at one point so the software knows where it needs to be reflecting the sunbeams. Spare parts will be available for the product, this way it is not needed to replace the whole mirror if a part breaks. SUNO will also try to make the product as self-reparable as possible.

5.5.5 Product Disposal/Recycling

As already mentioned in section 5.2.1 all the products will be recyclable. PVC without additives are used, this way also here recycling will not be a problem. As the client himself can assemble the product, it will be easy to separate the different materials. Also, spare parts can be bought at a local supplier. The client can get a discount if he/she returns the broken part, this way SUNO can make sure the broken part is recycled the way it should be.

5.6 Conclusion

To conclude, it is not difficult to prove that the solar mirror is an eco-friendly device, as it is used to provide more solar energy. Though this is not enough, if the manufacturing pollutes more than the energy the solar mirrors provide, it's not sustainable. Using green energy, renewable materials and also materials that do not have to transport over long distances, can do this. To make the product as sustainable as possible we have to take in to account the 3 P's: people, profit and planet. Especially the planet, the environmental development is here a high concern. To develop a sustainable product, it is also important to develop a good LCA. Next the ethics concerning the solar mirror will be discussed.

6. Ethical and Deontological Concerns

6.1 Introduction

When discussing ethics, it is important to note that ethics is not always a simple case of right and wrong. It can at times concern "competing rights" or indeed two wrongs [74]. It is imperative that the project team analyses different approaches to ethics in order to deal with any ethical issues which may arise during the course of the project. A deontological approach would see the team deal with issues based on a strict set of rules applied to each issue regardless of the consequence. A utilitarian approach would see the team make decisions for the greater good. It is likely that the team will use a mixture of both approaches when issues arise. From this analysis the team has created an ethical code of conduct to work by during the course of the project as can be seen in **Fig.** 31. Any unethical behaviour within the team must always be challenged.

Team 3 Code of Ethics

- Always challenge unethical behaviour
- Do not perform hazardous work you are not trained to carry out
- Reference all sources of information correctly
- Do not manipulate data or present data in a misleading way
- Be honest and transparent
- Treat all team members equally and with respect

Figure 31: Team 3 Code of Ethics

6.2 Engineering Ethics

The project team is made up of five members with different engineering backgrounds and experience. It is essential to draw upon this knowledge and experience when tackling ethical issues. In terms of the engineering of the product, steps are being taken by the team to ensure ethical conduct. These steps include correct referencing and crediting of sources of information to avoid plagiarism. The use of properly licensed software and only carrying out technical work which members have the appropriate level of knowledge and training to carry out. This will ensure the safety of everyone involved with the project. The product prototype will be made from various components from many different manufacturers and the team will be considering as much as is possible the ethical conduct of these manufacturers. The same applies to the suppliers, who undergo a vetting process carried out by ISEP.

6.3 Sales and Marketing Ethics

As the product has multiple uses it will be of benefit to many different types of user, however in the marketing of the product the team has been careful not to make false claims about its capabilities. The product has been priced in such a way that all development and production costs are covered but also so that a profit can be made in order to support continued production and further product development. The product is priced fairly to provide value for money to the consumer. The price covers the costs of development, materials and labour/production and makes a reasonable profit to ensure commercial viability. This is an important issue for the team as the development of the product is not financially motivated but environmentally.

6.4 Environmental Ethics

Natural resources are being consumed at an alarming rate and global warming is becoming an undeniable reality. For many companies, sustainability and the environment are an afterthought and for others a mere marketing tool. As one of the objectives of the self-oriented solar mirror is to encourage the transition to clean energy, environmental ethics are at the forefront of the teams' vision. One purpose of the mirror is to improve the efficiency of solar thermal water heating systems and another is to bring light to dark rooms without using a lot of electricity from non-renewable sources. With this in mind and within the constraints of the 100 € budget the team have tried to develop the product using the most sustainable materials available. The team will also provide consumers with information on how to recycle the product at the end if its usable life, however, the product is designed in such a way that broken parts may be easily replaced so that a system may be repaired instead of wasted. The team intend to use as much recycled material as possible from pervious projects to limit their environmental impact. The product may be powered from a small solar panel or battery.

6.5 Liability

To satisfy the requirements of the project semester the product is developed in accordance with the following EU directives:

- 2006/42/CE 2006-05-17 (Machinery Directive)
- 2004/108/EC 2004-12-15 (Electromagnetic Compatibility Directive)
- 2014/35/EU 2016-04-20 (The Low Voltage Directive)
- 2014/53/EU 2014-04-16 (Radio and Telecommunication Terminal Equipment Directive)
- ROHS (Restriction of Hazardous Substances in Electrical and Electronic Equipment)

It is important to note that some of these directives do not apply to the SUNO Self-Oriented Solar Mirror. For example, the Low Voltage Directive (LVD) applies to electrical equipment with input or output voltages between 50 and 1000 V alternating current (AC) and 75 and 100 V DC [75]. The General Product Safety Directive is more relevant to the product being developed, however, the LVD may be relevant in the future if the product is upscaled somehow. As the product does not make use of any radio or telecommunication equipment this directive also does not apply, but as before it may apply in future iterations of the product.

According to the Machinery Directive definition of machinery, "Machinery consists of an assembly of components, at least one of which moves, joined together for a specific application. The drive system for machinery is powered by energy other than human or animal effort [76]". As the SUNO device is covered by this definition the team must refer to and comply with the directive. The aim of the directive is to protect workers and consumers who are involved with the product. Should the product reach the market, non-compliance with the directive would be illegal as well as unethical.

The Electromagnetic Compatibility Directive (EMC) is designed to ensure that electronic and electrical products do not interfere with each other and with radio and telecommunication equipment within reasonable limits. As the SUNO device contains electronic and electrical parts adherence to this directive is required.

The ROHS restricts the use of certain substances which are deemed to be hazardous to the environment and to human health in electronic and electrical equipment. Substances such as lead, mercury and cadmium. Producing products which do not contain these substances makes it easier for products to be recycled safely which reduces the impact of the waste of electronic goods on the environment. The team will not be producing any electronic parts but rather sourcing them from suppliers. Therefore, in order to comply with the directive, the team will have to ensure that each part purchased is ROHS compliant. Generally speaking, this will be an easy task as most products state that they are compliant and within the European Union (EU) it will be hard to find non-compliant products.

Compliance with these directives ensures the team are operating within the law and reduces their liability in the event of negative outcomes related to the product or its production. The team are also considering the consequences of misuse of the product as concentrated solar power may have harmful effects if used improperly and relevant safety information will be provided with the product.

6.6 Conclusion

There are many ethical issues to consider during the course of the project. Through research and through the support classes provided the team will try to navigate these issues in the most ethical way. The creation of a code of ethics is one solution the team has chosen to help them in this area. Environmental ethics and legal responsibilities have caused the team to think carefully about the selection of materials. Compliance with ROHS for example has the team ensuring they buy from certain suppliers. Also, the selection of wood instead of plastics for the construction of the product has come from the study of environmental ethics. Improving referencing skills has been needed to ensure ethical conduct from an engineering and academic standpoint and the marketing of the product in an honest and transparent way makes certain that the team acts ethically in the area of sales and marketing. The next chapter of the report deals with the development of the project.

7. Project Development

7.1 Introduction

This chapter describes the product's development process. It consists of two main parts. Structure and mechanics of the mirror are one of them and the other is the control of the system. The aim is to achieve enough accuracy of the mirror for the budget given. The user experience is crucial as well.

7.2 Power Transmission and Actuators

7.2.1 Power Transmission

Power transmission is when energy is moved from its place of generation to a place where it can actually perform work. There are different ways of transmitting power; most of them can be classified in electrical, mechanical and fluid systems.[77] For this project, mechanical transmission will be used, due to:

- The limitations of an electric transmission.
- The little control offered by pneumatics, due to the absence of a force in the opposite direction.
- The expensive and nonsense of the use of hydraulics, due to the low load to realize.

7.2.1.1 Mechanical power transmission

Mechanical power transmission systems employ a variety of kinematic mechanisms such as belts, chains, pulleys, sprockets, gear trains, bar linkages, and cams. They are suitable for the transmission of motion and force over relatively short distances. The disadvantages of mechanical systems include lubrication problems, limited speed and torque control capabilities, uneven force distribution, and relatively large space requirements.
Within the mechanical transmissions, highlights the gears. A gear is a rotating machine part having teeth, which mesh with another part to transmit torque. Therefore, it is useful to transmit rotary motion. The different types of gears to be studied, are introduced below:

- **Spur gears** (**Fig.** 32): Are used to transmit rotary motion between parallel shafts. They are cylindrical, and the teeth are straight and parallel to the axis of rotation [78].

Figure 32: Spur gears [79]

- **Worm gears** (**Fig.** 33): Are used for large speed reduction with concomitant increase in torque. The shafts are normally perpendicular. Is a species of helical gear, but the difference is that the worm may have as few as one tooth. In a worm-and-gear set, the worm can always drive the gear. However, if the gear attempts to drive the worm, it may not succeed [80] .

Figure 33: Worm gears [81]

- **Rack and pinion** (**Fig.** 34): It is a type of linear actuator that comprises a pair of gears which convert rotational motion into linear motion A circular gear called “the pinion” engages teeth on a linear “gear” bar called “the rack”; rotational motion applied to the pinion causes the rack to move relative to the pinion, thereby translating the rotational motion of the pinion into linear motion [82].

Figure 34: Rack and pinion [83]

7.2.2 Movement Technology

Once explained the different elements available that can be used in the design of the movement's mechanism, there are several options that can be implemented.

7.2.2.1 Azimuth movement

Fig. 35 shows one option to get the movement in azimuth. The mechanism has the following parts:

- **Stepper motor**: The stepper motor provides the power necessary to move the whole solar mirror.
- **Pinion**: The pinion is a spur gear, which is connected directly to the stepper motor. It actuates the toothed platform.
- **Toothed platform**: This platform supports the solar mirror, and it has an internal gear which is actuated by the pinion gear, in order to get the azimuth movement.
- **Bearing**: The bearing connects the fixed structure with the toothed platform.It allows the relative movement between both.

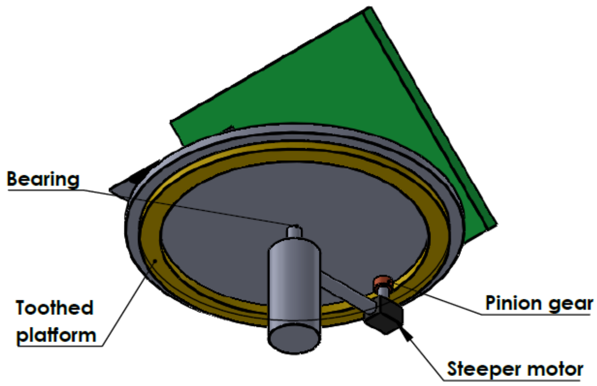

Figure 35: Toothed platform movement

Another option to get this movement, as shown in **Fig.** 36, it is to use and worm-and-gear arrangement. The mechanism is formed by:

- **Stepper motor**: The stepper motor provides the power necessary to move the whole solar mirror.
- **Worm**: The worm is directly connected to the stepper motor. It actuates the gear.
- **Gear**: This gear is coupled to the azimuth shaft and, actuated by the worm, it allows the azimuth movement.

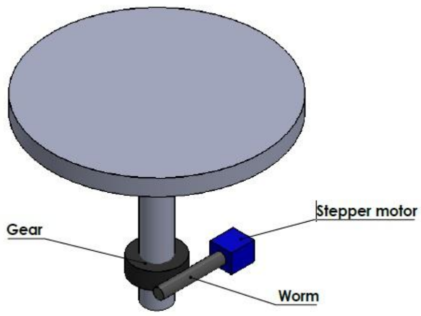

Figure 36: Worm-and-gear set rotation

7.2.2.2 East-West movement

As shown in **Fig.** 37,in order to raise the mirror, an option is use a rack and pinion system, with the following components:

- **Stepper motor**: The stepper motor provides the power necessary to move the solar mirror.
- **Pinion**: The pinion is a spur gear, which is connected directly to the stepper motor. It actuates the rack.
- **Rack**: The rack is connected to the said structure and, through the drive throught the pinion, it allows to modify the angle's inclination of the same.

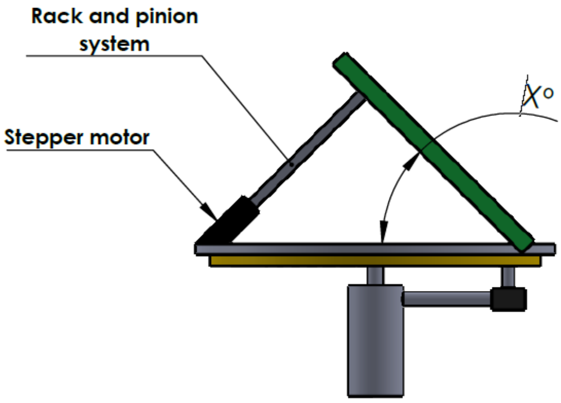

Figure 37: Rack and pinion mechanism movement

Finally, another way to modify the inclination of the solar mirror, is using a leadscrew mechanism, shown in **Fig.** 38:

- **Stepper motor**: The stepper motor provides the power necessary to move the structure where the solar mirror is.
- **Drive wheel**: The drive wheel, which is usually a nut, is connected directly to fix part of the structure.
- **Screw**: The screw, which is actuated by the stepper motor, allows to modify the angle's inclination of the solar mirror.

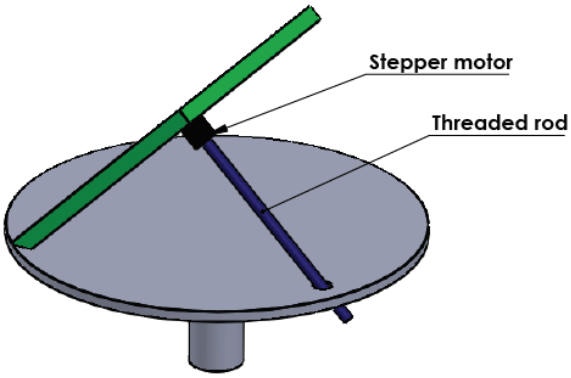

Figure 38: Leadscrew mechanism movement

7.2.3 Conclusion

Having seen the different possibilities in terms of movement technology, it is important to determine the advantages and disadvantages of the same. This is shown in **Table** 12:

Table 12: Movement technologies comparison

Technology	Advantages	Disadvantages
Azimuth movement		
Toothed platform	The mechanism is robust	Toothed platform is expensive to manufacture
		Lubrication may be required
Worm-and-gear	..	..
East-West movement		
Rack and pinion	It is a cheap and robust system	A lot of space is necessary, due to the rack's length
		It exists a los of friction in the mechanism, therefore much power is required
		Also, due to the friction, it is produced a big amount of heat
Leadscrew	Easy to design and manufacture, no specialized machinery is required	A lot of space is necessary, due to the length of the screw
	Smooth, quiet and low maintenance	It is a very low-efficient system
	Self-locking	

7.3 Sun Tracking Technology

Fig. 39 shows the general principle of operation the heliostat. To result in a still spot of reflected light the normal to the mirror needs to be exactly half way between the Sun inclination angle and the line to the desired spot. That means that for each change of the solar elevation and azimuth angle the mirror has to rotate accordingly vertically and horizontally exactly half that much.

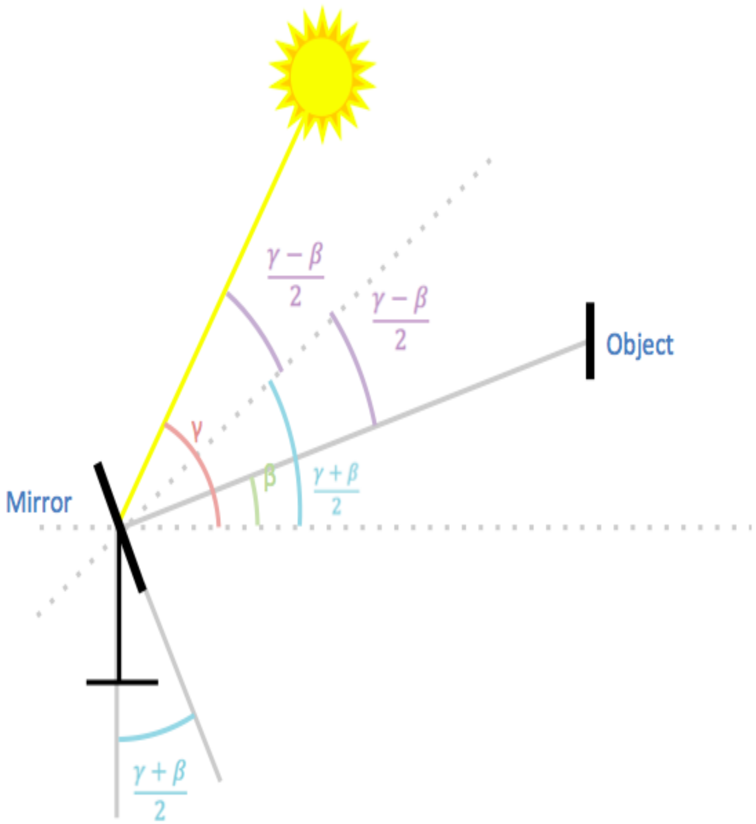

Figure 39: General principle of operation

7.3.1 Sun Azimuth and Altitude Calculation

The position of the Sun can be calculated if the exact date-time and geographical location is known. The example of such an algorithm is *Sun Position Algorithm* (SPA) from *National Renewable Energy Laboratory* (NREL).[84] For extremely precise calculations also elevation, temperature and air pressure can be used, nevertheless such a precision is not needed and obtaining that data would only cause unnecessary complications or costs. This solution does not involve any additional mechanics nor light sensors. On the other hand it needs:

- An exact geographical location, either a *Geographical Positioning System* (GPS) sensor or an user input.
- A clock, because date and time has to be set by user.
- A compass, though the orientation can be either constant or set by the user.

This means that the cost of such a solution is some additional setup and only optionally additional sensors.

7.3.2 Movable Sun Tracker

Sun tracking in 2-axis can be easily achieved by using 3 light sensors (one used for two axes, see **Fig.** 24), or two pairs of sensors. This system might not be reliable under the foggy or dusty conditions and can also get stuck on some bright spot instead of following the Sun.[85]

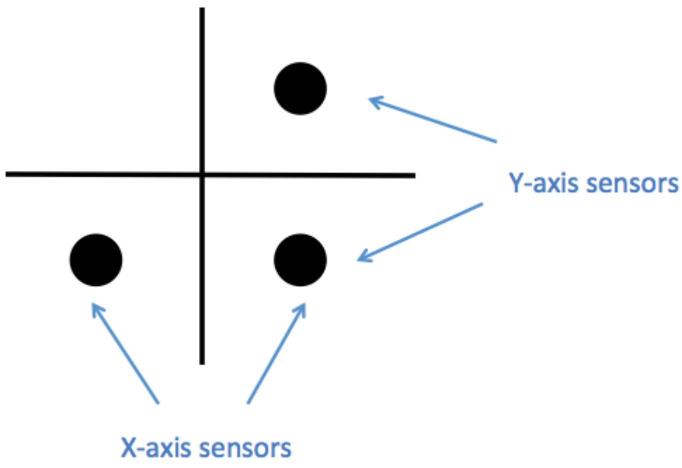

Figure 40: Sun tracking sensor

If the difference between the light intensity detected by the sensors appears the tracker needs to be rotated in the direction of the higher intensity as shown in **Fig.** 41.

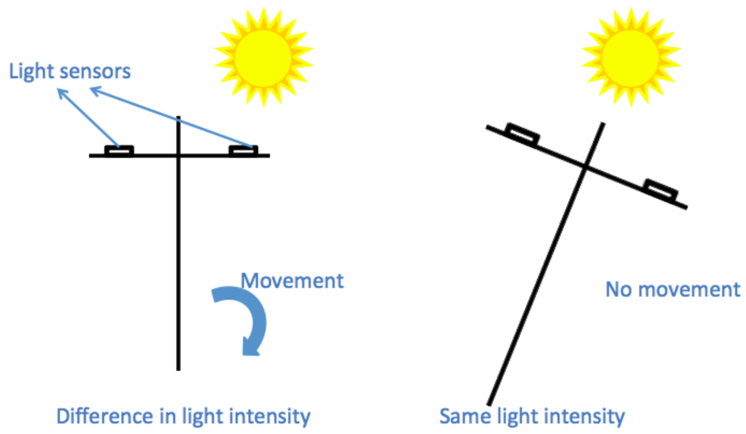

Figure 41: Tracking Sun with a movable sensor

The mirror only needs to be moved by the half of the angle the tracker is rotated. This solution does not involve any additional setup and can be used with artificial light sources. On the other hand it involves more complicated mechanics and costs (materials, sensors and motors).

7.3.3 Light Detecting Matrix

Following the mentioned in section 2.2.1.2, a solution similar to the way the camera works can be applied to find the angle of light incidence. A light detecting matrix (active pixel sensor) placed inside a box with a hole, as shown in **Fig.** 42. It will detect the light spot coordinates from which the angle of incidence can be calculated.[86] Such a solution provides a simple way of finding the position of the Sun, but it involves costly and difficult to find sensors.

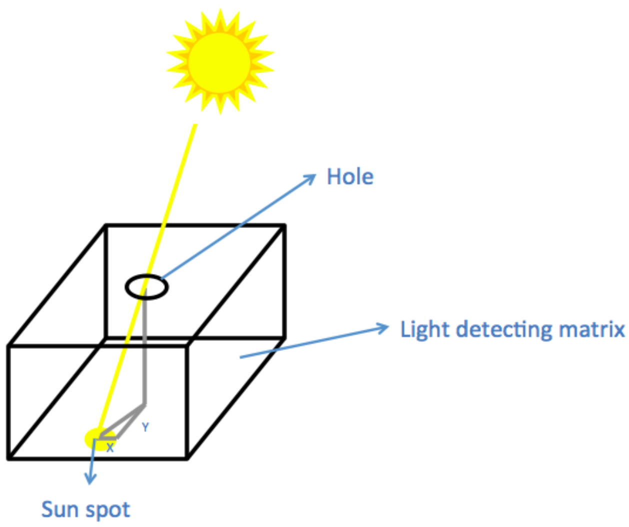

Figure 42: Finding the angle of light incidence with an APS

7.4 Control System

7.4.1 Control System Analysis

Fig. 43 shows the black box diagram of the system. It shows the input, output, system components and power supply. As it is just an initial draft, it might change during the process of development.

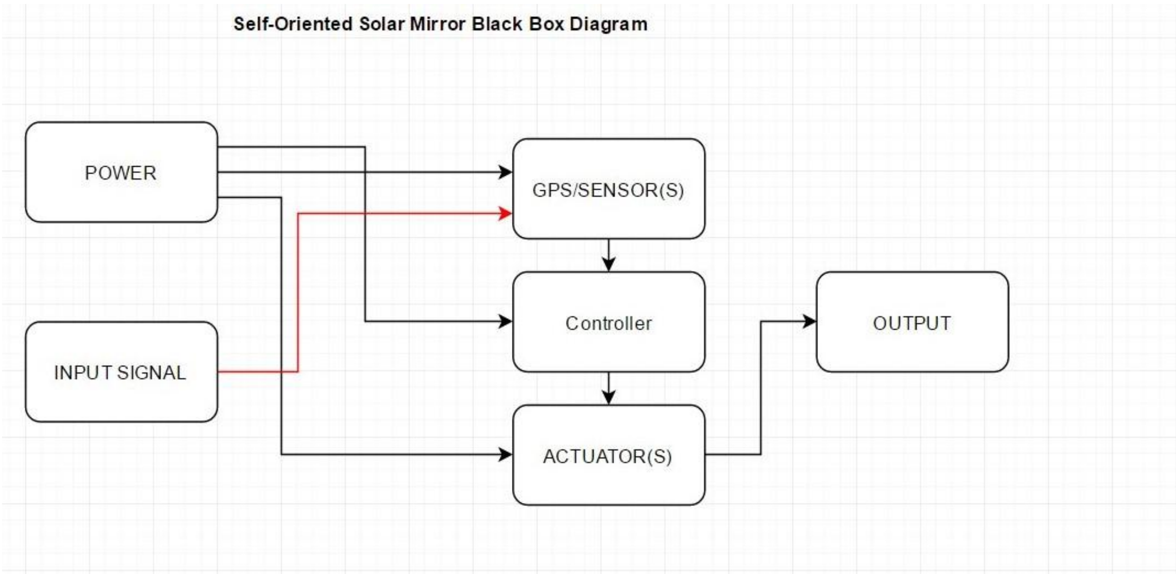

Figure 43: Black Box Diagram

As the operational principle of the control system is a crucial part of product development a significant amount of time has been allocated to the analysis and the final decision. After the initial research four solutions are proposed to choose from, described each one in detail below.

7.4.1.1 Two sensors - both mechanically dependent on the mirror

As mentioned in section 7.3.2, two pairs of sensors (each for one axis) are enough to track the Sun. As the mirror must move exactly half of the way that the Sun tracking sensor does a system of gears can be used to achieve this. This way it is not necessary to calculate the desired angle, only make sure that the sensors are facing the Sun. One issue that this solution raises is that is necessary to somehow detect the end of the movement range. This could be achieved simply using stepper or servo motors or by including rotary encoders in the system that would allow the monitoring of the mirror displacement. The other way would be to just add sensors (touch sensors, buttons, magnetic field sensors plus magnets) at the end of the range, that would trigger when the motors need to stop. Moreover, while it is relatively simple to place a pair of sensors at the side of the mirror and move it twice as much vertically, the problem is to transfer the rotary movement from the base of the mirror to its top (so the sensors are not covered by the mirror). This is because the mirror is moving in two axes and therefore a flexible shaft and a more complicated system of gears and bearings would be needed. The disadvantage is also that the sensor needs to be mechanically readjusted when the user wants to change the focus point.

7.4.1.2 One independent sensor plus one dependent sensor

The idea is two use an additional motor to move the top sensor independently of the mirror movement and move the side sensor as in previous solution (see section 7.4.2. This solves the issue of the rotary shaft, but makes the control system a bit more complicated and requires an additional motor, which makes the costs higher.

7.4.1.3 Two independent sensors

This solution is simpler from the mechanical point of view and provides more control over the system. There is no need to move the sensors manually during the setup. On the other side it requires two motors and monitoring of the sensor angles. This makes the control system more expensive and complicated.

7.4.1.4 No sensors

As the position of the Sun can be calculated knowing the geographical location and date time. Example of such an algorithm is NREL's SPA[87]. For this is necessary to keep track of the time and the position of the mirror. It is possible to use a real time clock and a 9-axis position/movement sensor (eg. MPU9250 [88]). The problem is that such a sensor does not allow to find the true north with a good accuracy easily and therefore the mirror position will not be measured precisely.[89] This indicates that using a different way of tracking the position of the mirror is crucial (servo or stepper motors or rotary encoders). After more in-depth analysis, it has been concluded that the initial position of the mirror is not needed to have a constant focus point. Only user calibration on setup is required to move the light spot to the desired position. The proof below (**Fig.** 44 and the Equations) shows that even if it is assumed some reference angle (e.g. true north or normal to earth surface) incorrectly the light spot will be still. Therefore, the user can set the focus point properly regardless of the mirror initial orientation. That simplifies the whole system, as it only needs to track the Sun and the mirrors relative position.

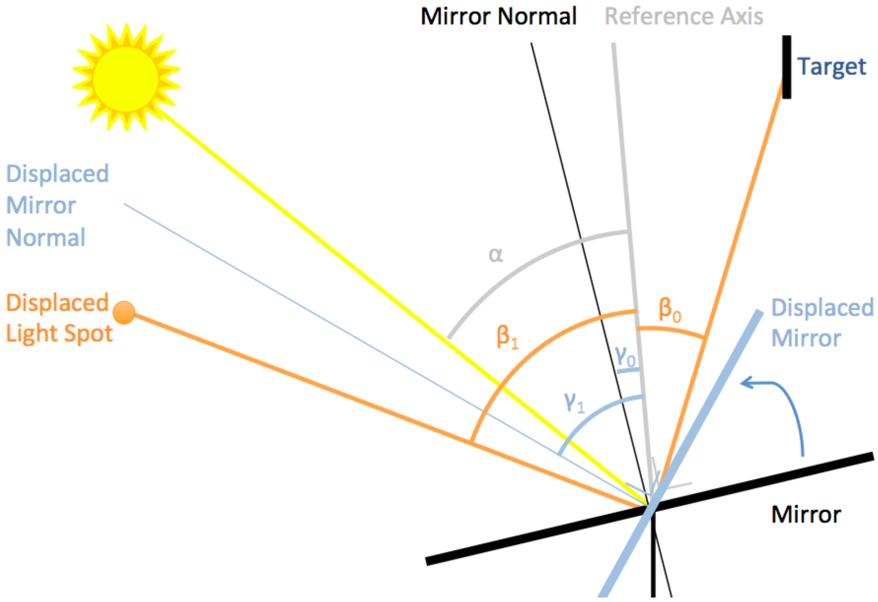

Figure 44: Pointing Sunbeams on object

α − Sun inclination or azimuth angle
β_0 − Intended Sun spot position
β_1 − Sun spot position after displacement of the mirror
γ_0 − Intended mirror normal
γ_1 − Mirror normal after displacement
$\delta\gamma$ − Mirror displacement
From the picture and the law of reflection we get:

$$\gamma_0 = \frac{\alpha + \beta_0}{2}$$

$$\gamma_1 = \frac{\alpha + \beta_1}{2}$$

$$\gamma_1 = \gamma_0 + \delta\gamma$$

$\delta\gamma$ and β_0 are constant, now to show that regardless of the initial mirror position the Sun spot will not move (will be in different place, but this place will not change) we need to prove that β_1 is constant:

$$\beta_0 = \gamma_0 - \alpha$$

$$\beta_1 = 2\gamma_1 - \alpha$$

$$\beta_1 = 2(\gamma_0 + \delta\gamma) - \alpha$$

$$\beta_1 = 2\gamma_0 - \alpha + 2\delta\gamma$$

and finally:

$$\beta_1 = \beta_0 + 2\delta\gamma$$

Since $\delta\gamma$ and β_0 are constant, we know that β_1 is constant, which ends the proof.

7.4.2 Control System Choice

The team has decided not to use sensors as it allows for a very precise movement and provides more control over the system. Since it is not necessary to use any orientation sensor, is needed to keep track of the mirror position to control its movement. Even using a stepper motor and counting the pulses there is a possibility of the motor doing more or less steps.

Using incremental rotary encoders to count the turns done would be a more reliable way of monitoring the mirrors position, as is taken into account the movement that actually takes place. In this case is necessary to store the information in the static memory not to lose it on the sudden power off. It is still not a robust solution as it is an open-loop system, so all the failures in proper counting will accumulate and the lost count will be irreversible.[90]

As it is needed a closed loop system, some absolute reference of the mirror orientation has to be included.[91] The most suitable and robust would be using a very precise absolute rotary encoder that would provide with reliable mirror orientation measurement at any time, without the need of counting the turns. Example of such an encoder would be an optical gray-scale encoder.

As such a robustness is only necessary for the final product, a resetting mechanism for the prototype can be used. The idea is to place sensors at the end of the movement range. A mechanical trigger or a magnet with a hall effect sensor will be suitable indicator of reaching the end of range. After the mirror moves too far the microcontroller will receive a signal that will trigger an interrupt stopping the motor and resetting the counter.

The final product might also include such a mechanism for the safety reasons, nevertheless it is not necessary as the position can be checked with the absolute encoder.

7.5 Architecture

7.5.1 Structural Drawings

Fig. 45 and 46) show the drawings with main dimensions that the final product may possibly have. Although these may vary, the drawing makes clear how it is going to look like.

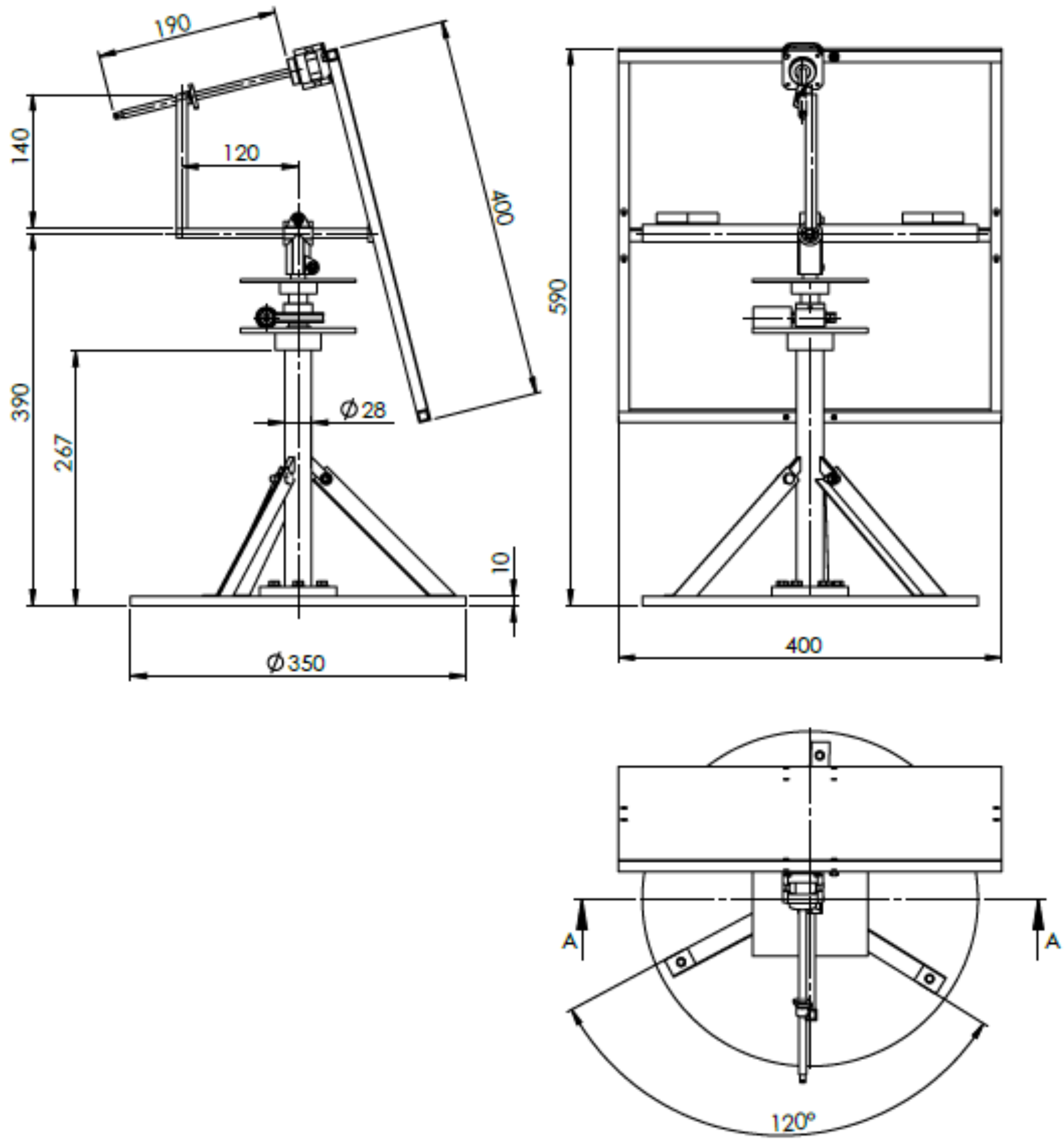

Figure 45: Structural Drawings

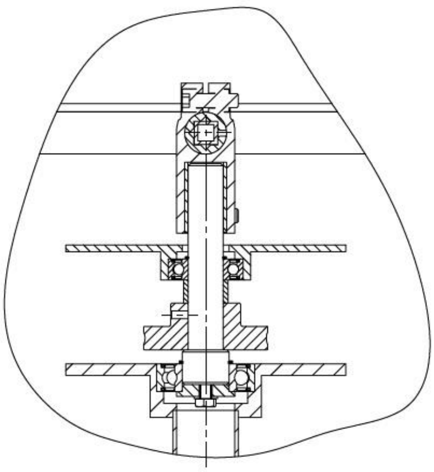

Figure 46: Structural Drawings

7.5.2 Cardboard Model

First of all, a cardboard model was made of the solar mirror. This was done to help to decide the dimensions and the ultimate moving system of the mirror. The model is shown in **Fig.** 47.

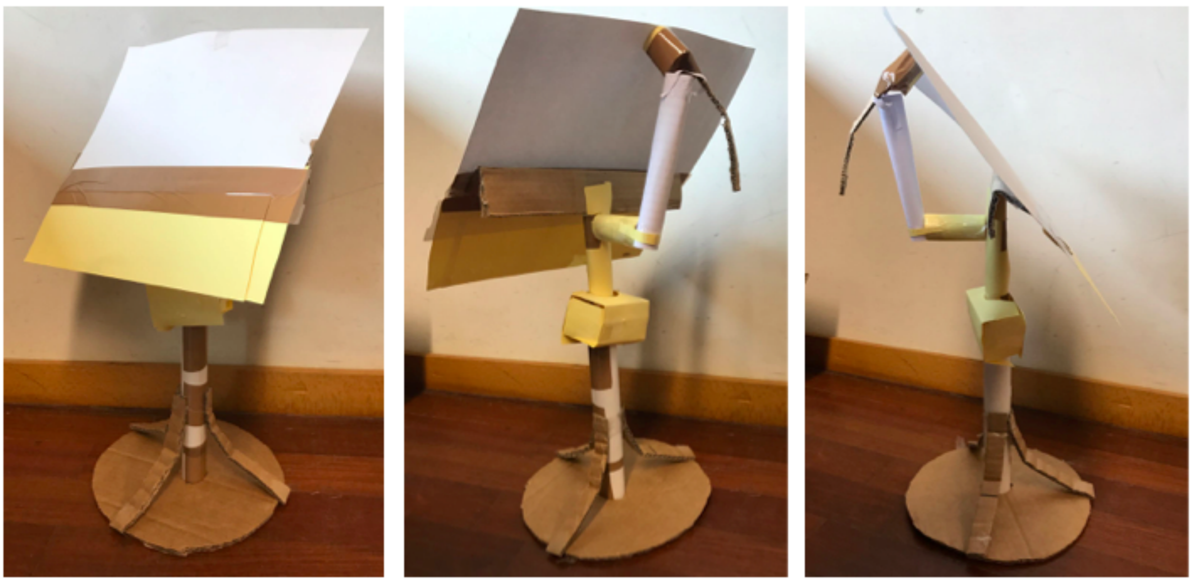

Figure 47: Cardboard model

7.6 Electrical components

7.6.1 Introduction

The initial schematics of the system is shown in **Fig.** 48. The schematics is a general base for the further development. As the 9-axis orientation sensor is not necessary the final systems will probably not include it. The motor control system is designed for controlling DC motors and might be changed depending on what kind of motors are decided to use (regular DC,stepper or servo motors).

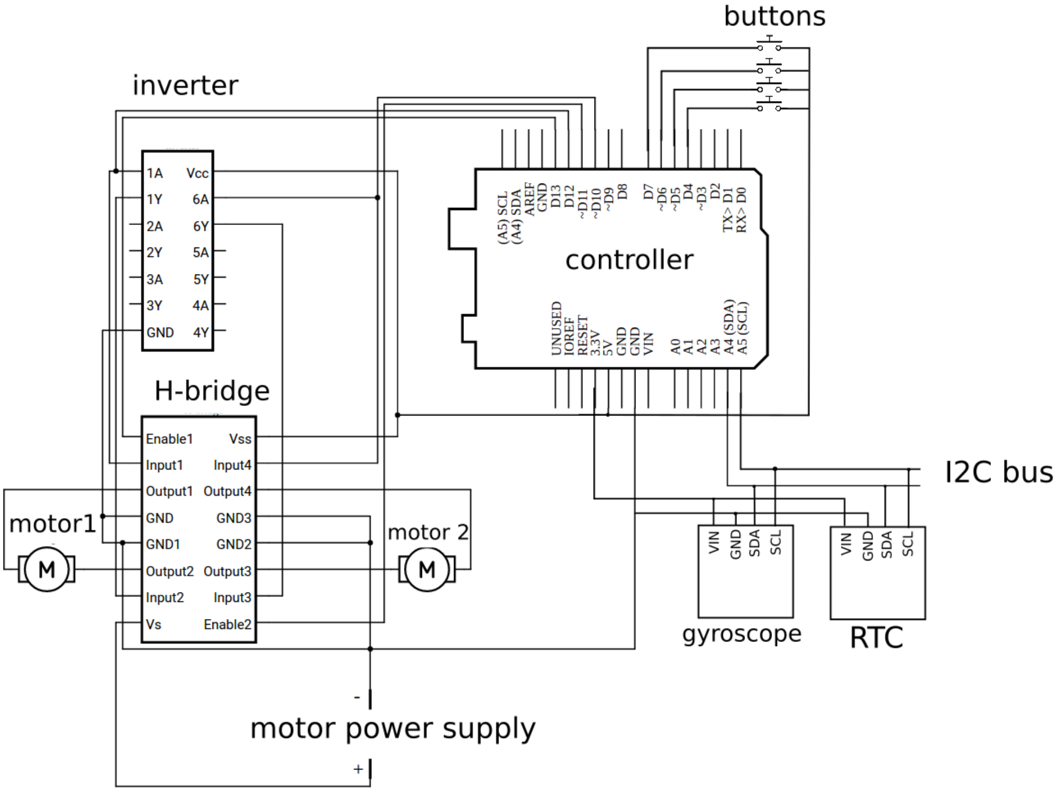

Figure 48: Initial system schematics

7.6.1.2 Microcontroller board

As the system requires calculation of the Sun position the choice of a suitable board is crucial. In **Table** 13 different microcontrollers are compared including their approximate price.[92] For the calculations double support might be crucial and the price is an important factor, as the budget is limited.

Table 13: Microcontroller board comparison

Board	Technology	Price [€] (V.A.T. Not included)	Link
Arduino Uno	8-bit	21.00	Arduino Uno
Arduino Mini	8-bit	14.00	Arduino Mini
TI MSP-EXP430G2	16-bit	9.99	TI MSP-EXP430G2
TI EK-TM4C123GXL	32-bit	12.99	TI EK-TM4C123GXL
Funspark redboard	8-bit	19.95	Funspark redboard
STM32VLDISCOVERY	32-bit	9.68	STM32VLDISCOVERY

Taking into account these factors Texas Instruments EK-TM4C123GXL will be a suitable board, as it is cheaper than Arduino Uno, while providing more pins and double precision numbers support.

7.6.1.3 Type of Motors

For the SOSM system, the chosen motors need to allow for good precision, but the speed is not an important concern as the mirror will rotate very slowly (about 15 ° per hour). Also, a relatively high output torque will be crucial to move it during a windy day. As two-way movement is necessary, the motor has to be bipolar. Stepper motors and gear DC motors are mainly considered.

Gear DC motors with very low gear ratio will allow for the desired precision and torque. On the other hand, it would be more difficult to control such a motor as it is not possible to anticipate the exact angle it will turn, so you have to rely on feedback from the encoder. It is not a significant disadvantage though and it allows a continuous movement.

A bipolar stepper motor with a good resolution will allow for precise movement and easy control, as it is known exactly how much it will rotate and it is only necessary need to check whether it does not skip any step. Bipolar stepper motors also feature a high torque and a holding torque without power supply. Stepper motors are used when precise positioning is needed and so it is in this case.

Considering all of this, stepper motors would be the most suitable for the final product as it allows to position the mirror very precisely. For the prototype any of these would be suitable, but gear motors would require a usage of rotary encoders, which in the case of the prototype can be omitted for stepper motors. Therefore, stepper motors will be used in the scale model, unless such a solution is much more costly.

7.6.1.4 Other Components

As it will provide user with more control over the mirror and also allow the mirror to inform the user about the need of calibration, it will be necessary to add some LEDS and LCD display. As for the display it should have two rows with 16 characters each. It should support SPI or I2C protocol to minimize number of pins used, unless the board has enough pins to support a display with parallel control. One or two LEDs will be enough and five buttons and an on/off switch should provide enough input from the user. Some additional resistors might be needed for the buttons as a pull down and capacitors for debounce. Except of that the system needs a safety mechanism for sensing end of movement range. In the full scale and mass production mirror a magnet and a magnetic switch or some mechanical trigger designed for that purpose would be a suitable way of indicating the end of range (switch triggers when the magnet is close or the circuit is closed, which informs about reaching the end of range). In the prototype buttons will be enough as such a situation would happen extremely rarely, only when the controller loses count of the angle. Apart from that a real time clock is needed. Any RTC with a place for its own battery and supporting I2C protocol will be suitable.

7.6.1.5 Power Supply

As the product is supposed to work only during the day and changes its position towards the Sun, it would be logical to use a solar panel to power the system. The motors drain would use much more power than the control system, however they do not work continuously, so they can be powered from a battery that would be charged by the solar panels. The system will hibernate when the Sun is out of range, which will minimize the power consumption. For the prototype has been decided not to use solar panel nor rechargeable battery as they are expensive and the scale model needs less power. The power can be supplied to the controller from the power plug via a USB cable. The motor will be powered either from the board or from a separate battery depending on the voltage needed.

7.6.2 List of Electrical Components

Below in **Table** 14 the electrical components needed are listed:

Table 14: List of electrical components

Component	**Price (€)**	**Link**
Texas Instruments EK-TM4C123GXL	12.62	TI EK-TM4C123GXL
Push buttons x 10	2.00	
Red LED x 3	0.58	Red LED
3 x 220 Ω resistor	0.27	220 Ω resistor
L293D H-bridge	2.49	L293D H-bridge
SN74HC04N inverter	0.49	SN74HC04N Inverter
2 x Bipolar Stepper Motor Hybrid Frame Size 200 Step 1.7A 3.4VDC	26.20	Stepper motor
Wire	Provided by ISEP	
Breadboard	Provided by ISEP	
Jumper cables	Provided by ISEP	
DS1307 - Timing, Real Time Clock (RTC) Evaluation Board	4.11	DS1307
On-off switch	0.99	On-off switch
LCD display	9.59	LCD display
Total (€)	**59.34**	

7.6.3 Final Schematics

The **Fig.** below (49 and 50) show the electronic schematics drawn using Fritzing tool.[93]

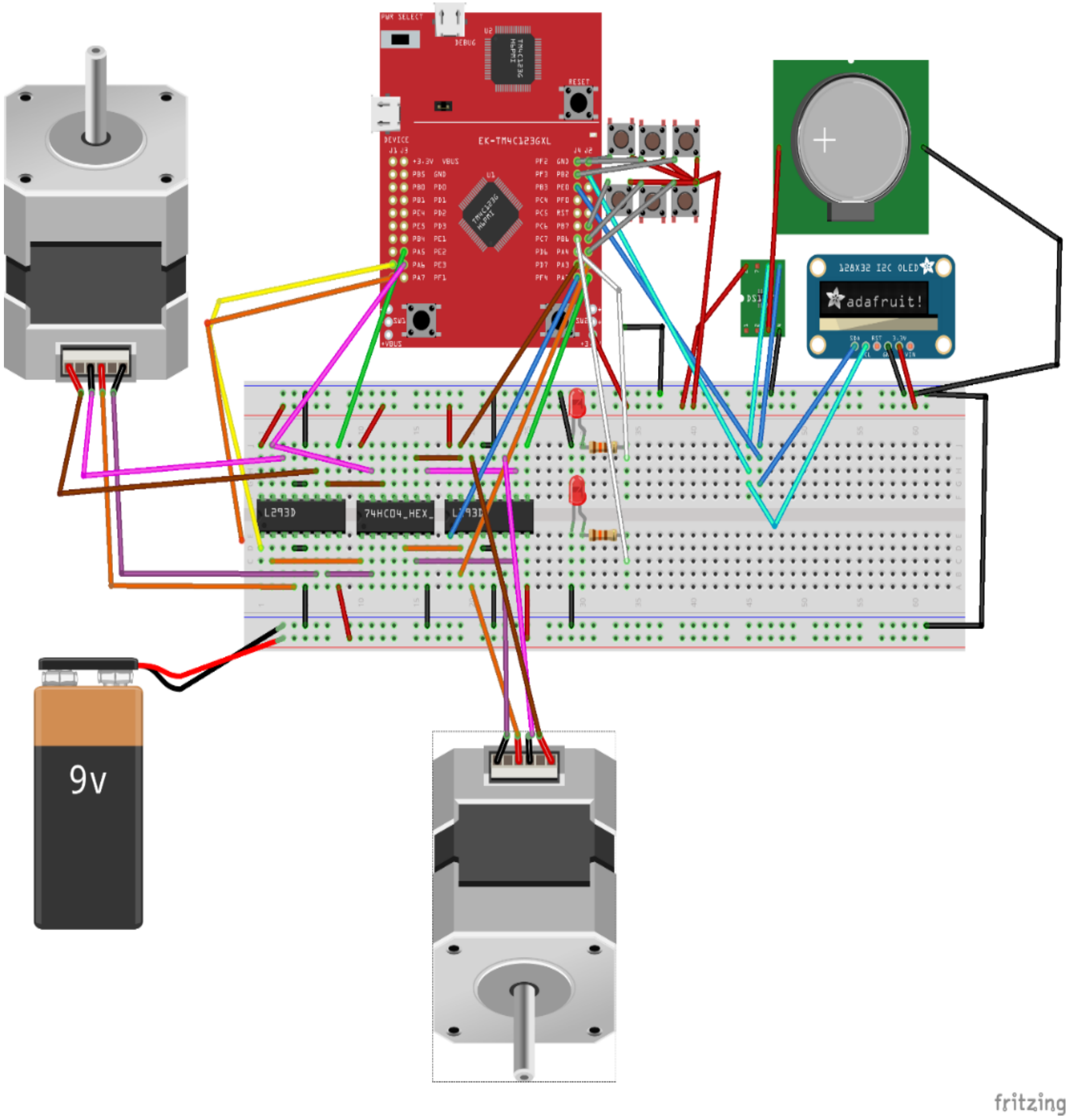

Figure 49: Components

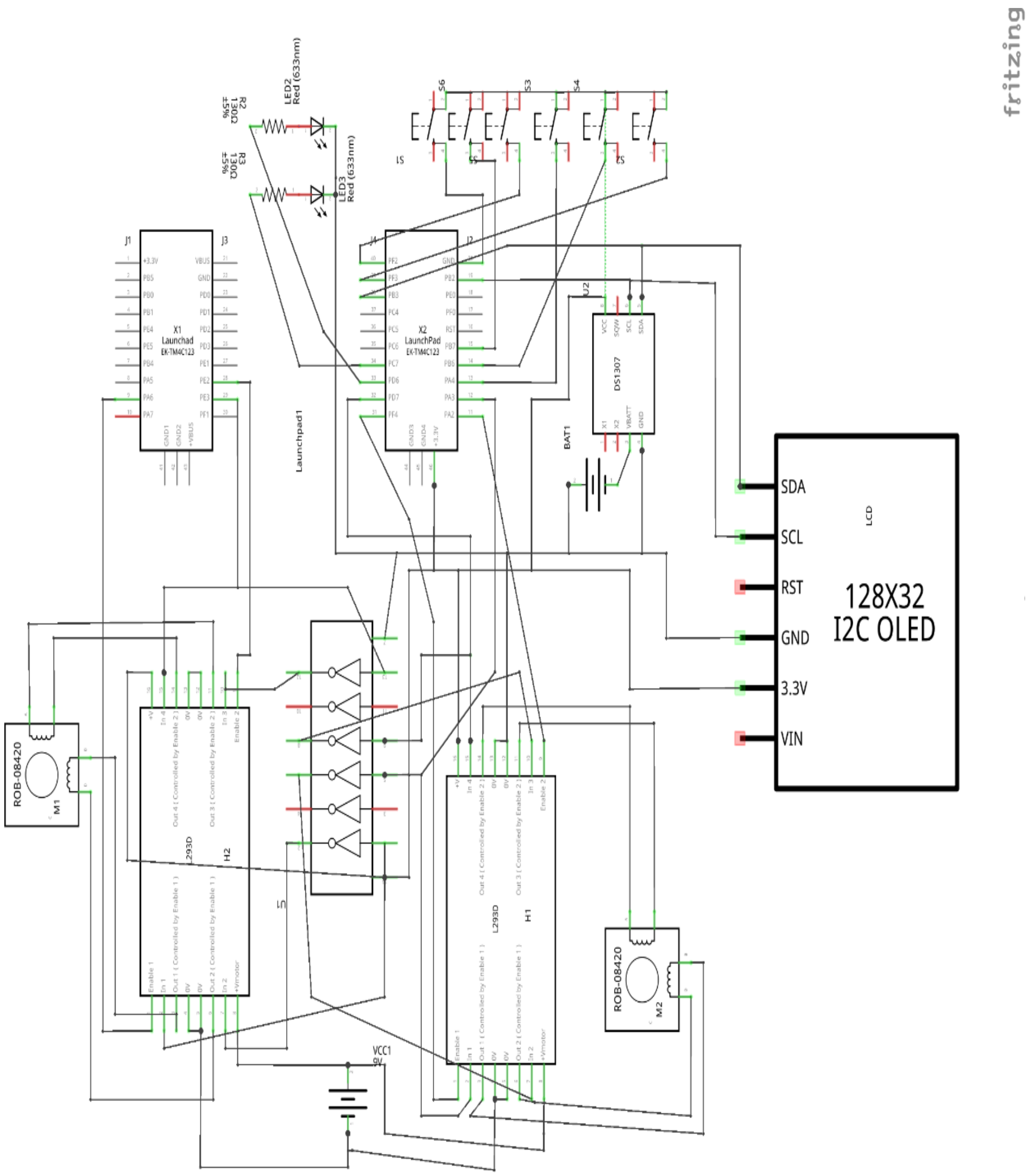

Figure 50: Schematics

7.7 Mechanical Components

The complete list of the mechanical components needed to build the prototype are included into **Table** 15.

Table 15: Mechanical components

Description	Material (Standard)	Supplier	Main dimensions (mm)	Quantity	Price (€)	Link
Edge profile	PVC	AKI	15×15/1 (1m)	1	2,69	PVC Edge profile
Radial bearing 6004-2Z	DIN 625	ABS Rolamentos	Ø25xØ42×12	1	4,36	ABS Rolamentos
Radial bearing 6002-2Z			Ø15xØ32×9	1	3,75	
Hinge	Steel	LEROY MERLIN	64x51x3	2	1,89	Hinge
Panel	MDF Wood		800x400x10	1	2,69	MDF Panel
	Flywood		800x400x5	1	2,99	Flywood panel
Plank	Pine tree		900x13x13	2	0,79	Pine plank tree
Hollow section circular profile	Steel	ND	Ø28xØ25 (1m)	1	…	…
Azimuth shaft	Aluminium	ND	Ø22×300	1	…	..
Worm gear	Plastic	KHK	Ø53xØ20×20	1	…	KHK gears catalog
Screw worm gear	Steel		Ø18xØ6×32	1	…	
Tube clamp	Plastic	NORELEM	Ø18	1	1,75	Tube clamp
Sleever reducer	Plastic		Ø18 to 10	1	0,83	Sleever reducer
Hexagonal screw	DIN 933	ND	M6x20	6	0,10	…
Hexagonl nut	DIN 931	ND	M6	6	0,10	..
Flat washer	DIN 125 A	ND	M6	6	0,10	…
Flat cotter	DIN 6885 A	ND	5x5x14	1	0,10	..
Elastic ring	DIN 471	ND	Ø20	2	0,10	…
Shaft spacer	Bronze	ND	Ø24xØ20×10	1	…	..
Elastic coupling	Steel	SDP/MULTIBEAM	Ø6 to Ø8	1	…	…
Trapezoidal threaded rod with flange nut	Steel	RepRap.pt	Tr8x2x300	1	11,80	Trapezoidal rod

7.8 Functionalities

7.8.1 Basic Functionality

The main purpose of the SOSM is reflecting the sun light to one spot. The focus point can be a window to light up a dark room, a garden to provide flowers with more sun or a solar water heater to improve its efficiency. Nevertheless, is not suggested only one function for SOSM, actually the user can find his own application for the heliostat.

7.8.2 Additional Feature

To target users that need more than just more light can be provided with some stickers or covers for the SOSM that will give the produced light spot a specific shape. **Fig.** 51 depicts the exemplary usage of such a cover.

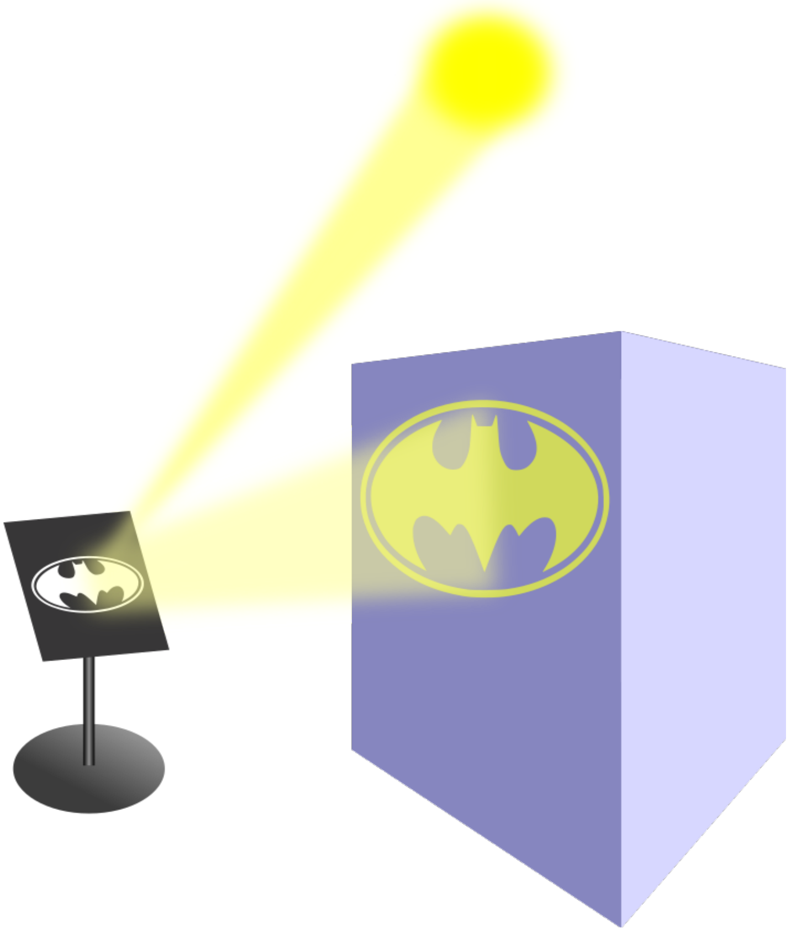

Figure 51: Example of using a sticker to change the shape of reflected light [94]

7.8.3 Use-Case Scenario

After ordering a product and providing with required information (geographical location for the mirror initial setup) the user needs to put the SOSM in a sunny place facing approximately south (for the north hemisphere). The orientation does not have to be that precise, but is recommended as it will allow the mirror to catch more Sun and this way it will not do unnecessary work while the Sun is out of range. After placing it, the user should turn it on and adjust the focus point placement using four buttons (left, right, up and down). This will end the setup face and the SOSM will work on its own. User should monitor whether the mirror is working properly and check LEDs and/or display panel for errors. **Fig.** 52 depicts instructions of how to setup the mirror.

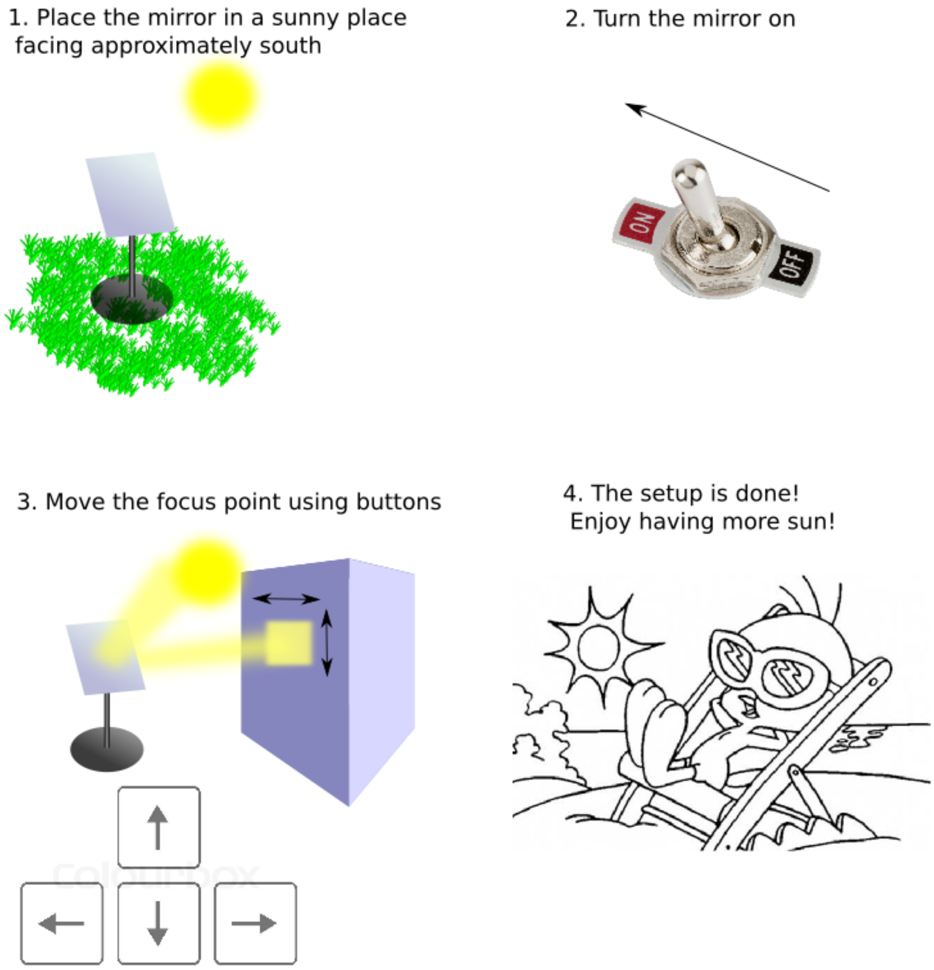

Figure 52: Setup procedure [95][96][97]

9. Annex

9.1 Electric Motors Sizing

One of the most important elements of the machine are the electric motors. These are responsible for providing the system with the needed energy to meet the required movement. Therefore, it will be necessary to analyse the different actions that oppose it, in order to size and select the electric motor available in the market that fits the needs. As is already known, there are two independent movements in the machine, which are discussed below.

9.1.1 Azimuth Movement

For the azimuth movement, those actions that oppose it are:

1. **Friction force**: The friction existing in the bearings of the mechanism, makes that part of the energy cannot be taken advantage of. For the bearings used in the same, the performance of the bearings is assumed to be around **η=0.90** .
2. **Wind load**: Wind is an important factor to consider. Depending on the speed and direction of the same and the position of the mirror as well, there will be a torque that must be countered when the whole system needs to move. To evaluate the effect of the same, EuroCode 1 will be used as a guide.[98]

The wind force F_w acting in the surface of the mirror can be determined directly by using the **equation** [1] :

$$F_w(N) = c_s c_d \cdot c_f \cdot S_f \cdot q_p \cdot A_{ref} \quad [1]$$

Where:

- $c_s c_d$ –Structural factor
- c_f –Force factor for the structural element
- q_p –Peak velocity pressure
- A_{ref} –Wind acts' area
- S_f –Security factor

The detailed procedure for calculating $c_s c_d$ factor can be done applying the **eq.** [2] :

$$c_s c_d = \frac{1+2 \cdot k_p \cdot z_s \cdot \sqrt{B^2+R^2}}{1+7 \cdot z_s} \quad [2]$$

However, for buildings or structures with a height less than 15m the value of $c_s c_d$ may be taken as 1.

- The c_f factor may be taken as 1.
- The S_f factor consider another actions that can not be controlled by the designer. Thus, it is important to oversize the structure, in order to avoid the failure of the same. As design factor, S_f is going to be taken as 2.
- The peak velocity pressure q_p should be determined following the **eq.** [3]:

$$q_p\left(\frac{N}{m^2}\right) = \frac{1}{2} \cdot \rho \cdot v_b^2 \quad [3]$$

Where:

- ρ –Air density (The recommended value is 1.25 kg/m^3)
- v_b –Wind velocity (ms)

The wind velocity design is taken as 25.00 m/s, which is the yellow limit warning in Portugal [99]. According the **eq.** [3], the value of q_p is:

$$q_p\left(\frac{N}{m^2}\right) = \frac{1}{2} \cdot 1.25 \cdot 25.00^2 = 390.63\frac{N}{m^2}$$

The A_{ref} area is the total area where the wind acts. It can be calculated by the **eq.** [4] :

$$A_{ref}(m^2) = b \cdot h \quad [4]$$

Where:

- b−Height of the mirror
- h−Length of the mirror

Applying the **eq.** [4] A_{ref} is equal to:

$$A_{ref} = 0.40m \cdot 0.40m = 0.16m^2$$

Once explained how to determine all the factor involved in the **eq.** [1], it is possible to determine the wind force F_w:

$$F_w(N) = 1 \cdot 2 \cdot 0.16 \cdot 390.63 = 125.00\ N$$

The application's point force *e* is, according to **eq.** [5], at a distance of:

$$e = \frac{h}{10} = \frac{0.40m}{10} = 0.04m \quad [5]$$

Therefore, the necessary torque to move the system in azimuth is, according the eq. [6] :

$$M_T(Nm) = F_w \cdot e = 125.00 \cdot 0.04 = 5.00Nm \quad [6]$$

Considering the losses due to friction in the bearings discussed above, the torque needed at the output of the shaft, according the **eq.** [7], is equal to:

$$M_{T_r}(Nm) = \frac{M_T}{\eta} = \frac{5.00}{0.90} = 5.56Nm \quad [7]$$

It should be noted that this the torque needed **at the output of the azimuth shaft**. Because in order to transmit the movement from the motor to the axis a worm gear is used, the electric motor's torque is calculated taking into account this gear's reduction rate, ***i***. The same. according the **eq.** [8], is equal to:

$$M_{em}(Nm) = \frac{M_{T_r}}{i} = \frac{5.56}{20.00} = 280.00mNm \quad [8]$$

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