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UNIVERSIDADE Ð COIMBRA

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CONCEPTUALIZATION AND MODELLING OF A GATEWAY STRUCTURE FOR SATELLITE COMMUNICATION

Dissertação no âmbito do Mestrado em Engenharia Mecânica, na especialidade de Energia e Ambiente, orientada pela Professora Doutora Ana Paula Betencourt Martins Amaro, e pelo Mestre Paulo Jorge Cunha Antunes e apresentada ao departamento de Engenharia Mecânica da Universidade de Coimbra.

setembro de 2022

1 2 9 0 FACULDADE DE CIÊNCIAS E TECNOLOGIA UNIVERSIDADE Ð COIMBRA

Conceptualização e modelação de uma estrutura de partilha de comunicação com satélite.

A dissertation submitted in partial fulfilment of the requirements for the degree of Master in Mechanical Engineering in the speciality of Energy and Environment

Conceptualization and modelling of a gateway structure for satellite communication.

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SPACEWAY IGNITING CURIOSITY **SPACEWAY**

Coimbra, September, 2022

ACKNOWLEDGEMENTS

The work presented here was only possible thanks to the collaboration and support of some people, to whom I cannot fail to thank for all the support both in the elaboration of this dissertation and throughout my academic career.

To my supervisors who were always present in this last semester, Doctor Professor Ana Amaro and Engineer Paulo Antunes. Thank you for the follow-up and advice in this last phase of my master's degree in mechanical engineering.

Parents, for having transmitted to me the values, to my sister, for having advised and listened to me, to my grandparents for their wisest advice and tireless support, to my soulmate and confidant Diana Sá, who was present in my best and worst moments, and to all my family and friends who, in any case, were essential to my journey.

A special thanks also to the Doctors Professors, Fernando Antunes, Miguel Panão, Miguel Clemente and Fátima Paulino that were always available to questions and suggestions.

Abstract

The main objective of this work is to develop a structure with the purpose of sharing data via satellite in remote locations, so it is done a conceptualization of a structure responsible to hold the necessary components, a solar panel, and a box with hardware.

Considering the wind effect, a design and static simulation were done to evaluate the material, thickness design and connection between structures. Was used the Solidworks® program.

The structure must have a minimum height of 2 m for the antenna location and to collect energy radiation from the sun using solar panels. For the purpose of transportation, the structure must be disassembled into modular components to have a smaller package volume.

The pole is divided into two poles, and the connection between them will be done by pins, this design is simulated together with the thickness and material evaluation. The results lead us to choose a structural steel S275, with a minimum pole thickness of 3 mm, minimum of 40 mm first pole diameter, 10 mm pin diameter and penetration between poles of 50 mm.

The fixture of the structure is also considered in this study. There were three modes possible to fix, a cement shoe, burry the pole around 50 cm in the ground and a base to be filled with sand or water. The cement shoe is not practical but is the best and most reliable way. Burry the pole as seen in the field is not practical. It depends on the soil and demands physical strength. As so, is calculated a base capable of resisting 32.4 m/s of wind velocity.

At last, was made a study of the box of hardware. Being all year exposed to the sun and a big variation of temperature, the inside of the box can get huge temperatures capable of damaging the components inside and getting moister. Thus, studies to improve box ventilation were taken into consideration. A new box design was performed with the purpose of creating a natural airflow and establishing a layout of the components. For this, an initial CAD and printed using a 3D printer. Although not justified to print a full box, being the time of printing too long as was seen, there were some improvements in the component's layout, such as fixing correctly the components, easy access, customization and better heat transfer.

Keywords: Simulation, 3D Printing, Cost, Transportation, usability, Materials.

Resumo

O principal objetivo do trabalho apresentado é desenvolver uma estrutura com a finalidade de compartilhamento de dados via satélite em locais remotos. Assim, é feita a conceptualização de uma estrutura capaz de conter os componentes necessários, um painel solar, e uma caixa com hardware.

Considerando o efeito do vento, foi dimensionada uma estrutura de acordo com os resultados encontrado por simulações à estática, assim como escolhido o material. Para isso foi utilizado o programa Solidworks®.

Esta estrutura deve ter uma altura mínima de 2 m para a localização da antena e para coletar a radiação de energia do sol por meio de painéis solares. Para fins de transporte, a estrutura deve ser desmontada em componentes modulares, de modo a ter um volume de embalagem menor.

O poste é dividido em dois postes, sendo a ligação entre eles feita por pinos, este projeto é simulado juntamente com a avaliação da espessura e do material. Os resultados conduziram à escolha de um aço estrutural S275, com espessura mínima do poste de 3 mm, diâmetro mínimo do primeiro poste de 40 mm, diâmetro do pino de 10 mm e penetração entre os postes de 50 mm.

A fixação da estrutura também é considerada neste estudo. Foram considerados três modos possíveis de fixação, uma sapata de cimento, enterrar o poste cerca de 50 cm no solo e uma base para ser preenchida com areia ou água. A sapata de cimento não é prático, mas é o modo mais seguro. Enterrar o poste como visto no campo não é prático, depende do solo e exige força física. Assim, calculou-se uma base capaz de resistir a 32,4 m/s de velocidade do vento.

Por fim, foi feito um estudo da caixa para colocar o hardware. Estando o ano todo exposto ao sol, e a uma grande variação de temperatura, o interior da caixa pode atingir altas temperaturas capazes de danificar os componentes internos, assim como ganhar humidade. deste modo, estudos para melhorar a ventilação da caixa foram tidos em consideração. Um novo *design* de caixa foi realizado com o objetivo de criar um fluxo de ar natural e estabelecer um *layout* dos componentes. Para isso foi feito um CAD inicial e impresso em impressora 3D. Apesar de não se justificar imprimir uma caixa completa, sendo o tempo de

impressão muito longo como se viu, houve algumas melhorias no *layout* do componente, tal como um bom afixamento, facilidade de montagem, e dissipação de calor.

Palavras-chave: Simulação, Impressão 3D, Custo, Transporte, Materiais.

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1. INTRODUCTION

UNIoT is a self-sustaining edge device enabling the management of remote assets through satellite communication, harvesting data for visualization on the web, making it possible for users to promote well-informed decisions.

The current prototype is not viable in terms of mechanical components, and the objective of this work is to develop a more robust and parameterized solution for the market.

The structure to be developed must have a minimum height of 2 m, minimizing the interference of the antenna with the ground, and ensuring the structure steadiness, which includes solar panels for energy harvesting. For the purpose of transportation, the structure components must be disassembled in modular components to have a smaller package volume and easy shipping.

The UNIoT parts consist of two poles, one with the solar panel support and the other with the hardware box support, a base, a solar panel, and a hardware box.

This study will initially focus on a theoretical simulation making use of finite element simulation. After the dimensioning is performed, Finite Elements Analysis (FEA) will be used to correlate the obtained results. Solidworks® provides a complete set of tools of design and simulation, which ease the iteration of the design, reaching a more robust solution with less effort and money spent. The structure parameters considered are the material characteristics, the diameter of the pole, thickness, and connection design between the poles.

After achieving ideal theoretical solutions, a market study will be done to understand the best price value relation in the market and to choose a company to build the prototype of the structure.

The fixture of the structure is also included in the study. The three possibilities envisioned are a cement shoe, burry the pole around 50 cm in the ground and a base to be filled with sand or water. The current version is to bury the pole in the ground. The pros and cons of each solution will be taken in account to choose the best way.

At last, there will be a study of the box to put hardware. Being continuously exposed to the sun and a big variation of temperature, the inside of the box can get high temperatures capable of damaging the components inside and get moister.

1.1. Objectives

To share the data, collected by various sensors, with satellites, there's a need to design a structure self-sustainable to operate in remote areas, making use of LoRa technology. For this, it is necessary a solar panel, a battery, an electric power manager, and all the electronic components, that read, process and share data, compacted in a box and the support structure.

The previous work by the company, made a prototype of this structure seen the Figure 1.1.

The work being here developed will present a more robust iteration of the structure capable to fill the needs, according to environmental constraints where this product will be deployed.

Figure 1.1. UNIoT.

The points to have in consideration in the new structure are:

- Transportation;
- Environment conditions;
- Price;
- Heat dissipation from the hardware box.

1.1.1. Transportation and assembly

The previous prototype was divided in two, but the connection needed improvement, as shown in Figure 1.2.

Figure 1.2. UNIoT previous conection.

We first considered a screw threaded connection for this connection, but after studying the market solutions, it would be more expensive. Thus, a simpler solution was considered, with a pin connection between poles. After the design and simulation, it will be implemented considering the connection tension

1.1.2. Environment conditions

To assure that the structure is self-sustainable for the long term we must consider the various situations in which it will be implemented, from days with a wide range of temperatures, to heavy rain. For an easier implementation and not to change the soil in the field, it is requested to fix the structure by making use of non-intrusive techniques. For this, a study was performed with a base with volume to the field with sand or water. This means that the structure will not be recessed, and the volume of the support stand should be enough to hold strong winds.

Another field of study is the pole itself. The connection between the two poles has to be analyzed and simulate the response in the most difficult conditions.

The electronic components that are responsible for processing the information, battery, raspberry pi and others, were initially sealed in a box attached to the pole. The heat from the components condensed the water vapor in the air and let them wet. Another issue is on the warmer days, which lead to big temperatures inside the box with no air circulation.

For this reason, it will be studied and designed a box with the purpose to resolve these issues.

1.1.3. Cost

To minimize the productions' cost of this product, and ensure the company's profit, it's needed to clearly define the main goal and related constraints. The structure requires an antenna and an energy module capable of keeping the system working. For this, it is required a solar panel and a battery are established according to the respective dimensioning provided with the electronic components' energetic necessities. It also needed all the components for reading and processing the information.

For the support, two connected poles were chosen. The material and the connection will be decided by understanding what the cheapest and most robust option can withstand the environmental conditions and transportation

1.2. Company

Spaceway, Figure 1.3, is focused on engineering and education solutions. As a technology company, is offered services that are at the forefront of innovation in the areas of IoT (The Internet of Things), Communications and Earth Observation[1]

Figure 1.3. SPACEWAY Logo [1]

IoT is a growing and inevitable paradigm with technical, social, and economic significance. In simple terms, IoT is a network of smart devices connected to the internet. This enables us to remotely (online) manage and monitor entire ecosystems of interconnected services and devices, such as sensors, consumer products and everyday smart home objects, cars, and industrial and health components[1].

UNIoT is a solution to provide IoT satellite connectivity anywhere, Figure 1.4, especially in remote locations. We join the LoRa (Long Range) communication technology with nanosatellites that act as message repeaters or gateways in space[1].

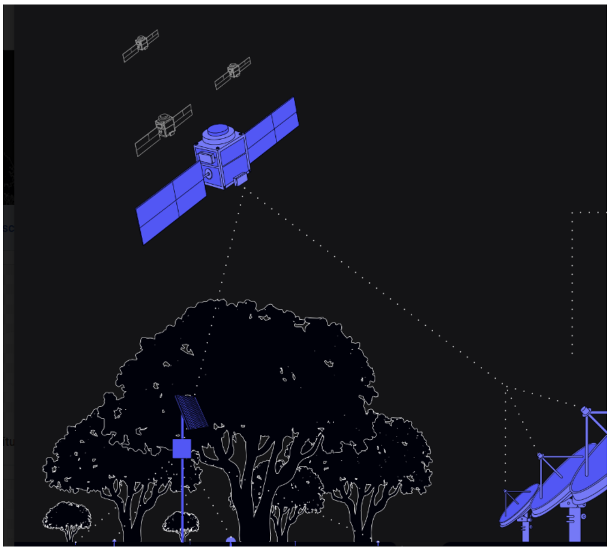

Figure 1.4. UNIoT work concept [1]

UNIoT.Agro device, a smart device for Agriculture 4.0 that uses UNIoT.Space technology integrated with precise, low-power and robust sensors tailored to viticulture and olive farming. UNIoT.Agro will allow us to build a pilot towards a sustainable business case with beta-users and potential customers. This is a demonstrator, but it also has the potential to become our first product or service. The in-situ smart monitoring devices offer an affordable farm wireless solution that can provide important data from remote locations to urban farming **Erro! A origem da referência não foi encontrada.**. Given the interest from our contacts established, it will be specifically developed for vineyards and olive groves[1].

1.3. Internship Value

My contribution within this internship in the company aims to develop a structure, ready to face the existing adversities.

As the core of the company is about the software and communication processes, there is not a structural mechanical engineer, responsible for the study of the components and materials. Being these components exposed to the environment, it is vital to assure stability and sustainability of the device in the years of operation.

As shown in the diagram in the Figure 1.5, the work as engineer in this project goes from a requirement gathering to building a prototype.

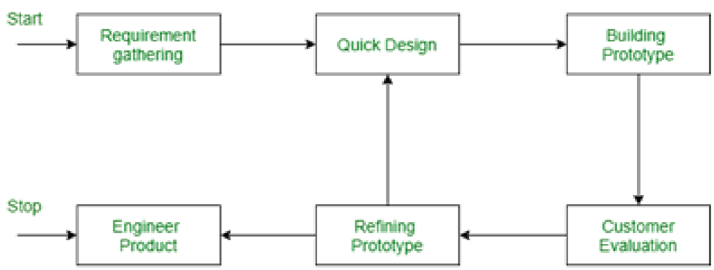

Figure 1.5. Prototype Model.

2. STATIC SIMULATION

This static simulation study aims to dimension a structure that assures sustainability in the worst-case scenario with 32.6 m/s of wind velocity, selected by the burnout table found in Annex A.

After the dimensioning is performed, Finite Elements Analysis (FEA) will be used to correlate the obtained results.

Initially, it was created as a detailed model, but as seen in some tests, meshing the details of the parts not important to the study reveals a much higher time of calculation and errors. In this way, a simpler model for the simulation was done with only the structure with the most decisive stress response.

This model includes only the poles where the hardware box and the panel will be fixed. For this study, there will be into consideration some parameters:

- Pole Dimensions (thickness and diameter);
- Material;
- Connection between the poles, pin diameters;
- Penetration between poles;
- External forces (wind speed, etc).

The first model will be done based on the current prototype deployed, and the mesh will be refined until the results are stable.

After this and according to the results, a study on the influence of the parameters referred will be done, by redesign and validation iteration Figure 2.1.

Figure 2.1. Sumulation cycle[2].

2.1. Structure Features first iteration

This chapter shows the forces considered in the simulation, which are going to be maintained in the other calculations, the dimensions, the fixtures and the material.

2.1.1. Dimensions and parts

.The structure will consist of three parts. The base, Figure 2.2, the first pole, Figure 2.3 and the second pole, Figure 2.4, which will have both the box and the solar panel attached. The dimensions of the first iteration can be seen in the figures 2.2-2.4.

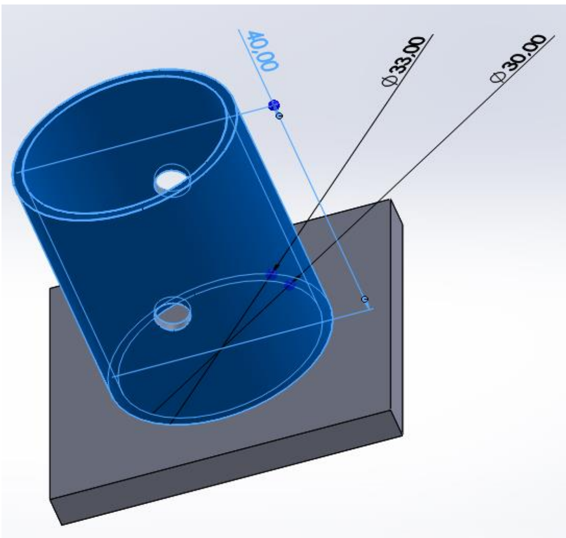

Figure 2.2. Part 1 base.

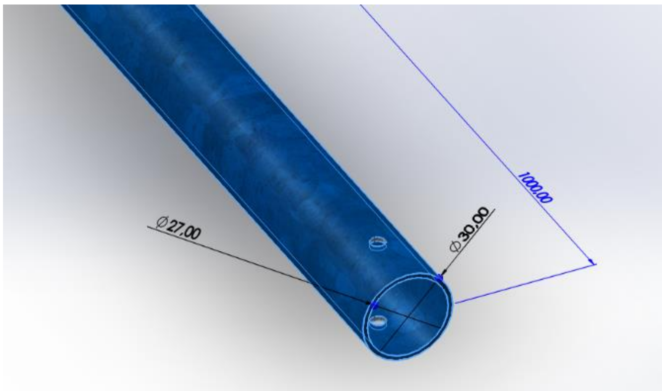

Figure 2.3. Part 2 pole.

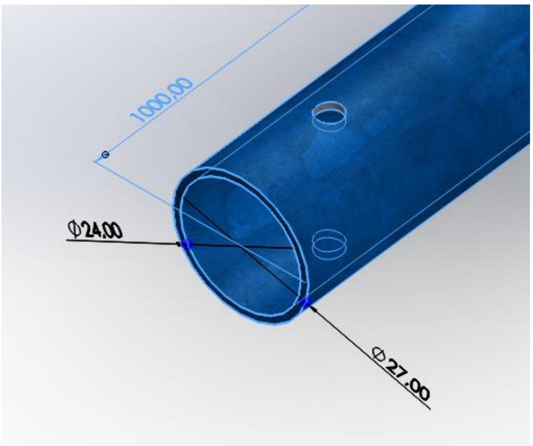

Figure 2.4. Part 3 pole.

Every part has a connection with each other by two pins. This pin is considered initial to have 5 mm in diameter and is located 20 mm from the end of the piece letting the parts penetrate 40 mm between them, Figure 2.5.

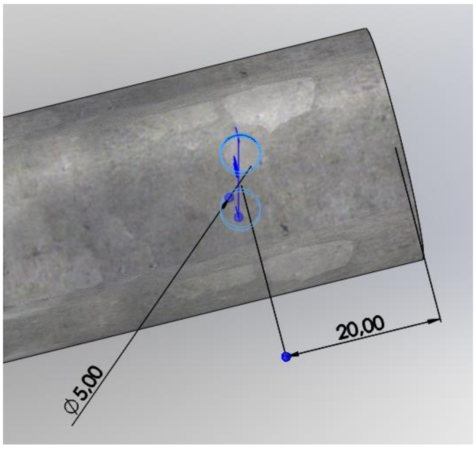

Figure 2.5. Pin dimensions.

2.1.2. External forces

2.1.2.1. Wind pressure in the pole

The wind pressure (P), in the pole is expressed by the equations (2.1), (2.2) and (2.3). This depends on the density of the air (ρ), velocity (v) and drag coefficient (C_D).

$$P = \frac{\rho \times v^2}{2} \tag{2.1}$$

$$P = \frac{1.2754 \times 32.6^2}{2} = 677.72\ Pa \tag{2.2}$$

Applying drag coefficient, final pressure (P_f) comes:

$$P_f = P \times C_D \tag{2.3}$$

$$P_f = 677.72 \times 1.2 = 812.64\ N/m\text{^}2 \tag{2.4}$$

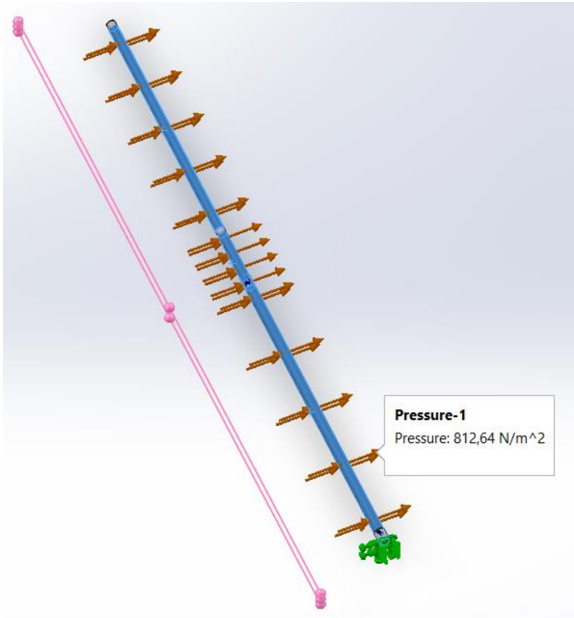

Figure 2.6. Wind pressure in the pole.

2.1.2.2. Wind force in the pannel

To calculate, equation (2.4), the force of the wind in the solar panel (F), certain parameters were taken into consideration, such as area of contact (A), drag coefficient and Pressure, Figure 2.7.

$$F = A \times P \times C_D = 0{,}435 \times 0{,}356 \times \sin(45º) \times 677{,}72 \times 1{,}2 = 88\ N \tag{2.5}$$

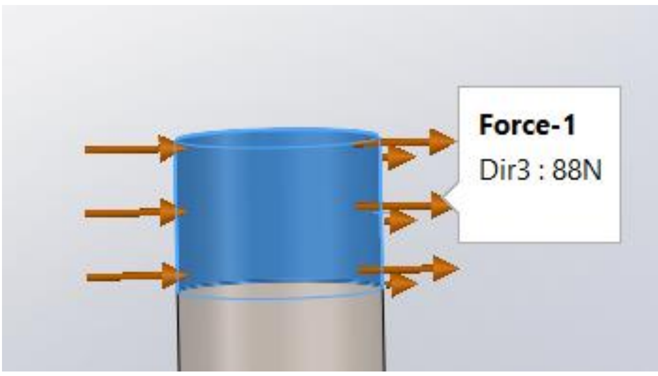

Figure 2.7. Wind force Panel.

2.1.2.3. Wind force in the box

To calculate, equation (2.8), the force of the wind in the box, certain parameters were taken into consideration, such as area of contact, coefficient of drag and Pressure, just like the wind force in the solar panel, Figure 2.8.

$$F = A \times P \times C_D = 0{,}365 \times 0{,}275 \times 677{,}72 \times 1{,}2 = 81\ N \tag{2.6}$$

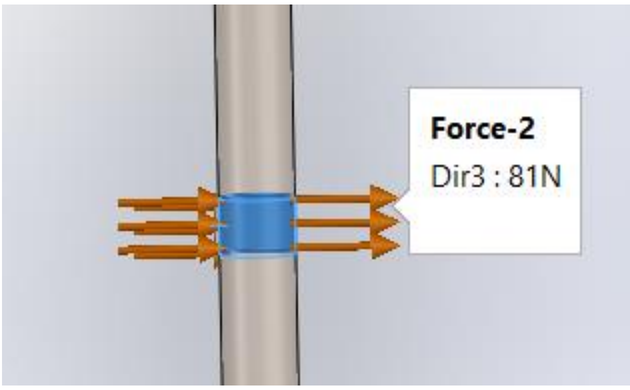

Figure 2.8. Wind force box.

2.1.2.4. Weight of the solar panel and box

It was considered that both the box and the solar panel represent each 50 N. This is a little estimated according to the previous models. The panel model and box hardware can change according to energy studies that are being done at the moment. There is also an assumption taking in account within this step, as the weight of the box is not vertical imputed in the pole, but also creates torque, Figure 2.9.

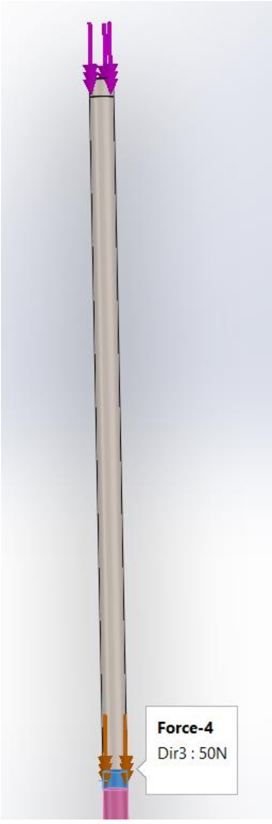

Figure 2.9. Weight of the solar panel and box.

2.1.3. Fixtures

The structure is fixed in the base, as shown in Figure 2.10. This part of the study does not have an account of the way that the structure is fixed in the ground, and this topic is discussed in the chapter, Figure 2.10.

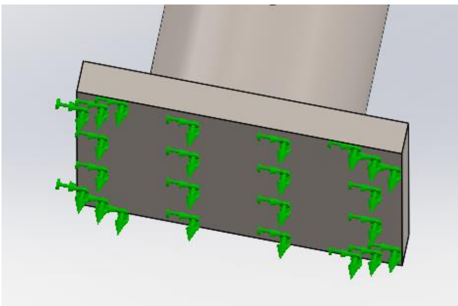

Figure 2.10. Fixtures.

2.1.4. Material

The material chosen for all the parts in the first iteration was alloy steel, from the SolidWorks Library with the properties shown in Figure 2.10.

Property	Value	Units
Elastic Modulus	2.1e+11	N/m^2
Poisson's Ratio	0.28	N/A
Shear Modulus	7.9e+10	N/m^2
Mass Density	7700	kg/m^3
Tensile Strength	723825600	N/m^2
Compressive Strength		N/m^2
Yield Strength	620422000	N/m^2
Thermal Expansion Coefficient	1.3e-05	/K

Figure 2.11. Alloy steel Solidworks library.

2.2. Mesh refinement

Meshing the structure is critical to have either good and valid results as well as to reduce computational time and costs.

In **Erro! A origem da referência não foi encontrada.**, we can see the iterations of the element size, and the parameters that lead us to choose the correct one.

Table 2.1. Element size study.

Mesh element size (mm)	Displacement (mm)	% of elements with aspect ratio <3
8	143.6	11.6
6	163.7	13.4
4	163.2	39.1
3.5	163.3	93.4
3	163.2	98.8
2	163.4	98.9

For this case, the initial mesh element size was 8 mm, and then iterate until it was found to have acceptable values. The increment elements for the area, lead to a significant increase in the calculation time.

Considering these two key factors, it was established a minimum of 90% of elements with an aspect ratio inferior to 3, noticing also that the displacement value did not change a lot from 6 mm element size, as we can see in Figure 2.12.

In conclusion, it is decided to go with 3.5 mm of the element size, being the biggest element size with a % of elements with aspect ratio less than 3 (< 3), Figure 2.13.

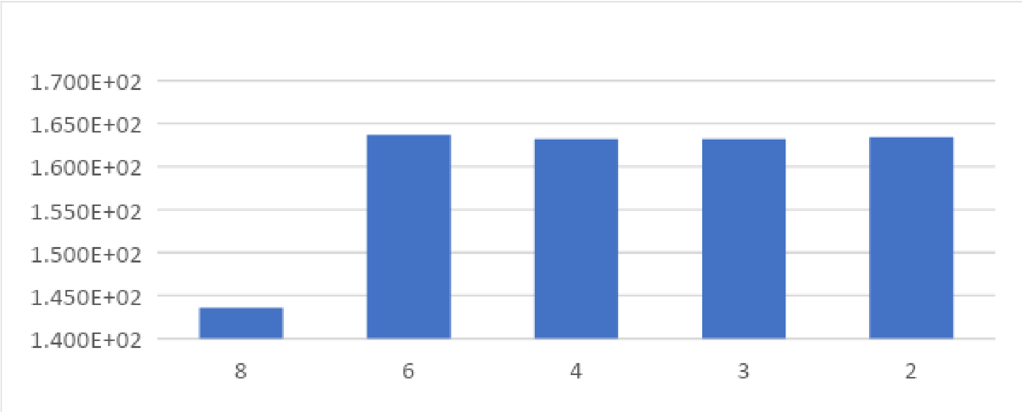

Figure 2.12. Displacement.

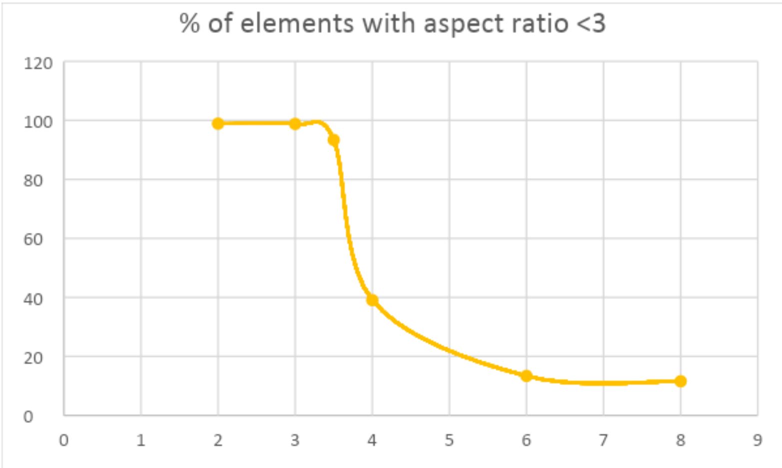

Figure 2.13. % of elements with aspect ratio <3.

2.3. Iteration study

The iteration of the structure design is described in Table 2.2, where we can see the impact of the variation of each parameter.

As mentioned in the main goals of the static stimulation, the parameters are:

- Pole Dimensions (thickness and diameter);
- Material;
- Connection between the poles, pin diameters;
- Penetration between poles.

2.3.1. Materials

Before this study, it was made a previous search in the industry of what dimensions and materials are available that fit the structure, to have.

2.3.1.1. Steel

The material initially was alloy steel from the Solidworks® library. This was the initial phase to choose the mesh parameters and have the first preview.

Some of the benefits of using steel in construction are its versatility, durability, readily, available and affordability.

After the industry search was chosen structural steel for our study. This is a standard construction material made from specific grades of steel and formed in a range of industry-standard cross-section shapes. Structural steel grades are designed with specific chemical compositions and mechanical properties formulated for applications. In Europe, it must comply with the European standard EN 10025 which is governed by the European Committee for Iron and Steel Standardization (ECISS), [3].

Structural steel must be defined using standard symbols. “S” denotes the fact that it is structural steel and the number, for example, 235, that gives the minimum yield strength of the steel (tested at a thickness of 16 mm) in N/mm^2. The yield strength measures the minimum force required to create a permanent deformation in the steel, [3]

This steel is described, by the local companies in question, by longitudinally welded cold formed and no subsequent heat treatment, with a very good price/quality relation. There are three structural steels in the calculations, S235, S275.

2.3.1.2. Polymer of Vinyl Chloride (PVC)

It is also tested PVC (polymer of vinyl chloride) with a bigger thickness. This material is lighter but offers less mechanical strength. For the current paradigm with huge rises in the cost of some materials especially steel, this could be a good choice if it was mechanical acceptable.

2.3.1.3. Aluminium

Aluminium alloy's significant difference from steel materials is the outstanding bare metal corrosion resistance of the 5xxx and 6xxx aluminium materials. Steel must have a coating comprising zinc, nickel, hard chromium, and other components in coating to achieve acceptable corrosion resistance, and this coating is not necessary for aluminium, [4].

Alloy Designations explication, and materials properties used, are described in Annex C.

We are going to test a 6061 and 6063. These two are the most popular extrusion alloys, being the AA6061 the most one. As alloys in the 6000 series, they both have magnesium and silicon as their primary alloying elements. Thus, they have many similar properties. AA6061 offers higher strength; however, it is often used for more structural applications, [5].

On the other hand, AA6063, is used for applications such as railing or trim, windows, and doors, due to its better appearance and corrosion resistance.

A range of heat treatments can be applied to aluminium alloys. A table of the description of each one of these treatments can be found in annexe C. It is going to be tested T4 and T6, respectably solution heat-treated and naturally aged to a substantially stable condition, and solution heat-treated and artificially aged,[6], [7].

2.3.2. Dimensions

The diameter and thickness of the structure have a huge impact on all structural mechanical resistance. As will be seen in the tests the critical point is in the lower part of the bottom pole.

The diameter of the bottom pole will be 40 mm and the thickness will range values from 1.50 mm to 4.00 mm.

The values of the pin diameter will be tested from 5 to 10 mm according to the results.

The penetration between poles range from 40 mm to 60 mm.

2.3.3. Criterion

In table 2.2 we can see a resume of the parameter's modification, yield strength and max stress annotation by von mises.

The von Mises stress is a criterion for yielding, widely used for metals and other ductile materials. It states that yielding will occur in a body if the components of stress acting on it are greater than the criterion. Is based on the von Mises-Hencky theory, also known as the Shear-energy theory or the Maximum distortion energy theory, [8].

The theory states that a ductile material starts to yield at a location when the von Mises stress becomes equal to the stress limit.

In terms of principal stresses σ_1, σ_2, σ_3, the von Mises stress is expressed as in the expression 2.6.

$$\boldsymbol{\sigma_{vonMises}} = \{[(\boldsymbol{\sigma_1} - \boldsymbol{\sigma_2})^2 + (\boldsymbol{\sigma_2} - \boldsymbol{\sigma_3})^2 + (\boldsymbol{\sigma_1} - \boldsymbol{\sigma_3})^2]/2\}^{1/2} \tag{2.7}$$

Table 2.2. Results of the simulations.

Iteration	Materials	Thickness (mm)	Pin diameter (mm)	Penetration poles (mm)	Max Stress Annotation (MPa)	Yield Strenght (MPa)
1	Alloy steel	1.50	5.00	40.00	2166	620
2	S235	4.00	10.00	40.00	229	235
3	S235	3.00	10.00	40.00	244	235
4	PVC	4.00	10.00	40.00	230	0.0423
5	S275	3.00	10.00	40.00	250	275
6	AA 6063 T6	3.00	10.00	40.00	223	215
7	AA 6063 T6	3.00	10.00	50.00	205	225
8	S275	3.00	10.00	50.00	217	275
9	AA 6061 T6	3.00	10.00	50.00	190	275

The elastic limit defines the region where energy is not lost during the process of stressing and straining. That is, the processes that do not exceed the elastic limit are reversible. This limit is also called yield stress. Above that limit, the deformations stop being elastic and start being plastic, and the deformation includes an irreversible part, [8].

The results can be seen in the appendix A, with photos and details of each change.

2.3.4. Results

In the beginning, it started to test alloy steel with 1.50 mm of thickness, this resulted in a non-valid solution which take us to the next iteration, a 4 mm thickness with a S235 alloy steel and 10 mm pin diameter. This in fact a valid solution. The pin diameter dimension is going to be fixed for the rest of the study.

Right now, we can understand and have a better perspective of what range of values are we in. In the market, the stock of already standardized alloy and aluminium tubes, the biggest thickness is around 3.2mm.

In this way, it is tested with the same alloy steel S235, but with 3 mm of thickness, taking us to a non-valid solution again. In this way, it requires testing an alloy with bigger minimum yield strength.

The S275 shows a valid solution with dimensions that make sense with the market inventory.

The next step is to try aluminium alloys. The AA6063 T6 with the same dimensions as before is not a valid solution, which leads us to try to increase the gap of penetration between poles from 40 mm to 50 mm. With this small improvement we have also a valid solution in aluminium.

For the S275 is also increased in the same way the gap, which led us to solution with a bigger margin of confidence.

The Aluminium AA6061 has better properties for this structure, as we can see in the Table 2.2.

Both alloys S275 and AA6061 are good choices for this project in the way that both are mechanical and capable to resist imposed conditions. Considering that the price of the aluminium is around 10-15% higher than the steel, in this phase of the project are choosing to go with the Steel alloy S275.

3. STRUCTURE FIXTURE

The UNIoT, is an autonomous device that provides robust satellite communication from remote locations, ensure network connectivity to IoT devices. For this purpose, it's required a support structure to withstand hostile conditions such as strong winds and high temperature amplitudes. To ease the installation of this device, it's intended to fix the structure to the ground.

3.1. Requirements and specifications

The dimensioning provided were established for the worst environmental conditions, including wind velocity and angle of incidence on the box of the solar panel because it will get the most possible area of contact, Figure 3.1.

To choose the wind value, it was used the Beaufort wind scale on land. Attached is the annexe. In this label was chosen the violent storm category, with 32.6 m/s of wind speed. This category was chosen to ensure a safety interval, considering that small trees start to blow up at 24.4 m/s.

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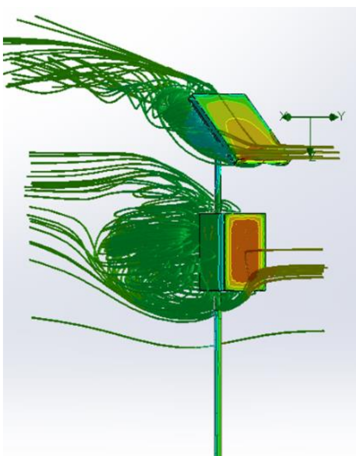


Figure 3.1. UNIoT flow simulation.

The force in consideration is the wind normal to the faces as shown in figure 3.1, from flow simulation in Solidworks® and the weight of all the components.

The requirements and specifications to study are:

- easy assemble;
- hold winds of 32.6 m/s;
- implement the structure in natural areas, with non-intrusive techniques;
- weight of the components (solar panel, poles and hardware box).

3.2. Hypotheses and assumptions

There were three solutions considered to fix the structure in the ground:

- Cement shoe;
- Bury the structure 50 cm in the ground without any fixing additives;
- Create a base to be filled with sand at the implementation site.

The first option has the problem that is not practical for the consumer to make a foundation in the field and one of the goals of the structure is easy assembly. Nevertheless, it is the best way to fix the structure on the ground as it provides a more robust base, able to withstand harsh conditions.

The second option was already used in previous prototypes. The vantage of this the simplicity of not requiring any extra parts. But, as experienced, it is not easy to bury 50 cm of the structure, and this process is a lot dependent on the soil quality. As the pole is circular it also lets the freedom to rotate.

The last and third option needs extra parts, but it is easy to assemble. In the next chapter, the calculations and the design of this structure will be provided.

3.3. Calculations

The force of the wind will be calculated taking into consideration the area of contact. The wind force will be applied normal to the surface of Figure 3.2, maximizing the contact area, as explained before.

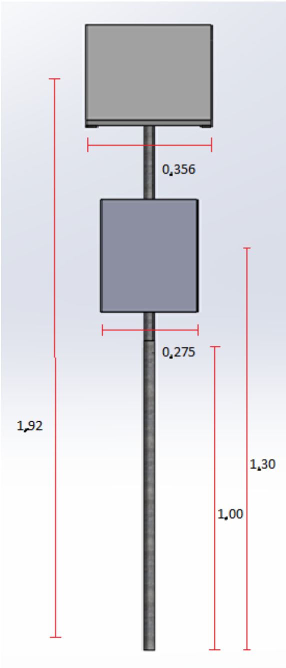


Figure 3.2. UNIot measures.

All the calculations are described in in appendix B.

The results lead us to a base with 70 kg, 0.4 m of width and 33 mm of height.

3.4. Design

It was idealized and design a structure of the base according to the results as we can see in Figure 3.3 and Figure 3.4. For this phase and having identical bases in the market, like a base for a parasol, it was decided to select a base of the market and implement it in the structure.

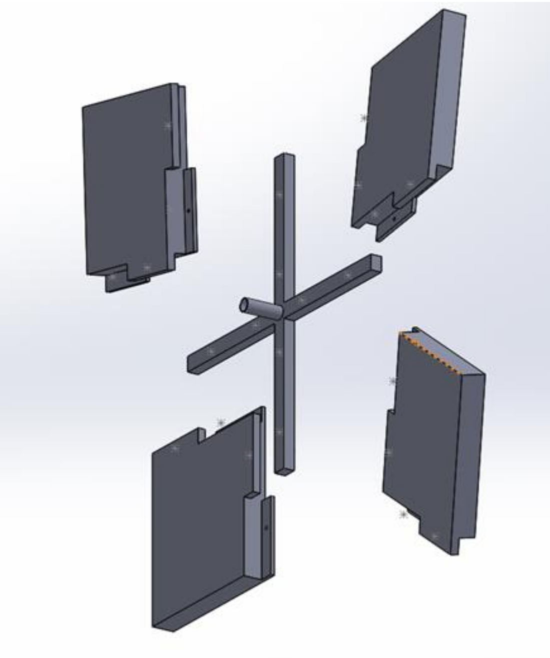


Figure 3.3. Base disassembly.

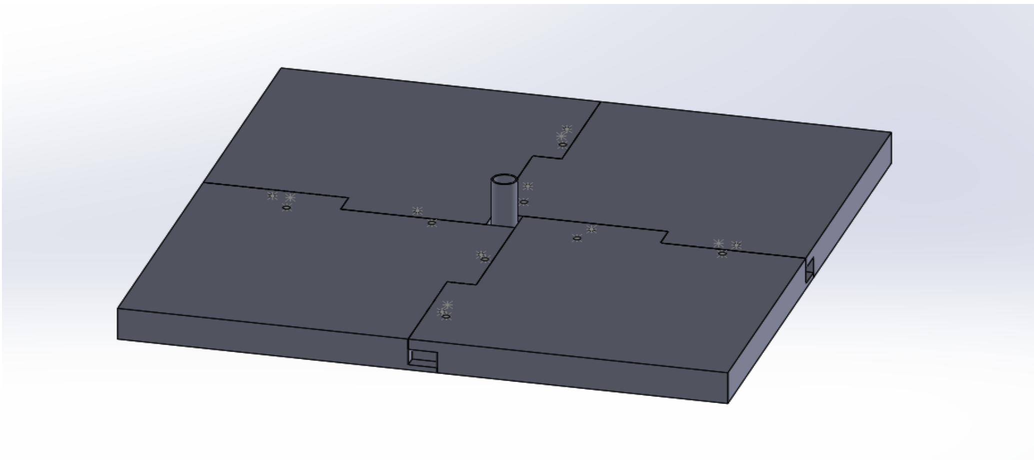


Figure 3.4. Structure base

4. STRUCTURE PRODUTION

The structure is going to be built according with the solutions found in the static simulation and the structure fixture, but with the difference of having the box in the lower pole. This was done because there was no more need to put the box higher for the antenna,

After some company research, we choose to go with COBEL - Contruções Eletro-Mecânicas da Beira SA.

The CAD (computer aided design) of the structure and some details can be seen in can be seen in Figure 4.1, Figure 4.2 and Figure 4.3.

Figure 4.1. UNIoT production CAD.

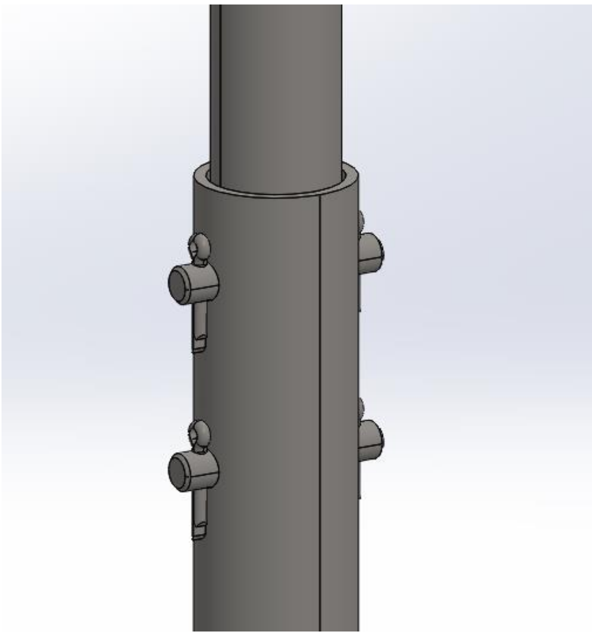


Figure 4.2. UNIoT production connection.

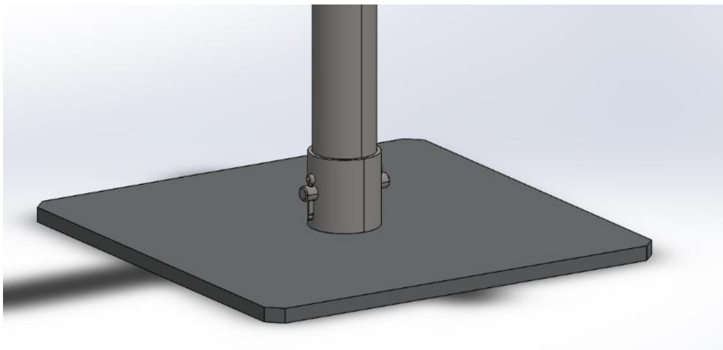


Figure 4.3. UNIoT base production.

The prototype already built, can be seen in the Figure 4.4 and Figure 4.5.

Figure 4.4. UNIoT final structure.

Figure 4.5. UNIoT base.

5. BOX HARDWARE

As said before the hardware box is responsible for holding the electronic components as well to protect them from the outside climate damage. This chapter aims to develop features to improve and assure the good maintenance and work of all components.

5.1. 3D Printing

3D printing is a type of “additive” production, where a three-dimensional object is ‘printed’ (built) by adding layer after layer of a specific material, which differs from the most usual “subtractive” (when an object is carved out of a block of raw material) or moulding/die-casting (when molten material is injected into a solid mould) types of producing, [9].

This production process has some advantages compared with the traditional manufacturing methods, such as:

- Flexible design;
- Rapid prototyping;
- Print on demand;
- Strong and light parts;
- Fast design and production;
- Minimising waste;
- Cost effective;
- Ease to access;
- Environmentally friendly.

Cons of 3D printing:

- Not homogeneous part structure;
- Limited materials;
- Restricted built size;
- Large Volumes;
- Design inaccuracies.

With this in mind the box seems to not be worth to print in 3D, being this structure something that we can find similar, easily on the market with low cost.

5.1.1. 3D Printing materials

Fused deposition modelling (FDM), also known as fused filament fabrication (FFF), is the most widely used form of printing at the consumer level, fuelled by the emergence of hobbyist 3D printers, [10].

Some of the most popular FDM 3D Printing Materials taking are:

- ABS (acrylonitrile butadiene styrene);
- PLA (polylactic acid);
- PETG (polyethylene terephthalate glycol);
- Nylon.

In Table 5.1, we can see the comparative relation between these four materials, in terms of strength, durability, flexibility, ease of use, resistance, safety and price. Being "1" the lowest score and "5" the biggest.

Table 5.1. 3D materials comparation, [10].

Materials	Strength	Durability	Flexibility	Ease of Use	Resistance	Safety	Price
PLA	2	1	1	5	2	5	5
ABS	3	4	3	3	4	2	5
PETG	4	4	4	4	4	4	4
Nylon	5	5	5	2	5	1	1

The material choose to this study was PETG having good benefits in every area, and having waterproof applications.

5.2. Passive heat transfer

The structure, as mentioned, is going to be exposed to the sun, and subsequently to great temperatures. The electronic components produce heat from their own working process, together with the heat from the radiation and convection, which could lead to extreme temperatures that can arm the components.

For example, the raspberry pi should not pass 85ºC, which can be reached in a closed office. Apply ventilation should be the best and easy way to manage this issue, but the energy supply is also a key factor here. Being in a remote area, the only source of energy is captured from the sun's radiation and stored in a battery. Therefore, the energy should not be wasted in anything more than the work of the components themselves.

A passive heat transfer of energy is the best way to try to deal with this issue.

First, one of the biggest ways of gaining heat is from the radiation, therefor the box should reflect the maximum of radiation. For this, was choose to have a white box.

Second, the way that the components are placed inside the box, can be a key factor to have the best air-cooling convection. Also, if close to the box walls, can gain heat from conduction as well.

For last, a way to remove heat could be to have a passive way of convection. For this it would be required an area to enter air from bellow, and other to remove the heat from up. A natural upwards heat transfer would be created. It must have in consideration the possibility of entering water from the rain.

5.2.1. Box printing study

All the components were crated with the printer Prusa i3mk3.

The first step was to create a model scale of the box. To do it was creating a box with the intake and outtake vents. This was also built with a roof to reduce the impact of the rain and don´t accumulate waste.

Was done a study that help us understand what would be the cost and time of producing this box. If worth it, it could be interesting to have a more customized box made to suit our goal. Have into consideration that the production of this box would be on a very small scale. The values that we can see in the Table 5.2, describe the cost, the weight and the time of the box with the thickness of 2.0; 3.0 and 3.5 (mm). These values were found by using the Prusa Slicer software, [11].

Table 5.2. Box printing study.

e (mm)	m(g)	Filament cost (€)	Energy cost(€)	Total cost (€)	Time (h:min:sec)
2.0	384.12	13.44	0.60	14.04	30:13:00
3.0	400.04	14.00	0.63	14.63	31:42:00
3.5	411.95	14.42	0.66	15.08	32:46:00

As a preliminary study and to understand the implications of this design was made a scale box 1:3 as we can see in Figure 5.1.

The conclusion was that the printing of a 3D box is not viable to do. Is a large object, with a not very difficult design and we can easily find similar in the market. Besides, the printing of such a big component is too much unpredictable to have a good print.

Figure 5.1. 3D printed scale box.

5.3. Components layout

For battery placement, it was furcal to make it steady in the middle of the box, as is the heaviest component. For that were created supports to holt it in the position pretended, Figure 5.2. In the production phase we can see that there is also a fixture with screw with this supports and a screw hole that already existed in the box, Figure 5.8. Being so, the box is completely stable.

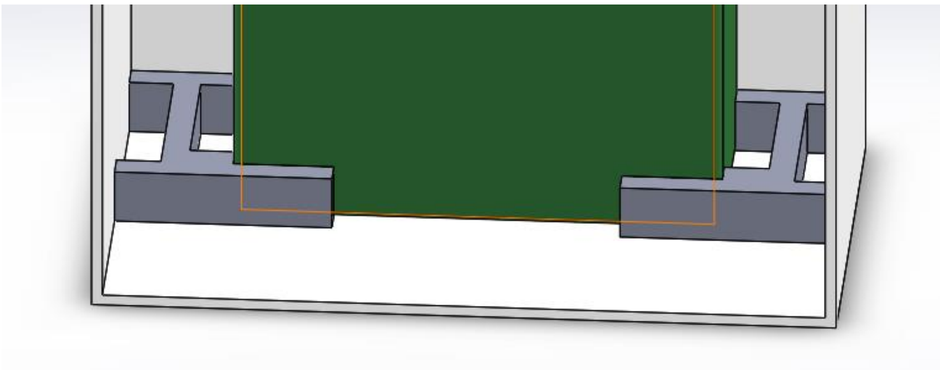


Figure 5.2. Battery suports.

For the rest of the components, it was created a removable platform, which offers a good position in the middle of the box for a better heat behaviour as to customize and easy access of all time, Figure 5.3.

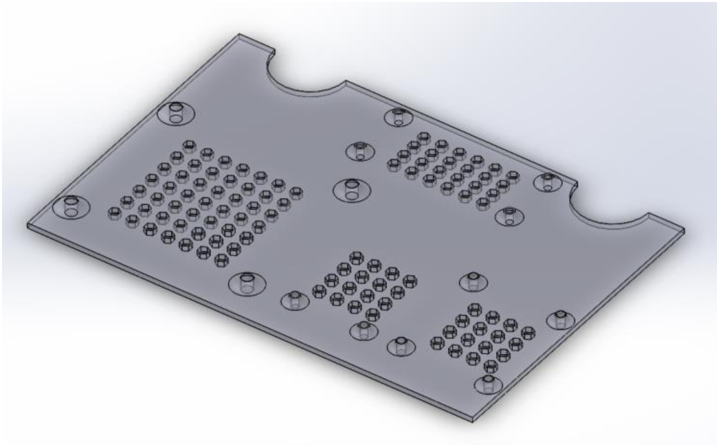


Figure 5.3. Box platform.

In the Figure 5.4 and Figure 5.5, it is possible to see how the components are positioned with the supports.

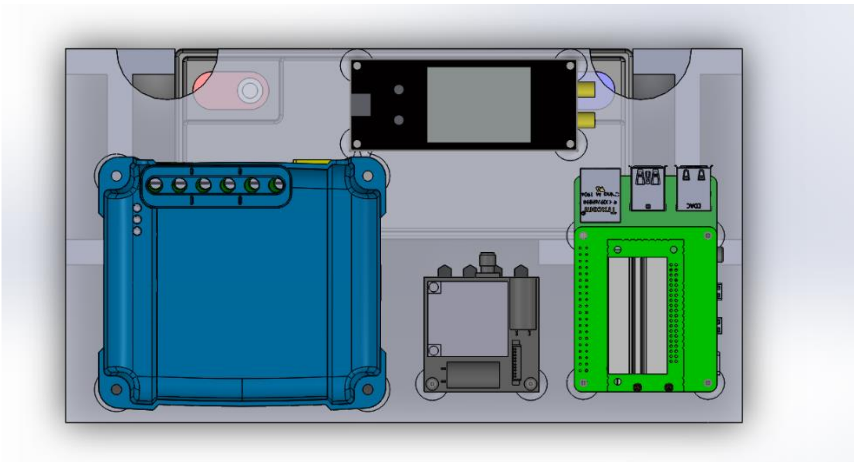


Figure 5.4. Components assembly.

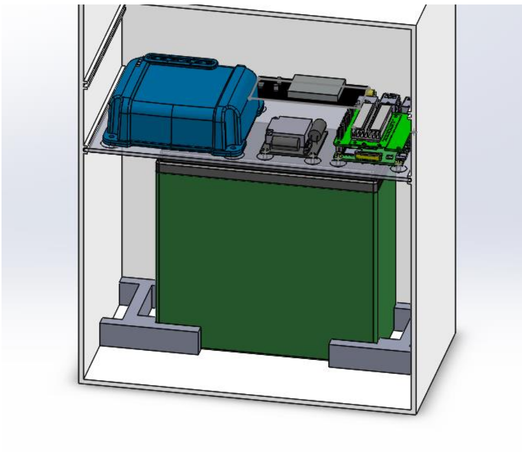


Figure 5.5. Box assembly.

In the box (module KVOM 2311), there is a depression between the entrance and side walls, so the drawer rails need have this in consideration, Figure 5.6.

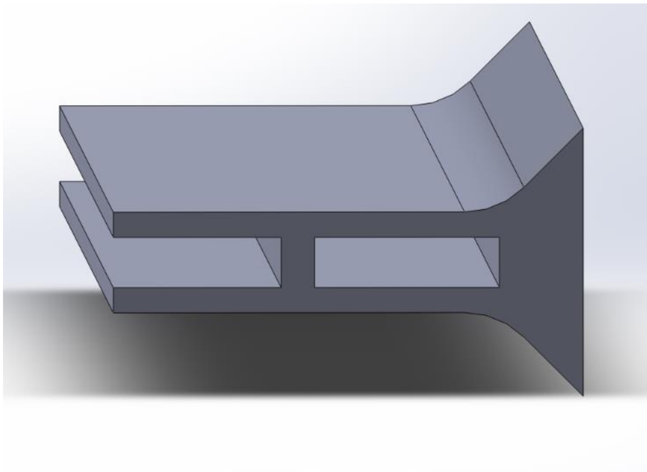


Figure 5.6. Drawer rails.

The costs, time and weight of each print can be seen in the Table 5.3.

Table 5.3. Print time, weight and costs.

	m(g)	Filament cost	Energy cost	Total cost	Time (h:min)
Drawer rails	51.94	1.88 €	0.12 €	2.00 €	5:50
Battery suports	44.8	1.62 €	0.10 €	1.72 €	4:54
Plataform	112.51	4.08 €	0.20 €	4.28 €	10:01

In the Figure 5.7, Figure 5.8 and Figure 5.9, it is possible to see the results of this implementations, with all the components layout inside.

Figure 5.7. Box layout.

Figure 5.8. Box layout.

Figure 5.9. Box layout.

6. CONCLUSIONS

The present work was done with the goal of developing and improve the structure of UNIoT. This aimed the structure support, the fixture, and the box holding the electronic components. In each part was done a previous study or simulations to understand and choose the final products. In each case was suggested and created a different feature for a better work, usability, and efficiency.

6.1. Pole

The final solution was good in function as well in design. Besides the correct work, it was noticing a slight slack in the connections. It was implemented a small O-ring to reduce the movement, but, if it proves in the future that is not viable, it must be chosen other solution to connect the structure, like for example a double male bushing.

Another point to have in consideration is the weight of the structure. Despite the steel being one of the best and cheap option, the final structure was a little heavy. If it proves in the future that, it is a furcal point for the consumer usability, it might be interesting think in other options, like the Aluminium Alloy showed, AA6061.

6.2. Fixture

The fixture of the structure implement was not the correct according to our calculations. This, because to have a first iteration, it was chosen a cheapest version.

There was difficulty to implement it in the pole because the thickness was smallest than the pole. Beside this, was implemented with success.

The next step is to choose a base according with the values achieved.

6.3. Box Hardware

The goals with the box of hardware were not all achieved. The 3D printing proved to be not worth it for the full box, and the vents were not implemented subsequently.

There were still some good improvements in the assembly of the components inside the box. The platform was proven to be versatile and ease of use. The connection between drawer rails and the platform were a little tight, and so, the next module should be done with a little more tolerance.

REFERENCES

[1] "Spaceway - O Novo Caminho para o Espaço." https://pt.wearespaceway.com/ (accessed Sep. 01, 2022).

[2] "The Value of Simulation: Which Design is the Best?" https://blogs.solidworks.com/solidworksblog/2020/04/the-value-of-simulation-which-design-is-the-best.html (accessed Sep. 02, 2022).

[3] "Structural Steel - S235, S275, S355 Chemical Composition, Mechanical Properties and Common Applications." https://www.azom.com/article.aspx?ArticleID=6022 (accessed Jul. 07, 2022).

[4] "Aluminium: Specifications, Properties, Classifications and Classes." https://www.azom.com/article.aspx?ArticleID=2863 (accessed Jul. 07, 2022).

[5] "Different Types of Aluminum Grades - A Thomas Buying Guide." https://www.thomasnet.com/articles/metals-metal-products/types-of-aluminum/ (accessed Jul. 08, 2022).

[6] R. A. Yildiz and S. Yilmaz, "Stress–Strain Properties of Artificially Aged 6061 Al Alloy: Experiments and Modeling," *J Mater Eng Perform*, vol. 29, no. 9, pp. 5764–5775, Sep. 2020, doi: 10.1007/S11665-020-05080-6/FIGURES/11.

[7] "6061 Aluminum: Get to Know its Properties and Uses - Gabrian." https://www.gabrian.com/6061-aluminum-properties/ (accessed Jul. 07, 2022).

[8] "What is Von Mises Stress in FEA? | SimWiki | SimScale." https://www.simscale.com/docs/simwiki/fea-finite-element-analysis/what-is-von-mises-stress/ (accessed Jul. 11, 2022).

[9] "What is 3D printing? How does a 3D printer work? Learn 3D printing." https://3dprinting.com/what-is-3d-printing/ (accessed Sep. 12, 2022).

[10] "PLA vs ABS vs PETG vs Nylon – 3D Printer Filament Comparison – 3D Printerly." https://3dprinterly.com/pla-vs-abs-vs-petg-vs-nylon/ (accessed Aug. 28, 2022).

[11] "3D Printing Price Calculator - Original Prusa 3D Printers." https://blog.prusa3d.com/3d-printing-price-calculator_38905/ (accessed Aug. 30, 2022).

[12] "Escala de Beaufort – Companhia da Escalada." https://companhiadaescalada.com.br/secao-tecnica/artigo-dicas-tecnicas-escalada/escala-de-beaufort/ (accessed Sep. 11, 2022).

ANNEX A

Table 6.1. Escala de Beaufort, [12]

Grau	Designação	nós	km/h	m/s	Aspecto do mar	Efeitos em terra
0	*Calmaria*	<1	<2	<1	Espelhado	Fumaça sobe na vertical
1	*Bafagem*	1 a 3	2 a 6	1 a 2	Pequenas rugas na superfície do mar	Fumaça indica direcção do vento
2	*Aragem*	4 a 6	7 a 11	2 a 3	Ligeira ondulação sem rebentação	As folhas das árvores movem; os moinhos começam a trabalhar
3	*Fraco*	7 a 10	13 a 19	4 a 5	Ondulação até 60 cm, com alguns *carneiros*	As folhas agitam-se e as bandeiras desfraldam ao vento
4	*Moderado*	11 a 16	20 a 30	6 a 8	Ondulação até 1.5 m, *carneiros* frequentes	Poeira e pequenos papéis levantados; movem-se os galhos das árvores
5	*Fresco*	17 a 21	31 a 39	9 a 11	Ondulação até 2.5 m, muitos *carneiros*	Movimentação de árvores pequenas; superfície dos lagos ondula
6	*Muito Fresco*	22 a 27	41 a 50	11 a 14	Ondas grandes até 3.5 m; borrifos	Movem-se os ramos das árvores; dificuldade em manter um guarda chuva aberto
7	*Forte*	28 a 33	52 a 61	14 a 17	Mar revolto até 4.5 m com espuma e borrifos	Movem-se as árvores grandes; dificuldade em andar contra o vento
8	*Muito Forte*	34 a 40	63 a 74	17 a 21	Mar revolto até 7.5 m com rebentação e faixas de espuma	Quebram-se galhos de árvores; circulação de pessoas difícil
9	*Duro*	41 a 47	76 a 87	21 a 24	Mar revolto até 9 m; borrifos afectam visibilidade	Danos em árvores; impossível andar contra o vento
10	*Muito Duro*	48 a 55	89 a 102	25 a 28	Mar revolto até 12 m; superfície do mar branca	Árvores arrancadas; danos na estrutura de construções
11	*Tempestade*	56 a 63	104 a 117	29 a 32	Mar revolto até 14 m; pequenos navios sobem nas vagas	Estragos abundantes em telhados e árvores
12	*Furacão*	>64	>119	>33	Mar todo de espuma; visibilidade nula	Grandes estragos

ANNEX B

Property	Value	Units
Elastic Modulus	2.1e+10	N/m^2
Poisson's Ratio	0.3	N/A
Shear Modulus	8.1e+10	N/m^2
Mass Density	7850	kg/m^3
Tensile Strength	435000000	N/m^2
Compressive Strength		N/m^2
Yield Strength	235000000	N/m^2

Figure 6.1. S235 properties.

Property	Value	Units
Elastic Modulus	2.1e+10	N/m^2
Poisson's Ratio	0.3	N/A
Shear Modulus	8.1e+10	N/m^2
Mass Density	7850	kg/m^3
Tensile Strength	450000000	N/m^2
Compressive Strength		N/m^2
Yield Strength	275000000	N/m^2

Figure 6.2. S275 properties.

Property	Value	Units
Elastic Modulus	2410000000	N/m^2
Poisson's Ratio	0.3825	N/A
Shear Modulus	866700000	N/m^2
Mass Density	1300	kg/m^3
Tensile Strength	52000000	N/m^2
Compressive Strength		N/m^2
Yield Strength	45800000	N/m^2

Figure 6.3. PVC

Property	Value	Units
Elastic Modulus	6.900000067e+10	N/m^2
Poisson's Ratio	0.33	N/A
Tensile Strength	124999998.5	N/m^2
Yield Strength	62052815.64	N/m^2

Figure 6.4. SS6061(0)

Property	Value	Units
Elastic Modulus	6.900000067e+10	N/m^2
Poisson's Ratio	0.33	N/A
Tensile Strength	310000002.1	N/m^2
Yield Strength	275000000.9	N/m^2

Figure 6.5. SS6061(T6)

Property	Value	Units
Elastic Modulus	6.9e+10	N/m^2
Poisson's Ratio	0.33	N/A
Shear Modulus	2.58e+10	N/m^2
Mass Density	2700	kg/m^3
Tensile Strength	90000000	N/m^2

Figure 6.6. SS6063(0)

Property	Value	Units
Elastic Modulus	6.9e+10	N/m^2
Poisson's Ratio	0.33	N/A
Shear Modulus	2.58e+10	N/m^2
Mass Density	2700	kg/m^3
Tensile Strength	240000000	N/m^2

Figure 6.7. SS6063(T6)

ANNEX C

Table 6.2. Designations alloy steels

1Xxx	Carbon Steels
13xx	Carbon-Manganese Steels
2Xxx	Nickel Steels
3Xxx	Nickel-Chromium Steels
4Xxx	Molybdenum Steels
41xx	Chromium-Molybdenum Steels
43xx	Nickel-Chromium-Molybde-num Steels
4340	Nickel-Chromium-Molybde-num Steel With 0.40 Percent Carbon
5Xxx	Chromium Steels
6Xxx	Chromium-Vanadium Steels
7Xxx	Tungsten-Chromium Steels
86xx	Nickel-Chromium-Molybde-num Steels (Less Nickel than 43xx)
9Xxx	Silicon-Manganese Steels

Table 6.3. Designations for wrought aluminium alloys

Alloying Element	Wrought
None (99%+ Aluminium)	1XXX
Copper	2XXX
Manganese	3XXX
Silicon	4XXX
Magnesium	5XXX
Magnesium + Silicon	6XXX
Zinc	7XXX
Lithium	8XXX

Table 6.4. Heat treatment designations for aluminium and aluminium alloys [4]

Term	Description
T1	Cooled from an elevated temperature shaping process and naturally aged.
T2	Cooled from an elevated temperature shaping process cold worked and naturally aged.
T3	Solution heat-treated cold worked and naturally aged to a substantially.
T4	Solution heat-treated and naturally aged to a substantially stable condition.
T5	Cooled from an elevated temperature shaping process and then artificially aged.
T6	Solution heat-treated and then artificially aged.
T7	Solution heat-treated and overaged/stabilised.

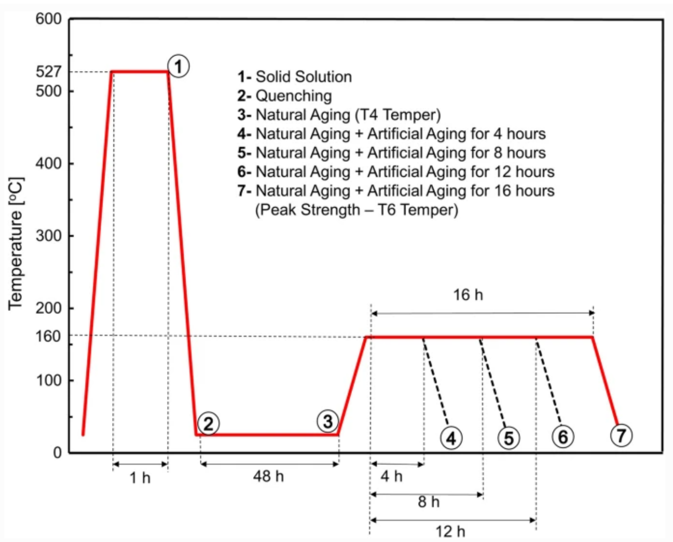


Figure 6.8. Heat treatment procedures for the Al-Mg-Si alloy [6].

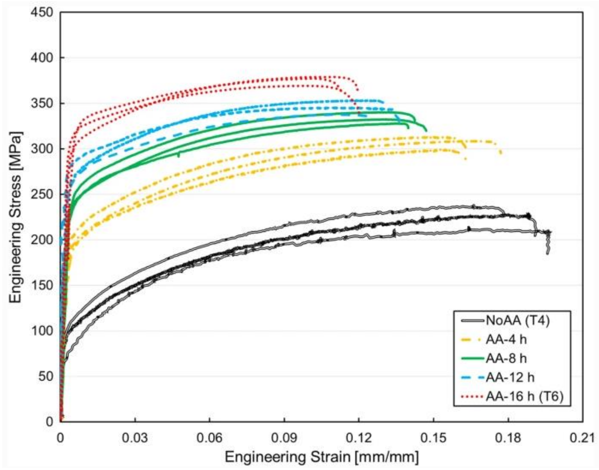


Figure 6.9. Engineering stress–strain curves of the 6061 aluminum alloy specimens tested [6].

APPENDIX A

First iteration, alloy steel Solid works Library simulation.

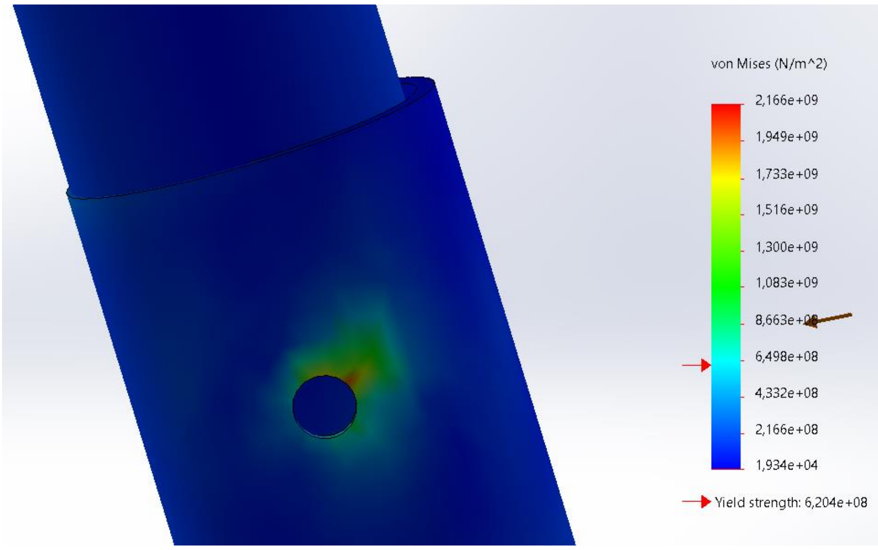


Figure 6.10. Alloy steel SolidWorks Library simulation.

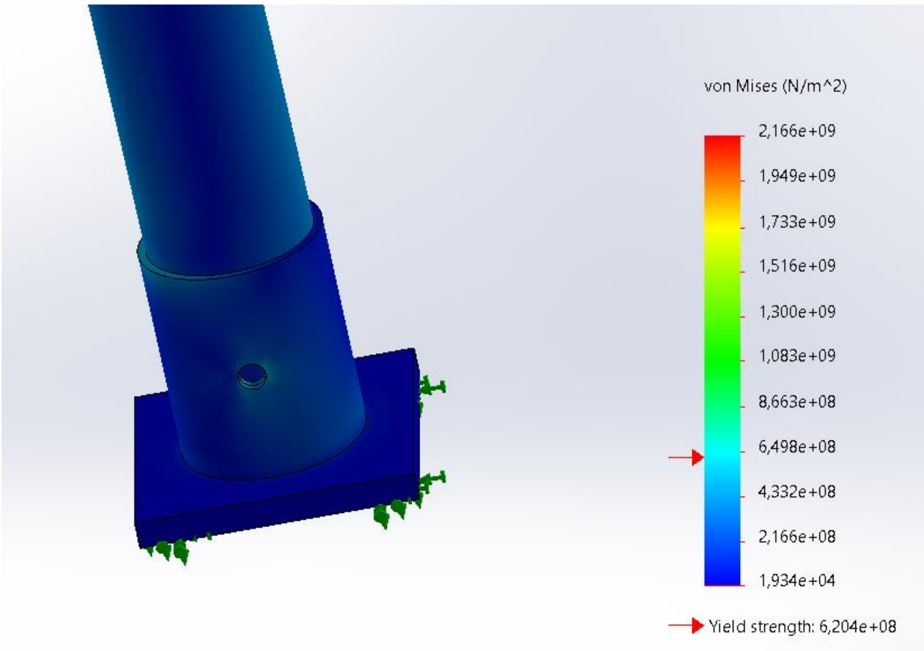


Figure 6.11. Alloy steel SolidWorks Library simulation detail.

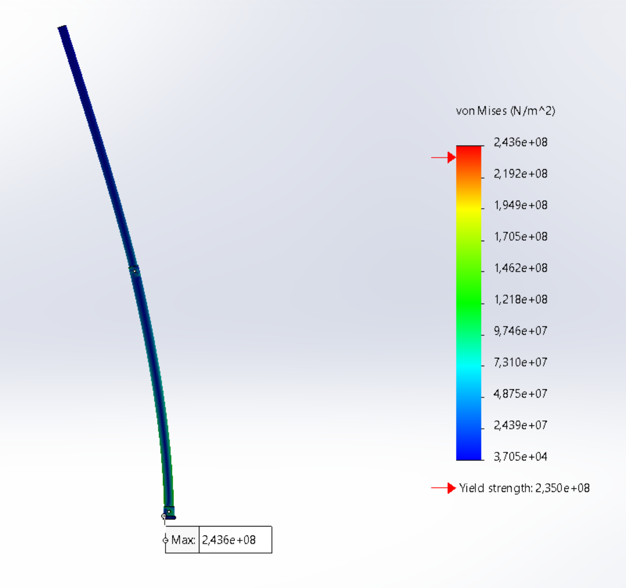


Figure 6.12. S235 Solid works Library simulation

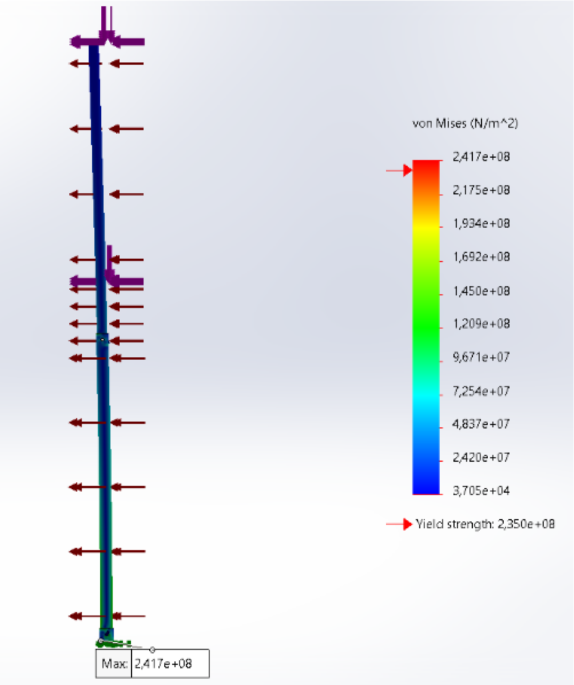


Figure 6.13. S235 with 3 mm of thickness Solid works Library simulation

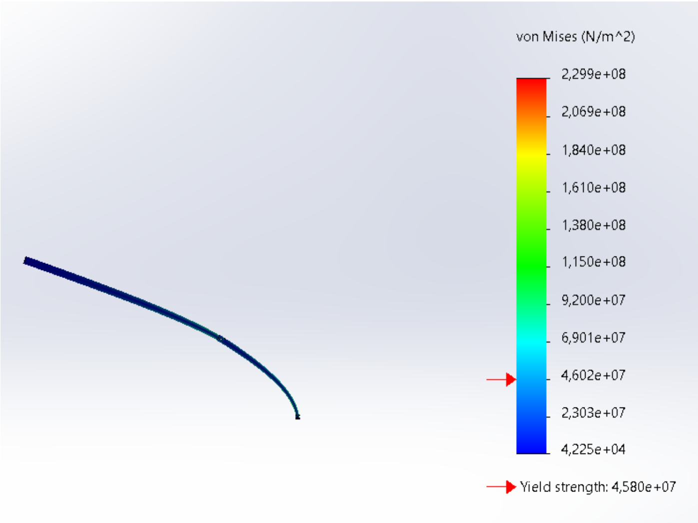


Figure 6.14. PVC simulation with 4 mm of thickness

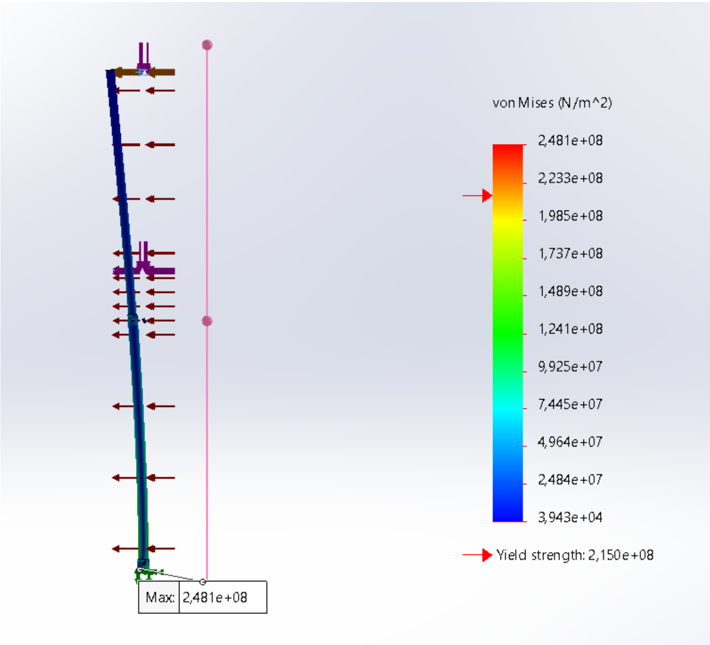


Figure 6.15. AA6063 T6 simulation.

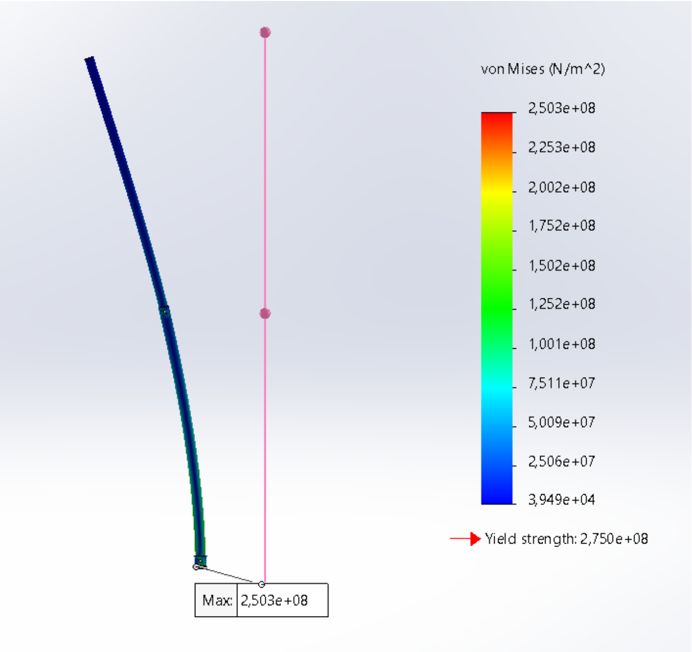


Figure 6.16. S275 simulation.

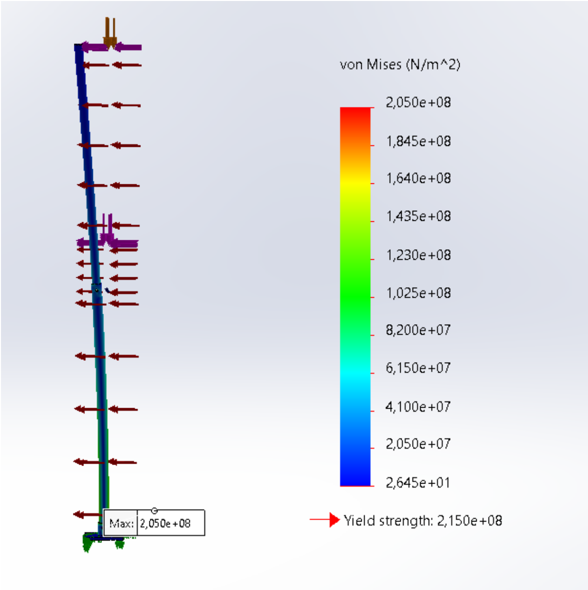


Figure 6.17. Aluminium 5 cm of connection simulation

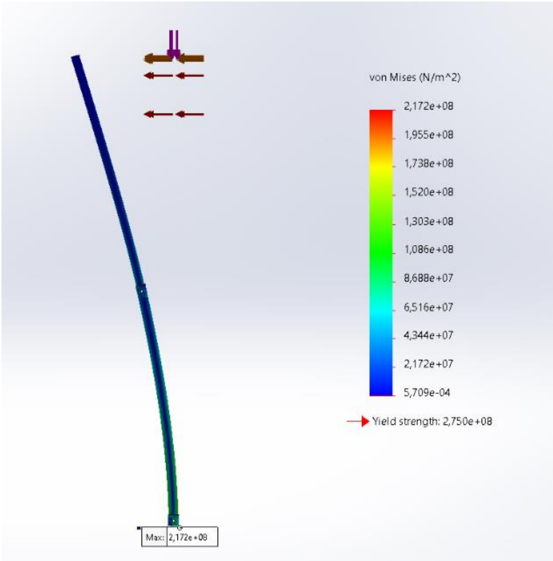


Figure 6.18. S275 with 5 cm of connection simulation

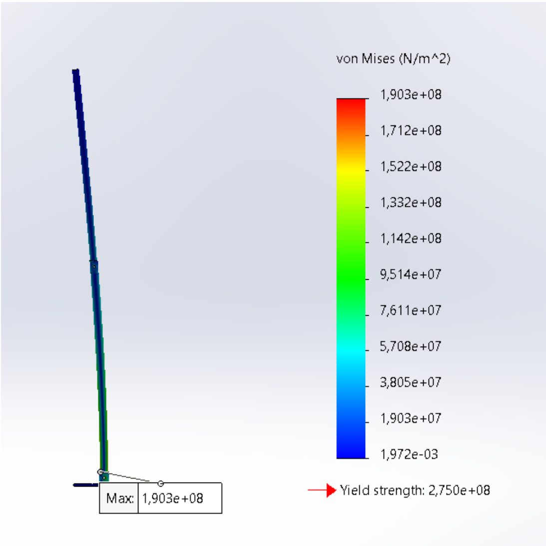


Figure 6.19. AA6061 SolidWorks simulation.

APPENDIX B

Total mass:

$$m_{total} = m_{solar\,panel} + m_{box\,encloser} + m_{pole}$$

$$m_{total} = 3 + 5 + 4.47 = 12.47kg$$

Wind force:

$$F = A \times P \times c_d$$

F = Wind force
A=Area
P= Dynamic pressure
C_d= Drag coefficient

$$A = A_{solar\ panel} + A_{box\ encloser} + A_{pole}$$

$$A = (2.07 - 0.365) \times 0.03 + 0.365 \times 0.275 + sin\,sin\,(45º)\ \times 0.435 \times 0.356 = 0.261\ m_2$$

$$P = \frac{\rho \times v^2}{2}$$

$$P = \frac{1.2754 \times 32.6^2}{2} = 677.72\,P$$

$$c_d = 1{,}2$$

$$F = 0.261 \times 677{,}72 \times 1.2 = 212.26\ N$$

To calculate the drag force:

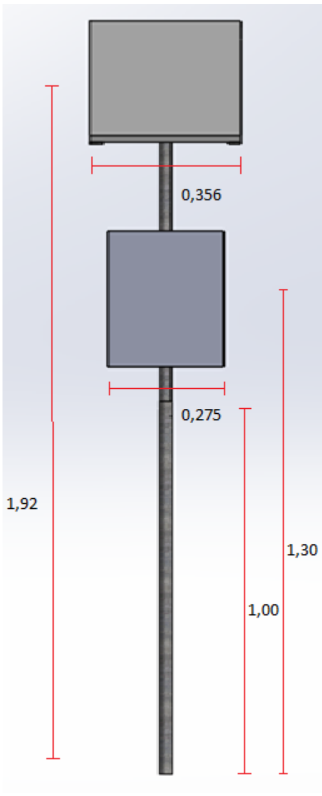
$$F_{ae} = \mu_e \times N$$

$$\mu_e = Coefficient\ of static\ friction$$

$$N = Normal\ force = weight\ of\ the\ structure + weight\ of\ the\ base$$
$$x = base\ weight$$

$$F_{ae} = 0.6 \times (12.47 + x) \times 9.81 = 212.26 \ll\gg x = 23.59\ kg$$

To calculate the torque necessary to make it fall:



$$\lambda_s = P \times b$$

$$M = F \times d$$

$$d = distance = center\ of\ mass$$

$$d = \frac{1 \times 0,3 + 1,3 \times 0,275 + 1,92 \times 0,356}{0,3 + 0,275 + 0,356} = 1,44m$$

$$M = 212,26 \times 1,44 = 305,74\ Nm$$

Iterations:

1. b=0.5 m ; m_{base}= 23.59 kg

$$\lambda_s = (12.47 + 23.59) \times 9.81 \times 0.5 = 176.87\ Nm$$

2. b=0.5m ; m_{base} = 50.00 kg

$$\lambda_s = (12.47 + 50.00) \times 9.81 \times 0.5 = 306.41\ Nm$$

3. b=0.4m ; m_{base} = 70.00 kg

$$\lambda_s = (12.47 + 70.00) \times 9.81 \times 0.4 = 323.61 Nm$$

For the conditions established in iteration 2 will be needed 50 kg in the base to fix the structure.

$$P = \rho_{areia} \times V \times g$$

$$\rho_{areia} = 1500\ kg/m_3$$

$$50 \times 9.81 = 1500 \times 1 \times h \times 9.81 \ll\gg h = 0.033m$$

For the conditions established in iteration 3 will be needed 70 kg in the base to fix the structure

$$70 \times 9{,}81 = 1500 \times 0.8 \times 0.8 \times h \times 9.81 \ll\gg h = 0.052m$$