UNIVERSIDAD SAN FRANCISCO DE QUITO USFQ

Colegio de Ciencias e Ingeniería

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Verónica Tatiana Barona Freire
Doménica Bonilla Montufar
Nicole Burneo Del Salto
Felipe Sebastián Pineda Villegas

Ingeniería Mecánica

Trabajo de fin de carrera presentado como requisito
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UNIVERSIDAD SAN FRANCISCO DE QUITO USFQ

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**HOJA DE CALIFICACIÓN
DE TRABAJO DE FIN DE CARRERA**

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Verónica Tatiana Barona Freire

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Felipe Sebastián Pineda Villegas

Nombre del profesor, Título académico	**Juan Sebastián Proaño Avilés, PhD**

Quito, 22 de diciembre de 2020

DERECHOS DE AUTOR

Nombres y apellidos: Verónica Tatiana Barona Freire

Código: 00130457

Cédula de identidad: 1722946942

Lugar y fecha: Quito, 22 Diciembre de 2020

DERECHOS DE AUTOR

Nombres y apellidos: Doménica Bonilla Montúfar

Código: 00130712

Cédula de identidad: 1717488421

Lugar y fecha: Quito, 22 Diciembre de 2020

DERECHOS DE AUTOR

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Nombres y apellidos:	Nicole Burneo del Salto
Código:	00136375
Cédula de identidad:	1718753302
Lugar y fecha:	Quito, 22 Diciembre de 2020

DERECHOS DE AUTOR

Nombres y apellidos: Felipe Sebastián Pineda Villegas

Código: 00131551

Cédula de identidad: 1004082838

Lugar y fecha: Quito, 22 Diciembre de 2020

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RESUMEN

Las totugas Podnocnemis Unifilis, presentes en el Tiputini, cuentan con una alta tasa de mortalidad como consecuencia de factores ambientales y socioculturales. El presente proyecto busca diseñar y construir una incubadora que aporte a la preservación de esta especie aumentando el éxito de la fase de incubación. El principal objetivo del proyecto y lograr recrear las necesidades naturales a las que están expuestos los huevos de las tortugas durante la incubación in situ. Además de los requerimientos económicos y estructurales realizados por el cliente, Estación de Biodiversidad Tiputini (TBS). Para alcanzar este objetivo se realizaron cálculos y simulaciones de: mecánica de fluidos, transferencia de calor, mecánica de materiales y vibraciones. Finalmente los requisitos que se cumplieron son: es una prototipo sustentable debido a la implementación de paneles solares y no requiere de energía eléctrica, al tener un peso menor de 100 kg permite que sea transportable sin el uso de maquinaria pesada, se diseño un sistema modular para su facilidad de ensamblaje, a través de los cálculos de consumo de energía y perdías por calor se confirmo su autonomía, los costos se ajustan al presupuesto pre establecidos, es un sistema automáticos por la implementación de controladores y con respecto a las necesidades biológicas se cumplido parcialmente. Esto se debe a que con los cálculos y simulaciones obtenidos el sistema funcionara correctamente, sin embargo, esto solo se verificara cuando se utilice la incubadora y las tortugas logren nacer.

Palabras clave: Incubadora, Podnocnemis Unifilis, Tiputini, Transferencia de Calor, Paneles Fotovoltaicos.

ABSTRACT

Podnocnemis Unifilis turtles, from Tiputini, have a high mortality rate due to environmental and sociocultural factors. This project seeks to design and build an incubator equipment that contributes to this species preservation by increasing the success of the incubation phase. The main objective of the project was to recreate the natural necessities to which turtle eggs are exposed during incubation in situ. In addition to economic and structural requirements made by the client, The Biodiversity Tiputinis Station (BTS). Calculations and simulations of: fluid mechanics, heat transfer, materials mechanics and vibrations were carried out to reach this goal. finally, the requirements that were met are: it is a sustainable prototype due to the implementation of solar panels and does not require electricity, as it weighs is less than 100 kg, it allows the equipment to be transported without using machinery, a modular design was created for easy assembly, through the calculations of energy consumption and heat transfer losses the autonomy of the system was confirmed, costs are adjusted to the pre-established budget, it is an automatic system for the implementation of controllers, and regarding the biological needs for a successful incubation, it was partially met. This is due to the fact that according to calculations and simulations the whole operation will be accurate, however this will only be verified when the incubator will be used and the turtles are born.

Key words: Incubator, Podnocnemis Unifilis, Tiputini, Heat transfer, photovoltaic panels, vents.

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INTRODUCTION

Executive Summary

Podonecmis Unifilis turtles mortality had increased in the past years. This reduction is a consequence of human illegal commercialization of them and consumption. Floods or infestation by pests. There have been a few simple solutions but none of them have contributed effectively with this species conservation. Development of this incubator is a process that requires to consider heating, humidification, energy, ventilation and dehumidification systems. Calculations and simulation will take place to confirm or to avoid different hypotheses proposed.

The design of an incubator for turtle eggs have required not only an extensive research about engineering knowledge but also about biological and climatological information. Consequently, creation of an equipment that satisfies necessities of the incubation process and as well as demands from the client, requires a methodic procedure. Therefore, the scope of the project is greatly reduced due to time and cost there are some future developments recommended to advance successfully with this project. In fact, a depth research of the species behavior and necessities might be the best way to improve each detail of the first prototype.

Since there is a limited budget most of the devices and materials selected for the manufacturing process are low. In addition, this prototype is not only affordable but is also environmentally friendly since its energy resource is provided by photovoltaic panels.

The project seeks to collaborate and contribute with the Biodiversity Station of the Tiputini and Universidad San Francisco de Quito. If the project works successfully it may even serve countries in the region that have the same problem, such as Brazil, Bolivia and

Venezuela. Future work will be required to improve the prototype and these modifications will be appearing during the experimental lapse.

Project statement and specification

The following project will present the design and manufacture of an incubator for *Podocnemis Unifilis* turtle eggs, powered by photovoltaic panels. This project will be carried out in conjunction with the Tiputini Biodiversity Station of the Universidad San Francisco de Quito. The station is situated in the Yasuní Biosphere Reserve in Ecuador, located in between the provinces of Pastaza and Orellana. This ecosystem was declared a National Park by the UNESCO in 1979 as consequence of its wide and diverse flora and fauna. The territory covered by the Yasuní sums up a total of 1.022.736 ha, containing countless animal species, and five indigenous settlements (Ministerio del Agua y el Ambiente n.d.). Different human activities such as oil drilling, deforestation or even communities daily practices, have led to the increase in mortality rates of different plants and animals. The specialists team of the station have been required to study some creatures behavior. In particular, the mortality of 91.3% of the Podocnemis Unifilis turtles has called their attention (Caputo, Canestrelli, and Boitani 2005).

In the urge to discover the main factors that prompt the species (Podocnemis Unifilis turtles) extinction, scientists have observed this animal life cycle throughout the past years (Romo, 2020). They have discovered that the main causes for this outcome corresponds to: human egg consumption, illegal commercialization, pests, climate change, and predators (Boulon et al. 1999). In order to reduce the number of deaths of this animal, it has been proposed to carry out ex-situ incubation of eggs. There have been other projects as an approach to preserve the collected eggs, unfortunately the result was not the expected since there were some factors that were not considered. The last project consisted in the recollection of at least 300 eggs to avoid hunting. They were sheltered in artificial nests that tried to reproduce natural conditions by leaving them outdoor and burying them in sand. The faults underlie in the incorrect selection of materials for the structure of the artificial nests. The implemented material, wood, led into termites pests. Since these prototypes where located at ground level, ants consumed some of the eggs. In addition, recent studies have discovered that the presence of a fungus species was a common problem developed in natural turtle nests. It is speculated that the appearance of these organisms occur in sand. Due to the climatic nature of Yasuní rain forest, floods caused by heavy rains are very common. For this reason, the incubation process is affected (Romo, 2020).

In addition, previous studies carried out in Yasuní assure that the main responsible for the mortality rate of this species are floods and community’s consumption. The experts, who conducted these studies in their effort to contribute to the species conservation, reached an agreement with Cofan community. It consisted in remunerating Cofan people for collecting eggs (following experts guidelines) from the Podocnemis Unifilis Turtles (Caputo et al. 2005). This problem is not exclusive to Ecuador, in Brazil, the largest-scale and longest-term wildlife conservation program takes place. The Brazilian government has developed a project denominated the “PQA Program”, that seeks to monitor and protect the incubation place of the turtle eggs. PQA aims to take care of the eggs by delimiting the access to the nesting area and avoiding the growth of vegetation that puts them at risk. Currently, this project continues to be the largest in the country. They used to be 11 protected localities in Brazil, unfortunately, due to lack of fund and support, some of these were closed in 2009. For this reason, the data base includes information from 1977 to 2008 (Eisemberg et al. 2019). This project could not reach its goal of reducing the turtle mortality rate. Other countries have also had the interest of analyzing this problem such as Peru and Venezuela (Caputo et al. 2005).

Within the scope of our knowledge, there are no patents that satisfy the needs of the present incubator proposal. Some of them are incubators for chicken eggs which rotate them, and others do not include a photovoltaic system. Nevertheless, they include characteristics that could contribute to the development of our incubation equipment. The patents selected for this purpose are: Automatic egg incubator, Egg incubation method, Portable solar generator, Method and apparatus for incubating and hatching eggs, Panels for solar heating system, Solar collector panel for heating ventilation air, Automatic turner for egg incubator, and Egg incubator tray (Cannon 1993; Diego et al. 1998; Howard J. Voren 1997; Luce 1960; Marsh 1972, 1974; Moran 2007; Porter 1978).

Podocnemis Unifilis eggs incubation period lasts a total of three months and requires specific conditions such as temperature, humidity, and others. To successfully accomplish this projects objective, the incubator must adhere to natural conditions parameters and client demands. It is known that the embryos gender responds to temperature variations between 27.7°C and 33°C (Lolavar and Wyneken 2020). Likewise, humidity requires to be 94% (Fierro and Terneus 2018). Additionally, the eggs need to be handled as little as possible, since reptile eggs require to have a fixed position throughout the incubation process (Ferrara, Vogt, and Sousa-Lima 2013). Due to the limited access of electrical energy it is necessary that the incubator uses a sustainable source of energy (Silva, de Oliveira Marco, and Severino 2010). Another factor to consider is the average size of the egg, approximately 20 mm radius (usually resemble a ping pong ball). For these reasons it is needed to design and build an incubator that satisfies the following requirements:

- Satisfy biological needs of the species
- Sustainable energy use
- Humidity and temperature automated control system

- Ease of assembly: the equipment might be assembled with a small set of tools following manual instruction. It will take two people for complete de assembly.
- Portability: the equipment might transportable without the use of heavy machinery
- Outdoor resistant materials
- Appropriate dimensions
- Minimum of 3 months of continuous operation
- Maximum cost of $1900

It is expected that through this project it will be possible to contribute to the conservation of the species by reducing its mortality rate. In order to achieve this goal, this project will complete the construction and design of the first prototype of an incubator that accomplish all the needs of the species and requirements of the client. The incubator is expected to be installed in the future at Tiputini's Biodiversity Station of the Universidad San Francisco de Quito. Finally, the incubator is expected to reach a level of success that allows it to get a patent, in order to help these cause and to be implemented in various communities of different countries. The following portfolio will present the steps followed to achieve the creation of this incubation equipment.

Terms of reference

This section seeks to efficiently communicate the work objectives, the group's methodology, and other vital information to understand how the project was successfully completed.

Table 1 Terms of reference

Name of group	Incubator Group B
Purpose/role of the group	Design and build an incubator for Podocnemis Unifilis turtles and thus contribute to the reduction of their mortality rate.
Accountability	The activities will be reported to the client, in this case David Romo (Tiputinis Biodiversity Station researcher) and David Escudero (USFQ instructor). Additionally, the project updates will also be directed to Professor Juan Sebastian Proaño.
Review	A review on how well the project has been progressing will be done one to three times a week.
Working methods / ways of working	All members of the group are responsible for everything related to this project. However, if subgroups are required, it will be done as long as the subsections update the rest of the team.
Meetings	Meetings are held at least 2 times per week. However, if a member of the group summons the rest of the team the number of meetings would increase.
Sharing of information and resources	The main communication and job-sharing channels are: Teams, Zoom, Outlook, WhatsApp, One Drive (Word, Powerpoint, Fusion 360, etc.).

Design concepts and selections

This project development seeks to adhere to its principal requirements: sustainability, ease of assemble, transportability, and cost. Considering these criteria, the main functions of the equipment were stablished. As a result of these considerations the best configuration was determined. The general concepts that allow the best combination are: Heating system, humification system, walls material, and energy source. The methodology implemented in order to find the best alternative consisted in the application of selection matrices. The weighted value of each function relies on its relevance considering incubator requirements and client demands. The table presented below resumes each requirement with its function and possible options.

Table 2 Morphological analysis materials selection

		OPTIONS			
Requirement	**Function**	**1**	**2**	**3**	**4**
Heating System	Control incubation temperature	Kit resistance + fan	Ceramic lightbulbs	3D printer warming beds	
Humidification System	Regulate internal humidity level	Humidity kit control	Ultrasonic humidifier	Incubators humidifier	
External Wall Material	Protect incubator from external risks	Asbestos Cement	Acrylic	Polycarbonate	Stainless Steel
Isolation Material	Reduce energy loss through walls	Cork	Polyurethane Foam	Fiberglass	
Energy Source	Provide required power for equipment	Photovoltaic panels + battery	Batteries	Diesel generator	

Subsequent sections will present detailed process of selection to determine the appropriate incubators composition. Preliminary sketch regarding incubator composition to respond each requirement presented in table 2 is shown below.

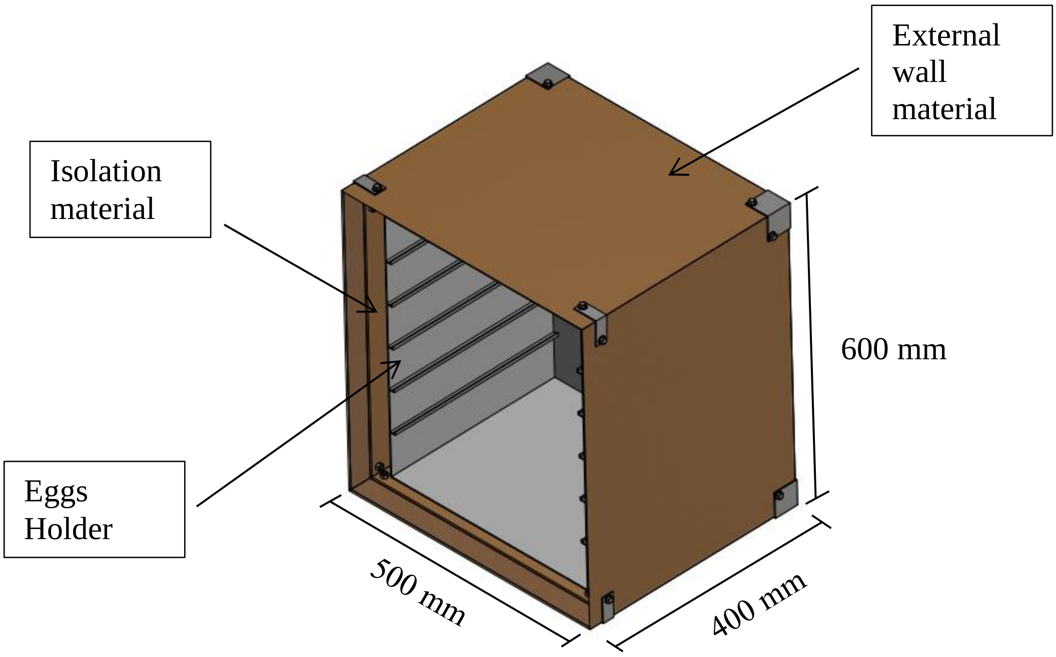


Figure 1 First approach design

Risk Analysis

Finding out imminent risks presents the opportunity to manage them, considering their impact on the project development. In order to guarantee all threats are taken into consideration, the incubation equipment was divided into subsystems as follows:

1. **Structural system:** It is the system that properly isolates the eggs, avoiding their exposure to predators and alteration in the conditions required for incubation. Calculations and heat transfer simulation through the walls of the equipment will be performed to determine the best material composition.
2. **Energy source system:** It oversees supplying the necessary energy for the operation of the incubator. The power required by all the components of the equipment will be determined in order to calculate the number of photovoltaic panels required and the type of battery that can be implemented.
3. **Humidification and ventilation system:** It is responsible for maintaining the humidity required for the incubation of the eggs and for distributing the airflow evenly in the system. Fluid simulations will be performed to recognize the most efficient structure and the best location for the fan.
4. **Temperature control system:** It provides the necessary heat to maintain the incubation temperature within the system. It is required to determine the power needed to regulate the temperature. The most critical cases will be considered (taking into consideration the incubation periods) so it can be assured that the equipment will work in all scenarios.

5. **Framing System:** It oversees supporting the incubator, solar panels and other elements of the system. Structural calculations are required (stress concentrators, bolt selection, dimensions, etc.).

6. **Shelves:** It is the carrying structure for the eggs so that there is no manipulation or movement. Mechanical calculations to determine maximum deflection and vibration simulations will be performed.

Proceeding with each of the sub-systems and their functions, a risk analysis was established. In combination with its impact and priority, different decisions where stipulated. Table presented below includes detailed measures.

Table 3 Risk management measures

CODE	DESCRIPTION	PRIORITY (IMPACT X PROBABILITY)	RESPONSIBLE	DECISIONTAKEN	STATUS	REMARKS
001	Difficulty in machining and assembling the materials of the equipment structure.	5x5= 25	Nicole Burneo	Delegate work to qualified personnel or services (laser or CNC cutting)	Done	An optimal assembly is needed, so cnc cutting was chosen.
002	Difficulty in developing temperature and humidity controller code.	3x3=9	Doménica Bonilla	Acquire controllers that do not require code for their configuration.	Done	Inkbird humidity and temperature controllers purchased require setting the desired values for each constrain.
003	Unknown behavior or utility of sand throughout the incubation period.	5x5=25	Nicole Burneo	Conduct experimental "ex-situ" studies	Done	Sand containers were monitored for five days with data logger and temperature sensors.

004	Not being able to generate the required energy needed by the incubator in the 3 month incubation period.	4x4=20	Verónica Barona	Implement an energy storage system (batteries) for cases where the solar panels are not usable.	In progress	Calculations on power required by each electronic device and time consumption per day are required. Assure the number of batteries for two days of autonomy.
005	Failure in the heating system.	5x5=25	Felipe Pineda	Implement a continuous heating system for the necessary incubation time, looking for a facility that is not affected by any external conditions.	Done	An analysis was made for each one of the different options, where it was obtained that the most effective would be the ceramic lightbulbs for reptiles.
006	Wall material of the structure not suitable for the environmental conditions. (humidity, temperature changes, rain, etc.)	5x5=25	Nicole Burneo	Carry out simulations. Talk with the station personnel to determine which materials have worked for them in-situ.	Done	Several simulations were carried out on different types of materials that meet the necessary conditions. Investigator from the station advised over the options considered.
007	Difficulty in obtaining or delay in the importation of materials necessary for the manufacture of the incubator.	4x4=20	Verónica Barona	Avoid purchasing materials that required importation.	Done	Due to the fact that we are in the middle of Covid-19 pandemic, it is difficult to import products, for this reason it was decided to acquire them in the national

						market. Except for three components that were not available in local market.
008	Flooding that damages the incubator infrastructure.	5x5=25	Doménica Bonilla	Increase the distance between floor and the incubator.	Done	Floods in Tiputini are frequent so it is essential to have an infrastructure that prevents the equipment from getting wet. It was opted for a design that keeps the incubator at a height of one meter, avoiding contact with water.
009	The internal temperature of the incubator exceeds the incubation temperature.	5x2=10	Felipe Pineda	Implement the use of controllers for the heating system.	In progress	Controllers oversee measuring the conditions inside the incubator and turning on or off the heating and humidification system to maintain optimal conditions.
010	Sunshine hits directly into the incubator.	5x5=25	Doménica Bonilla	Create a roof from the solar panels in such a way that they fulfill their function of transforming sunlight into electrical energy and at the same time cover the structure.	Done	If you have direct exposure to the sun, the incubator may take higher temperatures than the medium. By placing the equipment under shade (underneath the structure that contains photovoltaic

						panels), the temperature can be prevented from rising by avoiding radiation from sun.
011	Incorrect installation of solar panels.	5x3=15	Felipe Pineda	Delegate a specialized and trained person for the connections required by the solar panels.	In progress	As it is an important component of the equipment it is appropriate that it has been previously tested by a qualified person.
012	Difficulty in transporting the incubator to Tiputini	5x5=25	Nicole Burneo	Design a modular structure so that its components can be transported in a more compact way.	Done	Due to the location of the incubator, transportation will involve people carrying the equipment manually. Creating a modular structure and easy assembly will facilitate both.

Project management

In order to assure an on-time completion of the project, task determination and distribution is fundamental. Having successful results is to a large extent determined by following the proposed assignments on time. In order to fulfill this objective, a Gantt Chart with detailed work was established (presented on the Appendix B). A summarized version of the general chores is presented below.

Table 4 Scheduled Project Tasks

	Name of the task	Duration	Start	End	% Completed
1	Scheduling	8 days	Wed. 2/9/20	Thu. 10/9/20	100 %
2	Design and calculations	93 days	Thu. 10/9/20	Sat. 12/12/20	100 %
3	Construction	53 days	Sun. 15/11/20	Thu. 07/1/21	35 %
4	Experimentation	5 days	Mon. 04/01/21	Sat. 09/01/21	0 %
5	Portfolio	76 days	Sat. 3/10/20	Fri. 18/12/20	100 %

In general terms, the incubators prototype can be successfully built if the available budget is not exceeded. In this occasion, the total existing money is $1900. The Tiputini Biodiverse Station will contribute with approximately 85% of this expense. The equipment budget was divided into nine different subsections to determine the elements that have a higher weighted value over the total cost. A condensed version of the budget is presented below. For detailed expenses, refer to Appendix B.

Table 5 Incubator cost plan by subsection

ITEM	DESCRIPTION	TOTAL
1	Electronics	$ 128.96
2	Subjection Elements	$ 69.44
3	Polycarbonate	$ 407.00
4	Fiberglass	$ 72.50
5	Manufacture	$ 349.35
6	3D Printing	$ 43.55
7	Cables	$ 40.00
8	Photovoltaic Panels	$ 773.50
9	Extra	$ 8.50
	TOTAL	$ 1,892.80

In order to have a visual representation and determine the sections that incur on higher expenses, a pie distribution is shown in figure 2.

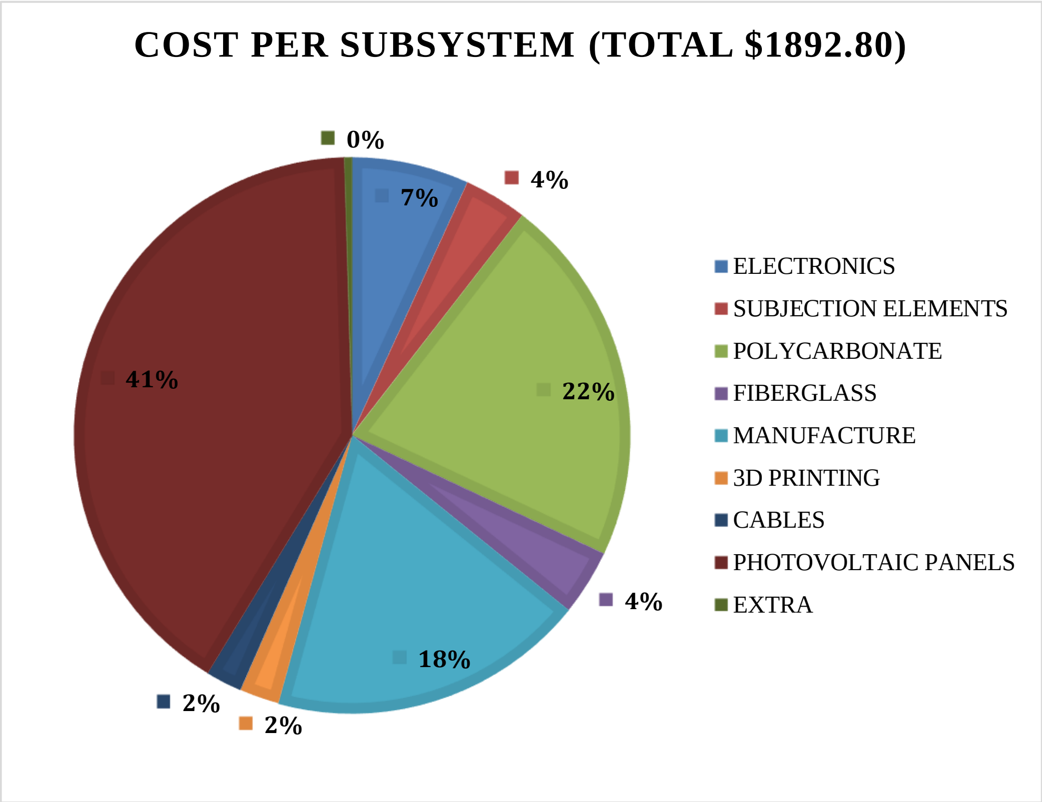


Figure 2 Weighted value cost per subsection

It can be concluded that main expenditures correspond to Photovoltaic panels, Polycarbonate and Manufacture. The last component high cost is a consequence of requiring precise manufacturing processes (CNC cutting), to assure an airtight structure. It is important to stand out that manpower cost is not considered in the budget.

Engineering Standards

The construction and design of a project must comply with local and international standards to be patented. Standards are commonly stablished by a committee or a group of professionals, so that the mandatory requirements settled assure product quality. Standards will allow the product to be reproduced not only in a specific country, but also in places worldwide that have similar necessities. The table below lists the possible standards for the most representative system functions (Werner Sölken, 2008 - 2020).

Table 6 Engineering standards

Functions	Standard	Application
Ventilation and humidification system	ACGIH: Industrial Ventilation Manual	Humidification and heating system.
Ventilation	ASTM E1292 - 94(2016) Standard Specification for Gravity Convection and Forced Ventilation Incubators	Humidification and heating system.
Insulation material	ASTM F683-14 Standard Practice for Selection and Application of Thermal Insulation for Piping and Machinery	Structural system.
Sustainable energy source	ASTM E3010-15(2019) Standard Practice for Installation, Commissioning, Operation, and Maintenance Process (ICOMP) of Photovoltaic Arrays	Energy system.
Automatization of temperature control	STP470A Manual on the Use of Thermocouples Temperature Measurement	Humidification and heating system.
Composite wall structure	STP118 Symposium on Structural Sandwich Construction	Structural system.

MATERIALS AND METHODS

Following the morphological analysis presented on Table 1, selection matrices are applied to determine the best components for each subsystem mentioned. In order to achieve this objective, every option was researched on the same characteristics in order to compare them. Depending on the subsystems function, different criteria was considered as determinant requirements.

Heating System

There are many methods of heat generation and heat transfer. For this reason, three ideas were chosen that are the most used in the design of incubators. The selection of the best heat generation system was based on ease of temperature control, energy consumption, price, ease of connection and acquisition. The evaluation of the three concepts were made based on the main needs of the client and factors like temperature and humidity control. Appendix A presents all the alternatives chosen for heating system that will be compared in the selection matrix. These options are:

- **Fan and resistance kit:** These are kits designed precisely for the design of small incubators. The temperature is easy to control. The implementation of forced convection will allow the appropriated the heat distribution within the incubator. (Beumer, Haarbosch, and Carpay 1996)
- **Ceramics lightbulbs:** These are bulbs designed precisely for the incubation and breeding of reptiles. They simulate darkness inside nests by providing the necessary heat without light generation. (Frey 1954)
- **3D printer warming beds:** This innovative idea was taken into account since its geometry allows more area with heat generation. Nevertheless, heat distribution is

not uniform. Difficulties during the installation process are another disadvantage of this option.

When designing an artificial incubator, the aim is to recreate the natural conditions to which the eggs are exposed. It is expected to choose the one that complies with energy control, has low energy consumption, ease of installation and finally ease of acquisition. The criteria were taken as follows:

High temperature control accuracy > low energy consumption > easy acquisition >low price> easy connection

The option with the highest temperature control accuracy, lowest energy consumption, easy acquisition, least costs and easy connections gets the highest score.

The most important criterion for the selection is that temperature can be controlled and modified according to necessary environmental conditions. Similarly, its energy consumption must be minimal because power source is limited. As many of these products are on the European and American market, we rely on their ease of acquisition and finally their connection. (Agidi, 2014) Each of these 5 criteria were evaluated through a selection matrix, obtaining the following results shown in Table 7.

Table 7: Heating System Matrix Selection Results

Heating System							
Conclusion	**Temperature control**	**Energy consumption**	**Price**	**Cabling**	**Acquisition**	**S**	**Priority**
Fan + Resistance	0,17	0,09	0,04	0,02	0,07	0,39	2
Ceramic Lightbulbs	0,11	0,13	0,07	0,03	0,10	0,44	1
3D Printer Bed	0,06	0,04	0,02	0,01	0,03	0,17	3

As shown in the table above, the chosen option would be the ceramic lightbulbs being the ones with higher weighted value.

Humidification System

The market offers a wide variety of humidifiers, which are intended for domestic, industrial, or medical purposes. However, a successful selection depends not only on the component's capacity to humidify, but also its capability to accomplish all the specific requirements of the incubator. A research about price and technical details (required power, weight, and dimensions) was developed. The selected criteria respond both, clients, and design requirements. Finally, it is important to underline that the incubator will include automated components that have to be compatible with the selected controller. The three selected options are:

- **Humidity control kit:** Compact components that can regulate humidity. The kit includes: Digital hygrostat with probe WH8040 220V, USB humidifier.
- **Ultrasonic humidifier:** this component humidifies, and it can be adapted to a controller. Additionally, the container that supplies water can be any standard disposable personal bottle (HoMedics, 2020).
- **Incubator humidifier:** component implemented on eggs incubators (Farges, Villon, & Bouattoura, 1998) (Escalante, 2020).

Every criterion selected was evaluated for each humidifier's alternative. Appendix A presents every components option and its characteristics. As the project aims to follow sustainability criteria, easy transportation, and durability; the selected component is expected to have reduced energy consumption, dimensions, and weight. Therefore, the importance of each criteria for the incubator is defined as:

Small dimensions > Low energy consumption > Low price > Low weight

The option with smallest dimensions, lowest energy consumption, least costs and lowest weight gets the highest score.

As the humidifier must be as adaptable as possible to any design, the dimensions are a priority. Moreover, on the seek to develop a project environmentally friendly with minimum electrical consumption (due to local limitations), energy consumption is the second on priority scale. As prices significantly varied one another, the third criteria correspond to this element. Finally, due to low weight differences, this criterion corresponds to the least important. Following a matrix selection, the results obtained are presented below.

Table 8 Humidifying System Matrix Selection Results

HUMIDIFIER						
Conclusion	**Price**	**Weight**	**Dimensions**	**Energy Consumption**	**S**	**Priority**
Controller + Humidifier	0,07	0,04	0,13	0,13	0,37	2
Ultrasonic Humidifier	0,03	0,02	|0,07	0,05	0,17	3
Incubator's Humidifier	0,10	0,04	0,20	0,13	0,47	1

According to the results presented on table 8, the best option out of the three listed out, is the incubator's humidifier. This is a consequence of its low energy consumption, reduced dimensions and weight, and its affordable price.

Walls Materials

In general terms, the incubators wall purpose it to isolate and protect the internal environment from its surroundings. To accomplish these purposes, the materials selection was completed by dividing the walls composition into layers. An isolating and exterior material were the selected layers. Throughout the selection matrix these layers where independently evaluated. These materials were weighed under the following criteria: thermal conduction, price, density, and ease of machining and assembly. It is important to note that each material is commercialized in different dimensions, to obtain comparable price data, it was decided to determine the price per cubic meter.

External material

For this layer, the primary consideration relies on the fact that the incubator is required to be outdoor throughout its lifetime. As consequence, the materials proposed correspond to those who are expected to have good performance under humidity, sun, and rain parameters. The studied materials are:

- **Asbestos-Cement:** cement backer boards in combination with natural fibers. Commonly used as raw material in construction industry. (PROMAC, 2020)
- **Acrylic:** polymethyl methacrylate (PMMA) plates. Most frequent applications include construction, illumination, machinery casing, etc. (POLYCASA, 2014)
- **Polycarbonate:** polymer available on solid sheets. Its main characteristic relies on its resistance, 200 times higher than glass, despite its reduced weight. (Arkos, 2020)

- **Stainless steel:** steel with highly corrosion resistant properties. Its main applications include maritime and food industry, construction, etc. (KUBIEC, s.f.)

From Appendix A presents the selection criteria corresponding to each selected material. With all this information, matrix selection is developed. As the external material main objective relies on protecting the equipment from the surroundings, the selection criteria are classified by:

Low price > Ease of assembly = Low density > Low thermal Conductivity

The option with least costs, ease of assemble with lowest density, and lowest thermal conductivity gets the highest score.

This layer's main criterion corresponds to lowest price because the quoted materials present high-cost differences with one another. Both, ease of assembly and low density have the same priority value, as they correspond to client's request. In this coat, low thermal conductivity is not a main concern as an isolating material will be implemented on the following layer. Matrix selection results are presented below.

Table 9 External wall matrix selection results

EXTERNAL MATERIAL						
Conclusion	**Thermal Conductivity**	**Price**	**Density**	**Assembly**	**S**	**Priority**
Asbestos cement	0,02	0,16	0,05	0,03	0,26	3
Acrylic	0,04	0,08	0,08	0,08	0,27	2
Polycarbonate	0,03	0,12	0,10	0,08	0,33	1
Stainless steel	0,01	0,04	0,03	0,08	0,15	4

According to the results presented on table 9, the material that adjusts on an optimum way to the external case is solid polycarbonate. Additionally, alternatives like acrylic and asbestos cement present similar priority calculations.

Insulating Material

The isolating layer will be located inside the exterior material. It is important to mention that it will not be exposed to outside risks. Although the incubation equipment will work under temperature rates that are similar to environment conditions, an insulating material prevents energetic losses. The considered materials are:

- **Polyurethane foam:** Polyurethane is a chemical compound. Also known as one of the most versatile plastics. Some of its applications include thermal insulation, ponds sealer, tires, etc. (Tecnitool, 2020)
- **Fiberglass:** Material made up of several glass threads that build up a mesh. Industrial applications are its principal use, such as automotive and artistic sectors. (Plaremesa n.d.)
- **Cork:** Is the bark of the cork oak. Some of its main properties include its high resistance, low weight, thermal and sound insulation ability.(Corkup n.d.)

The matrix selection for the insulating material considers all the criteria detailed on Table A4, Appendix A. Contemplating that the main objective of this layer reduces to isolate the internal ambient with the medium, the following criteria priority is established:

Low thermal conductivity > Low precio > Ease of assembly = Low density

The option with lowest thermal conductivity, least costs, ease of assemble with lowest density gets the highest score.

A low thermal conductivity is required in order to reduce transferred energy from the system to its surroundings through walls. Price is considered an important criterion due to the high-cost difference between the selected options. Finally, ease of assembly and density are requirements set up by the client, locating both on the same priority level. Once the matrix selection is established, the following results are found out:

Table 10 Insulation wall material matrix selection results

INSULATION MATERIAL						
Conclusion	**Thermal conductivity**	**Price**	**Density**	**Assembly**	**S**	**Priority**
Polyurethane Foam	0,2	0,15	0,08	0,08	0,50	1
Fiberglass	0,1	0,08	0,05	0,03	0,25	2
Cork	0,1	0,08	0,03	0,05	0,25	2

As presented on table 10, using polyurethane foam as an isolating material is the most favorable material according to the selection matrix results. While fiberglass and cork implementation would involve the same weighted value, when being incorporated.

In general terms, the incubator walls conformed by two layers (external + isolation material) should be made up of: Polycarbonate + Polyurethane Foam. This structure assures minimum energy loss and protection for the equipment from outside conditions.

Energy Source

According to the client's requirements, it was specified that as an energy source it is necessary to use renewable resources in order to create the least environmental impact at the

Tiputini Station. As a main idea it was suggested to have solar photovoltaic panels as an energy source. However, when carrying out a project, other possible solutions should be studied to verify that the pre-selected one is the best available option. In this way, an investigation involving other sources of energy was carried out. It should be considered that since the station is located in the Amazon rainforest, electricity is not constantly available, reason why this alternative was discarded as the main source. Therefore, two additional ideas were selected.

The first one is the use of batteries and the second the use of a diesel-based generator. (Free, Generator A Diesel 110 / 220v 3800 W Forest Garden, nd). Finally, it was agreed that an extra battery should be added to the idea of solar photovoltaic panels in case the weather of the station is not optimal for its operation. In this way, at some point where there is a lack of sunlight or at night and the machine needs power, it will be able to use the energy stored in the battery. (Free, Bosch Batteries From 65 Dollars at Home, s.f.)

A brief description of the chosen systems is presented below:

- **Solar panels:** devices that allow the conversion of sunlight into electricity. Photovoltaic cells are used. (Daniel Kraemer, 2011)
- **Batteries:** devices that serve as electrical accumulators. (Ecuador, s.f.)
- **Diesel generator:** equipment that uses mechanical energy to produce electrical current. (Electric, 2020)

The parameters that were taken in consideration to carry out the selection process are:

- **Price:** must be adapted to the project budget.
- **Sustainability:** do not generate pollution and use renewable energy.

- **Dimensions:** it must be adapted to the measurements of the incubator, so that it is neither greater nor less than the general measurements of the machine.

To make the products easier to acquire, options in markets within the national territory were analyzed. For solar photovoltaic panels, several options are presented in terms of their technical specifications, because later engineering calculations of adequate dimensions and powers must be carried out. The price of a kit containing a solar panel + batteries + charge controller + voltage inverter is also presented. (Free, Solar Energy Kit Inverter Battery Controller Panel 12v, s.f.)

Based on the data presented in Table A5, Appendix A, the selection matrix is made. According to the criteria set out above, they are classified as follows:

Sustainability> Low price > Small dimensions

The option with more sustainability equipment, least costs and smallest dimensions gets the highest score.

A study of each solution presented is done to select the best option. The complete analysis is attached in an Excel document. The conclusion of the results is presented below.

Table 11: energy source matrix selection results

ENERGY SOURCE					
Conclusion	**Price**	**Sustainability**	**Dimensions**	**S**	**Priority**
Solar panels + batteries	0,06	0,25	0,04	0,35	1
Batteries	0,17	0,08	0,08	0,33	2
Diesel Generator	0,11	0,17	0,04	0,32	3

As it was predisposed in the client's requirements, it is verified that the solar panels are the best option for the energy source of the incubator. This is because it satisfies all the established parameters. It should be noted that the use of batteries is exclusively reserved to moments where weather conditions are not adequate, in this way the machine will have continuous operation.

According to the selection matrices result the best configuration for the incubator would include the following components:

Table 12 Matrices selection results

Matrices selection results	
Function	**Result**
Heating system	Ceramic lightbulbs
Humidification system	Incubator humidifier
External wall material	Polycarbonate
Isolation material	Polyurethane foam
Energy source	Photovoltaic panels + batteries

According to this results the configuration would be determined by the table presented above. Nevertheless, in order to respond to the student criteria, it was accorded to create a multilayer structure conformed by 3 different materials. The sandwich structure would be conformed by the following layers (starting with the external to the internal one): polycarbonate, fiberglass, and polycarbonate. This decision was taken in response to the urge to have a smooth surface for the egg shelves. From now on, the external material has the function of protecting the equipment from impacts and making a pleasant appearance. When referring to the insulating material, polyurethane foam had the best score mainly, due to its affordable price. However, fiberglass will provide improved surface finishes, attributable to its uniform sheet presentation (5cm thickness). Finally, it was contemplated the necessity of the egg shelves to have a stable fixed position and to slide into the incubator smoothly. For this reason, the defined inner extra layer is polycarbonate because of its regular surface.

Design for manufacturing

The present section describes in detail the manufacturing process of each component that makes up the incubator.

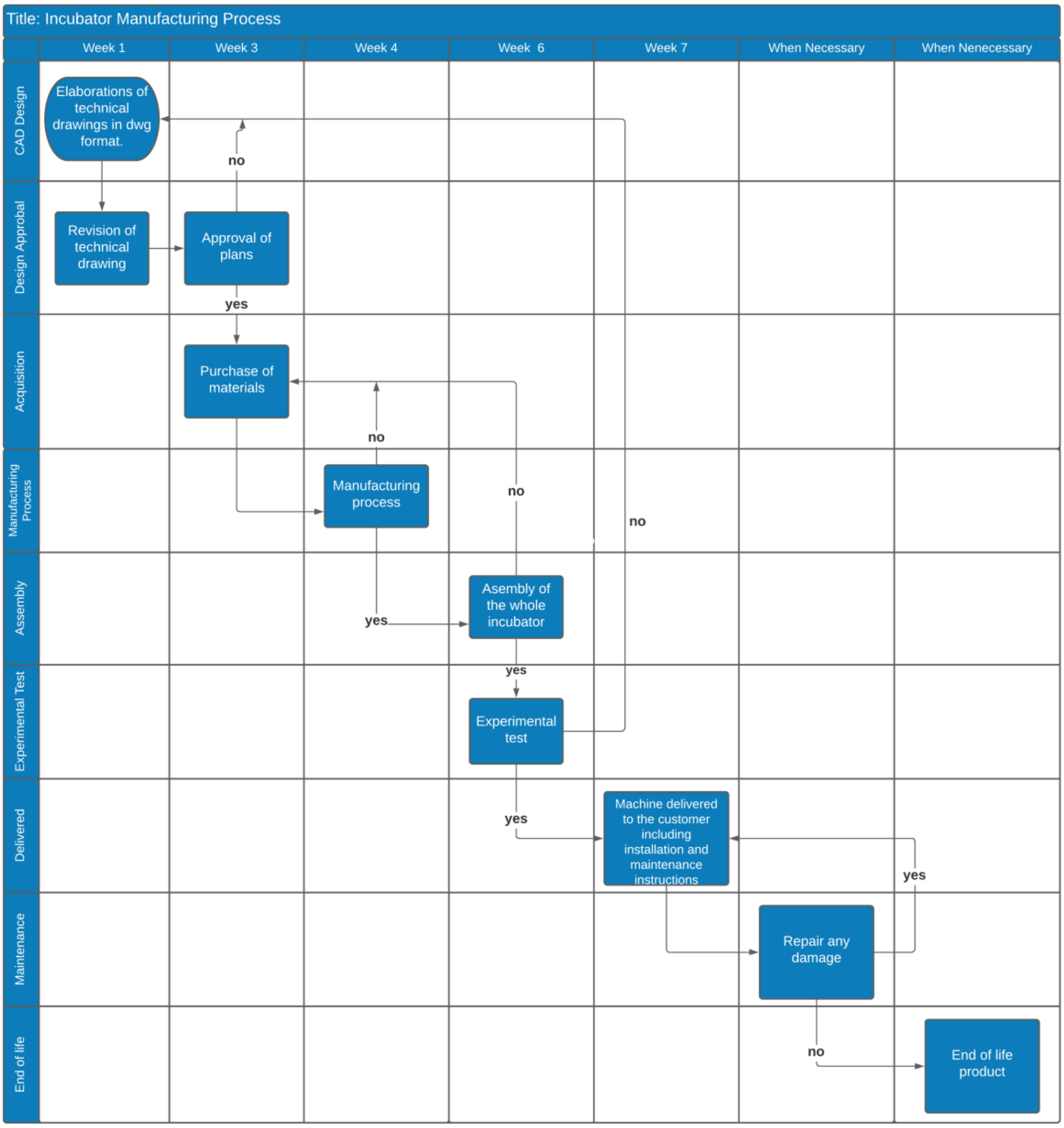


Table 13 will describe:

- Item: Part of the incubator that makes up the final design. This component can be manufactured or purchased. In the same way it can have subcomponents.
- Material: Material with which the item is made
- Components: Number of components that make up the item. Example: external polycarbonate structure is made up of 9 sheets of different dimensions. The number of components would be 9.
- Manufacturing process: Process that the part requires to be manufactured. Example: oxyfuel, laser cutting, etc.

Table 13 Incubator components and manufacturing process

Item	Material	# Components	Manufacturing Process
Internal incubator layer	Polycarbonate (3 mm thickness)	7	Milling + Saw Cutting/ Dremel cutting
Middle incubator layer	Glass fiber (50 mm thickness)	7	Utility knife
External incubator layer	Polycarbonate (3 mm thickness)	13	Milling + Saw Cutting/ Dremel cutting
Eggs holder structure	Polycarbonate (5 mm thickness)	8	Milling + Saw Cutting/ Dremel cutting
Corner stops	PLA	4	3D Printing
Rails	PLA	10	3D Printing
Lateral stops	PLA	17	3D Printing
Humidifier container	Polycarbonate (3 mm thickness)	5	Milling + Saw Cutting
Electronics container	Polycarbonate (3 mm thickness)	6	Milling + Drilling + Saw Cutting/ Dremel cutting

Photovoltaic PANELS structure	Galvanized steel (3 mm thickness)	8	Milling + Drilling+ Saw Cutting/ Dremel cutting
Bulbs socket holder	Galvanized steel (3 mm thickness)	1	Drilling+ Saw Cutting/ Dremel cutting
Arduino mega 2500	Multiple	1	Purchase
Humidifier	Multiple	1	Purchase
Peltier module	Multiple	1	Purchase
Ceramic bulbs	Multiple	2	Purchase
Fan	Multiple	1	Purchase
Hinge	Stainless Steel	4	Purchase
Shelf bracket	Stainless Steel	4	Purchase
Hexagon bolt m10 x 80	Stainless Steel	2	Purchase
Hexagon bolt m5 x 80	Stainless Steel	58	Purchase
Hexagon bolt m5 x 16	Stainless Steel	18	Purchase
Hexagon nut m5	Stainless Steel	76	Purchase
Hexagon nut m10	Stainless Steel	2	Purchase
Plain washer m5	Stainless Steel	76	Purchase
Plain washer m10	Stainless Steel	2	Purchase
Humidity and temperature sensor	Multiple	2	Purchase

Table 14 describes the type of manufacturing processes mentioned in table 1, it is requirements or data to work, the respective cost and the tolerance of each process.

Table 14 Manufacturing processes requirements

Manufacturing process	Manufacturing description	Requirement	Cost	TOLARANCE
3D Printing	Additive manufacturing process that elaborates 3D parts from digital designs.	Quality finish of the piece. Design in digital format, commonly. STL	$3,00/hour	±0.75 mm
Drilling/Saw Cutting/Dremmel cut	Process that requires handwork from trained staff.	Diameters Thickness of the material Material	$4/hour	±2 mm
CNC Milling Machine	Process that manufactures a material in all 3 axes with the contact of the slot drill and the part to be worked.	Diameters Thickness of the material Material	$10/hour	± 0.41 mm
Blade cutting	Process that cuts materials with the contact of the part and a blade.	Longitudinal measurements	$1,5/meter	± 2 mm

The table below shows the cost and total time that each component will require to manufacture. Additionally, a person in charge is assigned in the same table for each component and its manufacture.

Table 15 Time and cost of that will require each component.

Material	Parameters	Total Time	Total time	Responsible – verification process
Polycarbonate (3 mm thickness)	Lineal measurements for Milling = 3981.34 mm Lineal measurements for saw cutting = 51716 mm	Milling = 0.5 hours Saw = 4 hours	Milling = $5.00 Saw = $16.00	Nicole Burneo – An electronic caliper gauge will confirm milling final measurements and saw cutting will be evaluated with a flexometer
Polycarbonate (5 mm thickness)	Lineal measurements for Milling = 33838.17 mm Lineal measurements for saw cutting = 26112 mm	Milling = 5.5 hours Saw = 2 hours	Milling = $55.00 Saw = $8.00	Nicole Burneo – An electronic caliper gauge will confirm milling final measurements and saw cutting will be evaluated with a flexometer
Glass fiber (50 mm thickness)	Lineal measurements = 15230.14 mm	Utility Knife = 6 hours	-	Verónica Barona – a flexometer is implemented to confirm final measurements
PLA	Total Material Weight = 130 g	13 hours	Material cost = $4.55 Printing cost = $39.00	Felipe Pineda – An electronic caliper gauge will confirm measurements for length and diameters
Galvanized steel (3 mm thickness)	Lineal measurements for saw cutting = 1328 mm	1.5 hours	$6.00	Doménica Bonilla – A flexometer will be implemented to confirm length measurements
Stainless steel	Lineal measurements for laser cut = 650.1 mm	7 minutes	$12.60	Doménica Bonilla – A flexometer will be implemented to confirm length measurements

Flow diagram for each manufacturing process is presented in Appendix A. Additionally, maintenance requirements are detailed in the maintenance and operation manual.

RESULTS AND DISCUSIONS

Design Report

Considering incubation and client requirements, calculations and simulations were developed to assure an appropriate equipment performance under environmental conditions. The incubator was designed to harbor 300 eggs under controlled temperature and relative humidity conditions. Additionally, the incubator operation should satisfy self-sustainable needs. For this purpose, subsystems will be analyzed as follows:

1. External Walls Structure: System that properly isolates the eggs, avoiding their exposure to predators and alteration in conditions required for incubation. Calculations and simulations in heat transfer through the equipment walls will be performed to determine the best material composition.
2. Energy source system: It is in charge of supplying the necessary energy for the operation of the incubator. Power consumption by all components present in the equipment will be determined in order to determine the number of photovoltaic panels required and the type of battery that can be implemented.
3. Eggs support system: the main purpose is holding eggs during incubation period. Trays will be required to support deflection and vibrational conditions. To prevent failure, simulations and calculations on deflection and vibrations will be performed.
4. Humidification / Dehumidification system: It is responsible for maintaining relative humidity levels required for incubation process. Calculations on condensation rates and Peltier module for dehumidification will be performed.

5. Temperature regulation system: It provides the necessary heat to maintain the incubation temperature within the system. It is required to determine how many times the system will turn on by recognizing how long it takes for the incubator to lose 1°C.
6. Ventilation: Proper ventilation and recirculation of air assures incubation takes place. For this purpose, fluid simulations will be done.

Design general considerations

Each subsystem analysis was carried out under ambient considerations and incubation requirements. In order to have a better understanding of the calculations presented on subsequent sections, values for several conditions are presented below.

Ambient critical conditions

The incubation equipment was designed expecting to operate twice a year, considering *Podocnemis Unifilis* turtles incubation periods. In order to assure the apparatus will be able to efficiently work throughout every environmental condition, temperature and humidity records were analyzed. For this purpose, the TBS provided the group with measurements on these variables recorded every 30 minutes for 5 years. The information was divided into four incubation periods between December 2011 and August 2013. Average values per hour were considered to establish 11 different categories that differ one degree Celsius one another. Finally, the most critical temperature (lowest value) for the corresponding incubation period was selected, since it involves higher difference with incubation temperature. The resultant categories and their corresponding values are presented on the following table.

Table 16 Temperature and Relative humidity for the incubation periods records.

	Incubation August – October		**Incubation December – February**	
Category	Temperature [°C]	Relative Humidity [%]	Temperature [°C]	Relative Humidity [%]
8 am	25.0	91.7	24.9	94.4
9 am	27.6	85.8	27.5	88.2
10 am	30.0	79.5	30.2	79.9
11 – 15 pm	31.8	70.6	30.0	76.4
16 pm	29.7	75.3	28.7	79.7
17 pm	28	80.5	27.7	83.6
18 pm	26.4	87.3	26.2	91.2
19 pm	25.0	90.0	24.8	92.1
20 pm	24.2	91.4	24.1	93.6
21 pm	23.7	92.2	23.7	94.2
22 – 7 am	22.1	94.6	22.2	99.3

As Table 16 presents, the most critical temperature presented on the considered records corresponds to 22.1 °C with relative humidity of 94.6%. These conditions will be considered throughout the project as ambient conditions for simulations and first calculations approach. The corresponding air properties obtained from EES for sea level pressure, due to despicable altitude from the station location, are:

Table 17 Ambient air property values

Property	**Variable Name**	**Value**	**Unit**
Pressure	Po	101.325	kPa
Density	rho_{air}	1.166	$kg/_{m^3}$
Specific Heat	cp_{amb}	1.036	$kJ/_{kg\ K}$
Enthalpy	h_1	62.52	$W/_{m^2\ K}$

Eggs incubation requirements

Ex-situ incubation successful results are highly determined by an accurate reproduction of natural temperature and relative humidity conditions. In the desire to have a better understanding of the in-situ substrate behavior, experimental sand temperature variations were recorded for five days. Detailed experiment constraints and results are presented on later sections. However, in this point it is important to mention that sand temperature variations are wide. Resulting in acceptable larger temperature difference trough the incubator. The selected design temperature corresponds to the highest value in the range detailed by Lolavar & Wyneken, being 33 ° Celsius (2020). Air constant values for this temperature and a relative humidity of 94% were obtained through EES and are presented below.

Table 18 Incubation air property values

Property	Variable Name	Value	Unit
Dew Point	dp	31.9	$°C$
Density	rho_{inc}	1.099	$kg/_{m^3}$
Specific Heat	cp_{inc}	1.064	$kJ/_{kg\ K}$
Enthalpy	h_2	111.3	$W/_{m^2\ K}$
Viscosity	mu_{air}	0.00001879	$kg/_{m\ s}$
Prandtl	Pr_{air}	0.7066	
Conductivity	k_{air}	0.02624	$W/_{m\ K}$

Incubator dimensions and components properties

Referring to physical characteristics of the equipment, several values are considered in following calculations. The table presented below indicates dimensions referent to the incubator.

Table 19 Incubator dimensions

Component	Variable Name	Value	Unit
External dimensions	E_d	675 x 872 x 1022	mm
Internal dimensions	I_d	560 x 760 x 910	mm
Contained volume	Vol	0.387	m^3
Total walls area	A_{walls}	3.264	m^2
Polycarbonate thickness	L_{poli}	0.003	mm
Fiberglass thickness	L_{fg}	0.050	mm

The use of values presented trough tables 16-19 will help in subsequent design calculations.

Engineering Analysis

For the incubator design it has been decided to establish the following elements: ceramic bulbs, a fan, humidifier, dehumidifier and photovoltaic panels. To guarantee the incubator has a successful performance, critical subsystems were established. Structural and incubation conditions are established as key subsections to analyze.

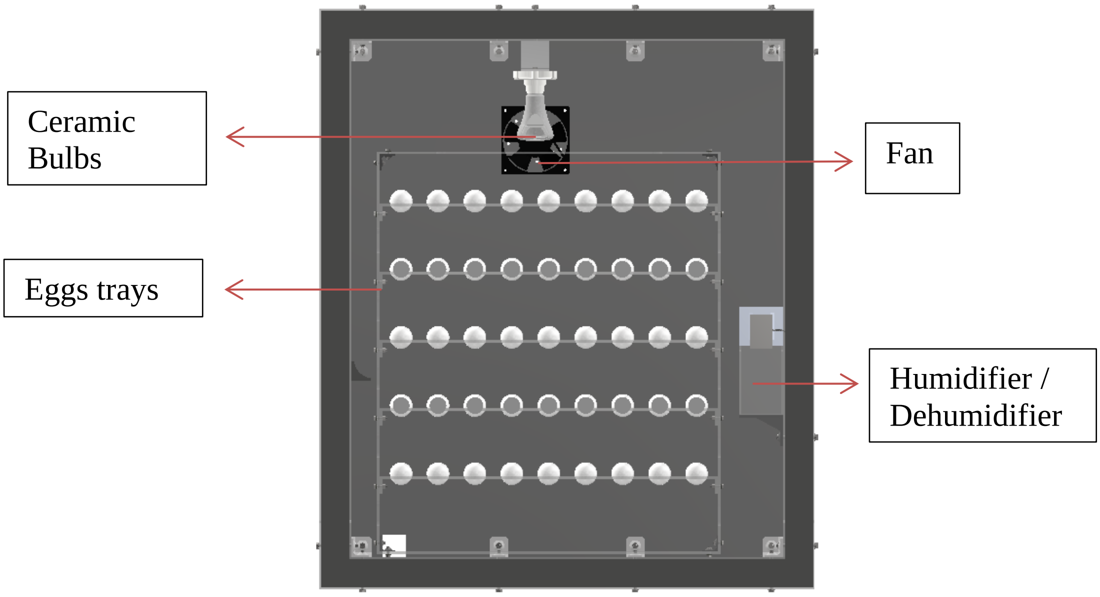


Figure 3 Visual incubator representation with principal components

Structural Subcomponents

This section will present calculations and simulations performed to support decisions taken during design process over this topic. Subsections analyze include eggs trays, incubator walls and photovoltaic panels structure.

Eggs trays

This section presents calculations on materials mechanics and vibrations for the egg's trays. For this analysis analytical and simulation evaluations where established.

Materials Mechanic analysis

The shelf will have two type of containers, A and B, to make air flux more effective. Type A has a capacity of 54 eggs and Type B container has a capacity of 63 eggs. This section will analyze the most critical egg container, being the one that carries more eggs. Each egg has a mass of 45 grams. The results will present a static analysis, maximum stress analysis, and safety factor.

Since it is required to have an effective air flux the geometry of the container A The study will consider most prone to fail zone. This as consequence of its reduced cross-sectional area.

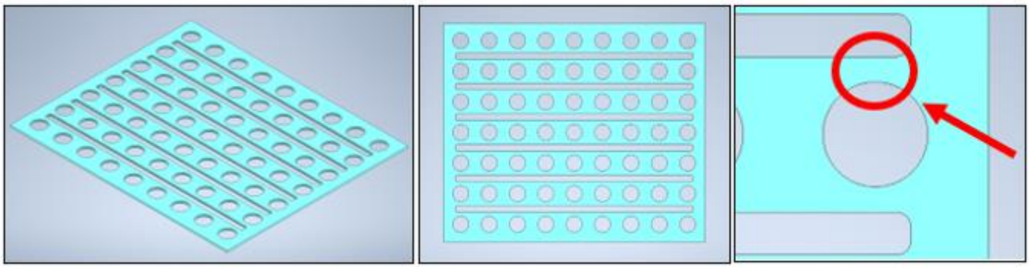


Figure 4 Smaller area in the geometry of the egg container with more egg capacity

Figure 5 presents the studied cross-sectional area dimensions.

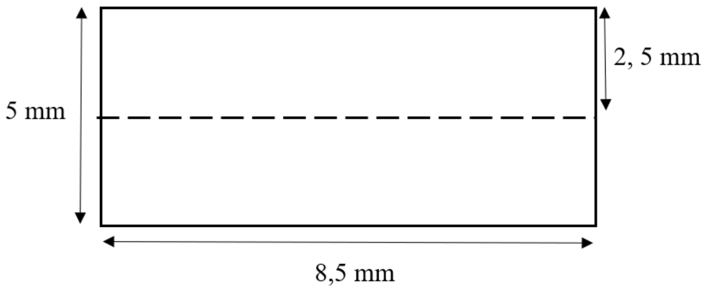


Figure 5 cross sectional area of the critical beam to analyze

Each egg force is applied at the hole center. Due to each row symmetry, it will be considered only one critical side of the structure. Forces on the beam analyzed are represented in Figure 6, assuming this slice of the part has half of the force applied for each row.

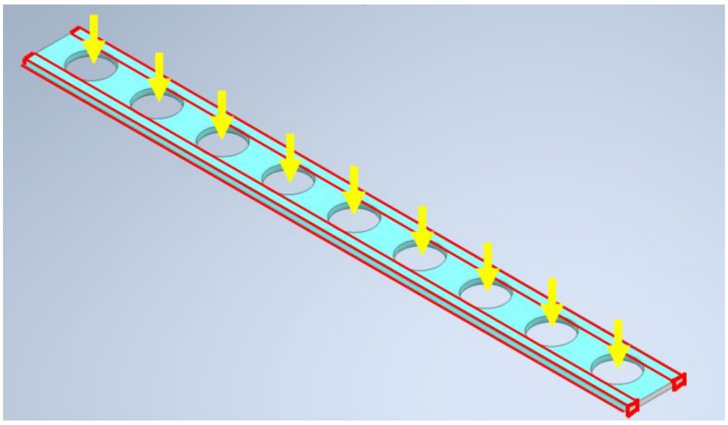


Figure 6 Applied forces and critical zones

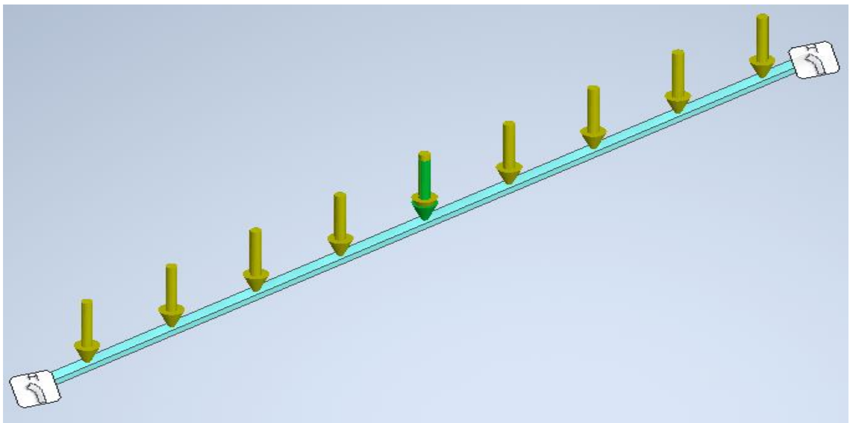


Figure 7 Applied forces during the inventor simulation.

- **Static study**

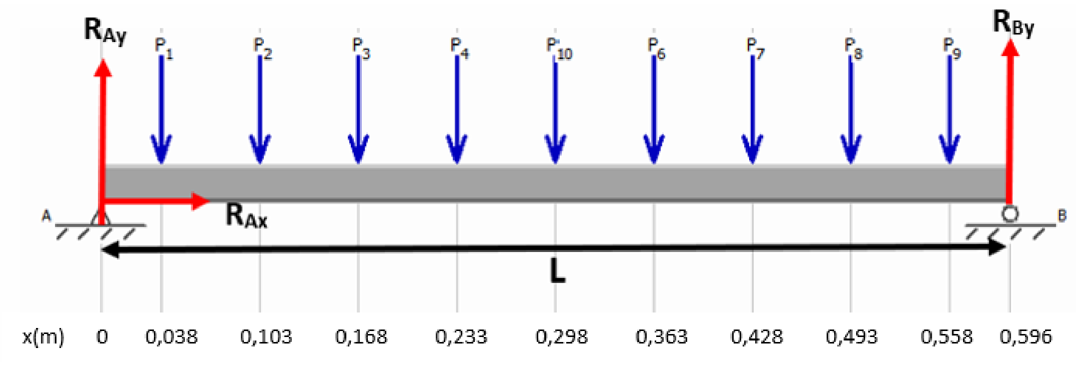


Figure 8 Free body diagram of the beam

Each force applied represent the weight of half an egg, since the analysis will be done on one side of the row (shown in figure 4)

Force produced by an egg:

$$P_{egg} = m \times g$$

$$P_{egg} = 0{,}043\ [kg] \times 9{,}806[\frac{m}{s^2}]$$

$$P_{egg} = 0{,}412\ [N]$$

Forces P_1, P_2, P_3, P_4, P_5, P_6, P_7, P_8, and P_9 are the same force.

$$P_{1-9} = \frac{P_{egg}}{2}$$

$$P_{1-9} = \frac{0{,}421}{2}\ [N]$$

$$P_{1-9} = 0.211[N]$$

Weight force of the egg container:

$$P_{10} = P_{part} = m_{container\ part} \times g$$

$$P_{10} = 0{,}031\ [kg] \times 9{,}806[\frac{m}{s^2}]$$

$$P_{10} = 0{,}304[N]$$

Dimensions of the geometry of the beam analyzed:

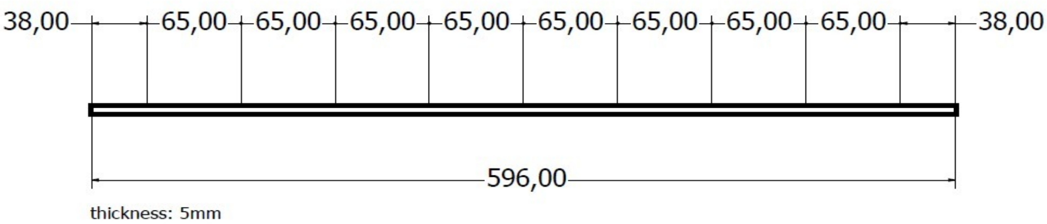


Figure 9 Dimensions of the geometry of the beam

Reactions:

Sum of forces in “x” axis.

$$\sum F_x = 0$$

$$R_{Ax} = 0$$

Sum of forces in “y” axis.

$$\sum F_y = 0$$

$$Ay + By - P_1 - P_2 - P_3 - P_4 - P_4 - P_5 - P_6 - P_7 - P_8 - P_9 - P_{10} = 0$$

$$R_{Ay} + R_{By} = 9P_1 + P_{10}$$

$$R_{Ay} + R_{By} = 9 \times (0{,}211)[N] + 0{,}304[N]$$

$$R_{Ay} + R_{By} = 2{,}203[N]$$

Due to symmetrical beam, reaction R_{Ay} is equal to reaction R_{By}

$$2R_{Ay} = 2{,}203[N]$$

$$R_{Ay} = 1{,}102[N]$$

$$R_{Ay} = R_{By} = 1{,}102[N]$$

Sum of punctual momentum in point “A” axis.

$$\sum M_A = 0$$

$$M_A + (0{,}038 + 0{,}103 + 0{,}168 + 0{,}233 + 0{,}298 + 0{,}363 + 0{,}428 + 0{,}493 + 0{,}558) \cdot P_{1-9} - L \cdot R_{By} = 0$$

$$M_A + 0{,}596\, R_{Ay} - 2{,}682\, P_1 = 0$$

$$M_A = -0{,}596\, R_{Ay} + 2{,}682\, P_1$$

$$M_A = -0{,}596\ (1{,}102) + 2{,}682\ (0{,}211)$$

$$M_A = 0{,}091\ [N \cdot m]$$

- **Maximum Momentum**

Since the beam analyzed is symmetrical, the maximum momentum will occur at 0,298 meters, which is the center of the part. The method of sections is used to recognize this value. It was decided to use the equation produced for the section between 0 mm and 298 mm as it's shown in figure 10.

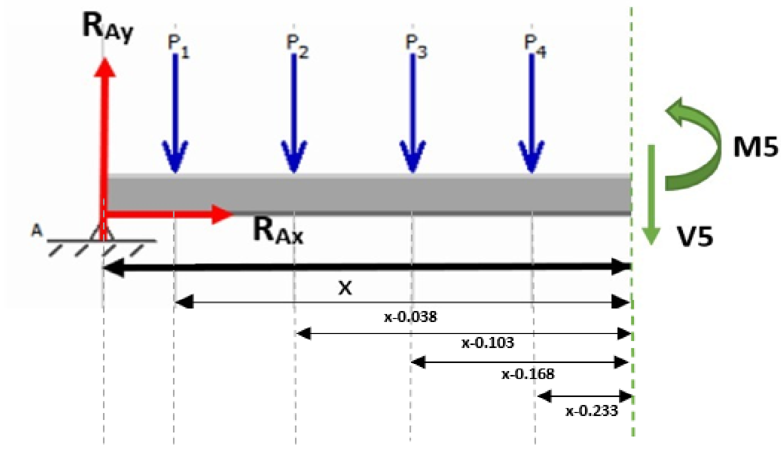


Figure 10 Cut section for the section method

Sum of forces in "y" axis for section shown in figure 10

$$\sum F_5 = 0$$

$$R_{Ay} - P_1 - P_2 - P_3 - P_4 - V_5 = 0$$

$$V_5 = R_{Ay} - P_1 - P_2 - P_3 - P_4$$

$$V_5 = 1{,}102[N] - 4(0.211)[N]$$

$$V_5 = 0{,}258[N]$$

Sum of momentums of the section in figure 10

$$\sum M_5 = 0$$

$$M_5 + P_1(x - 0{,}038) + P_2(x - 0{,}103) + P_3(x - 0{,}168) + P_4(x - 0{,}233) - R_{Ay}(x) = 0$$

$$M_5 = R_{Ay}(x) - P_1(x - 0{,}038) - P_2(x - 0{,}103) - P_3(x - 0{,}168) - P_4(x - 0{,}233)$$

$$M_5 = 1{,}102(x) - (0{,}211)[(x - 0{,}038) + (x - 0{,}103) + (x - 0{,}168) + (x - 0{,}233)]$$

$$M_5 = 1{,}102(x) - (0{,}211)(4x - 0{,}542)$$

$$M_5 = 0{,}258(x) + 0{,}114$$

$$x = 0{,}298\ [m]$$

$$M_{max} = M_5 = 0{,}191\ [N \cdot m]$$

These calculations are compared with the results obtained with MDSolids: Educational Software for Mechanics of Materials. This validation is shown in figure 11 were it is exposed load, shear, and moment diagrams.

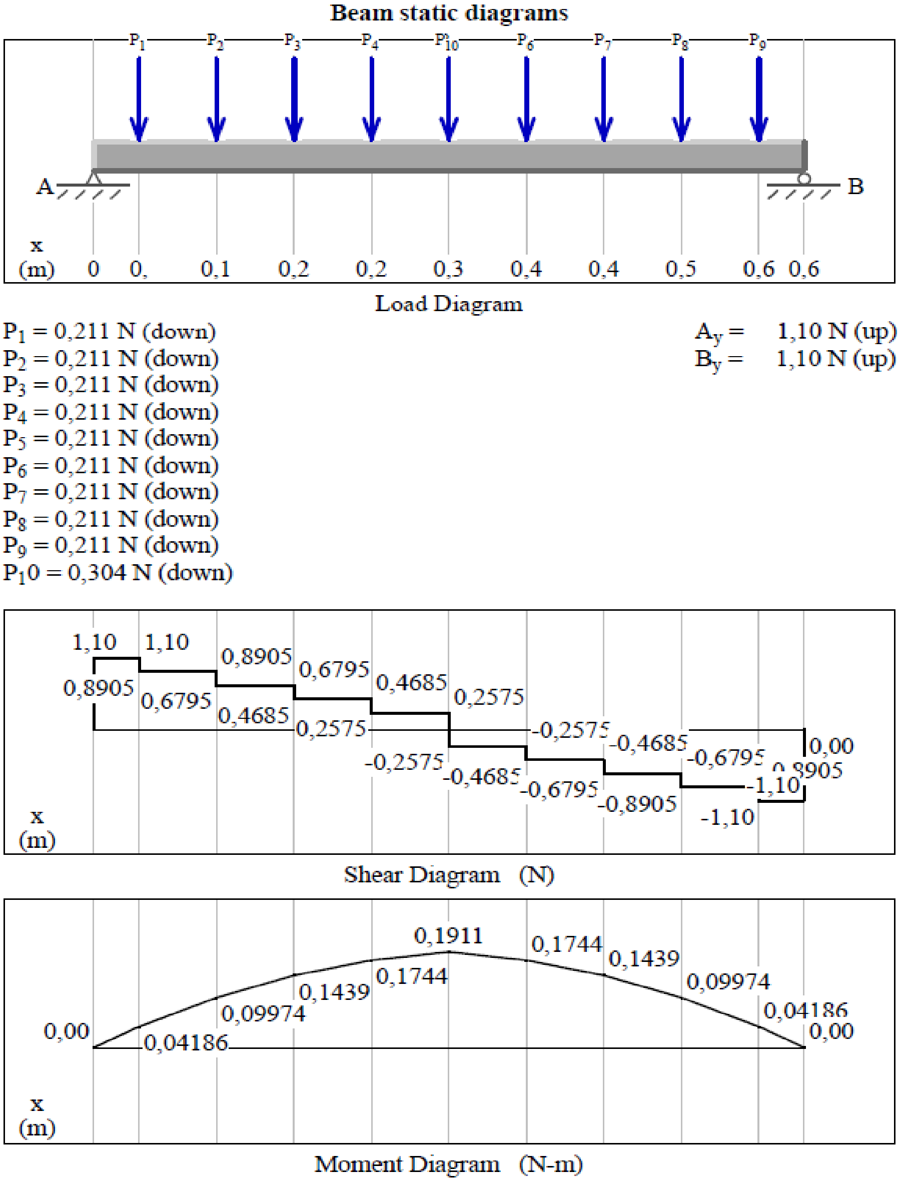


Figure 11 Beam diagrams

- **Maximum Stress**

Inertia calculations:

Using dimensions show in figure 5, the total inertia will result:

$$I_{yy} = I_{Total}$$

$$I_{yy} = \frac{1}{12} bh^3$$

h: Thickness of the geometry, in the figure 5 is represented by “t”

b: base dimensions of the geometry figure 5

$$I_{yy} = \frac{1}{12}(0{,}0085)(0{,}005)^3$$

$$I_{yy} = 8{,}8575 \times 10^{-11}\ [m^4]$$

Since the maximum momentum and the inertia of the body was already obtained, a stress analysis will be determined.

$$\sigma = \frac{M_{max} * c}{I_{yy}}$$

Where:

M_{max}: Bending moment.

c: Distance from neutral axis to outside

I_{yy}: Beam inertia

$$M_{max}{=}0{,}191\ [N \cdot m]$$

The distance C is calculated from the neutral axis to the outside of the beam as shown in the figure 5:

$$c = \frac{t}{2}$$

$$c = \frac{5\ [mm]}{2}$$

$$c = 2.5\ [mm] \cdot \frac{1\ [m]}{1000[mm]}$$

$$c = 0{,}0025\ [m]$$

Maximum stress result:

$$\sigma = \frac{0{,}191\ [N \cdot m] * 0.0025[m]}{8{,}8575\ \times 10^{-11}\ \ [m^4]}$$

$$\sigma = 5390911[Pa]$$

$$\sigma = 5{,}39[MPa]$$

Safety factor

In engineering design safety factor (η) is defined as "how much could a system withstand beyond the expected loads or actual loads". (Maria, 2016). This factor is defined by the follow equation

$$\eta = \frac{S_y}{\sigma}$$

Maximum allowable stress of polycarbonate is:

$$Sy_{poly} = 60\ [MPa]$$

(Manufacturing, n.d.)

$$\eta = \frac{60\ [MPa]}{5{,}39[MPa]}$$

$$\eta = 11.13$$

Stress and deformation simulations

- MD Solid Software

Data introduce to the analysis:

  - Elastic modulus: 2,515 [GPa] (POLYCASA, 2014)
  - Cross sectional area: 8,5 [mm] x 5 [mm]

- Bending moment: 0,191 [N-m]

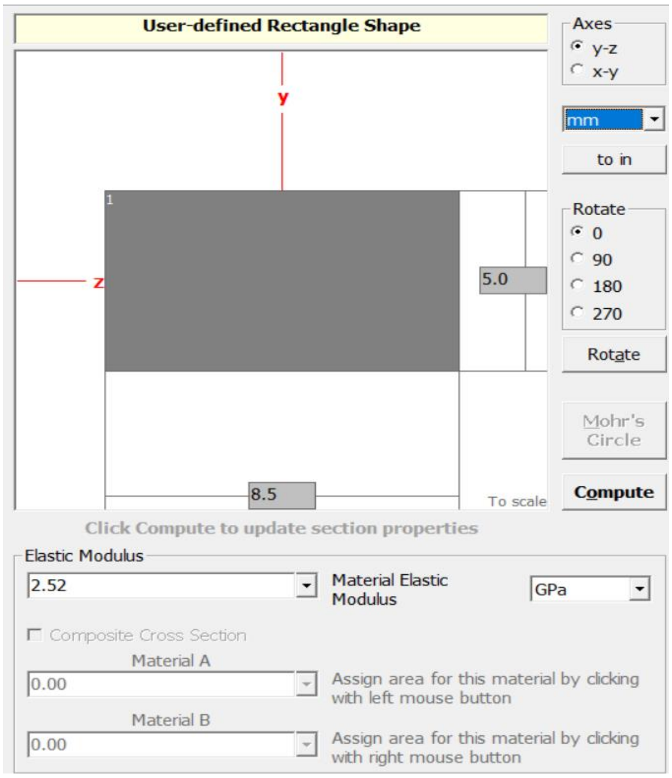


Figure 12 Defined cross-sectional area to be analyzed in MDSolid software.

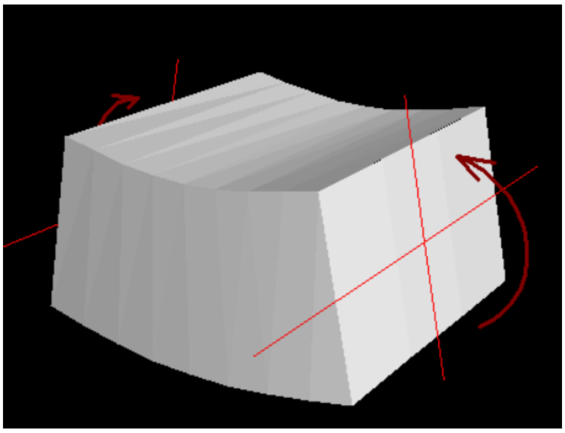


Figure 13 3D Solid Rendering of the solid in MDSolids software

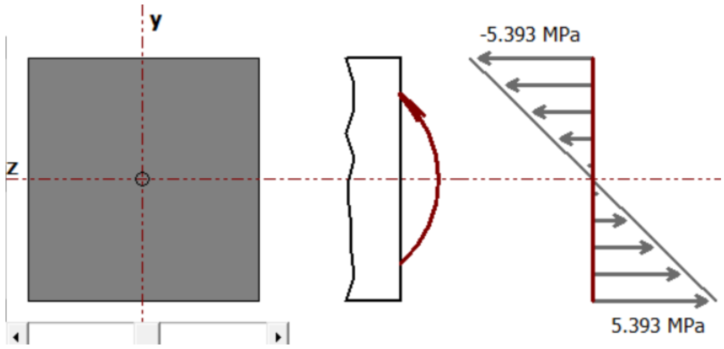


Figure 14 Normal stress calculated with MDSolids Software

Result:

$$\sigma_{MDsolid} = -5{,}393\ [MPa]$$

- Inventor Autodesk

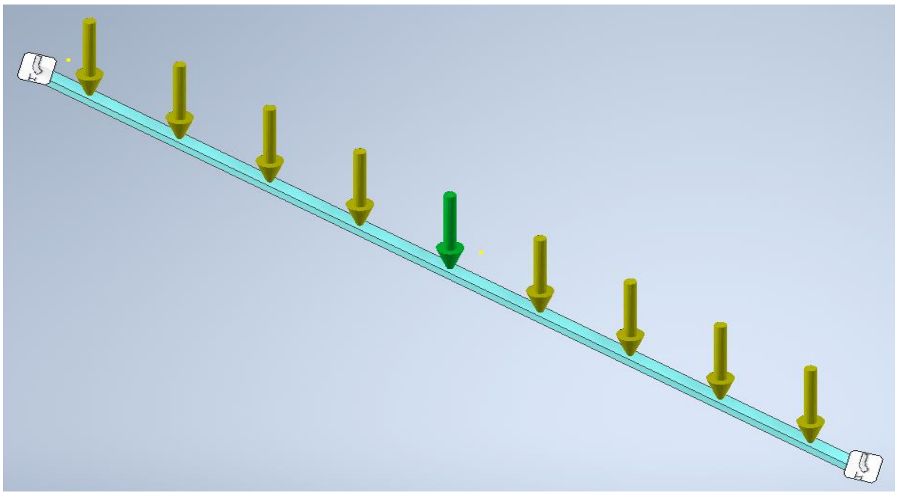


Figure 15 Forces applied in the critical zone during the simulation

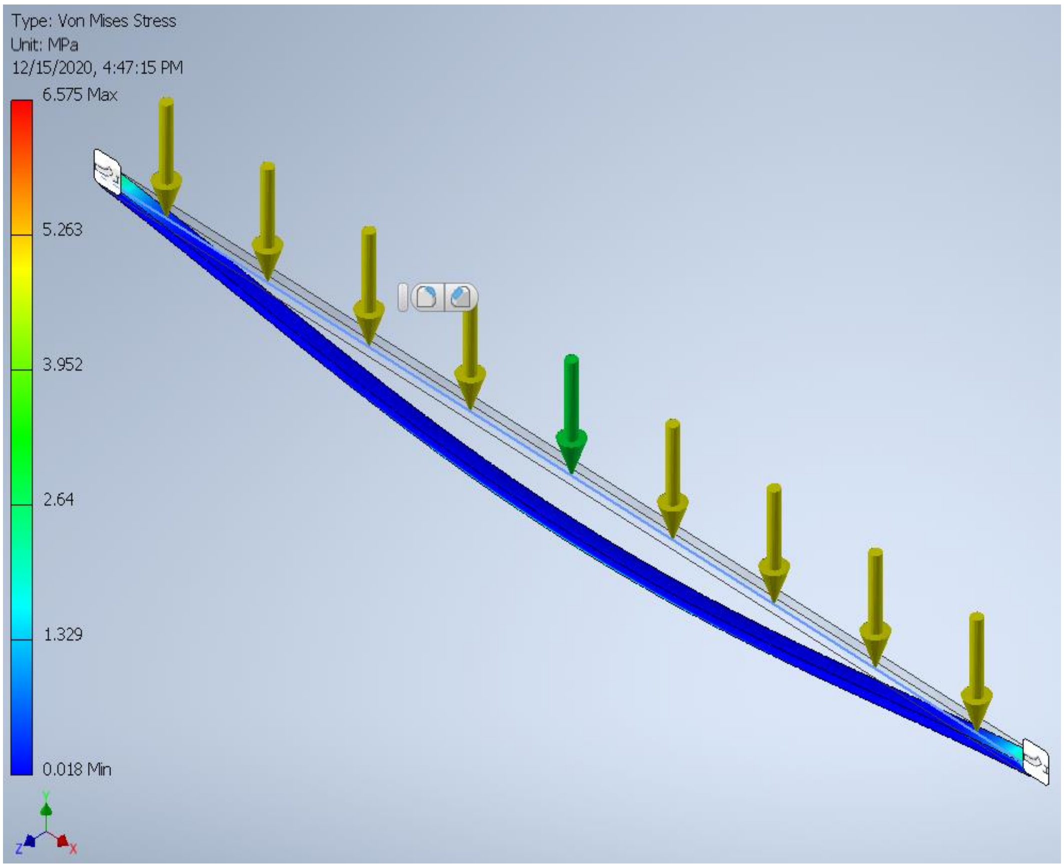


Figure 16 Maximum stress of the critical zone

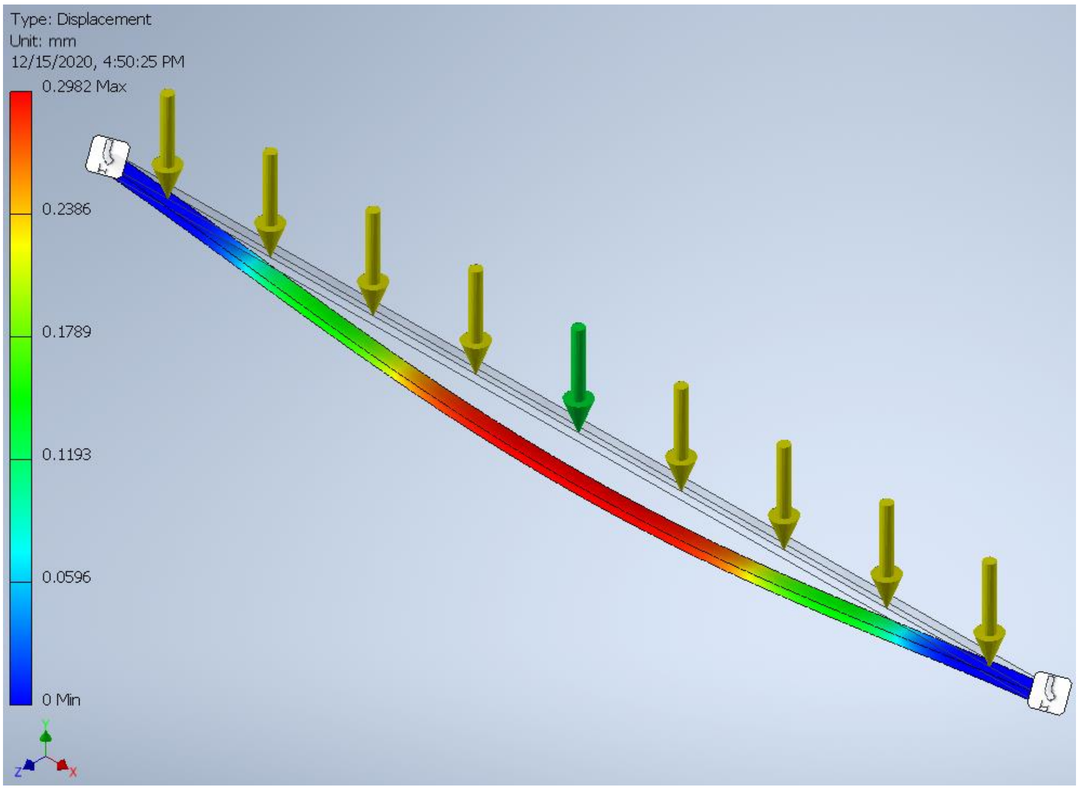


Figure 17 Maximum deflection of the critical zone

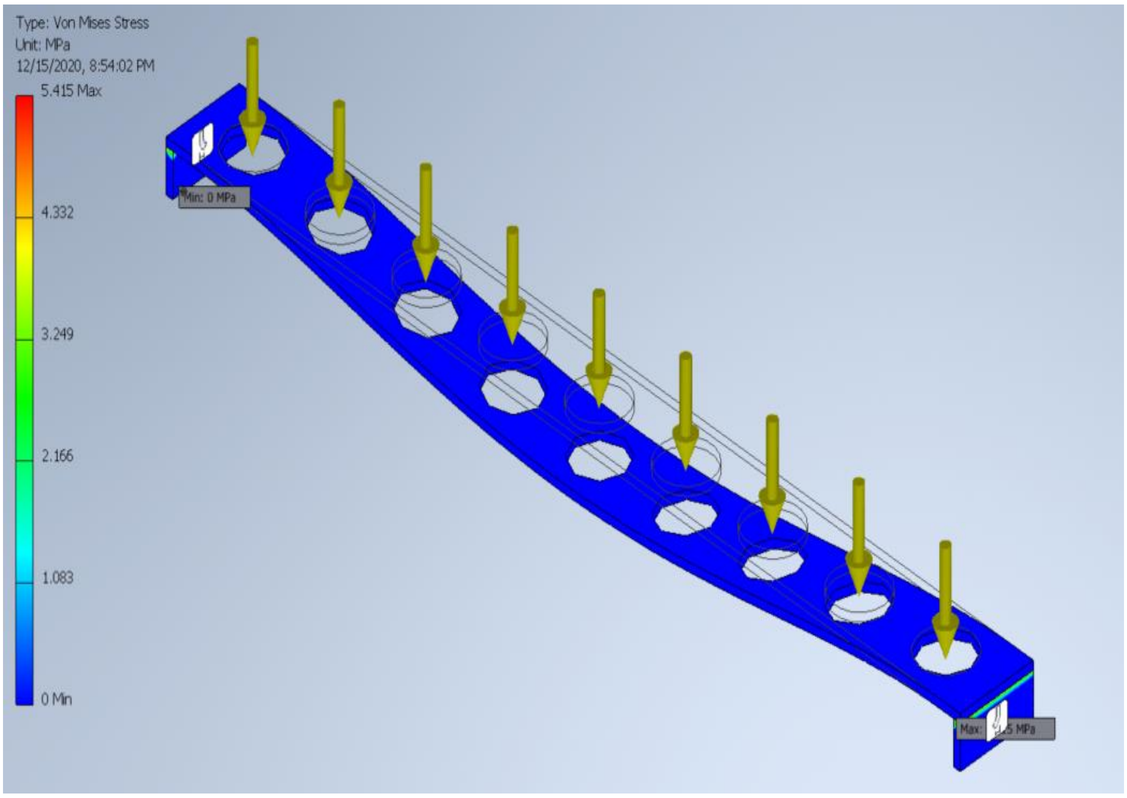


Figure 18 maximum stress of the beam

- **Absolut error**

Maximum stress

$$error = \frac{|\sigma_{real} - \sigma_{teorico}|}{\sigma_{teorico}} \cdot 100\%$$

$$error = \frac{|5{,}39[MPa] - 6{,}575[MPa]|}{6{,}575[MPa]} \cdot 100\%$$

$$error = 18\%$$

Static studies with embedment:

Sum of forces in “x” axis.

$$\sum F_x = 0$$

$$R_{Ax} = 0$$

Sum of forces in “y” axis.

$$\sum F_y = 0$$

$$R_{Ay} + R_{By} - 9P - W = 0$$

$$R_{Ay} + R_{By} = 9P + W$$

$$R_{Ay} = R_{By}$$

$$R_{By} = \frac{9P + W}{2}$$

$$R_{By} = R_{Ay} = 1{,}102$$

Sum of punctual momentum in point “A” axis.

$$\sum M_A = 0$$

$$M_A + By * L$$
$$- P(0{,}038 + 0{,}103 + 0{,}168 + 0{,}233 + 0{,}298 + 0{,}363 + 0{,}428 + 0{,}493 + 0{,}558) = 0$$

$$M_A + 0{,}596\ R_{By} - 2{,}682\ P = 0$$

$$M_A = -0{,}596\ R_{By} + 2{,}682\ P_1$$

$$M_A = -0.091$$

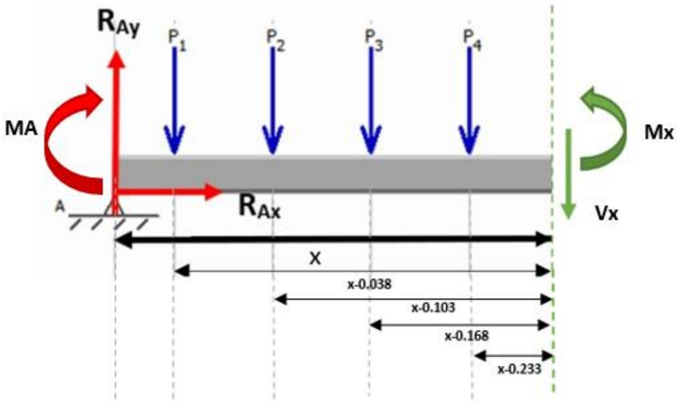


Figure 19 Embedment section cutter for the section method

$$\sum F_y = 0$$

$$R_{Ay} - 4(P) - V_x = 0$$

$$V_x = R_{Ay} - 4(P)$$

$$V_x = 1.102 - 4(0.211)$$

$$V_x = 0.258\ [N]$$

$$\sum M_x = 0$$

$$-M_A - R_{Ay}(x) + P[(x - 0{,}038) + (x - 0{,}103) + (x - 0{,}168) + (x - 0{,}233)] + M_x = 0$$

$$M_x = M_A + R_{Ay}(x) - P(4(x) - 0.542)$$

$$M_x = -0.091 + 1.102x - 0.211(4x - 0.542)$$

$$M_{max} = M_x = 0.258x + 0.023$$

$$M_{max} = M_x = 0.258(0.298) + 0.023$$

$$M_{max=}0{,}099\ [N \cdot m]$$

Maximum stress result:

$$\sigma = \frac{M_{max} * c}{I_{yy}}$$

$$\sigma = \frac{0{,}099\ [N \cdot m] * 0.0025[m]}{8{,}8575\ \times 10^{-11}\ \ [m^4]}$$

$$\sigma = 2819192[Pa]$$

$$\sigma = 2{,}81[MPa]$$

Maximum deflection

$$EI \cdot \frac{d^2 y}{dx^2} = M(x)$$

$$EI \cdot y_{max} = \iint M(x) \cdot dx$$

$$EI \cdot \frac{dy}{dx} = \frac{0.258x^2}{2} + 0.023x + C1$$

$$EI \cdot y_{max} = \frac{0.258x^3}{6} + 0.023\frac{x^2}{2} + C1x + C2$$

Boundary Conditions

x=0; y=0

$$EI \cdot y_{max} = \frac{0.258(0)^3}{6} + 0.023\frac{(0)^2}{2} + C1(0) + C2$$

$$C2 = 0$$

x=L; y=0

$$C1 = -\frac{1}{0.596}\left(\frac{0.258(0.596)^3}{6} + \frac{0.023(0.596)^2}{2}\right)$$

$$C1 = -0.022$$

$$y_{max} = \frac{0.258(0.298)^3}{6} + 0.023\frac{(0.298)^2}{2} - 0.022(0.298)$$

$$y_{max} = -4.39E - 3m$$

$$y_{max} = -4.39mm$$

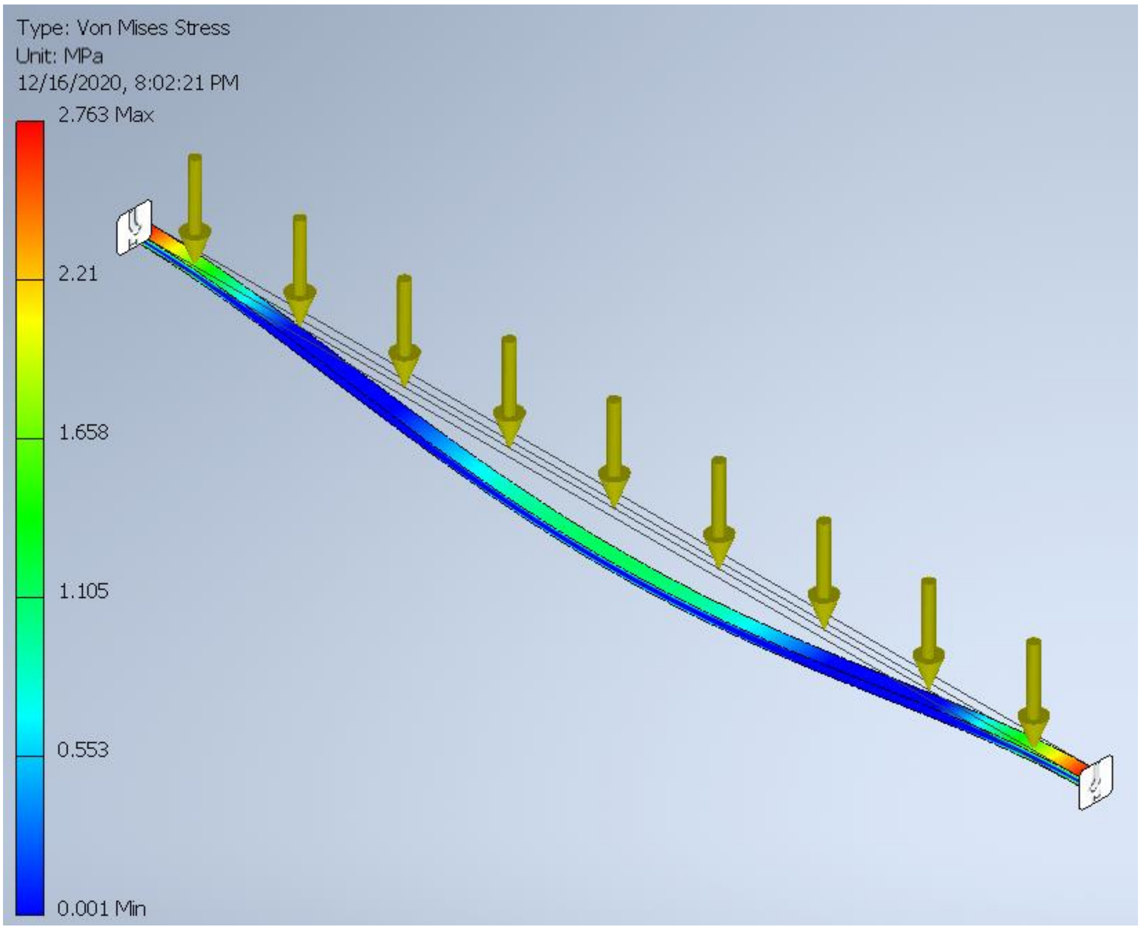


Figure 20 Maximum stress of the critical zone embedment

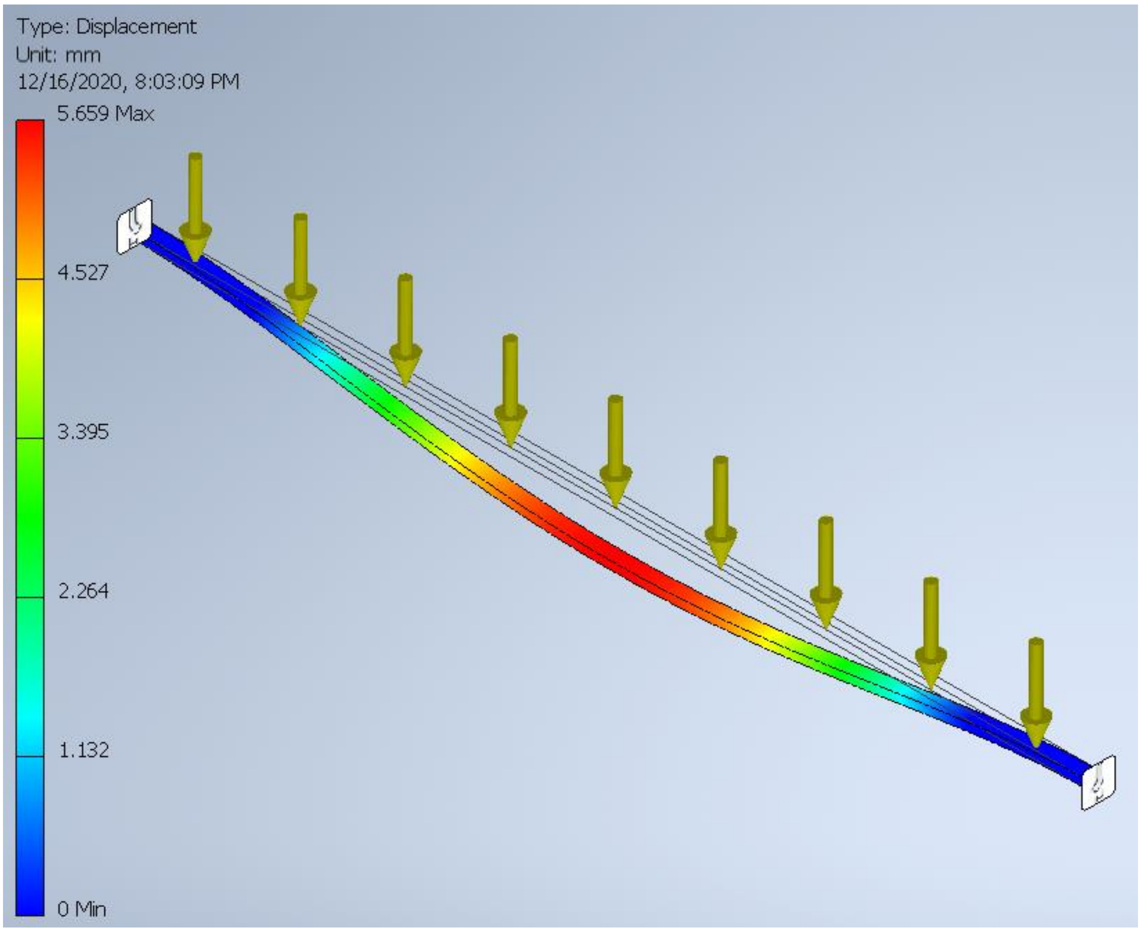


Figure 21 Maximum deflection of the critical zone embedment

- **Absolute error**

Maximum stress

$$error = \frac{|\sigma_{real} - \sigma_{teorico}|}{\sigma_{teorico}} \cdot 100\%$$

$$error = \frac{|2{,}81[MPa] - 2{,}76[MPa]|}{2{,}76[MPa]} \cdot 100\%$$

$$error = 1{,}81\%$$

Vibrations

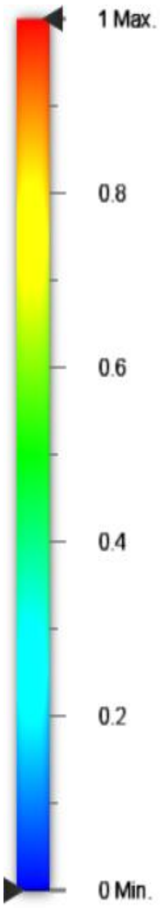
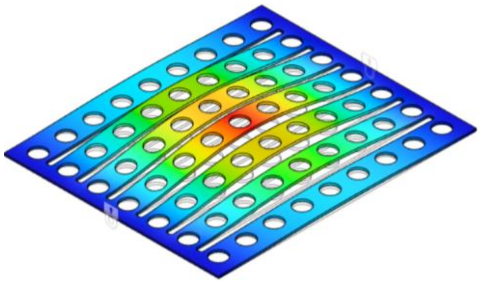
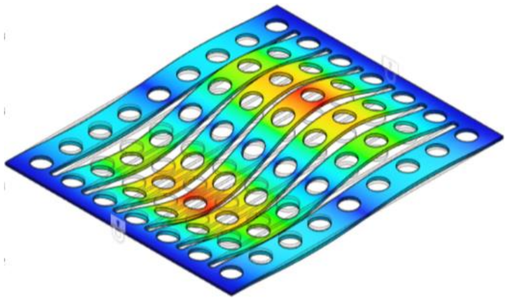
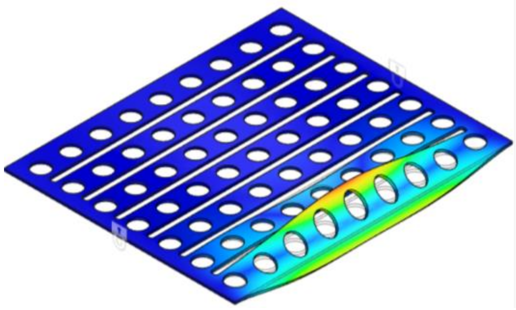
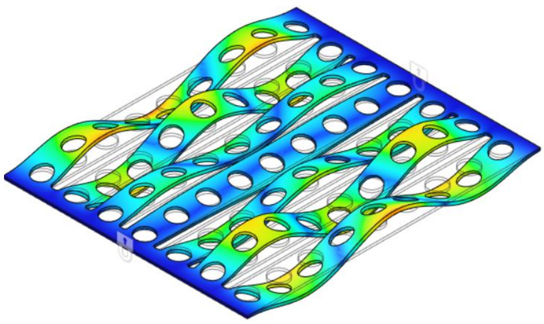
Through vibration analysis it can be evidenced materials or parts oscillations of a system, that might put it at risk. Since the main goal of this project is to contribute to the conservation of *Podocnemis Unifilis* turtles, ensuring their welfare is the highest priority. Because eggs will be laying on an egg container, this component is the one analyzed. Using software Fusion 360 from Autodesk, it was possible to simulate the natural vibrations of the component. Table 20 enlists first 21 mode of vibrations of the egg container initially design. Table 21 show mode simulation 1, 8, 15 and 22 of the containers with no modifications.

- Initial egg container simulation results

Table 20 Modes of vibrations on the egg container

Mode of vibration	Hertz
1	18.88
2	18.99
3	19.12
4	19.27
5	19.39
6	19.49
7	19.57
8	52.33
9	52.63
10	53
11	53.42
12	53.76
13	54.1
14	54.34
15	97.14
16	97.99
17	102.8
18	103.3
19	104
20	104.8
21	105.8

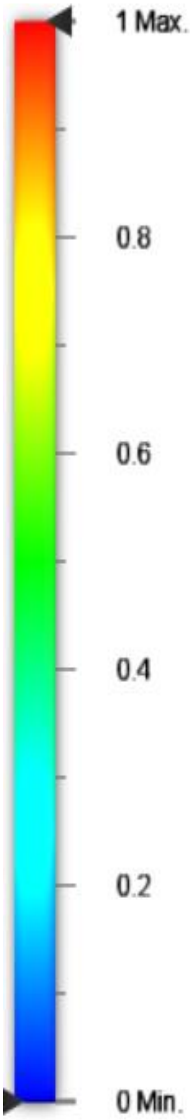
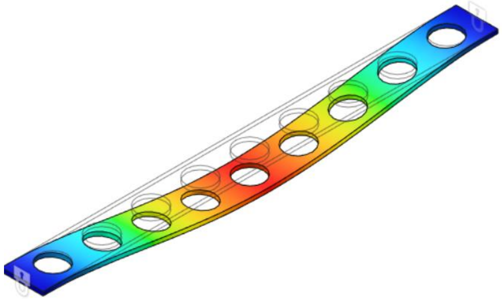
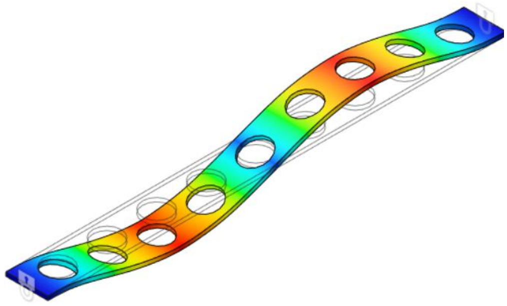
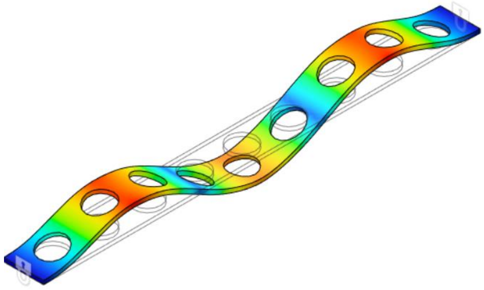
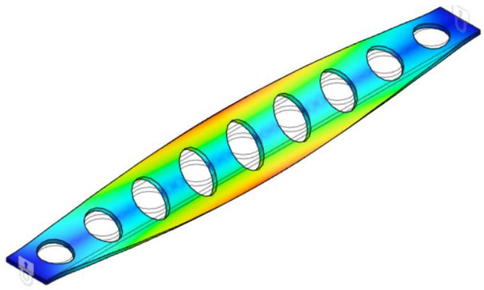
Table 21 Modes of vibration of egg container

Scale	Mode of vibration	Hertz	Simulation Result
	1	18.8	
	8	52.33	
	15	97.14	
	22	106.8	

Results of Table 20 and table 21 seem to show Fusion 360 software recognize each row of the container as an individual beam. For this reason, the table below brings under vibration analysis to the individual beam. First four vibration modes of the single beam are represented in table 22.

- Initial beam

Table 22 Modes of vibration of the beam

Scale	Mode of vibration	Hertz	Simulation Result
	1	18.4	
	2	50.96	
	3	100,9	
	4	110,6	

Stiffening an element requires usually a more rigid material. Seeking the mitigation of the first modes of vibration (which are the most critical), it is designed an extra component with higher rigidity. Since the future location of the incubator has a high relative humidity, avoid corrosive materials is a requirement. Organic materials are another restriction due to its natural trend of harbor pests. For such reasons, the selected material is Aluminum 6061, and its geometry is a U shape beam (0,5 mm thickness) as shown in figure 22.

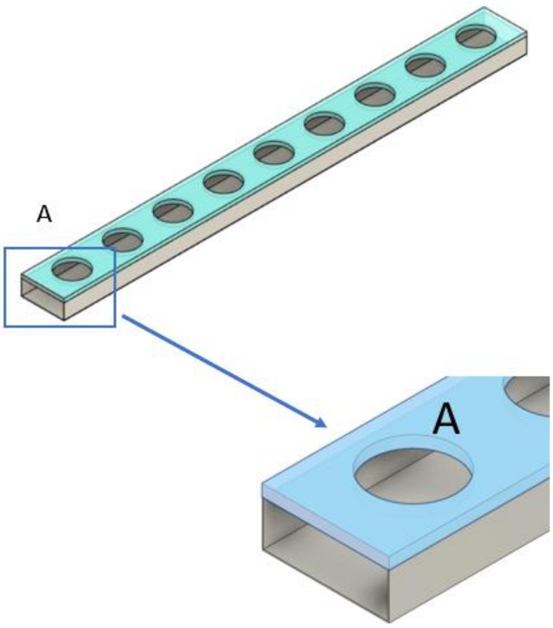
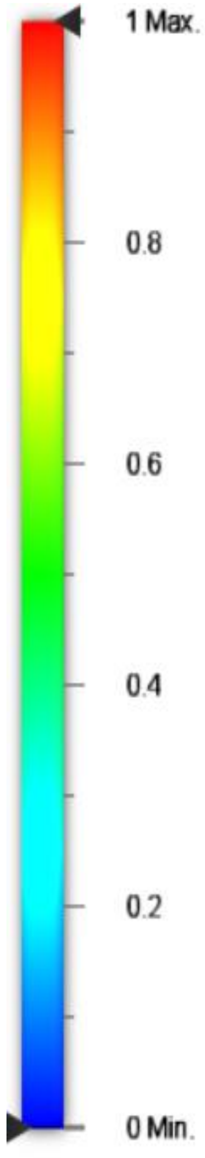
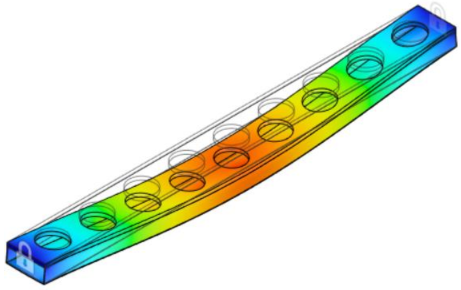
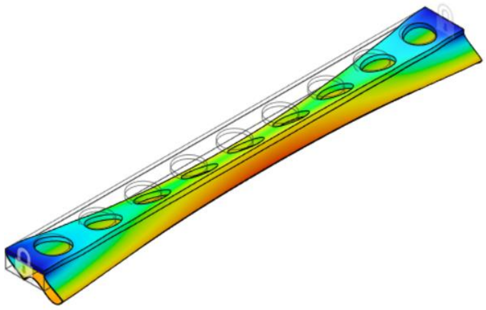
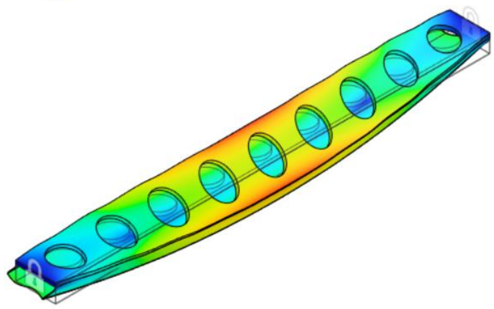
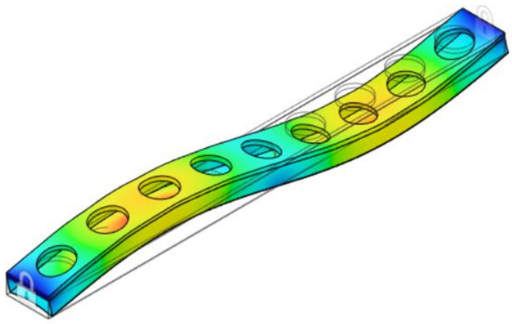


Figure 22 Rigidized beam

Table 23 and table 24 show the simulation of the beam and the full part (egg container) after stiffnening, respectively.

- Rigidized beam

Table 23 Modes of vibration of the rigidized beam

Scale	Mode of vibration	Hertz	Simulation Result
	1	174.2	
	2	245.8	
	3	332.9	
	4	394.	

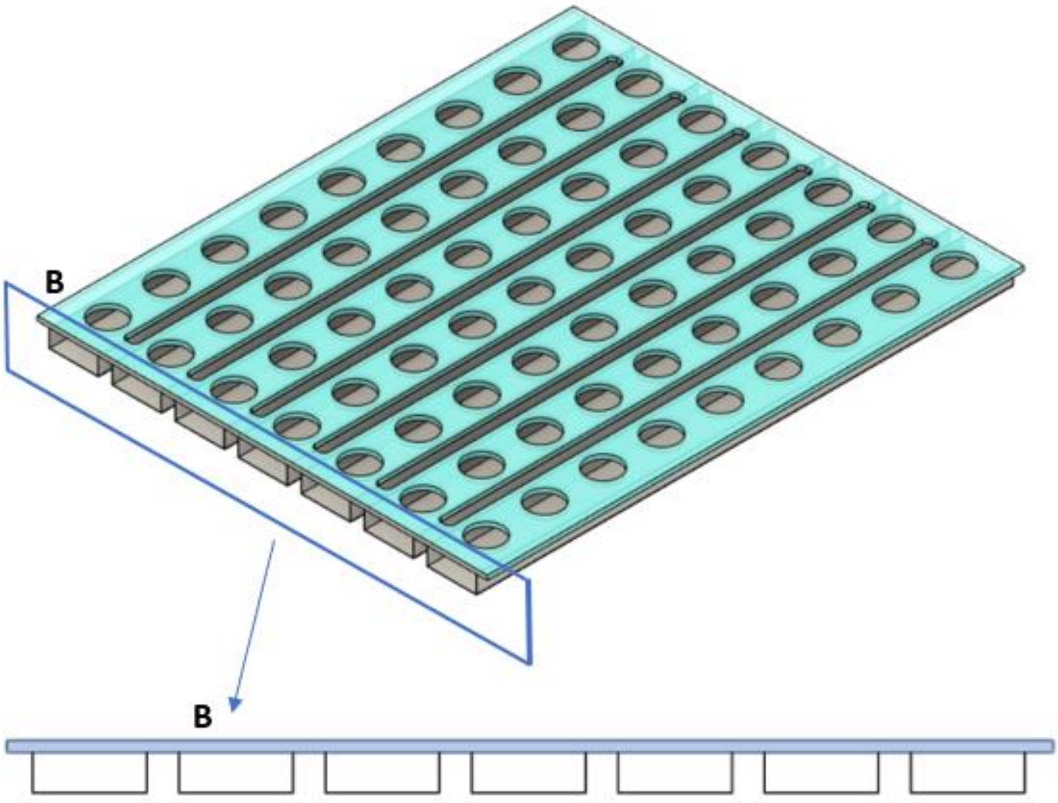
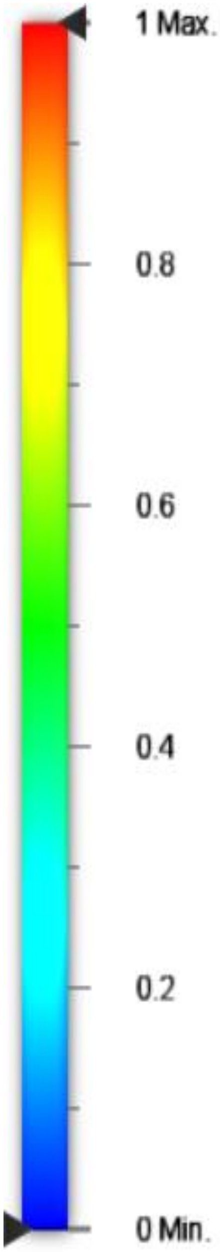
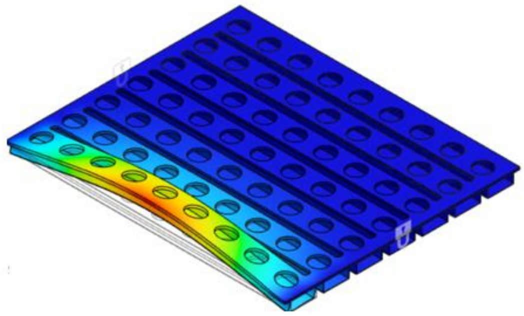
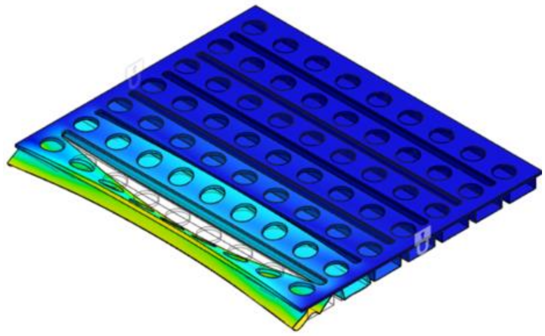
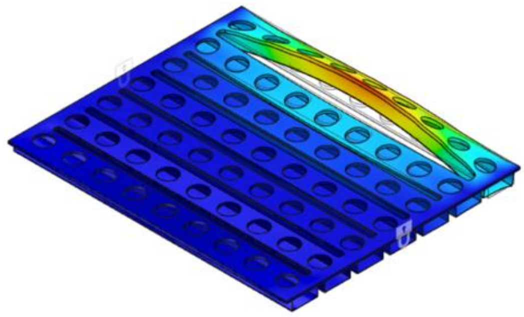
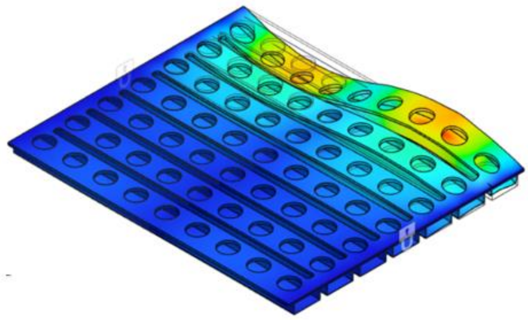


Figure 23 Rigidized egg container

- Rigidized egg container

Table 24 Modes of vibration on the rigidized egg container

<table>
<tr><th>Scale</th><th>Mode of vibration</th><th>Hertz</th><th>Simulation Result</th></tr>
<tr><td rowspan="4">
</td><td>1</td><td>167.2</td><td></td></tr>
<tr><td>8</td><td>244.3</td><td></td></tr>
<tr><td>15</td><td>312.7</td><td></td></tr>
<tr><td>22</td><td>392.6</td><td></td></tr>
</table>

Resonance

After obtaining the most critical vibration modes of the beam, it is necessary to do a comparation with the natural frequencies of the fan. This analysis is to prevent resonance inside the incumbation chamber. In order to prevent resonance the natural frequencies of the egg container and the fun must not have the same value.

Since the fan work at 2400rpm, we have that:

$$1Hz = 60\,rpm$$

$$2400\,rpm = 40\,Hz$$

After rigidizing the egg container, it was obtained that the most critical mode of vibration occurs at 167 Hz. Comparing both values, it is verified that there will be no resonance.

Incubator walls

As defined on the selection matrix section, incubator walls composition includes three layers. Two polycarbonate sheets for internal and external exposition, and fiberglass as insulation material. In order to achieve incubation temperature, forced convection will be implemented as heat source. For this purpose, a fan absorbing ambient air will direct flow through ceramic bulbs incrementing entering air temperature. Since air flowing in will have a velocity, air recirculation will be induced. During this process, heat loss through walls will be determined. The following figure illustrate thermal conditions that the equipment will face while heating system is turned on.

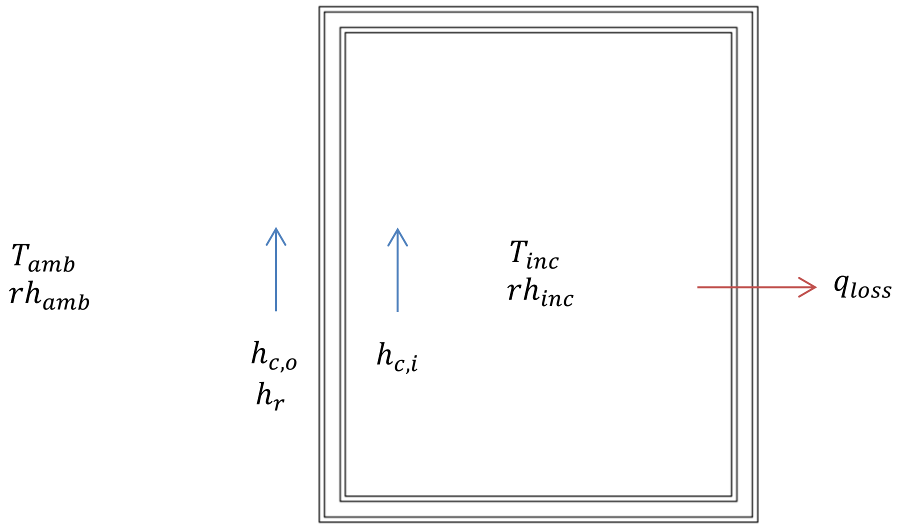


Figure 24 General heat transfer sketch

Figure 24 presents a general heat flow analysis were convection and radiation are considered. A zoom into a wall to analysis looks like figure 25, where all forms of heat transfer present in the system are considered.

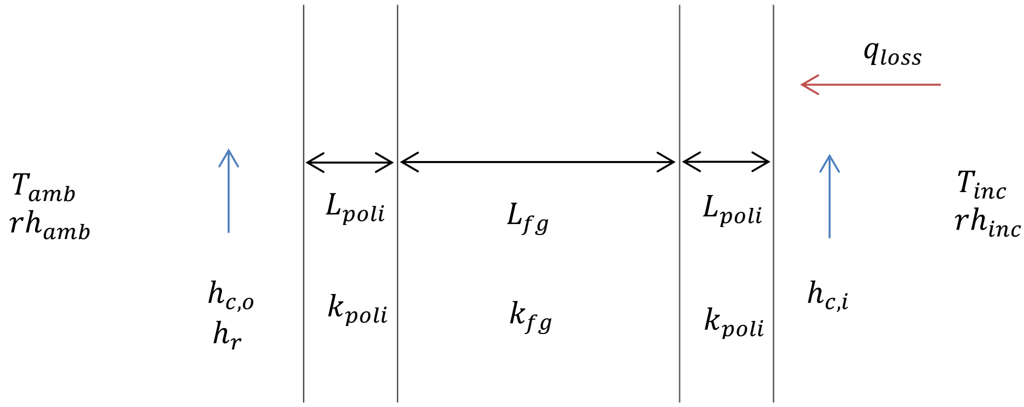


Figure 25 One dimensional heat flow through composite wall diagram

Assuming steady, one dimensional heat flow through plane walls, the system is simplified into a thermal resistance network. Since external wall has radiation and convection, a parallel resistance is considered. For conduction and convection with inner walls, resistance in series is implemented.

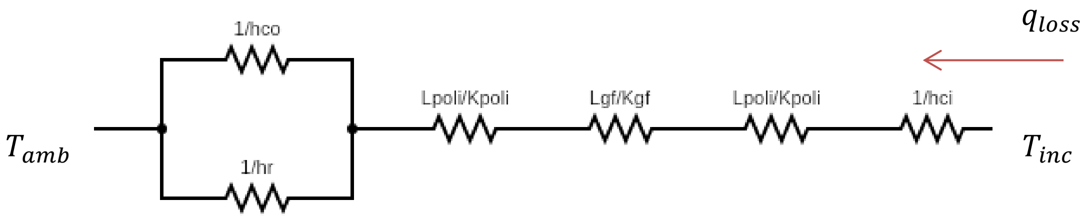


Figure 26 Representative resistance circuit for heat flow through walls

Heat transfer rate trough the composite wall can be obtained by thermal resistance definition:

$$q_x = \frac{\Delta T}{R_T}$$

$$q_{loss} = \frac{T_{inc} - T_{amb}}{\left[\frac{1}{h_{ci}} + \frac{L_{fg}}{k_{fg}} + \frac{2L_{poli}}{k_{poli}}\right]\frac{1}{A_{walls}} + \frac{\frac{1}{h_r A_{walls}} \cdot \frac{1}{h_{cov}(A_{L1} + A_{L2})} \cdot \frac{1}{h_{cou}(A_{UD})}}{\frac{1}{h_r A_{walls}} + \frac{1}{h_{cov}(A_{L1} + A_{L2})} + \frac{1}{h_{cou}(A_{UD})}}}$$

In order to obtain numerical solutions for heat transfer rate, it is necessary to determine convection and radiation coefficients.

- **Internal convection coefficient when fan is turned on**

Since internal fan is turned on, forced convection will take place inside incubator. Assuming air speed is uniform inside the incubator, it can be obtained with the component properties.

Table 25 Fan technical data

Fan of 230Vac 120x120x38 mm			
Maximum Load	$\boldsymbol{Q_v}$	105.5 CFM	0.04979 $[m^3/s]$
Fan Area		A_{fan}	0.009503 $[m^2]$

According to the fan properties, air speed can be determined:

$$vel_{air} = \frac{Q_v}{A_{fan}}$$

$$vel_{air} = 5.239 \quad [{}^{m}/_{s}]$$

Corresponding Reynolds number is calculated with air properties at incubation temperature as mentioned on table 15:

$$Re = \frac{vel_{air} \cdot L}{\mu_{air}}$$

$$Re = 302261$$

According to Incropera And DeWitt (2011), if Reynolds number is under $5x10^5$ flowing over a flat plate, the fluid behavior corresponds to parallel laminar flow. For this condition, and a Prandtl value higher than 0.6 (Table 18), Nusselt number is given by:

$$Nus_x = 0.664 \cdot Re^{\frac{1}{2}} \cdot Pr_{air}^{\frac{1}{3}}$$

$$Nus_x = 325.3$$

Finally, forced air convection coefficient can be determined. In the following equation, L corresponds to the characteristic length, in this case internal altitude L= 0.91 m.

$$h_{ci} = \frac{Nus_x \cdot k_{air}}{L}$$

$$h_{ci} = 9.083 \quad \left[{}^{W}/_{m^2\,K}\right]$$

- **External radiation coefficient**

For this analysis, the ambient temperature and the superficial temperature of the structure outer layer are considered (since this is the material exposed to the environment). The radiation coefficient is determined with the equation presented below

$$h_r = \varepsilon_{poli} \cdot \sigma \cdot (T_{poli} + T_{amb}) \cdot (T_{poli}^2 + T_{amb}^2)$$

$$h_r = 5.518 \quad \left[{}^{W}/_{m^2\,K}\right]$$

Where σ corresponds to Stefan Boltzmann constant 5.67 $\left[{}^{\mathrm{W}}/_{\mathrm{m}^2\ \mathrm{K}^4}\right]$, and $\varepsilon_{\mathrm{poli}}$ to polycarbonate emissivity coefficient equal to 0.9 (Martinez, 1995). In order to obtain polycarbonate superficial temperature, resistance equation is restated (leaving aside external radiation and convection terms) considering heat flow remains constant.

$$q_{loss} = \frac{T_{inc} - T_{poli}}{\left[\frac{1}{h_{ci}} \vdash \frac{L_{fg}}{k_{fg}} + \frac{2L_{poli}}{k_{poli}}\right]\frac{1}{A_{walls}}}$$

$$\mathrm{T_{poli}} = 23.22 \quad [\mathrm{C}]$$

- **External convection coefficient**

According to TBS ambient records, Tiputinis air velocity can be neglected. Meaning the equipment will be exposed to natural convection on its outer surface. Convection coefficient in this scenario has to be determined separately for vertical walls and horizontal ones. External free convection flow requires determining temperature at film layer and the volumetric thermal expansion coefficient as follows:

$$T_{film} = \frac{T_{amb} + T_{poli}}{2}$$

$$\mathrm{T_{film}} = 22.66 \quad [\mathrm{C}]$$

$$\beta = \frac{1}{T_{film}}$$

$$\beta = 0.00338 \quad [K^{-1}]$$

For the $\mathrm{T_{film}}$ determined, fluid properties are obtained from EES and presented on the following table.

Table 26 Tfilm fluid properties

Property	Variable Name	Value	Unit
Prandtl	Pr_{film}	0.7079	
Kinematic Viscosity	υ_{film}	0.00001577	$m^2/_s$
Thermal Diffusivity	α_{film}	0.02107	$m^2/_s$
Conductivity	k_{film}	0.02541	$W/_{m\,K}$

Grashof number for external free convection flow is given by

$$Gr_L = \frac{g\beta\left(T_{poli} - T_{amb}\right)L^3}{\upsilon^2}$$

$$Gr_L = 1.12\text{x}10^8$$

Rayleigh number calculation is given by

$$Ra_L = Gr_L Pr$$

$$Ra_L = 7.96\text{x}10^7$$

Where g corresponds to gravity 9.81 $m/_{s^2}$, L characteristic length equal to the equipment height and kinematic viscosity and thermal diffusivity values are presented on table 26.

Since Rayleigh number is $Ra_L \leq 10^9$, air has a laminar flow over external wall.

- For vertical plate, Nusselt is obtained by:

$$\overline{Nu}_L = 0.68 + \frac{0.670\ Ra_L{}^{1/4}}{[1 + (0.492/Pr)^{9/16}]^{4/9}}$$

$$\overline{Nu}_{\mathrm{L}} = 49.25$$

Therefore, vertical walls convection coefficient is

$$\bar{h}_{cov} = \frac{k_{film}}{L}\overline{Nu}_{\mathrm{L}}$$

$$\bar{h}_{cov} = 1.375 \quad \left[\mathrm{W}/_{\mathrm{m}^2\ \mathrm{K}}\right]$$

- For horizontal plate, Grashof and Rayleigh are obtained for the characteristic length L = 0.76 m:

$$Gr_L = 6.56\mathrm{x}10^7$$

$$Ra_L = 4.64\mathrm{x}10^7$$

For horizontal top plate Nusselt is obtained by:

$$\overline{Nu}_H = 0.52\ Ra_L{}^{1/5}$$

$$\overline{Nu}_H = 17.75$$

Therefore, horizontal top wall convection coefficient is

$$\bar{h}_{cou} = \frac{k_{film}}{L}\overline{Nu}_H$$

$$\bar{h}_{cou} = 0.59 \quad \left[\mathrm{W}/_{\mathrm{m}^2\ \mathrm{K}}\right]$$

Horizontal bottom wall is not considered for this analysis since the incubator will be laying on this face. This means no convection on this layer will be taking place.

Replacing every coefficient on the thermal resistance model, the energy lost through walls when heating system is turned on and ambient temperature is the lowest registered in 4 incubation periods is

$$\mathrm{q}_{\mathrm{loss}} = 22.96 \quad [\mathrm{W}]$$

In order to determine the heat loss through walls for each temperature and relative humidity scenarios presented on table 16, previous calculations where iterated on EES. The corresponding code is presented on Appendix A. Parametric tables with variable T_{amb} and rh_{amb} generated the following results:

Table 27 Heat loss through walls for every temperature range

	Incubation August – October	**Incubation December – February**
Category	q_{loss} [W]	q_{loss} [W]
8 am	16.88	17.09
9 am	11.4	11.61
10 am	6.34	5.917
11 – 15 pm	2.536	6.34
16 pm	6.974	9.085
17 pm	10.56	11.19
18 pm	13.93	14.35
19 pm	16.88	17.3
20 pm	18.56	18.77
21 pm	19.61	19.61
22 – 7 am	22.96	22.75

Time required for system stabilization from start point

This section will present the time required for the equipment to get into incubation temperature once eggs are placed in. For this analysis it is important to mention that the incubator should be turned on before eggs enter the system. They should be located inside once internal air temperature reaches 33 ° C. For this study, the lowest air temperature registered was considered as ambient conditions. This assumption assures required time on any other scenario will be lower.

- **Time required for heating empty incubator**

When considering ambient preheating, total air volume is considered. Air mass content is determined as follows

$$m_{air} = \mathrm{Vol} \cdot \rho_{\mathrm{air}}$$

$$m_{air} = 0.454 \quad [kg]$$

The amount of heat is obtained

$$Q = m_{air} \cdot c_{p,air} \cdot (T_{inc} - T_{amb})$$

$$Q = 5126.75 \quad [J]$$

Considering 300 W input power from ceramic bulbs and power lost through walls, the total available entering power is 277.04W. Considering required heat amount to reach incubation temperature and accessible power, time can be determined:

$$t = \frac{Q}{q_{available}}$$

$$t = 18.51 \quad [s]$$

- **Eggs heat absorption**

Once eggs enter the system, they will absorb heat to reach incubation temperature. Assuming turtle eggs are mainly composed of water, properties of this fluid at ambient temperature will be used for the analysis.

Table 28 Eggs properties

Property	Value	Unit
Total eggs contained	297	$unit$
Mass per egg	43	g
Cpw at 22.1 ° C	4183	$^{J}/_{kg\ K}$

$$Q = m_{eggs} \cdot c_{p,water} \cdot (T_{inc} - T_{amb})$$

$$Q = 582.3 \quad [kJ]$$

For a total input power of 277.04 W, the time required is determined:

$$t = \frac{Q}{q_{available}}$$

$$\mathrm{t} = 2101.86 \quad [\mathrm{s}] = 35 \quad [min]$$

These calculations determine that in the most critical scenario, it will take 35 minutes to heat eggs once they enter the system. It is important to mention that these conditions would apply if eggs were to place between 22 pm and 7 am. According to client's previous experiences, this process generally takes place at noon. During this period, the most critical temperature corresponds to 30 ° C. Following previous analysis with properties at this ambient temperature, heating time is determined. According to EES, specific heat for water at 30 ° C is 4183 $^{J}/_{kg\ K}$.

$$\mathrm{Q} = \mathrm{m_{eggs}} \cdot \mathrm{c_{p,water}} \cdot (\mathrm{T_{inc}} - \mathrm{T_{amb}})$$

$$\mathrm{Q} = 160.3 \quad [\mathrm{kJ}]$$

Total available power is obtained by subtracting heat loss rate from the 300W provided from ceramic bulbs. Obtaining q_{loss} for this temperature range from table 27, accessible power is 285.65 W. Therefore, total required time is given by:

$$t = \frac{Q}{q_{available}}$$

$$\mathrm{t} = 561.18 \quad [\mathrm{s}] = 9.4 \quad [min]$$

Photovoltaic panels

To satisfy the clients request of electrical autonomy and sustainability, it was decided to implement photovoltaic panels. For this purpose, it is required to determine the total power consumption of the equipment under critical conditions (minimum ambient temperature), this assures the incubator will be able to work under any external circumstances. Entering power and operating time for each component is presented below.

Table 29 DC Loads consumption per hour by incubator

DC Loads				
Loads	**Quantity**	**Power [W]**	**Time of operation per day [h]**	**Watts.h**
Humidifier	1	10	1	10
Peltier Module	1	18	1	18
Fan Dehum	1	6	1	6
Fan	1	6	2	12
Sun Controller	1	0.13	24	3.12
			Total DC Energy (Wh)	49.12

Table 30 AC Loads consumption per hour by incubator

AC Loads				
Loads	**Quantity**	**Power [W]**	**Time of operation per day [h]**	**Watts.h**
Ceramic Bulbs	2	150	2	300
Temp. Controller	1	0.15	24	3.6
Hum. Controller	1	0.15	24	3.6
			Total AC Energy (Wh)	307.2

Table 29 and 30 present detailed DC and AC loads required by incubation equipment. Whether the charge corresponds to direct or alternating current is determined by the component. Expected time of operation per day correspond to several assumptions. On one hand, controllers must work uninterruptedly in order to assure all variables are maintained as desired. In contrast, ceramic bulb + fan will turn on when one degree is lost inside the incubator. This analysis is presented in subsequent sections. Additionally, the humidification and dehumidification systems are expected to work one at a time. The most critical assumption establishes that these systems must turn on the same number of times the heating system does. This means a total of 40 times for three minutes each. Resulting in one hour for each system.

Once power consumption is determined, total Watts required per day are calculated. For this purpose, it is important to select an inverter to transform DC into AC current. The selected component for the incubator includes the following characteristics:

Table 31 Selected inverter technical properties

Inverter Properties	
Voltage	12 V
Efficiency	0.85
Continuous power	500 W

**Note: Adapted from https://suredom.en.alibaba.com/product/60640297342-804266924*

Considering system losses in wiring and modules equal to 30% (Messenger & Ventre, 2005), daily consumption is given by:

$$Daily\ Energy = \left(\frac{AC\ daily\ loads}{Inverter\ efficiency} + DC\ daily\ loads\right) \cdot (1 + System\ loads)$$

$$Daily\ Energy = 534\ Wh/day$$

Proceeding with battery sizing, selected battery properties are presented in the following chart:

Table 32 Selected inverter technical properties

Battery Properties	
Capacity	33 Ah
Voltage	12 V
Efficiency	0.9
Discharge limit	0.7

**Note: Adapted from http://www.efirstpower.com/PDF/LFP1233.pdf*

System DC voltage is established as 12 V. This means photovoltaic panels, batteries and inverter work at this voltage. The selected value responds to components availability in local market. With this constraint, daily required amperes per hour can be determined

$$Amp\ per\ hour = \frac{Daily\ energy}{System\ DC\ voltage}$$

$$Amp\ per\ hour = 44.5\ Ah$$

Therefore, amperes per hour required by the batteries to assure two days of autonomy is determined considering the battery properties detailed on table 32 as follows:

$$Amp\ per\ hour\ required\ by\ battery = \frac{Amp\ per\ hour * Autonomy\ Days}{Discharge\ Limit}$$

$$Amp\ per\ hour\ required\ by\ battery = 127.1\ Ah$$

Finally, since batteries work on same DC voltage as de system, no batteries are required to be connected in series. Parallel batteries required is determined by:

$$\#\ of\ batteries = \frac{Amp\ per\ hour\ required\ by\ battery}{Battery\ capacity}$$

$$\#\ of\ batteries = 4$$

Photovoltaic panels array sizing requires determining average sunshine peak hours at Tiputini Biodiverse Station. Global horizontal irradiation value is equal to sun peak hours. The following table presents irradiation values por the studied location.

Table 33 Irradiation values at Tiputini

Tiputini Irradiation Information		
Global tilted irradiation	GTI	4.733 $\left[{}^{kWh}/_{\text{m}^2\ \text{per day}}\right]$
Optimum tilt of PV modules	OPTA	2°
Global horizontal irradiation	GHI	4.731 $\left[{}^{kWh}/_{\text{m}^2\ \text{per day}}\right]$

**Note* Adapted from https://globalsolaratlas.info/map?c=-0.789234,-75.529155,11&s=-0.789234,-75.529155&m=site*

Total energy required from pv panels array can be determined by system total energy required over batteries efficiency. The obtained value for this calculation is 593 Wh/day. The selected panel datasheet presents the following values:

Table 34 PV panel properties

Photovoltaic panel properties	
Power	100 W
Loss factor	0.9
Corrected Power	90 W

**Note Adapted from https://articulo.mercadolibre.com.ec/MEC-428348343*

Panel actual energy output is determined

$$Energy\ output = Sun\ peak\ hours * Loss\ factor * Power$$

$$Energy\ output = 383.2\ Wh/day$$

Therefore, the required number of panels is given by

$$\#\ of\ panels = \frac{Energy\ required\ by\ pv\ panels\ arrays}{Energy\ output}$$

$$\#\ of\ panels = 2$$

Calculations in this section demonstrate that 2 panels and 4 batteries supply the proper amount of energy required for two days of autonomy of the system.

Incubation Conditions subsystems

Successful incubation is highly determined by having appropriate temperature and humidity control over contained air. For this purpose, subsystems that regulate contained air conditions underwent trough simulation and thermodynamical analysis. The purpose of this studies is to understand contained air behavior and assure requirements are effectively accomplished.

Dehumidification system

The Peltier cell, diffuser and its fan will work as a dehumidifier system. The cold side of the Peltier cell will condensate water until the controller reaches de required humidity of 94%. The most critical scenario for this element would be air having a 100% of relative humidity. The required quantities of water to be condensate and the time this condensation will take place will require the following data and calculations.

Symbols:

- Incubation temperature (T_{inc}=33°C)
- Total mass of water in the volume (m_v)
- Vapor Pressure at Incubation temperature (P_g=5.033kPa)
- Internal Volume of the incubator (V=0.387 m^3)
- Due Point temperature at incubation temperature and atmospheric pressure (T_s=31.95 K)
- Mass required to be condensate (m_6)
- Mass flow rate of condensate water ($\dot{m}$)
- Relative humidity (R_h)
- Saturation Temperature at atmospheric pressure.
- Gravity (g)
- Viscosity (μ_l)
- Jakob number (Ja)
- Specific heat (Cp)

- Dimensions of the vertical plate (LxW)

Assumptions:

- Laminar flow with constant properties
- Pure vapor with uniform temperature equal to saturation temperature
- Vapor with no velocity

Equations:

$$R_h = \frac{P_v}{P_g}$$

$$L = 6 \times 10^{-2}\ m$$

$$W = 4 \times 10^{-2} m$$

$$A = L \times W$$

$$m_v = \frac{P_g V}{R T_{inc}}$$

$$m_6 = 0.6 \times m_v$$

$$q = \bar{h}_L A (T_{sat} - T_s)$$

$$\overline{Nu_L} = 0.943 \times \left(\frac{k_l L (T_{sat} - T_s}{\mu_l\, h'_{fg} \left(\frac{v_l^2}{g}\right)^{\frac{1}{3}}}\right)^{-\frac{1}{4}} \qquad \text{For this case}$$

$$\dot{m} = \frac{q}{h'_{fg}}$$

$$h'_{fg} = h_{fg}(1 + 0.68 Ja)$$

$$Ja = \frac{c_P, L\ (T_{sat} - T_s)}{h_{fg}}$$

$$t = \frac{m_6}{\dot{m}}$$

Results:

Table 35 Condensation results comparison

Variable	Value (Incropera equations)	Value (EES Professional equation solver)	Error [%]
$\boldsymbol{m_v}$	0.01386 [kg]	0.01386	0
$\boldsymbol{m_6}$	0.0008315 [kg]	0.0008315 [kg]	0
$\boldsymbol{\dot{q}}$	1290 [W]	1290 [W]	0
$\boldsymbol{\dot{m}}$	0.000499	0.0005085 [kg/s]	1.868
$\boldsymbol{t}$	1.66	1.635	1.529

Temperature regulation system

The designed incubation equipment heating system consists of two heating ceramic bulbs in conjunction with a fan to induce forced convection in the system. Once internal air has reached incubation temperature, heating components turn off. At this point, forced convection ends and natural convection takes place. Following steps detailed on external coefficient determination section, natural internal convection coefficients are determined. Obtained values trough EES are detailed in the following table.

Table 36 Internal natural convection coefficient

Internal natural convection coefficient			
Vertical plates	$\mathrm{h_{vi}}$	1.148	$\left[\mathrm{W}/_{\mathrm{m^2\ K}}\right]$
Horizontal top plate	$\mathrm{h_{hti}}$	0.4386	$\left[\mathrm{W}/_{\mathrm{m^2\ K}}\right]$
Horizontal bottom plate	h_{hbi}	1.288	$\left[\mathrm{W}/_{\mathrm{m^2\ K}}\right]$

In order to have a better understanding of heat loss through walls once incubation temperature is reached, transient simulation was executed with the use of Nastran software.

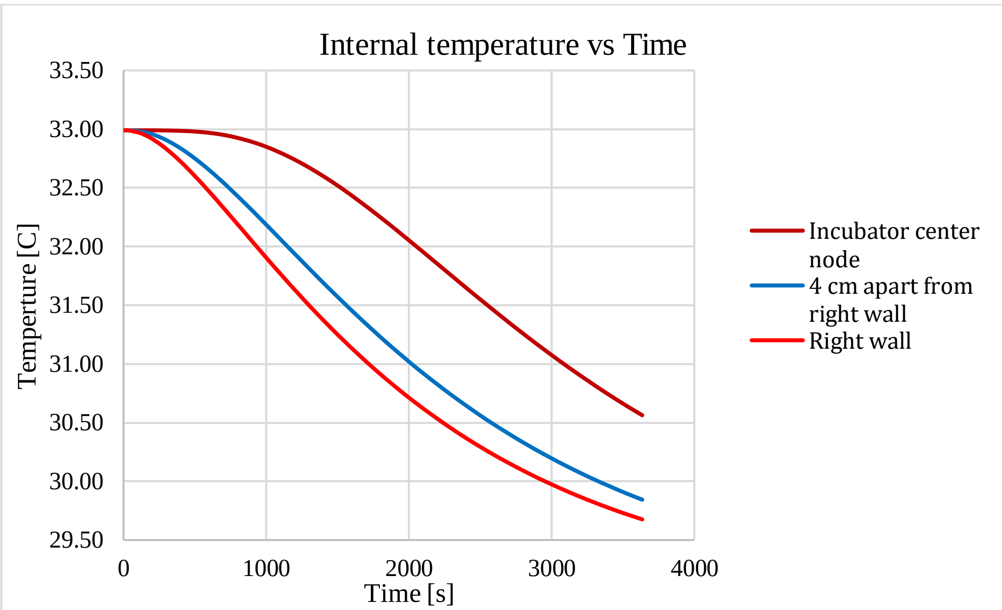
For this simulation three-layered walls with corresponding material properties and vent entries were analyzed. In terms of heat transfer, external natural convection and radiation, plus internal natural convection were constraints stablished for the study. As previous calculations, ambient temperature was set to critical value of 22.1 ° C. It is important to mention that differentiated mesh size was set over the body. Smaller elements conform vent geometry, while larger elements obey regular geometries like uniform walls.

To estimate the time, it takes the incubator to lose 1 °C when heating system is turned off, three nodes where analyzed.

- Incubator center node: Node that is in the center point of the incubator. This position takes the longest to lower one degree since its location is surrounded by air that behaviors as an extra resistance.
- Right wall node: Node located on top of right wall internal face. Eggs containers are located closer to this wall since the opposite one carries the humidification / dehumidification system
- 4 cm apart from right wall node: The behavior of this node is fundamental for the incubator temperature control. At this point, the thermocouple will be located. Additionally, in this location eggs trays are positioned, meaning this is the last point where temperature variation will not affect the eggs.

The temperature variation over time graph obtained from the simulation for these points is presented below.

Table 37 Temperature variation over time



From table 37 it can be observed that at the sensor location, blue line, a degree Celsius is lost in 1155 seconds. In contrast, incubator center point takes 2115 seconds to decrease its temperature in the same amount. Schematic representations of temperature loss in function of time can be appreciated on table 38. It can be observed how outer incubator components reduce their temperature faster.

Table 38 Temperature transient simulation results for two points in time

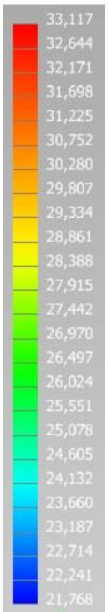
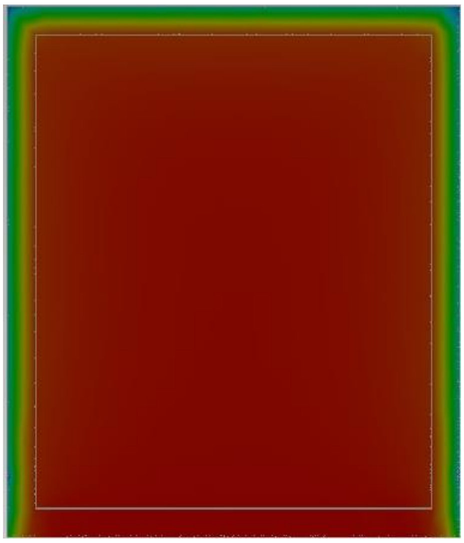
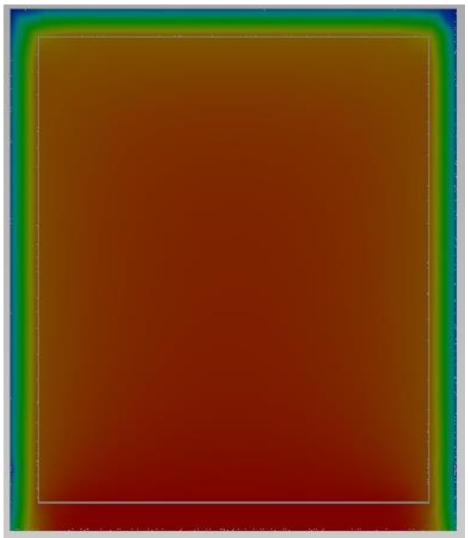
Temperature transient analysis result		
		
Temperature Scale [C]	Step 18, Time 1075 [s]	Step 32, Time 2195 [s]

Figure 27 presents temperature variation caused by vents. It can be inferred that these cavities will not cause mayor temperature losses on the system.

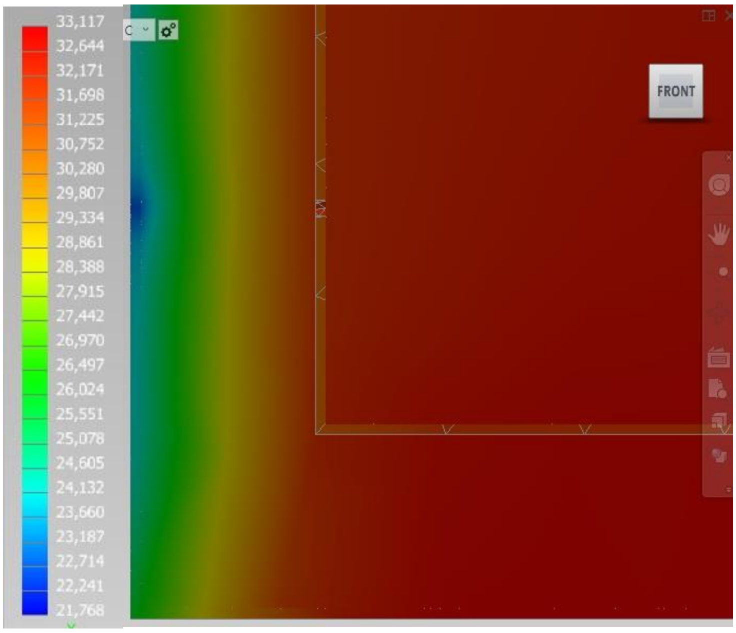


Figure 27 Temperature variation in vents transient simulation

Temperature and Ventilation behavior

Successful incubation results are largely related with appropriate temperature and ventilation constraints. In the urge to have a better understanding of natural incubation substrate, sand experimental temperature values were recorded for 5 days.

The experiment consisted in locating 30 kg of sand into a container with approximately 5 liters of water. The thermocouple K type was located 10 cm deep to measure internal temperature changes. Data was saved on EL-USB-TC data logger. Figure 28, presents a picture of the initial conditions.

Figure 28 Sand container with data logger and thermocouple

Additionally, simultaneous environmental temperatures were tracked. It is important to mention that the test took place in Quito. Although ambient conditions differ from Tiputini's circumstances, recording environmental temperatures allows having a better understanding of sand behavior depending on its medium atmospheric variations. A graphical representation of the temperature difference reported between sand and the environment is presented in the following graph.

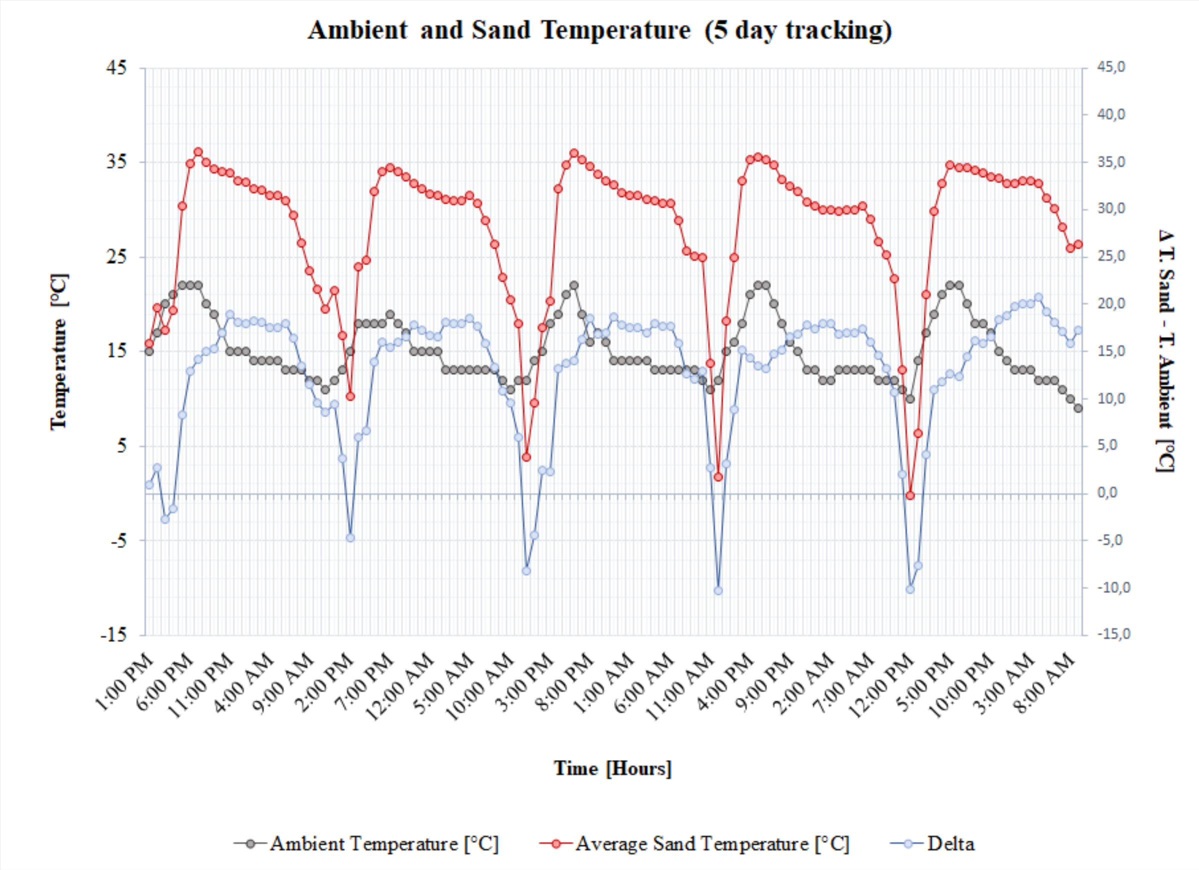


Figure 29 Average sand temperature vs Ambient temperature

Figure 29 presents a comparison between sand and ambient temperature for simultaneous measurements. Additionally, the variation in temperature between these two conditions is represented with the blue line. Maximum and minimum values for variation are registered in the following table. These points present an average critical temperature variation.

Table 39 Temperature variation Tsand - Tamb

Maximum and minimum temperature variation	
Time	Variation [C]
7:00 PM	14.1
2:00 PM	-4.7
7:00 PM	15.5
12:00 PM	-8.2
6:00 PM	14
12:00 PM	-10.2
5:00 PM	13.5
12:00 PM	-10.2
5:00 PM	12.7

Previous chart present higher temperature variation values. Negative values correspond to lowest sand temperature conditions, while positive difference explains higher sand temperature.

Fluid and Thermodynamical First Design

The simulations shown below will consider real material properties and critical temperatures on the air in and outside the incubator. There will be two simulations, one with the first design and a second simulation of a modify version. The boundary conditions will consider: 33°C inside the incubator (air temperature) and 22.1°C outside the incubator (ambient temperature). Labels will considered velocity and temperature .

First Design

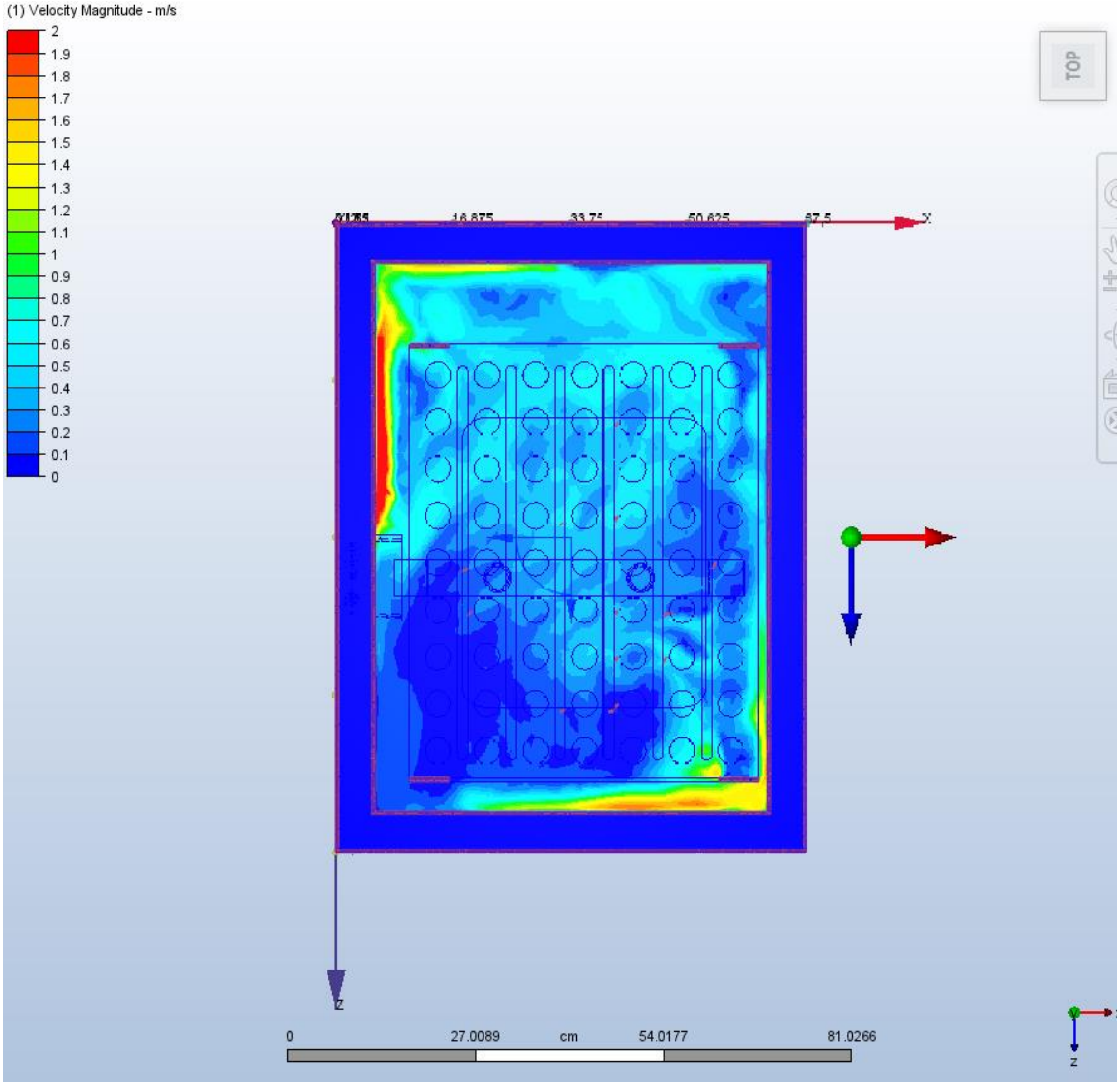


Figure 30 Top view first design CFD heat and fluid simulation

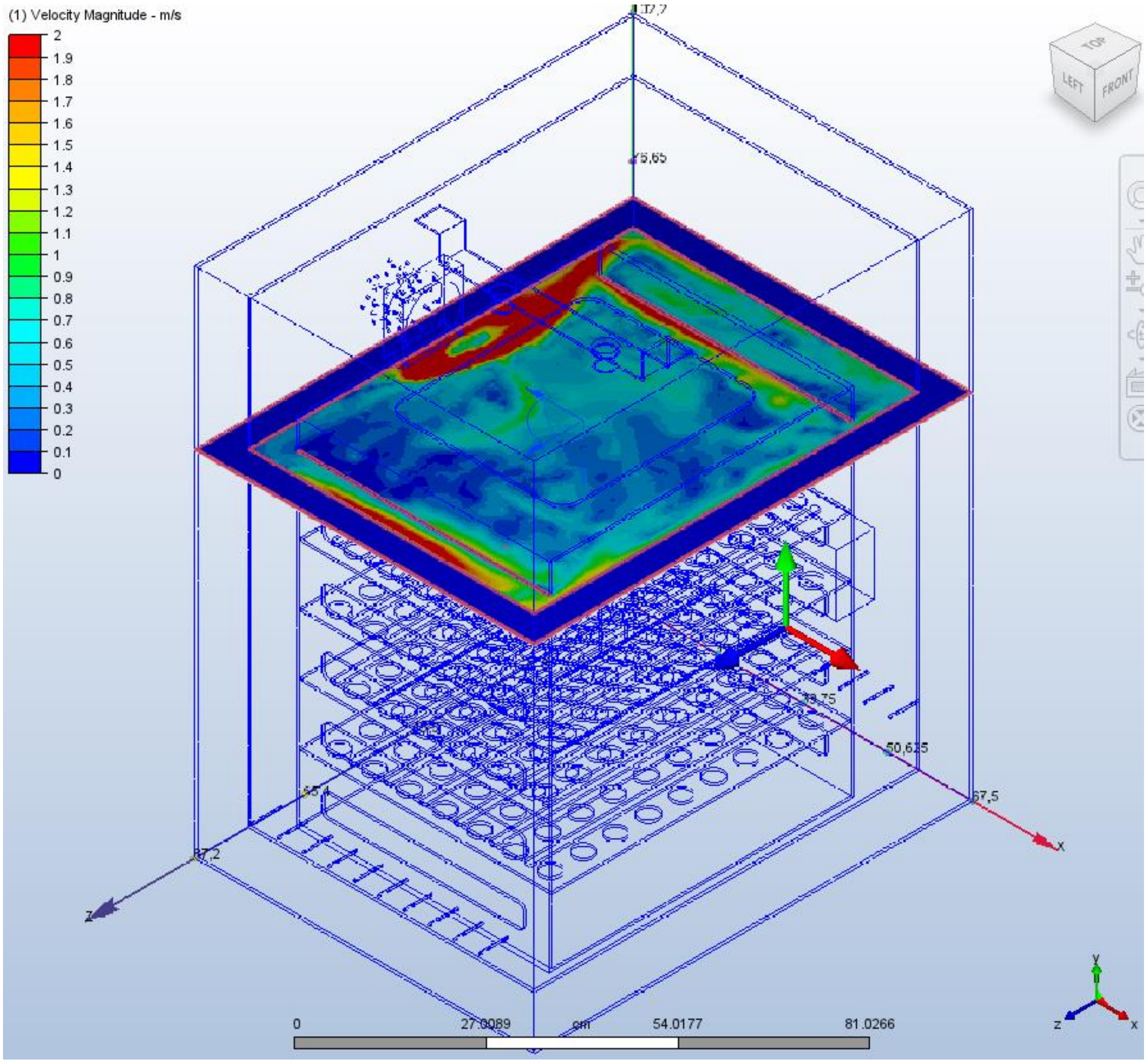


Figure 31 Offset plane first design CFD heat and fluid simulation

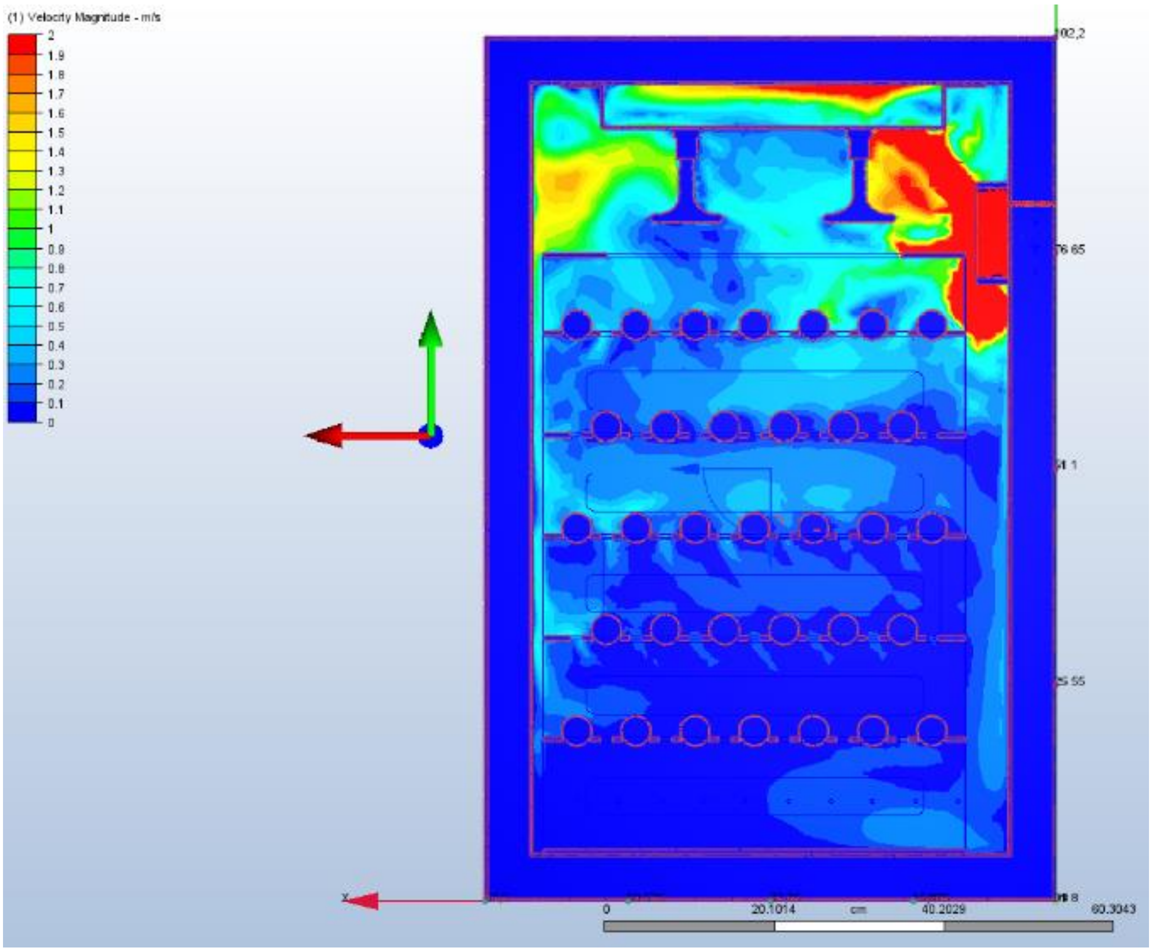


Figure 32 Lateral view first design CFD heat and fluid simulation

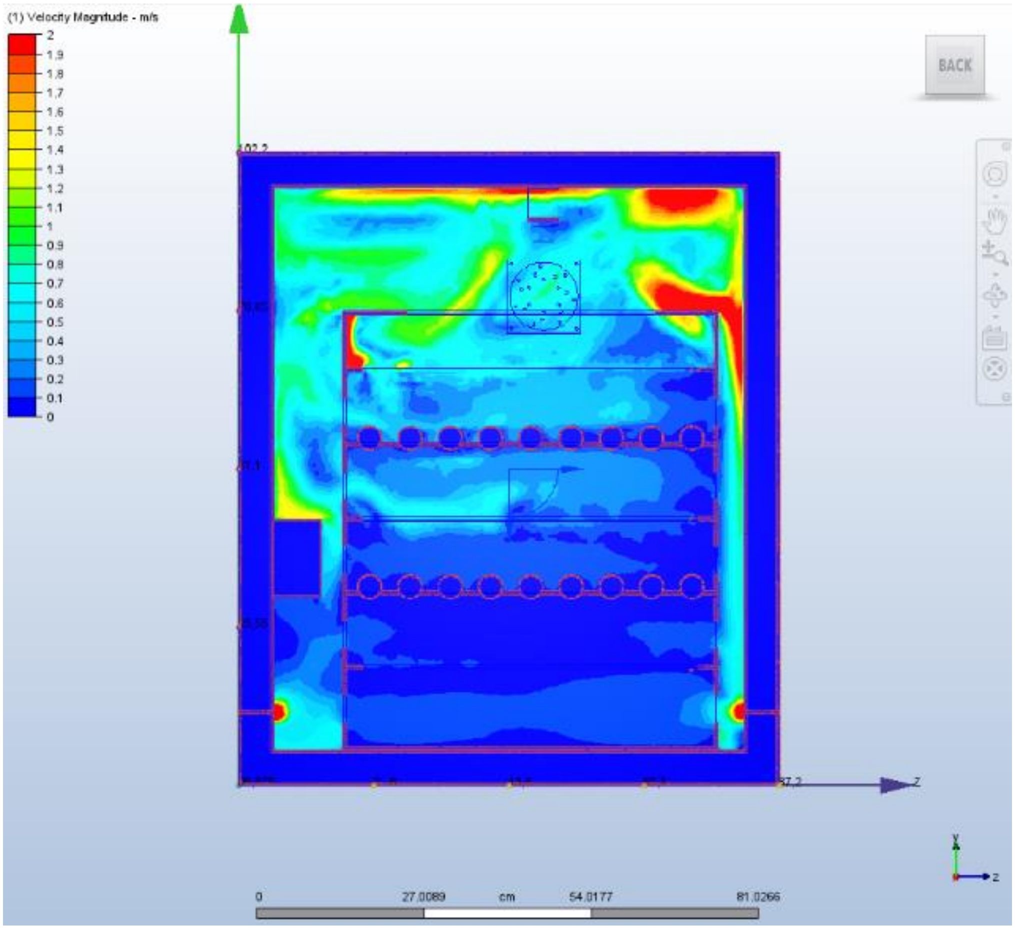


Figure 33 Front view first design CFD heat and fluid simulation

Second Design

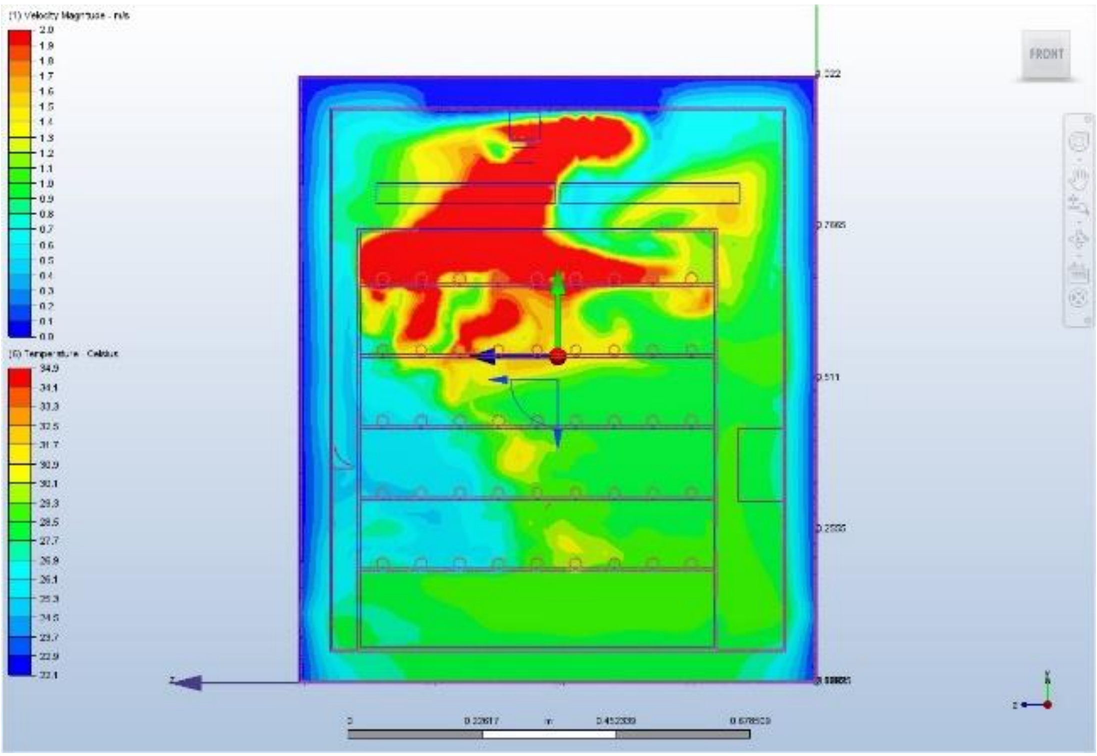


Figure 34 Front view second design CFD heat and fluid simulation

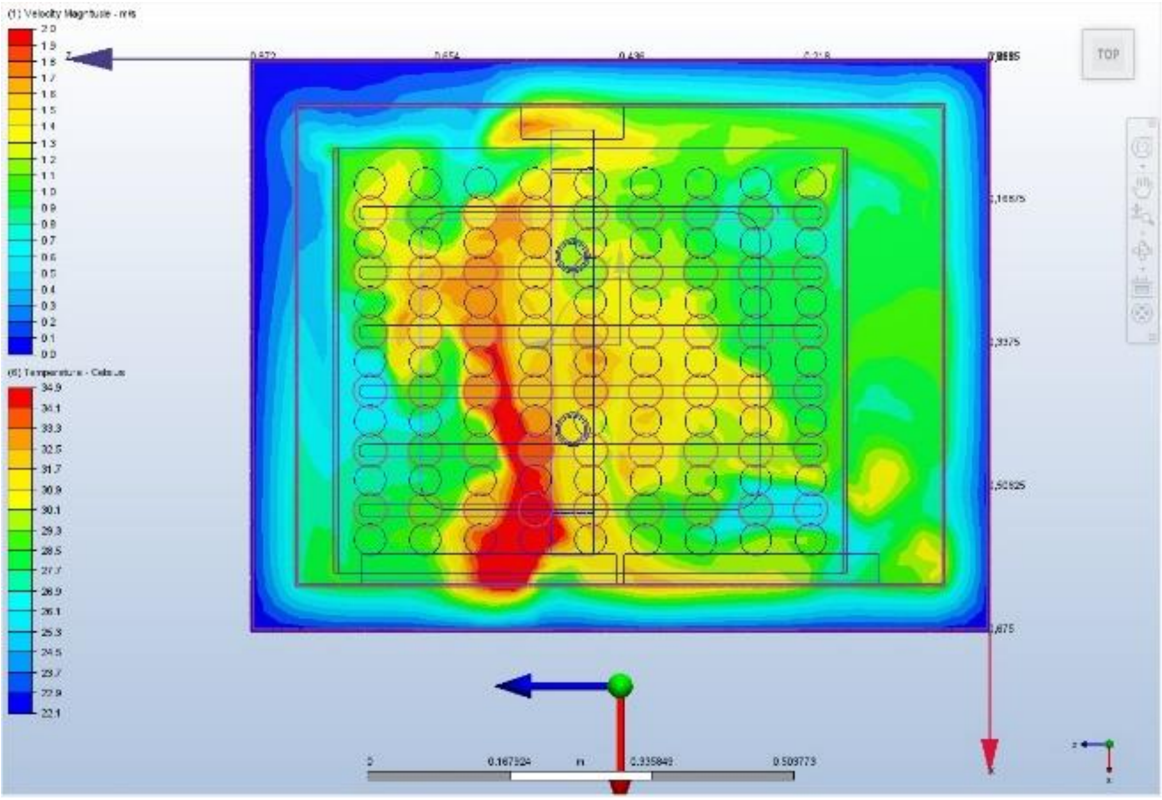


Figure 35 Top view second design CFD heat and fluid simulation

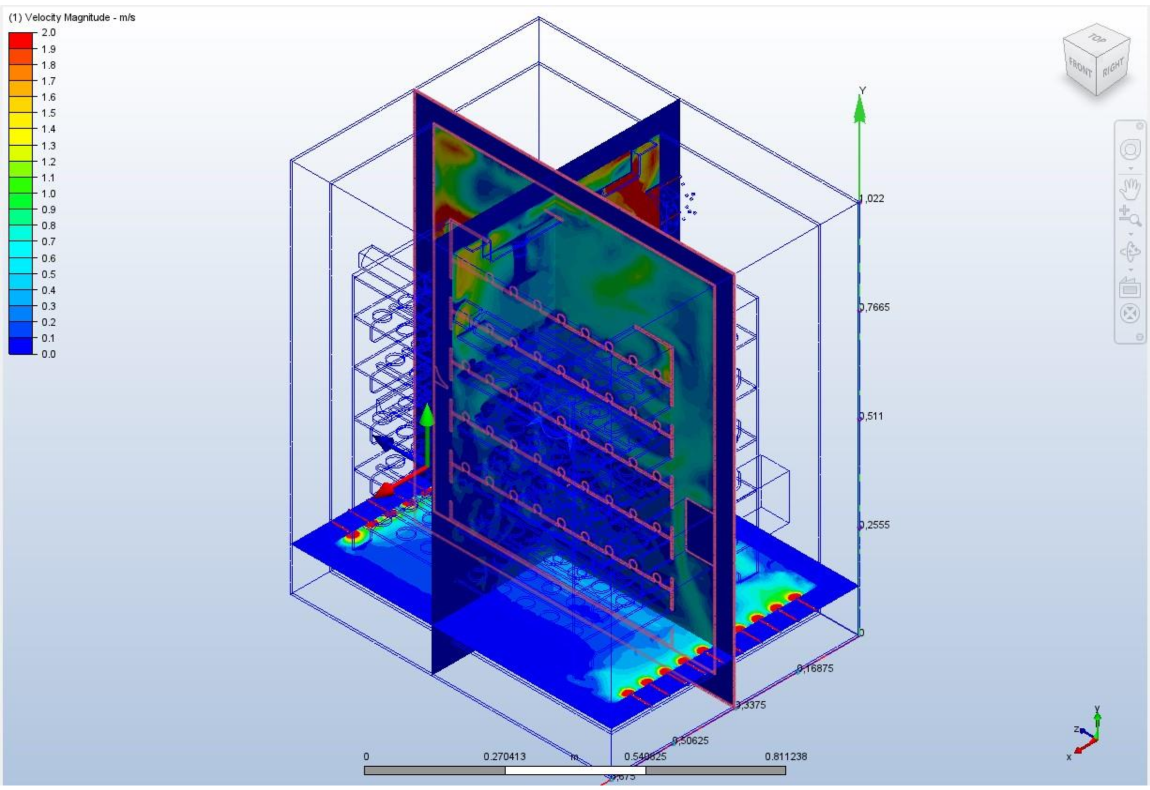


Figure 36 multi offset planes view second design CFD heat and fluid simulation

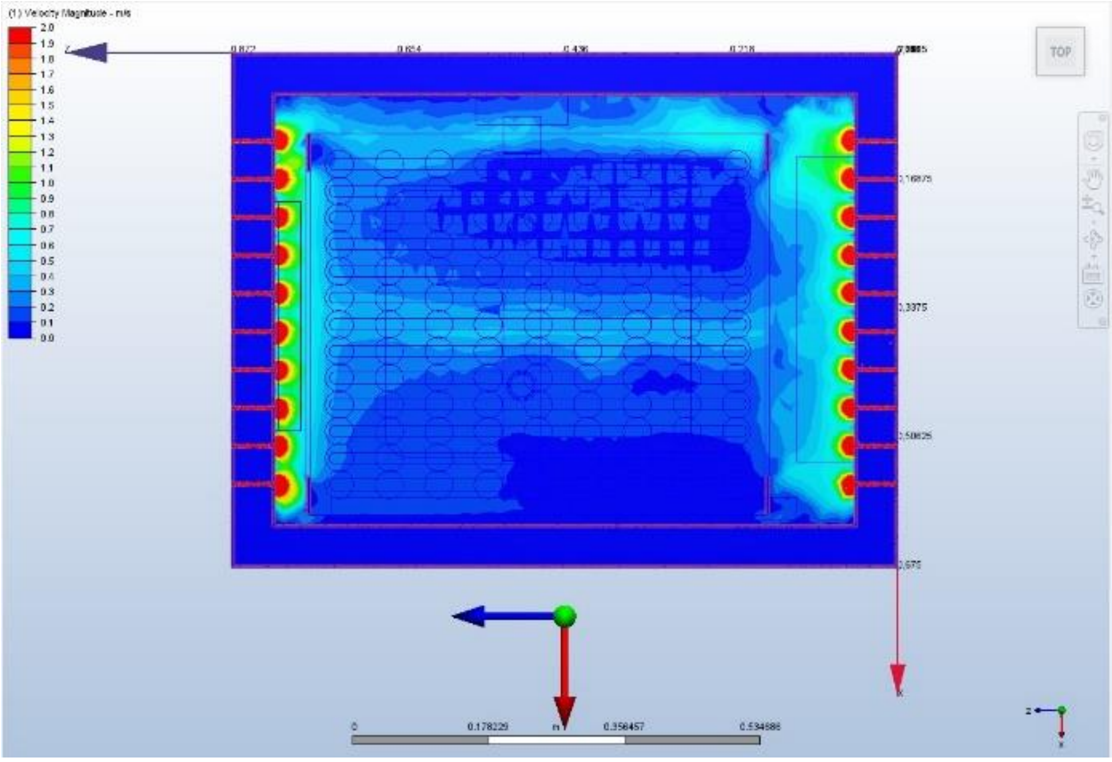


Figure 37 Top sliced view second design CFD heat and fluid simulation

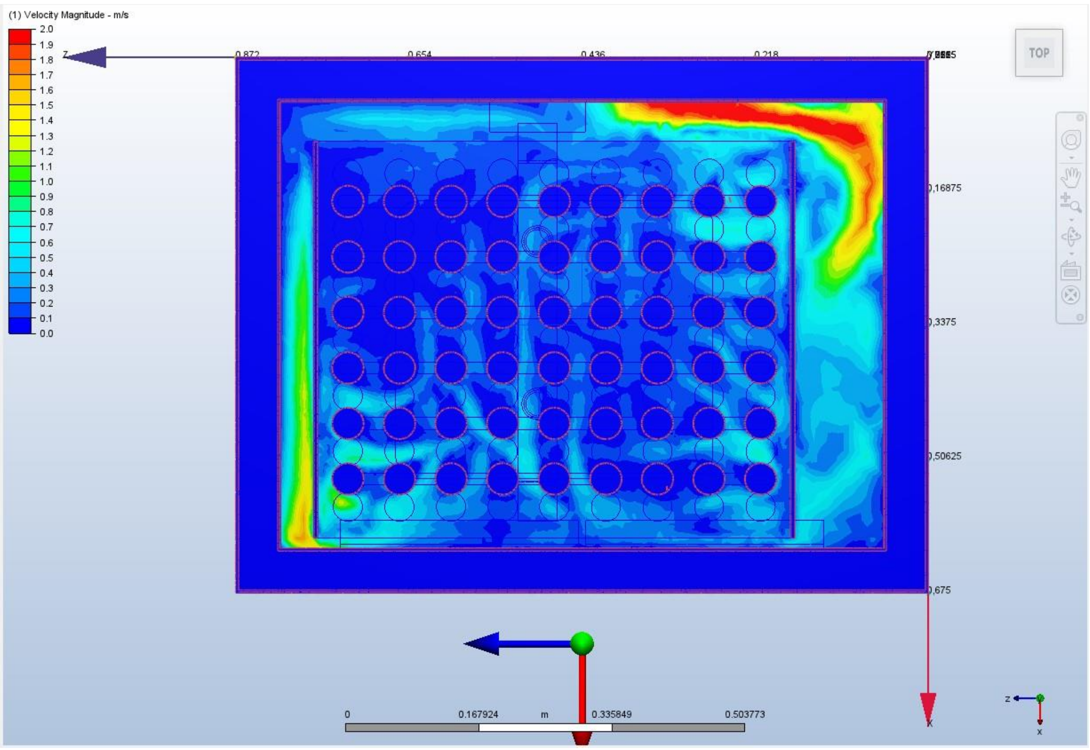


Figure 38 Top view second design CFD heat and fluid simulation

Table 40 Temperature volumetric representation (33,30,28) °C

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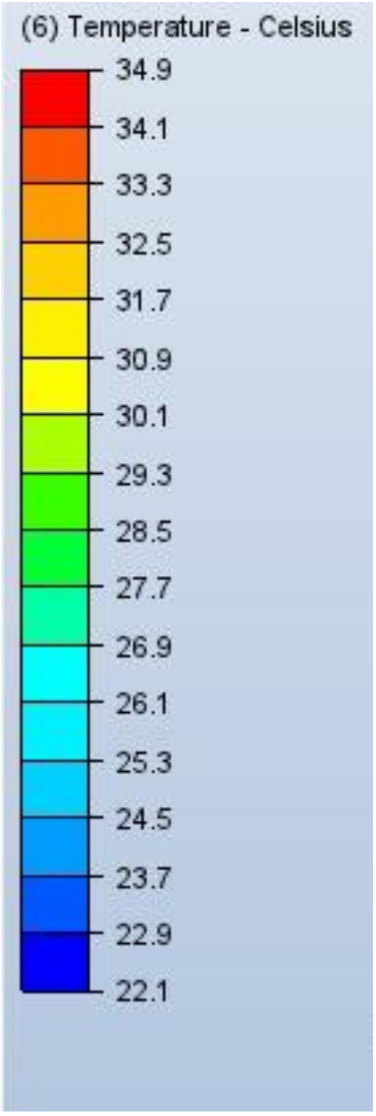
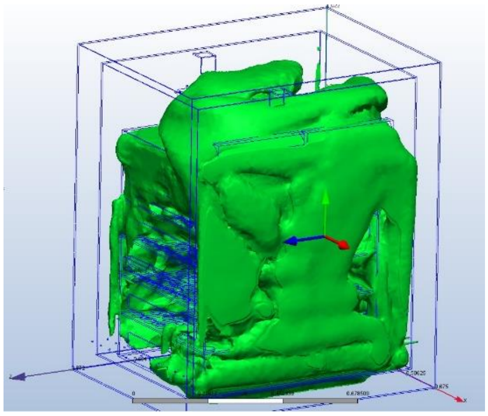
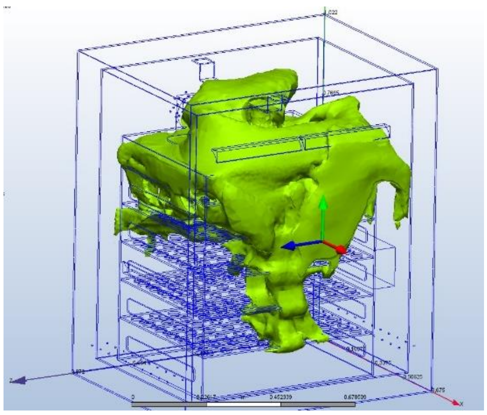
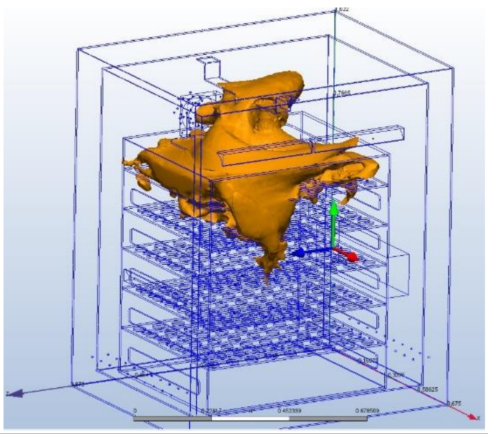
<tr><td rowspan="3">
</td><td>28</td><td></td></tr>
<tr><td>30</td><td></td></tr>
<tr><td>33</td><td></td></tr>
</table>

Prototype test plan

It is a testing plan designed to evaluate performance which is expected to meet the established parameters. The table 40 shows the tests carried out:

Table 41 Prototype test Plan

Prototype Test Plan				
Test	**Requirement to validate**	**Sub-System**	**Method for validation**	**Check**
Incubation Temperature	Biological necessities	Automated control and heating system	Reach the incubation temperature between 27 and 33	
Incubation humidity	Biological necessities	Automated control and humidity system	Reach 94% incubation humidity	
Sustainable energy use	Sustainable equipment	Energy source system	Use solar panels to generate the necessary energy.	
Humidity and temperature automated control system	Biological necessities	Automated control and heating system	Use a temperature and humidity controller to maintain incubation conditions.	
Ease of assembly	Ease of assembly	Structural system	Easy build system	
Portability			Ease of transport.	
Outdoor resistant materials	Biological necessities	Structural system	Use materials that are resistant to natural conditions.	
Maximum cost	Assigned budget	Client requirement	Maximum manufacturing cost of $1800	
Appropriate dimensions	Portable system	Structural system	Dimensions for 300 eggs	

Each test will be validated according the following sub-systems validations.

Automated control system validation

The temperature and humidity inside the system must be controlled. In table 41 can be appreciated the steps to follow to configure the controller.

Table 42 Automated control system validation

Action to complete	Check
Connect the humidification and heating system to the controller.	
Verify that the system turns on.	
Read the controller's user manual.	
Set up the controller with the incubation conditions.	

Heating System Validation

One of the main requirements is to control the temperature. The pyrometer was used to check the temperature. Table 42 shows the steps to follow to verify that the system works correctly.

Table 43 Heating System Validation

Action to complete	**Check**
Connect the ceramic Bulbs to the controller with the thermocouple	
Verify that the system turns on	
Verify that the system is heating up	
Verify that you are measuring the system temperature	
Checking if the controller is working properly	
Set to incubation temperature.	

Humidification System Validation

Maintaining humidity of 94% is another requirement of the project, where in table 43 it can be observed the steps to follow to verify the proper functioning of the system.

Table 44 Humidification system validation

Action to complete	Check
Connect the controller to the humidifier, dehumidifier and the sensor.	
Verify that the system turns on.	
Verify that the system is humidifying	
Verify that the dehumidifier is working properly.	
Verify that you measure the humidity correctly	
Checking if the controller is working properly	
Set to incubation Humidify.	
Make sure that when the required humidity is exceeded, the humidifier is turned off and the dehumidifier is turned on.	

Energy source system Validation

The system must be self-supporting, a multimeter was used to verify that the batteries are charging, in table 44 you can see the steps to follow to verify the proper functioning of the system.

Table 45 Energy source system validation

Action to complete	Check
Connect the solar panels to the batteries.	
Verify that the system turns on.	
Verify that the panels are working properly	
Verify that the batteries are charged	

This plan is designed based on the necessary requirements and for a continuous test time of 24 hours.

Safety through design

There can be many risks that can affect the incubator or also the staff.

1. **Too much handling and movement of the eggs.**
   - **Impact:** If there is a lot of movement of the eggs, incubation could be difficult.
   - **Management Strategy:** Move the Humidifier and Dehumidifier to the right side so that when changing the water in the system it does not affect touching or moving the eggs and thus doesn’t affect their incubation.
2. **Instability of the egg cups.**
   - **Impact:** If there is a lot of movement of the eggs, incubation could be difficult.
   - **Management Strategy:** Reinforce the shelf with steel to avoid vibrations in the egg cups.
3. **Difficulty in generating energy.**
   - **Impact:** Lack of irradiation for daily energy generation.
   - **Management:** Use batteries to collect energy needed for 2 days of continuous work.
4. **Too much energy consumption.**
   - **Impact:** Increased costs and energy and difficulty of energy generation.
   - **Management:** Use of deflectors to optimize the energy in the incubator and make it more efficient.

5. **Contaminated air inside the incubator.**
    - **Impact:** Lack of oxygenation in the eggs.
    - **Management:** Vents for contaminated air circulation and fan for air renewal inside the incubator, 4 air renewals per day.
6. **Contamination of insects and dirt inside the incubator.**
    - **Impact:** Insects and garbage that can affect and damage the systems or affect the incubation of the eggs.
    - **Management:** Small vents that help the air circulation and that there is no accumulation of garbage.
7. **Contaminated humidifier water.**
    - **Impact:** Damage to the humidifier due to contaminated wastewater.
    - **Management:** Water filter in the humidifier to clean the water of any dirt.
8. **Fan damage.**
    - **Impact:** Polluted air can damage the fan and generate vibrations that affect the eggs and burn the fan.
    - **Management:** Small vents that helped to relocate the fan inside the incubator.
9. **Contamination inside the incubator.**
    - **Impact:** Accumulation of waste within the system that affects incubation.
    - **Management:** Daily hygiene plan.
10. **High temperatures in the ceramic bulbs.**

- **Impact:** When cleaning the incubator or collecting eggs the high temperature of the light's bulbs can burn us.
- **Management:** Increasing the distance between the eggs and the lights for the user's safety.

Maintenance and Operation Manual

List of parts

Table 46 List of assembly parts

Part Number	Code	Name	Material	Quantity
1	STC-001	External Structure: External Layer	Polycarbonate 3 mm thickness	1
2	STC-002	External Structure: Middle Layer	Fiberglass 50 mm thickness	1
3	STC-003	External Structure: Internal Layer	Polycarbonate 3 mm thickness	1
4	STC-004	Incubator Door (three-layer composition)	Polycarbonate 3 mm + fiberglass 50 mm thickness	2
5	STC-005	Air Deflector	PLA	3
6	STC-006	Water Container	Polycarbonate 3 mm thickness	1
7	STC-007	Water Container Filter Structure	Polycarbonate 3 mm thickness	3
8	STC-008	Egg Shelf	Polycarbonate 4 mm thickness	1
9	STC-009	Egg Container Type A	Polycarbonate 4 mm thickness	3
10	STC-010	Egg Container Type B	Polycarbonate 4 mm thickness	2
11	STC-011	Rail	Polycarbonate 4 mm thickness	10
12	STC-011	Socket Holder	Stainless Steel	1
13	SUB-001	Hinge	Stainless Steel	4
14	SUB-002	Corner Brace M6	PLA	4

15	SUB-003	Lateral Brace M6	PLA	12
16	SUB-004	Water Container Brace	PLA	2
17	SUB-005	Lateral Brace M5	PLA	8
18	SUB-006	Cap Screw M6 x 70	Stainless Steel	66
19	SUB-007	Hex Nut M6	Stainless Steel	66
20	SUB-008	Flat Washer M6	Stainless Steel	66
21	SUB-009	Cap Screw M5 x 20	Stainless Steel	30
22	SUB-010	Cap Screw M5 x 16	Stainless Steel	16
23	SUB-011	Hex Nut M5	Stainless Steel	46
24	SUB-012	Flat Washer M5	Stainless Steel	76
25	SUB-013	Bearing Bush	PLA	66
26	ELE-001	Ceramic Heater	Ceramic	2
27	ELE-002	Lightbulb Socket	Ceramic	2
28	ELE-003	Fan 120x120x38 mm	Glass-filled polymer	1
29	ELE-004	Humidifier	Multiple	1
30	ELE-005	Dehumidifier (Peltier module + fan + heat sink)	Multiple	1
31	ELE-006	Temperature Controller	Multiple	1
32	ELE-007	Thermocouple type k	Multiple	1
33	ELE-008	Humidity Controller	Multiple	1
34	ELE-009	Hygrometer	Multiple	1
35	ELE-010	Solar Charge controller	Multiple	1
36	ELE-011	Photovoltaic Panel	Multiple	2
37	ELE-012	Batteries	Multiple	4
38	VAR-001	Water Filter	Sponge	1

Assembly drawing with labels

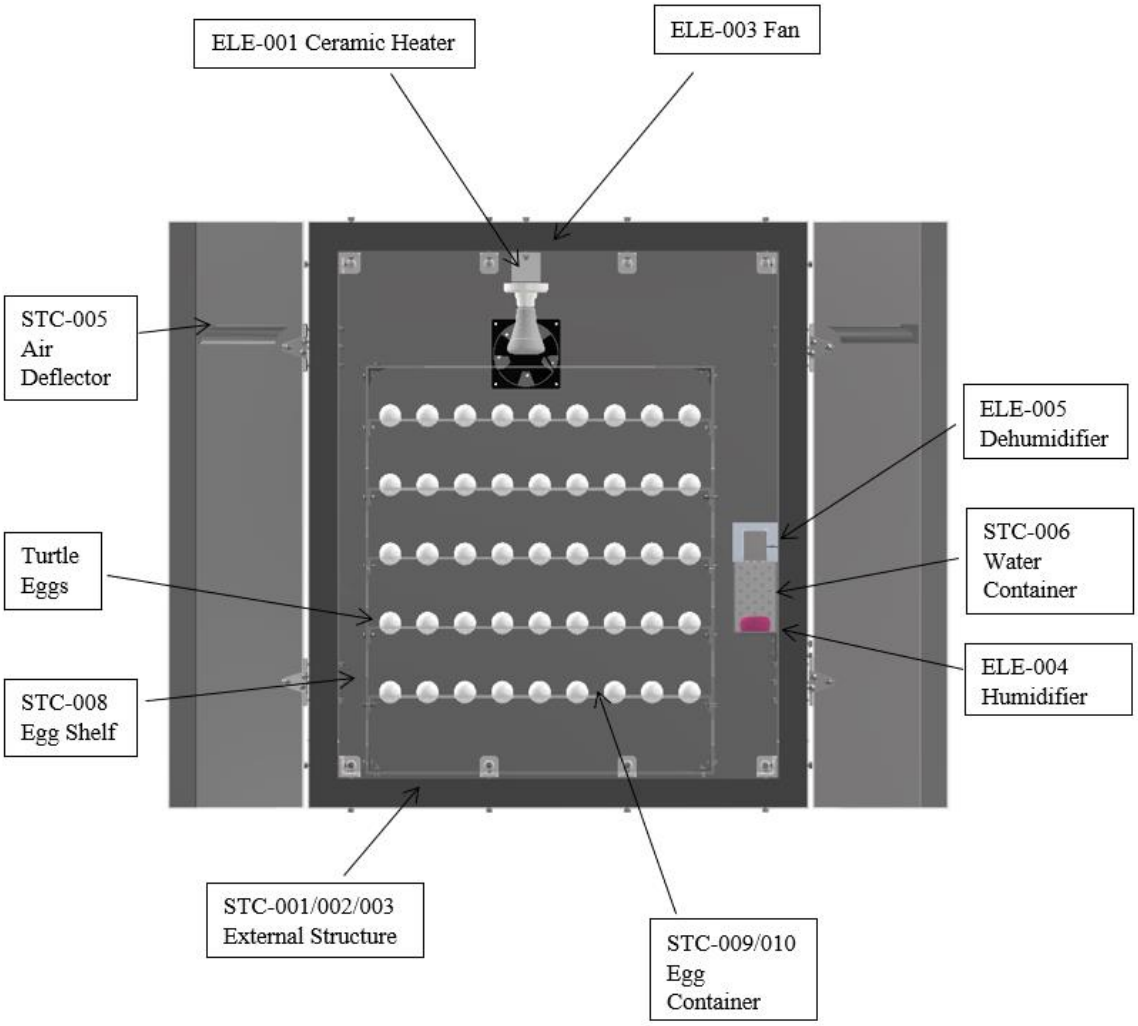


Figure 39 Assembly with labels

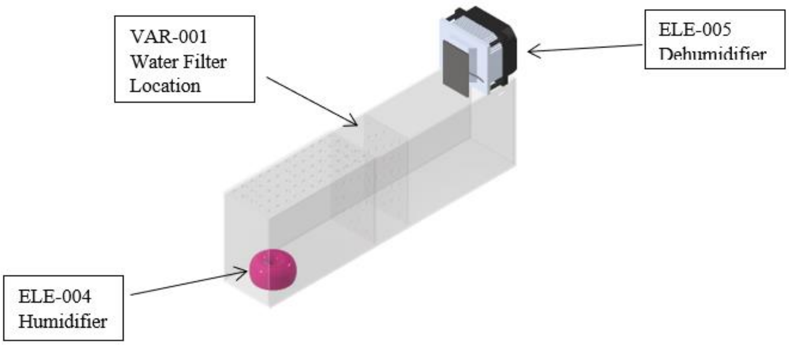


Figure 40 Water container assembly

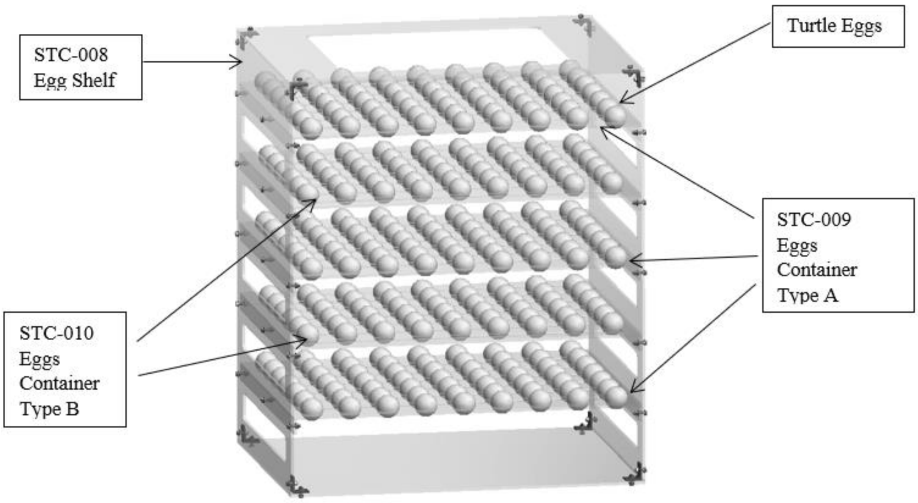


Figure 41 Eggs shelf assembly

Safety information

- Always secure the incubator door tightly.
- Make sure internal components are properly located.
- Do not manipulate electronic elements. It includes a fan, Peltier cell, and heat diffuser.
- Make sure the humidifier contains water before use.
- Do not manipulate the bulbs if they are on.

General product description and features

- Structural System: It consists of the implementation of layers that protect and enclose the incubator chamber. The first and last layer are made of 3mm polycarbonate while a 50 cm fiberglass sheet is used as the middle layer to serve as a thermal insulator. The configuration of these layers creates a cubic structure with external dimensions of: 67.3x87.2x102.2 cm and an internal dimension of:56x76x91 cm.

- Humidifier System: It has a rectangular base made of polycarbonate where the humidifier is found. It also has the implementation of a Peltier Cell which helps the dehumidification in necessary cases. It functions with water and condensation of water is reused when humidification is needed.
- Energy System: The energy supply will be obtained through the implementation of solar panels. These will be located on the top of an infrastructure where the client decides to place them. Additionally, batteries are used for energy storage considering that there might be days when sunlight is not abundant.
- Heating System: This serves to keep the internal temperature of the incubator. Two ceramic heaters of 150W are located on top of the incubator. It also has a fan that distributes the air flow inside the incubator. Basically, this system uses forced convection to reach the required temperature in most of the eggs.

Start up

1. Verify that all components are correctly located.
2. Place electronic elements such as ceramic heaters and humidifier in the corresponding place as is shown in assembly drawings.
3. Place the eggs containers in the correct order as is shown in the assembly drawings. And fill them with the eggs.
4. Place the egg container into the shelf.
5. Located delicately the shelf inside the incubator.
6. Review the manual of the solar panels to know the startup function.

7. Set the temperature necessary for the incubation. This requires the user to review the manual of the humidification and heating controller.
8. Preheat and humidify the incubator
9. Close the doors properly.

Operation

1. Check that the controllers are working and sensors are not obstructed.
2. Change the humidify water every day and clean its container.
3. Check that the vents are not clogged and clean them every day.
4. Review the manual of the solar panels to know the mode of operation.

Shut down

1. Check that all turtles have been collected.
2. Turn off the subsystems of humidification and heating.
3. Review the manual of the solar panels to know the shutdown function.
4. Remove, clean and store the humidifier inside a plastic bag.
5. Check that the fan blades no longer rotate.
6. Remove, clean and store the ceramic heater.
7. Remove, clean and store egg containers and the shelf in the respective box.
8. Collect all fragments from egg shells.
9. Make sure the inside of the incubator is completely clean.
10. Check that the vents are not clogged.

11. Close the doors properly.

12. Cover the structure of the incubator with a cloth.

*Note: the process of cleaning requires the use of a clean cloth and an organic or a non-toxic disinfectant (alcohol, vinegar, etc.), to not disturb turtle incubation process.

Storage

1. Store the ceramic heater, humidifier and fan inside the corresponding boxes provided in the installation.
2. Store egg containers and the shelf inside the corresponding boxes provided in the installation.
3. Wrap the structure with plastic packaging and place it inside the box provided in the installation.

*Note: components inside their boxes must be located away from sunlight, water or any factor that could modify them.

Controls and operation variables range

Table 47 Incubator variables

Characteristic	Units	Description
Shelf egg capacity	# eggs	297
Humidification water requirement	ml	200
Autonomy	hours	48
Lifetime of ceramic heater	hours	20000
Fan speed	rpm	2400
Dimension	m x m x m	0.675x1.022x0.872
Weight	kg	107.2

Maintenance schedule

Table 48 Maintenance schedule

Type of Maintenance	Maintenance Frequency
Corrective	When necessary
Preventive	Daily during incubation period.
Storage	Post incubation period.

Maintenance recommendations

- Corrective Maintenance:

    1. Replace the electronic element for a new one with the same characteristic (Voltage, Current, dimensions, etc.)

    2. Make use of the technical draws to recreate a broken part. (3D printed part, polycarbonate structural layer, egg containers etc.)

- Preventive Maintenance:

    1. The process of cleaning requires the use of a clean cloth and an organic or a non-toxic disinfectant (alcohol, vinegar, etc.), to not disturb turtle incubation process.

2. Change humidifier water container every day and clean the humidifier box.
3. Check that the controllers are working, and sensors are not obstructed.
4. Change the humidify water every day and clean its container.
5. Check that the vents are not clogged and clean them every day.
6. Clean photovoltaic panels and remove any type of obstacle that might obstruct sunlight irradiation on its surface.

- Storage:
    1. Components inside their boxes must be located away from sunlight, water or any factor that could modify them.

Discussion

This document sought to obtain all heat transfer and design critical values to assure a functioning incubator prototype for *Podocnemis Unifilis* turtle eggs. Several subsystems were analyzed through analytical models or simulations. Different software facilities allowed obtaining comparable results with handmade calculations. In order to have a better results analysis, this section will be divided into every subsystem.

Egg trays

Materials mechanics

Considering that the support of the containers is simple, the type of stress studied corresponds exclusively to normal stress. Although the calculation is based on the most critical area, Autodesk Inventor software, does consider the whole body. The absolute error obtained between the simulation and the calculations is 18%. This may be due to some factors:

Simple support considered for manual calculation, but not considered by software. The contact restrictions in this software only allow embedment's between bodies. This boundary condition will promote the creation of punctual momentums at beam ends.

Real inertia of the body vs inertia of the critical body analyzed in calculations. In due course the inertia of the whole body will not only consider the critical zone as it was done in calculations.

To corroborate the simulations made on inventor were correct it was considered a manual calculation where the supports of the beam are embedment. In this both cases have the same boundary conditions. The absolute error obtained between the simulation and the calculations is 1.81%. After making this comparison. It is stated that the data obtained by the inventor simulation is correct and the error obtained is due to the previously exposed.

Vibrations

Simulation of frequencies in the complete piece (egg container) shows that each row behaves as an independent element. Table 21 shows the results in Hz of the complete container. Evaluating these results, it can be confirmed that vibration modes are practically the same every seven values. Considering that the complete part has 7 rows, the hypothesis is confirmed. The individual movement of each beam shown in table 22 verified that it was correct to analyze a single row as an individual element. The most critical vibration modes of the evaluated beam correspond to 18.4 Hz, 50.96 Hz, 100.9Hz and 110.6 Hz. Since eggs of this species require as little movement as possible throughout their incubation, mitigating the vibration modes is a valid preventive measurement. Eliminate vibration modes, commonly require the use of more rigid materials than the material of the piece to be treated. On this occasion, aluminum was chosen due to its low radiation coefficient and its very low probability of corrosion. Figure 22 shows the behavior of the part after adding the stiffening element. The values after this modification are higher than those shown before the adjustment (shown in table 22). The increase of frequency of the renewed piece, confirm the increase in rigidity of the element, resulting in vibrations reduction.

Incubator walls

Heat loss through walls is inevitable. In order to reduce the ease with which the incubator loses energy, it was decided to implement a sandwich like wall that includes an insulation layer. This assures that middle layer material has a low capacity of conducting heat, as consequence less energy lost per time unit.

The system was simplified into a thermal resistance model. This analysis was developed for every temperature range presented over incubation periods. Table 27 demonstrates that higher energy loss is directly related with higher temperature variation between incubation and ambient conditions. For this reason, it was correct to assure that the most critical scenario is given by the lowest registered temperature. Meaning more power is required to mitigate heat loss will intending to reach incubation temperature.

During incubation period, power required by the system to increase one degree is minimum compared to start energy consumption. In this particular case, it was estimated that during critical temperature, placing 297 eggs on the equipment will require 35 minutes to reach incubation temperature. In contrast, if this process was performed at 10 am, required time decreases in 73 %. This result is a direct consequence of assuming entering eggs are at ambient temperature and lower heat loss through walls. It is important to stand out the fact that during this calculation it was assumed 297 eggs were placed simultaneously in the equipment. Nevertheless, in practical terms this will not happen. The recommended procedure for eggs placing states that each egg tray is filled up and located on the structure one at a time. This gives a considerable time lag in which inside eggs might increase their temperature.

Photovoltaic panels

Having a self-sustainable equipment was part of the client requirements. Sizing photovoltaic panels array and required batteries and controller is fundamental to have an operating incubator. For these calculations it was required to determine power consumption per hours. These values were estimated under critical assumptions. This means the incubator will be able to provide its own energy even if some contingencies take place. Having two photovoltaic panels with 4 batteries will assure two days of autonomy. This means that in case the equipment would not be able to reach sun irradiation, the incubator is going to be able to continue with normal operations for two days.

According to Global Atlas data, the optimum tilted angle at Tiputini is 2 °. This means that panels placed with this angle would be able to catch more irradiation. However, since Global horizontal value for panels placed with no inclination represents only 0.04% less peak sunshine hours per day, it was decided to ignore tilt angle. This decision will mean less money spent on structural profiles to place panels at desired angle. Additionally, since the angle has a low value, it would represent high efforts to obtain it with no significant consequences.

Dehumidification system

Values obtained through equations systems have not much difference with the results obtained with the equation solver software EES, since most of the properties are almost the same for both cases (Incropera Table 6 and EES properties library). This calculation may vary from real results due to the assumptions required to use the equations. Real scenarios do not count with constant properties, pure vapor, uniform temperature, or velocity of the gas equal to zero. However, this calculation may provide an approach so that a first prototype can be design and build. This system has the intention of reusing its water for the humidification system, however when showing the small amount that must be able to condense in the most critical case it is recognized that it does not contribute significantly to the humidification system.

Temperature regulation system

Temperature regulation inside incubators is fundamental to reach desired environmental conditions. This system is designed to have a continuous monitoring of temperature and turn on bulbs and fan when required. In order to maintain incubation requirements, design parameters were stablished. In temperature concerns, the controller is to be set in 1 °C difference. This means that if the thermocouple measures 32 °C, the heating system will be turned on.

Transient simulation study was performed in order to obtain time required to lose one degree when ambient temperature corresponded to the most critical value. Table 37 presents a diagram with temperature variations over time for three nodes. Four centimeters apart from right wall was a location of interest since the thermocouple will be located at this point. The selection of this spot responds to the fact that eggs holding structure starts at this position.

Since temperature reduces from the outside to the inside (as shown on table 38) it is an accurate assumption to establish sensor measurement at this point as last frontier before eggs lose temperature on their surroundings. Additionally, since humidifying and dehumidifying components are located at left wall, this side will fell temperature drop in longer periods of time.

Pictures presented on table 38 make a visual representation of the efficient performance of fiberglass as insulation material. While outside polycarbonate layer has an approximate superficial temperature of 26 °C, only 5 cm inside, polycarbonate inner layer has a superficial temperature of 31 °C. Finally, vents will not affect inside temperature as presented on figure 27. Two reasons may be inferred for this result. On one hand, the fact that cross-sectional area of vents is equal to $7.85x10^{-5}$ m^2, in total they represent only 4.8% in wall area. Making their holes an insignificant portion of total walls area. Additionally, due to buoyancy, hot air tends to go up instead of leaving the system through vents.

Temperature and Ventilation behavior

In order to have a better understanding of incubation natural subtract behavior, an experimental study was developed. Simultaneous measurements of ambient and sand temperatures were compared for 5 tracked days. Figure 28 presents actual conditions for the executed experiment. It is important to mention that the thermocouple was buried 10 cm. This was established with the intention to understand inside behavior. From figure 29 it can be inferred that sand can storage energy. First experimental day, sand was exposed to irradiation throughout the morning and afternoon. In contrast, subsequent days the weather deteriorated each day having cloudier days as the experiment continued. This environmental conduct has a direct impact on sand temperature by reaching lower temperature values each day. This means that sand has the capacity to storage energy obtained from irradiation. This energy allows internal temperature to maintain higher values than external ones. Additionally, sand can catch energy during the day in order to maintain internal high temperatures until this energy is exhausted. Table 39 makes this performance evident since days with higher irradiation exposure reached higher temperature differences with environment at later hours and energy was drained on later hours.

In terms of designed incubator, control over temperature will be more accurate. There will be no drained energy dependent to sun irradiation. It is important to mention that in natural incubation scenarios, temperature difference between nests and environment will be lower. This as consequence that turtles create an air layer on top of their nests. This empty space is an insulation resistance that reduces energy loss. Nevertheless, it is important to extract from this experiment that sand temperature differential throughout a day is significant in comparison to the equipment designed conditions. This means that if any unexpected situation takes place, and more that a degree is lost, no significant impact on incubation process may be caused.

Air flux simulation

First simulation shown in figure 30 to figure 33 correspond to the first design of the incubator. Holes were design to allow air flux through each container in order to distributed uniform heat along the complete volume. It is observed that the behavior of the fluid is not most efficient one. Commonly the factors that reduce optimal air movement are sharp edges, wrong position of fans, and others. To confirm if sharp edges were the main disadvantage of this prototype three deflectors were design and located on strategic locations. It can be appreciated on the simulations that almost half of the eggs (from lower half part of the incubator) were not receiving enough air flux. In contrast simulations after the modification (second design) due have a better distribution of air flux. A front view shown in figure 34 front second design approves the effectiveness of the added deflectors. The temperature distribution is resume in table 40, showing that almost all the volume is covered by the temperature range required by incubation process.

Conclusions

Podocnemis Unifilis turtle's preservation will benefited with by the design and construction of this incubation equipment. Through the design process, the main functions where considered. In order to assure both, clients and incubation requirements; simulation, calculus, and selection tools were implemented.

Structural design

The structure of the incubator prototype has proposed a sandwich wall structure. Root cause of this decision is the isolation necessity. This multilayer structure will be composed with three different layers and two different materials. Outer and internal layer are made with polycarbonate, a polymer material with high resistance, with a Yield Strength of 60[MPa] (POLYCASA, 2014). As changes are made, new needs and limitations are discovered. Structural design has had also multiple changes along the design process. Some requirements and restrictions are:

- Isolation necessity
- Enough volume for eggs and elements
- Affordable costs
- Prevention of natural risks (corrosion, insects, pests, etc.)
- Use of reusable and non-toxic materials.

- Air renovations need.

The current prototype has considered this requirement by changing materials, dimensions, and other factors through the incubator development. Polycarbonate accomplished most of this requests list. This polymer has not a high conductivity coefficient, so it contributes the isolation system. Dimensions planned for this first prototype were stablished to afford close to ten turtle nests, this means almost three hundred eggs. This design has the capacity to also afford all the required devices and elements (egg containers, ceramic heaters, fan, etc.). Its strong properties allow the material to be a protection for the system. Analyzing market costs, polycarbonate fit the budget stablished by the client.

On the other hand, polycarbonate porosity is reduced, and it protects the system from undesirable liquids. It is not considered an organic material; this becomes a benefit since turtle's eggs need to avoid any type of pests or invading insects. End of life design of every polycarbonate part is to be either reused or recycled, so it could be considered as an ecological material. This design does not use any type of paint or other artificial covering to prevent negative reactions from eggs. Renovation of air was also considered, so the structure as ventilation holes that will allow the renovation of air.

Shelf and egg containers

Seeking to optimize air flux, shelf and egg containers were designed to let air move as uniform as possible. Due to the method of heating (forced convection), it is necessary that air reaches all the eggs properly to promote a successful incubation. A vibration study was carried out to evidence how vibration could affect the movement of the turtles. Since turtles require a fixed position, mitigate vibration was the last improvement and will be an optional change for the client to make, since the costs required for this change were not considered from the beginning. As it was shown in the material mechanic calculation, the egg container structure can afford the normal stress made by the egg's weights and the part weight too. This is confirmed with the result of the safety factor of 11,13. Even though vibrations were not a first consideration it is recommended to implement the improvement of the stiffness elements.

Heating system

Since the entire incubator seeks not only to comply with the requirements set out, but also with the needs of the turtles, the darkness within the incubator was a highly evaluated parameter. As consequence of this necessity, the chosen heating method are a couple of ceramic heaters, since they do not produce any type of light and accomplish the main goal of heat the environment of the turtles. The method used to heat the eggs and their surroundings, is forced convection, so a fan and an air input and output are part of this system. Transient simulation was carried out, considering the sensor position (4 cm off the wall), and it show that it was required almost 19 minutes under the most critical conditions to drop 1°C (from 33° to 32°), so that will be the time require to start the heating process. This is considered for selection of panels and batteries

Humidifier system

During the day there are hours when we need to humidify the system to keep the incubation conditions constant so an incubator humidifier was used which will help us keep the system stable.

Dehumidifier system

The implementation of a dehumidifying device already on the market can avoid complications both in control and calculations. However, due to budget limitations, the team has been forced to devise a system that fulfills the same function but for a much more accessible price. The results obtained appear to be quite efficient since the condensation time, once the surface reaches the dew point, is just under 2 seconds. The vertical position of the plate seeks that due to gravity the water that accumulates is directed to the water container that supplies the humidifier. However, since for each time the cell condenses (in the most critical case) it will produce only 0.8 ml of saturated water. In conclusion condensed water does not represent a significant amount of mass for the humidifier.

Heating and ventilation system

After analyzing the previously two scenarios, the main conclusion is that the addition of deflectors is an improvement to the air flux. The effectiveness of air distribution along the volume did improve. Since all the eggs achieve the required temperature for the incubation process this modification will stay for the final design incubator prototype.

Future Work

Since the scope of the project limited. Some considerations are presented that could help for improve the design.

- Make a study of vibrations on natural frequencies of sand, where egg nests are located, it would be adequate to be simulated.
- Make a study of vibrations on the natural frequencies that affects the turtle eggs, since it would be important not to reach those frequencies.
- Implementation of air filtration.
- Study of mechanics of materials and vibrations of the external structure.
- Implementation of an alarm to warn if any system stopped working or if it is working incorrectly.

- Check the maintenance of the metallic elements from time to time to avoid corrosion.

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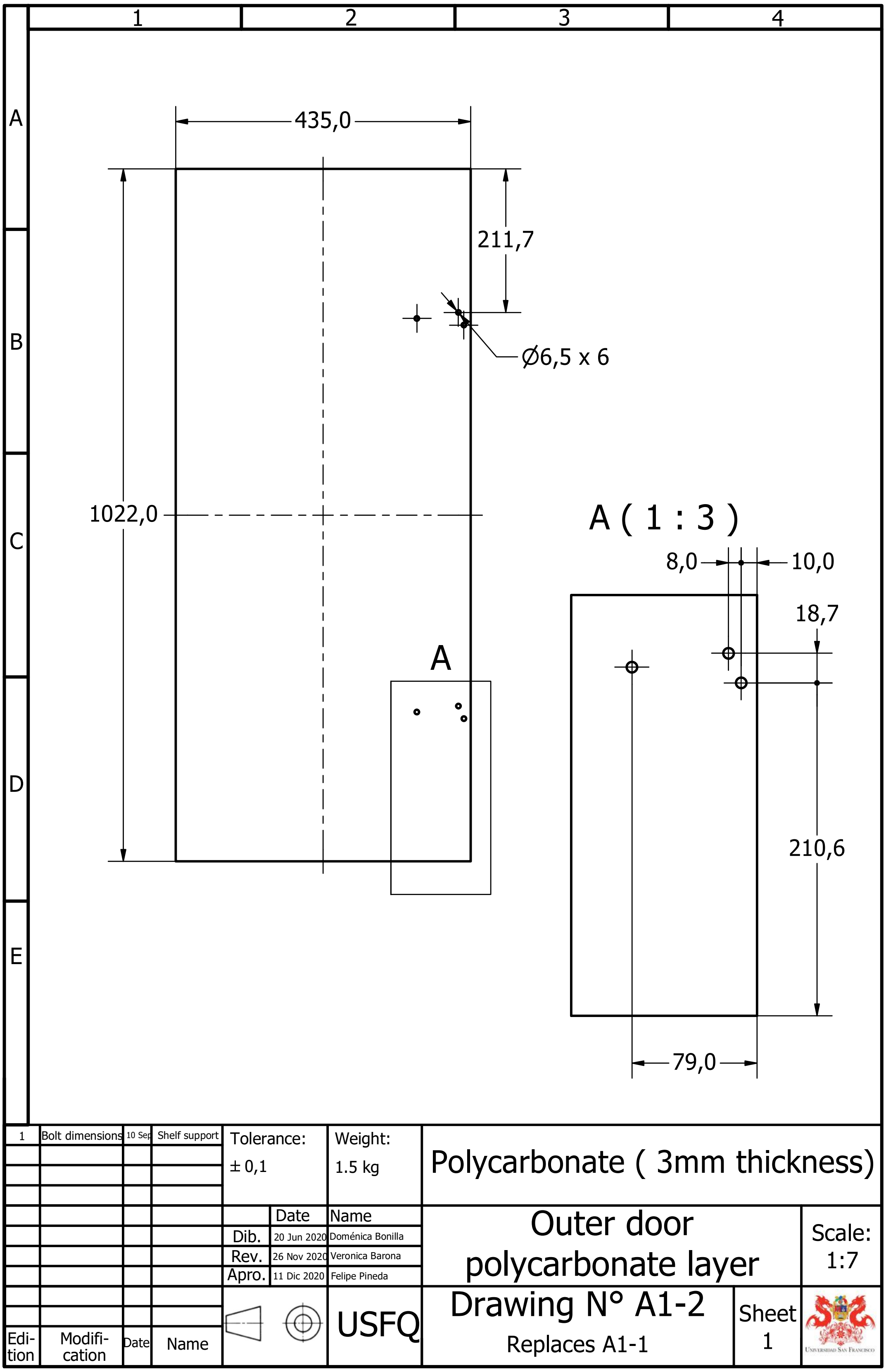
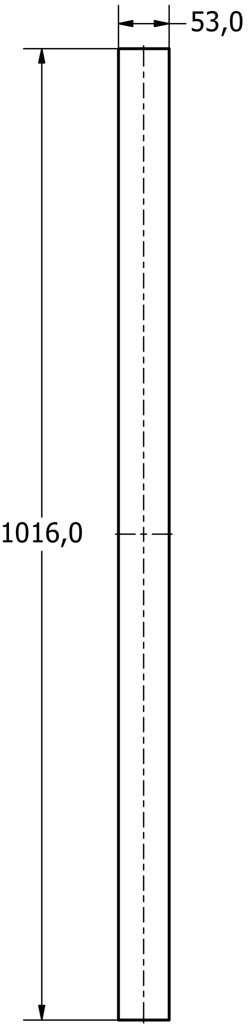
APPENDIX A

Engineering Drawings

In this appendix section, engineering drawings for the incubator manufacturing are presented. They follow INEN norm MC 01.01-601 for mechanical drawing. This norm corresponds to the Ecuadorian compilation of ISO and other international organizations that regulate technical drawing.

Walls structure

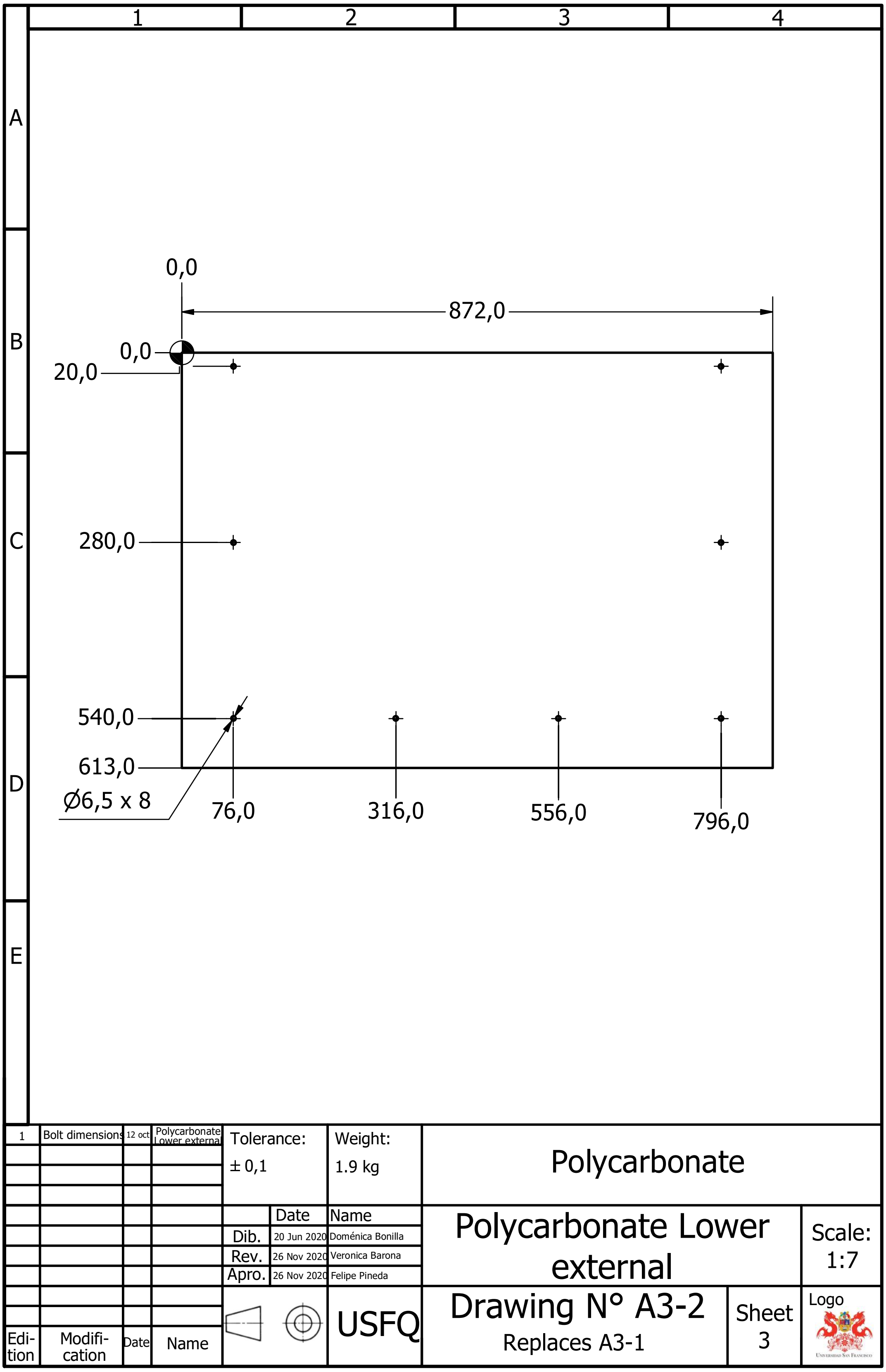




Tolerance:	± 0,1
Weight:	0.19 kg
Material	Polycarbonate (3mm Thickness)
Title	Lateral Polycarbonate external door layer
Scale:	1:6
Drawing N°	A2-2
	Replaces A2-1
Sheet	2
Logo	
	USFQ

	Date	Name
Dib.	20 Jun 2020	Doménica Bonilla
Rev.	26 Nov 2020	Veronica Barona
Apro.	26 Nov 2020	Felipe Pineda

Edi-tion	Modifi-cation	Date	Name



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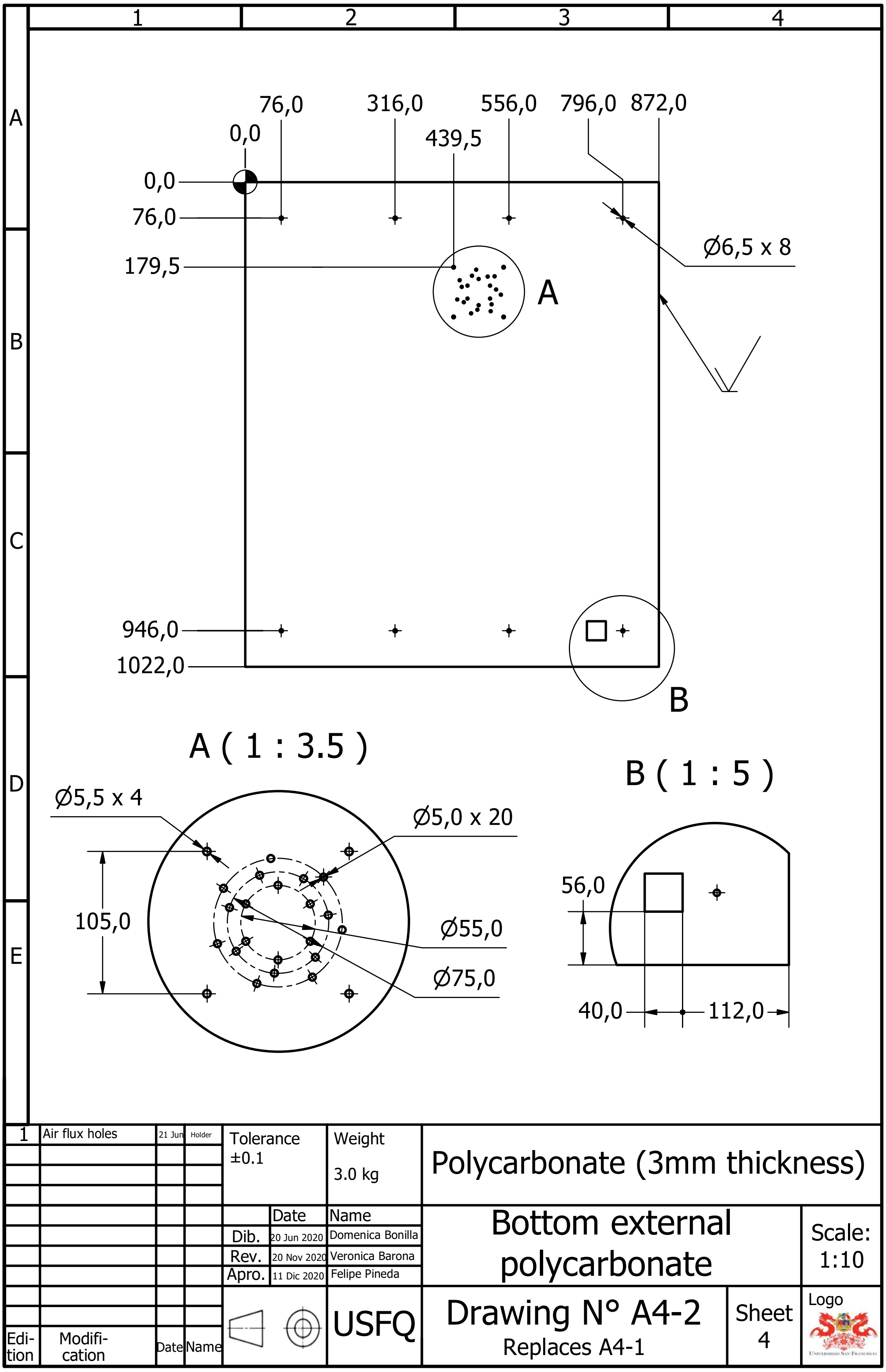
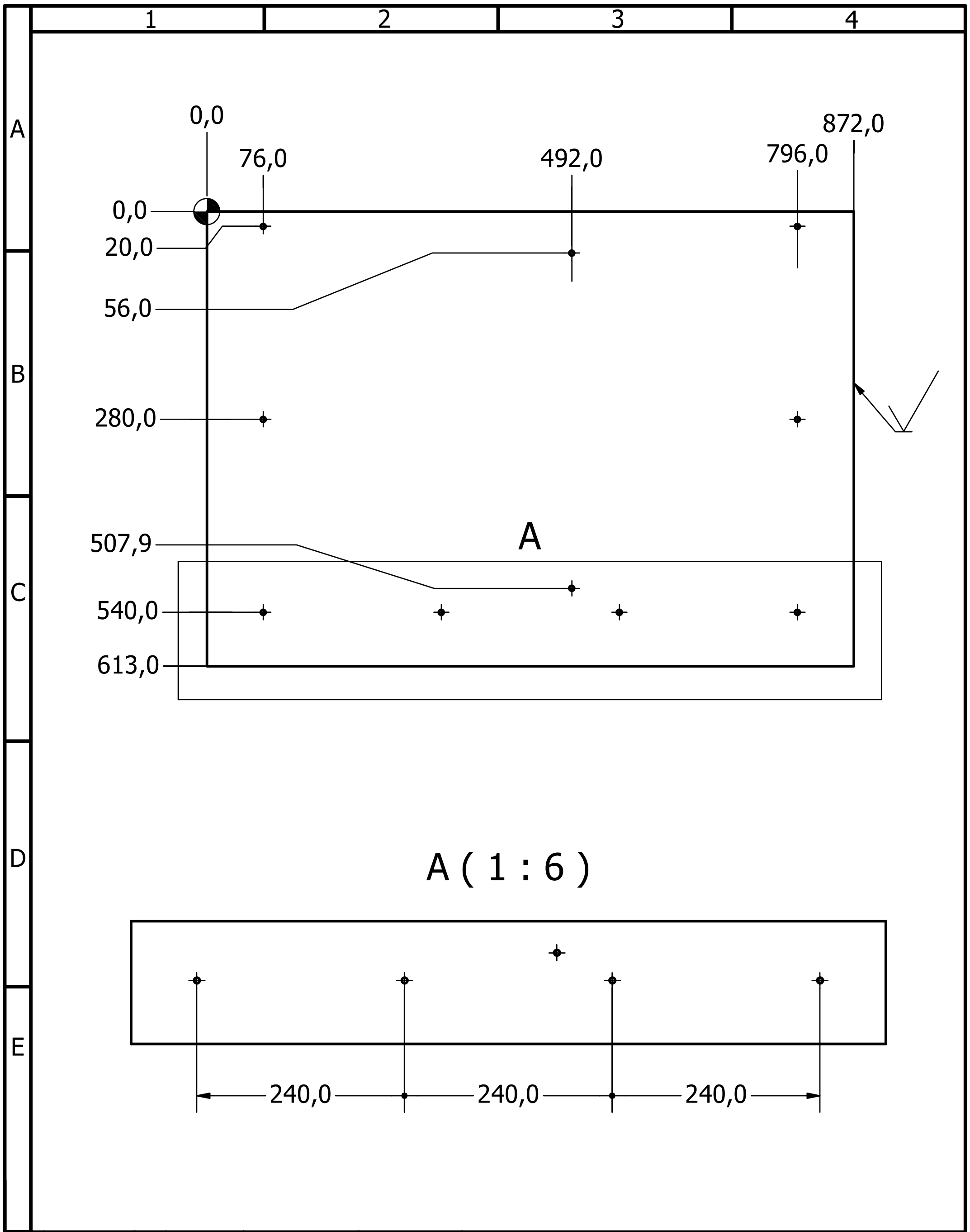
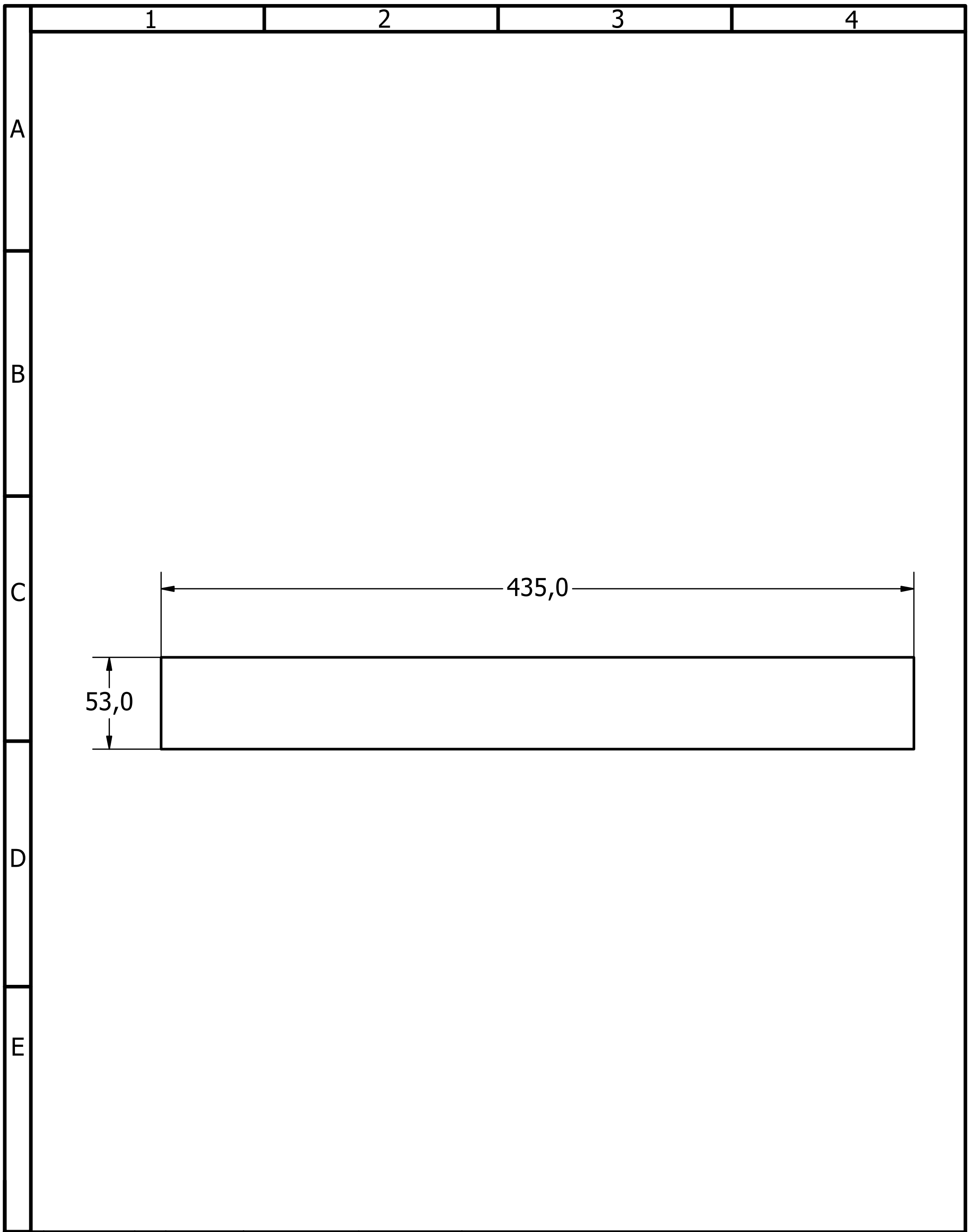
4
A
B
C
D
E
0,0
872,0
0,0
20,0
280,0
540,0
613,0
Ø6,5 x 8
76,0
316,0
556,0
796,0
1
Bolt dimensions
12 oct
Polycarbonate Lower external
Tolerance:
± 0,1
Weight:
1.9 kg
Polycarbonate
Date
Name
Dib.
20 Jun 2020
Doménica Bonilla
Rev.
26 Nov 2020
Veronica Barona
Apro.
26 Nov 2020
Felipe Pineda
Polycarbonate Lower external
Scale:
1:7
Edi-tion
Modifi-cation
Date
Name
USFQ
Drawing N° A3-2
Replaces A3-1
Sheet
3
Logo


1
2
3
4
A
B
C
D
E
76,0
316,0
556,0
796,0
872,0
0,0
439,5
0,0
76,0
179,5
Ø6,5 x 8
A
946,0
1022,0
B
A (1 : 3.5)
B (1 : 5)
Ø5,5 x 4
Ø5,0 x 20
105,0
Ø55,0
Ø75,0
56,0
40,0
112,0
1
Air flux holes
21 Jun
Holder
Tolerance
±0.1
Weight
3.0 kg
Polycarbonate (3mm thickness)
Date
Name
Dib.
20 Jun 2020
Domenica Bonilla
Rev.
20 Nov 2020
Veronica Barona
Apro.
11 Dic 2020
Felipe Pineda
Bottom external polycarbonate
Scale:
1:10
Edi-tion
Modifi-cation
Date
Name
USFQ
Drawing N° A4-2
Replaces A4-1
Sheet
4
Logo



Tolerance: ± 0,1	Weight: 1.9 kg	Polycarbonate (3mm thickness)			
	Date	Name	Superior Polycarbonate external Layer		Scale: 1:7
Dib.	20 Jun 2020	Doménica Bonilla			
Rev.	26 Nov 2020	Veronica Barona			
Apro.	26 Nov 2020	Felipe Pineda			
		USFQ	Drawing N° A5-2 Replaces A5-1	Sheet 5	Logo

Edi-tion	Modifi-cation	Date	Name



Edi-tion	Modifi-cation	Date	Name

Tolerance: ± 0,1	Weight: 0.08 kg	Polycarbonate (3mm Thickness)	
	Date	Name	Superior and Inferior Polycarbonate door external layer	Scale: 1:3
Dib.	20 Jun 2020	Doménica Bonilla		
Rev.	26 Nov 2020	Veronica Barona		
Apro.	11 Dic 2020	Felipe Pineda		

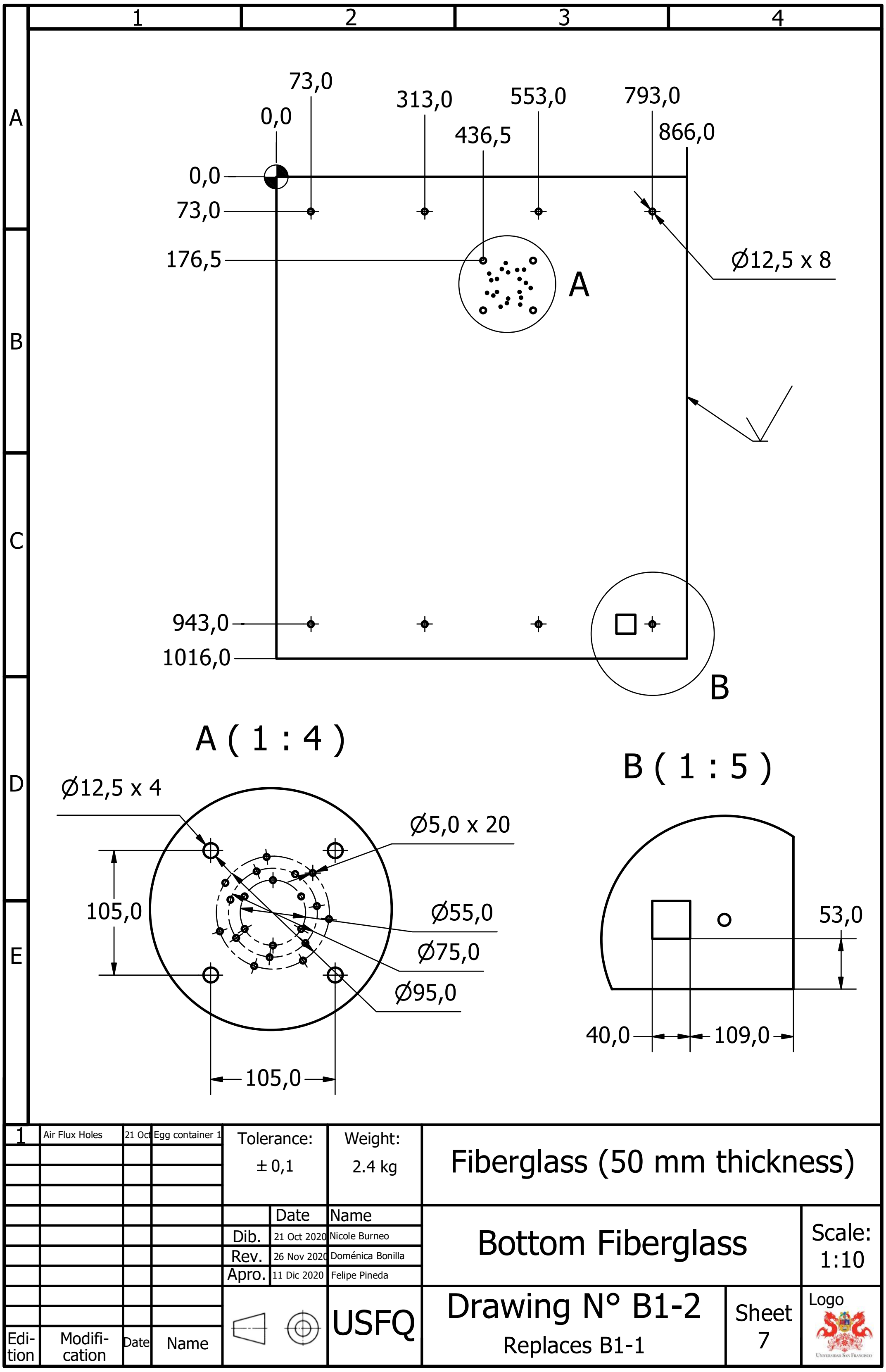
USFQ

Drawing N° A6-2

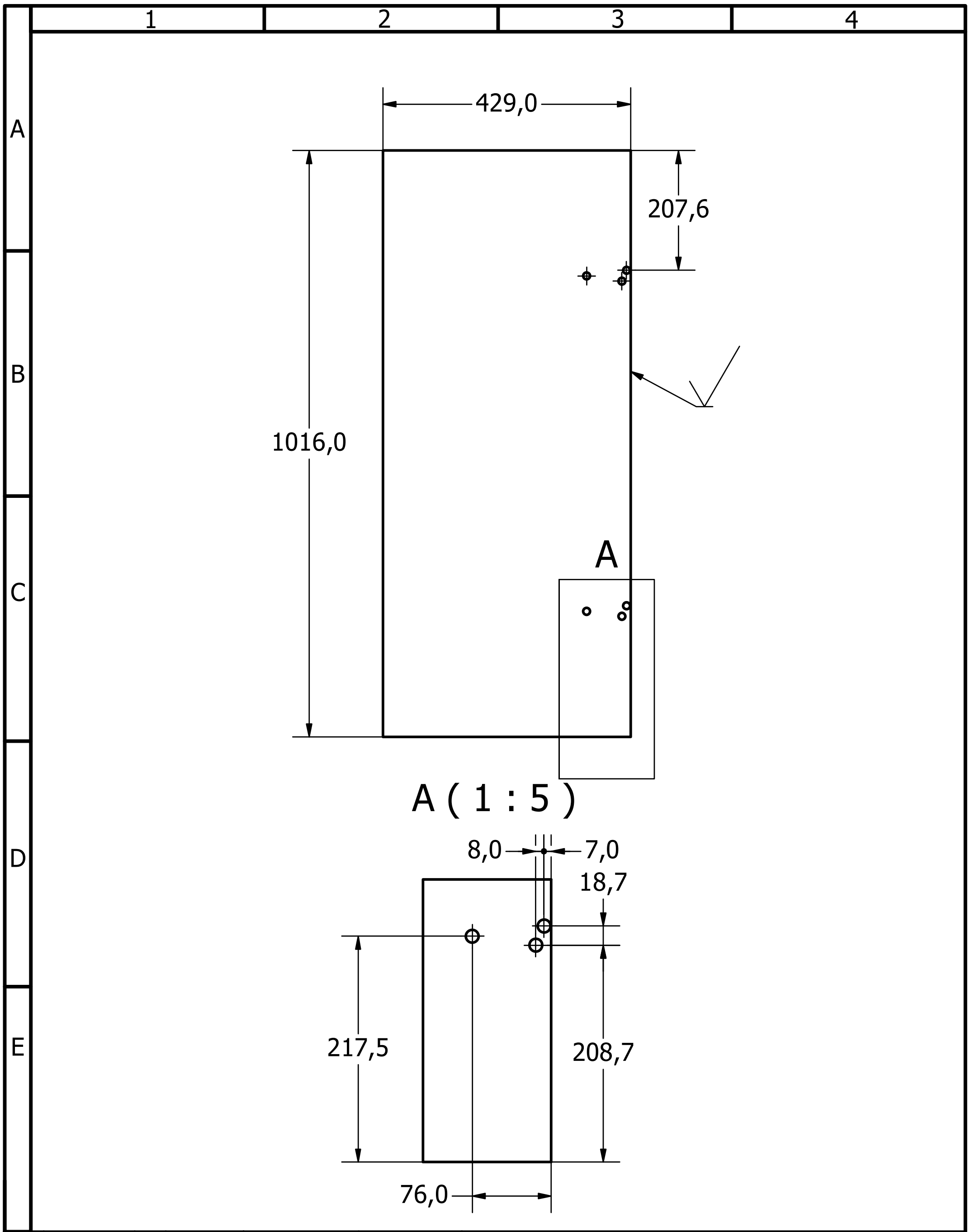
Replaces A6-1

Sheet 6

Logo

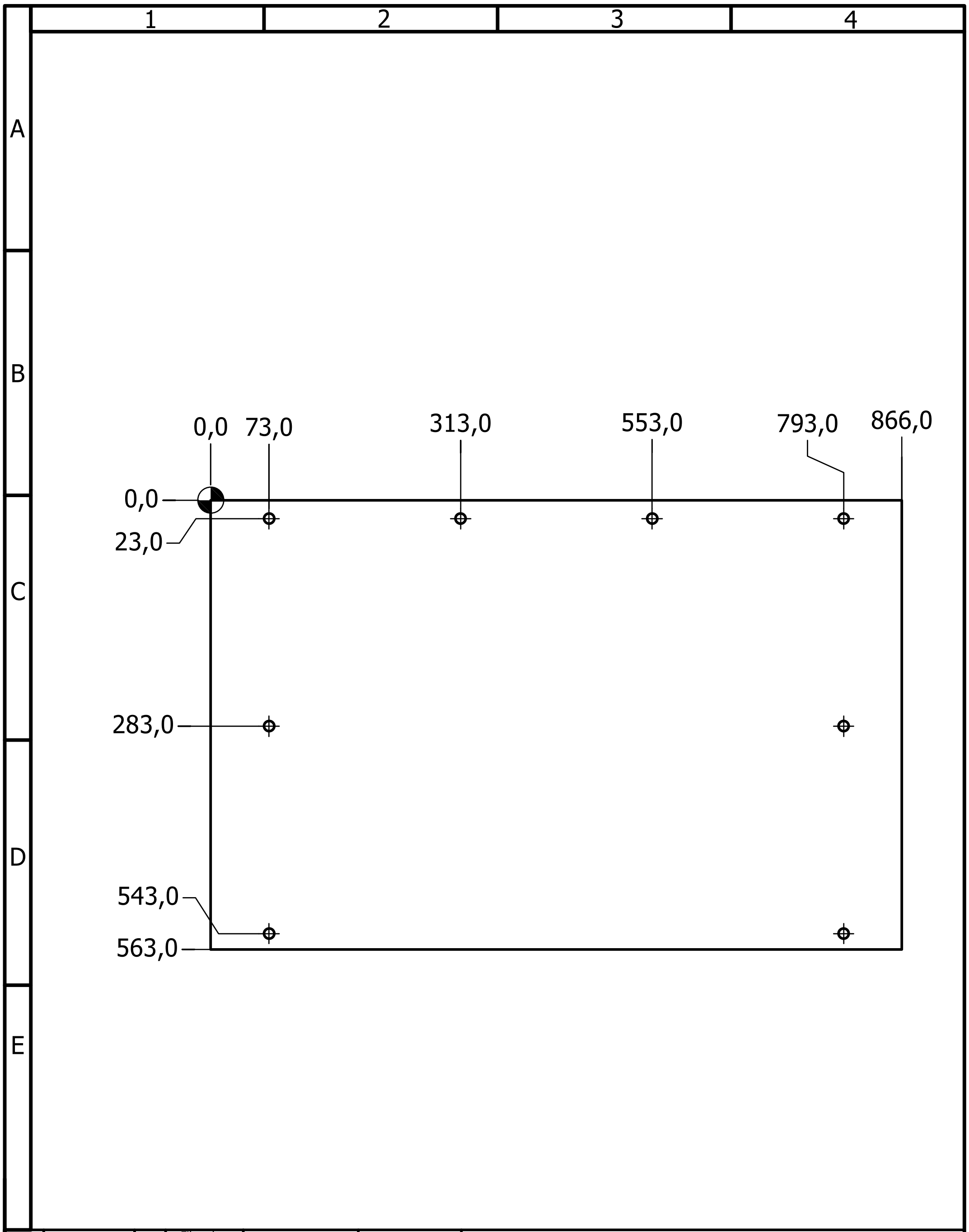


1
2
3
4
A
B
C
D
E
73,0
0,0
313,0
553,0
436,5
793,0
866,0
0,0
73,0
176,5
Ø12,5 x 8
A
943,0
1016,0
B
A (1 : 4)
Ø12,5 x 4
Ø5,0 x 20
105,0
Ø55,0
Ø75,0
Ø95,0
105,0
B (1 : 5)
53,0
40,0
109,0
1
Air Flux Holes
21 Oct
Egg container 1
Tolerance:
± 0,1
Weight:
2.4 kg
Fiberglass (50 mm thickness)
Date
Name
Dib.
21 Oct 2020
Nicole Burneo
Rev.
26 Nov 2020
Doménica Bonilla
Apro.
11 Dic 2020
Felipe Pineda
Bottom Fiberglass
Scale:
1:10
Edi-tion
Modifi-cation
Date
Name
USFQ
Drawing N° B1-2
Replaces B1-1
Sheet
7
Logo



Tolerance: ± 0,1	Weight: 1.1 kg	Fiberglass (50 mm thickness)	
	Date	Name	
Dib.	21 Oct 2020	Nicole Burneo	
Rev.	26 Nov 2020	Doménica Bonilla	Door Fiberglass layer — Scale: 1:9
Apro.	11 Dic 2020	Felipe Pineda	
USFQ	Drawing N° B2-2 Replaces B2-1	Sheet 8	Logo

Edi-tion | Modifi-cation | Date | Name



Edi-tion	Modifi-cation	Date	Name
1	Bolt dimensions	12 oct	Fiberglass Underlayer
2	Material/Thick-ness	28 Oct	Fiberglass Underlayer

Tolerance: ± 0,1

Weight: 1.2 kg

Fiberglass (50mm thickness)

	Date	Name
Dib.	20 Jun 2020	Doménica Bonilla
Rev.	26 Nov 2020	Veronica Barona
Apro.	26 Nov 2020	Nicole Burneo

Fiberglass Underlayer

Scale: 1:6.5

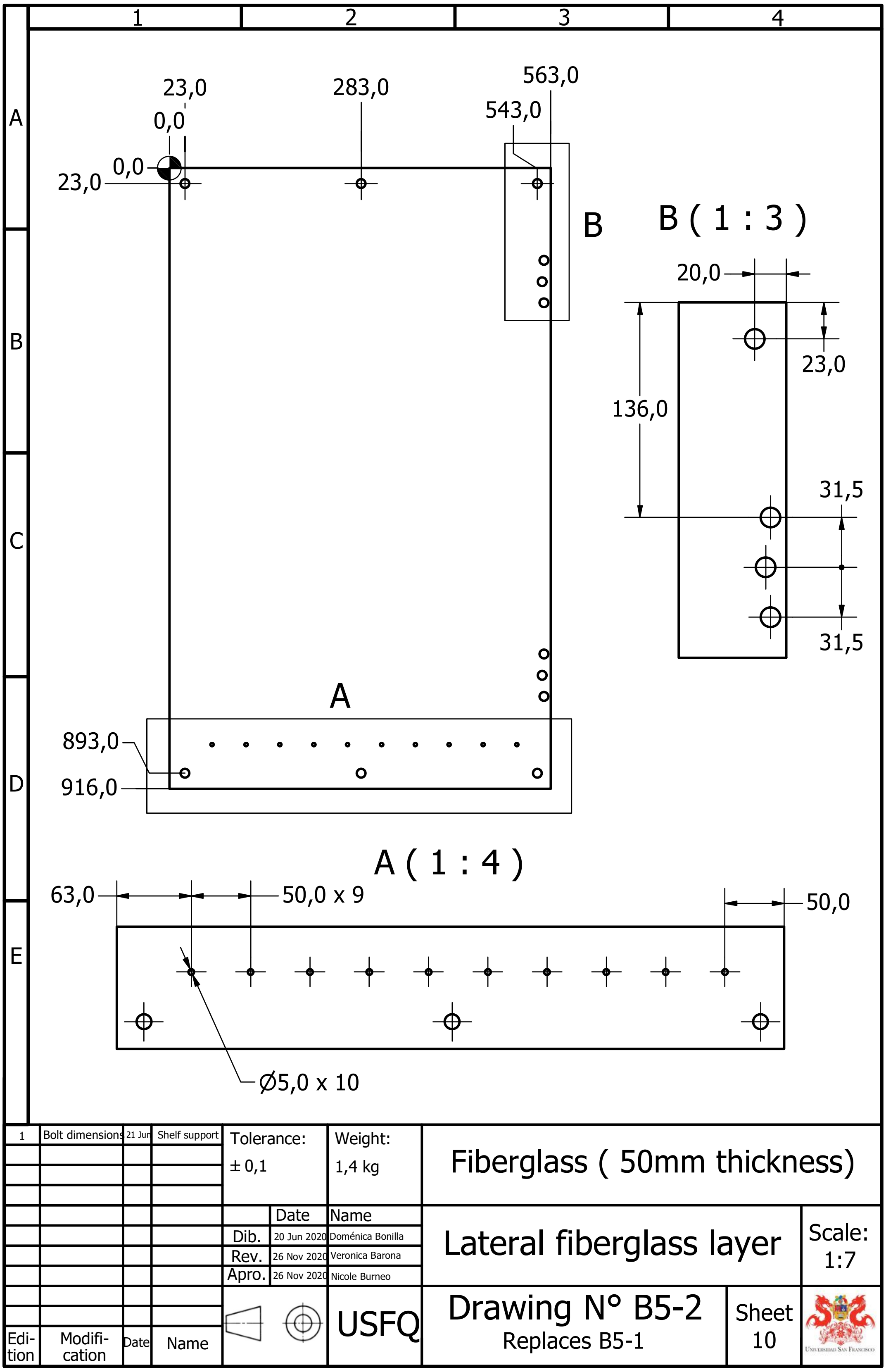
USFQ

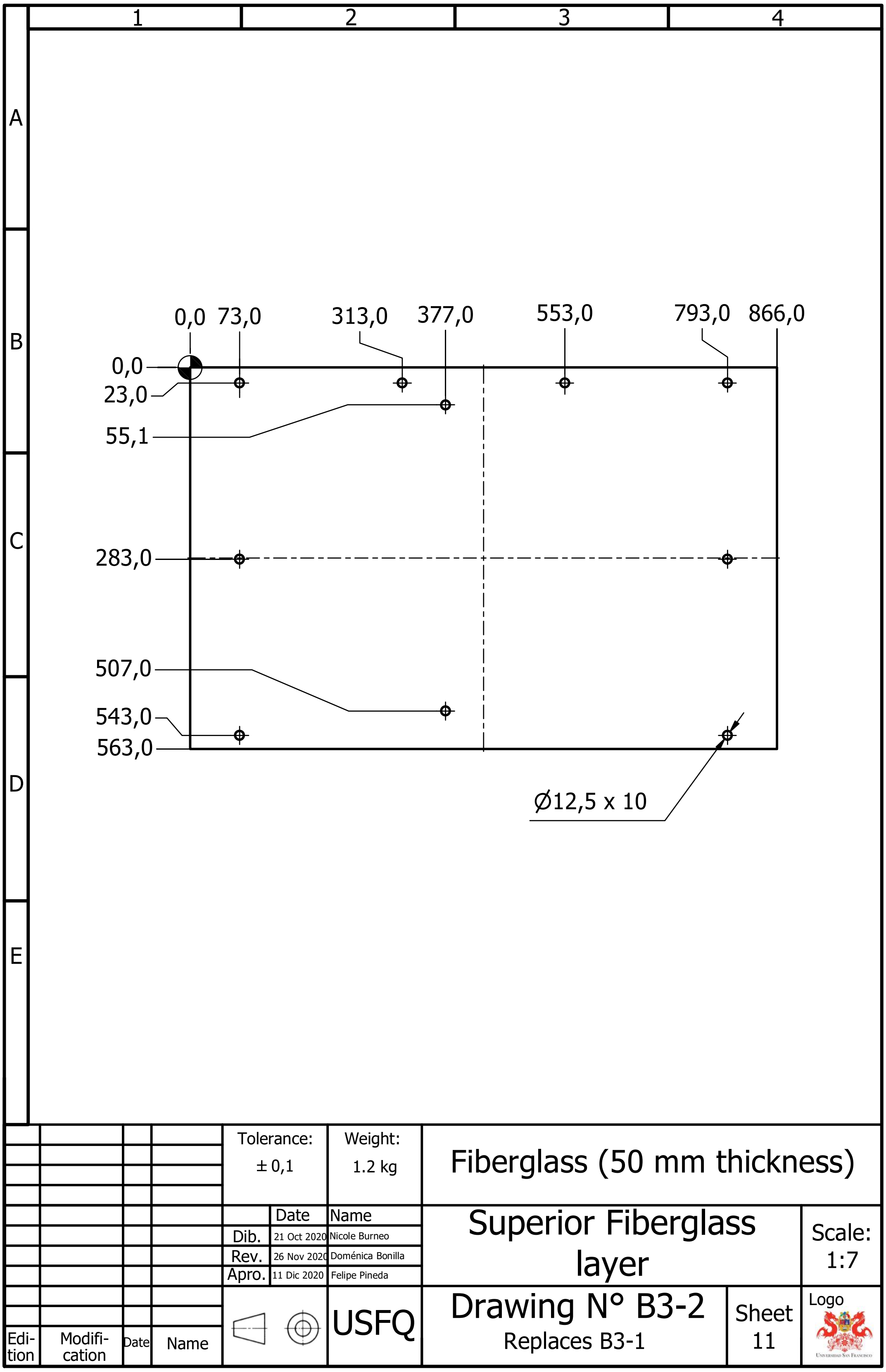
Drawing N° B4-2

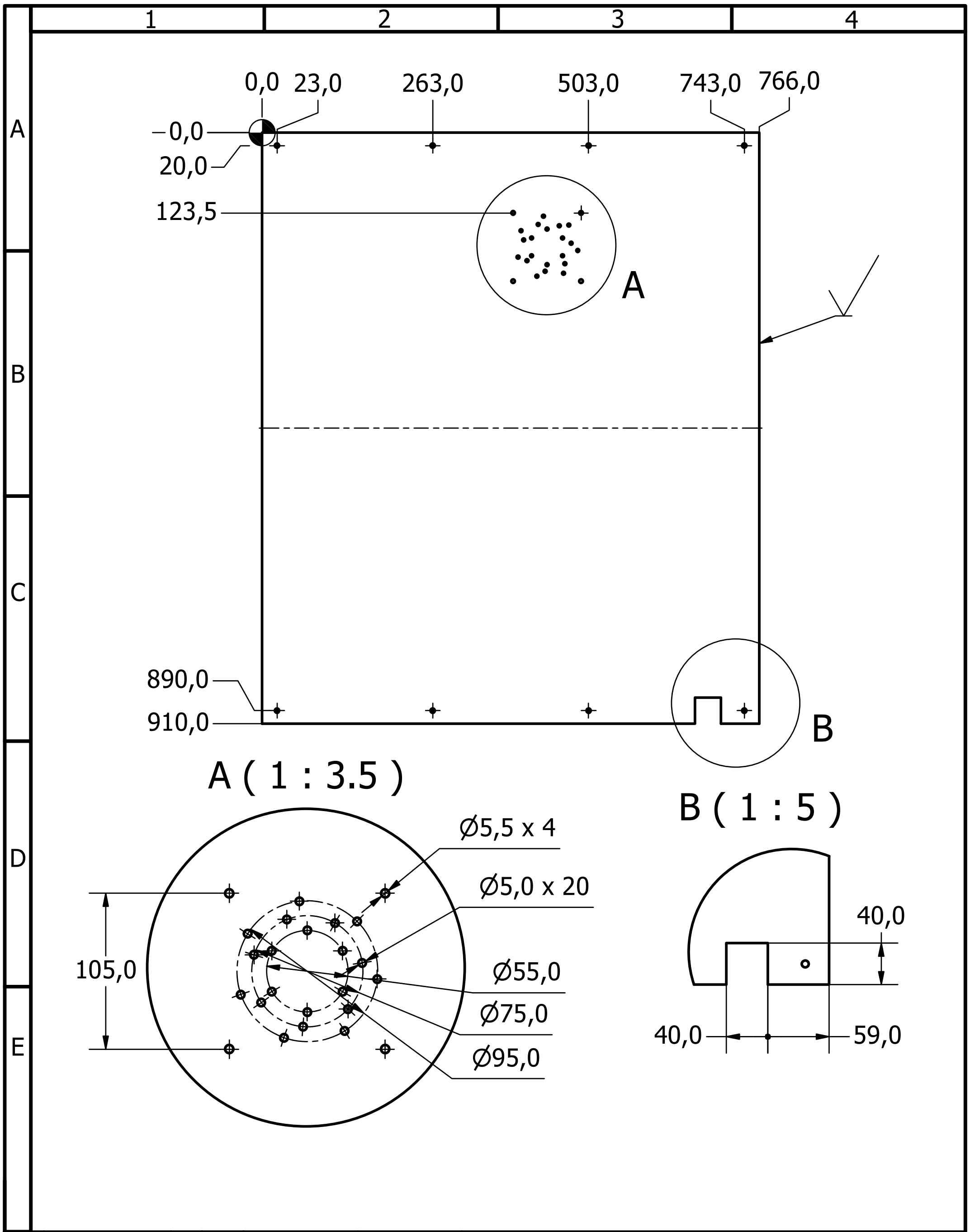
Replaces B4-1

Sheet 9

Logo


1
2
3
4
A
B
C
D
E
23,0
0,0
283,0
563,0
543,0
23,0
0,0
B
B (1 : 3)
20,0
23,0
136,0
31,5
31,5
A
893,0
916,0
A (1 : 4)
63,0
50,0 x 9
50,0
Ø5,0 x 10
1
Bolt dimensions
21 Jun
Shelf support
Tolerance:
± 0,1
Weight:
1,4 kg
Fiberglass (50mm thickness)
Date
Name
Dib.
20 Jun 2020
Doménica Bonilla
Rev.
26 Nov 2020
Veronica Barona
Apro.
26 Nov 2020
Nicole Burneo
Lateral fiberglass layer
Scale:
1:7
USFQ
Drawing N° B5-2
Replaces B5-1
Sheet
10
Edi-
tion
Modifi-
cation
Date
Name


1
2
3
4
A
B
C
D
E
0,0 73,0 313,0 377,0 553,0 793,0 866,0
0,0
23,0
55,1
283,0
507,0
543,0
563,0
Ø12,5 x 10
Tolerance: ± 0,1
Weight: 1.2 kg
Fiberglass (50 mm thickness)
Date Name
Dib. 21 Oct 2020 Nicole Burneo
Rev. 26 Nov 2020 Doménica Bonilla
Apro. 11 Dic 2020 Felipe Pineda
Superior Fiberglass layer
Scale: 1:7
Edi-tion
Modifi-cation
Date
Name
USFQ
Drawing N° B3-2
Replaces B3-1
Sheet 11
Logo



Edition	Modification	Date	Name
1	Air flux holes	21 Jun	Holder

Tolerance ±0.1

Weight 2.37 kg

Polycarbonate (3mm thickness)

	Date	Name
Dib.	20 Jun 2020	Domenica Bonilla
Rev.	20 Nov 2020	Veronica Barona
Apro.	21 Dic 2020	Felipe Pineda

Bottom inner polycarbonate

Scale: 1:8

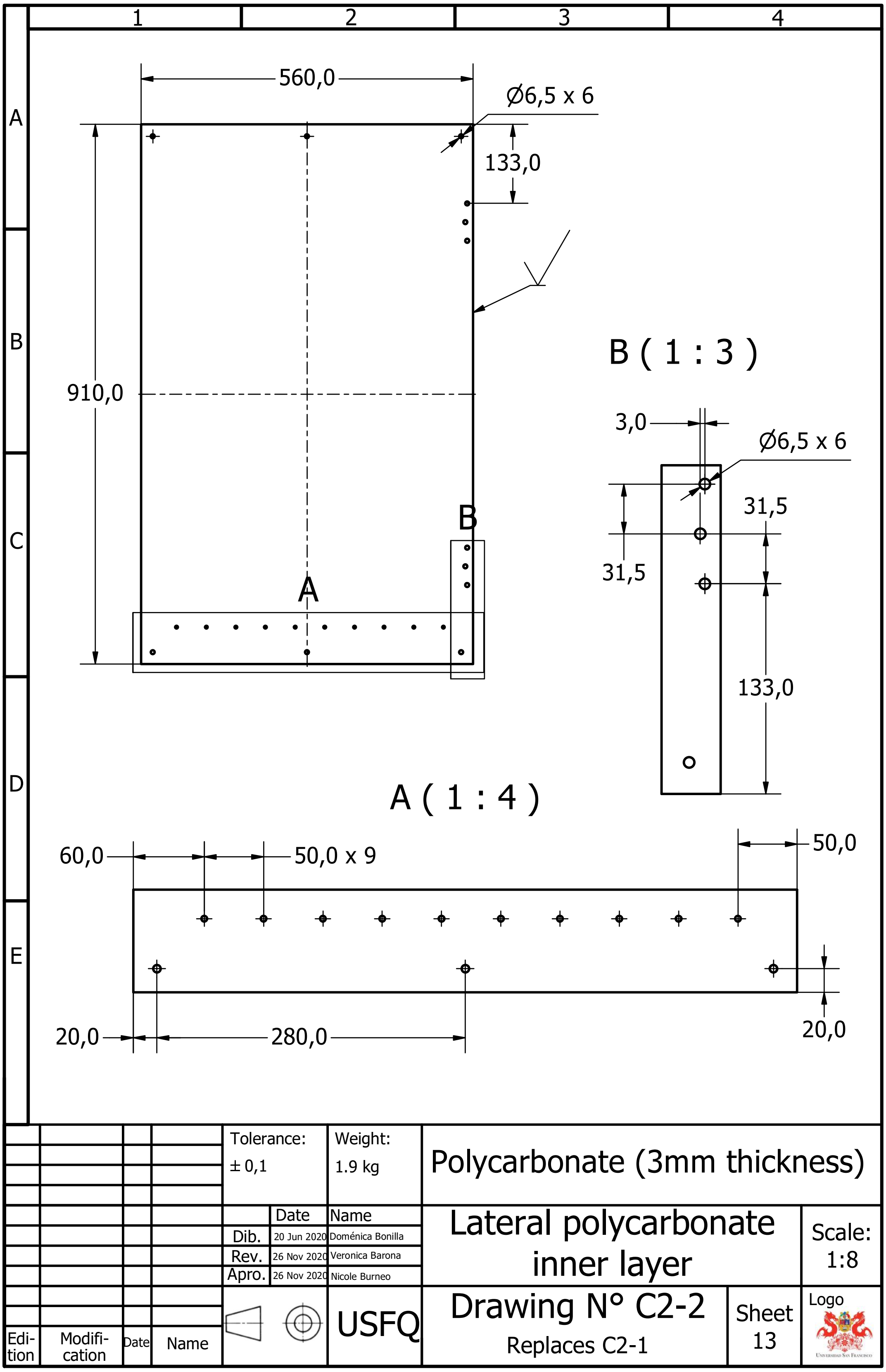
USFQ

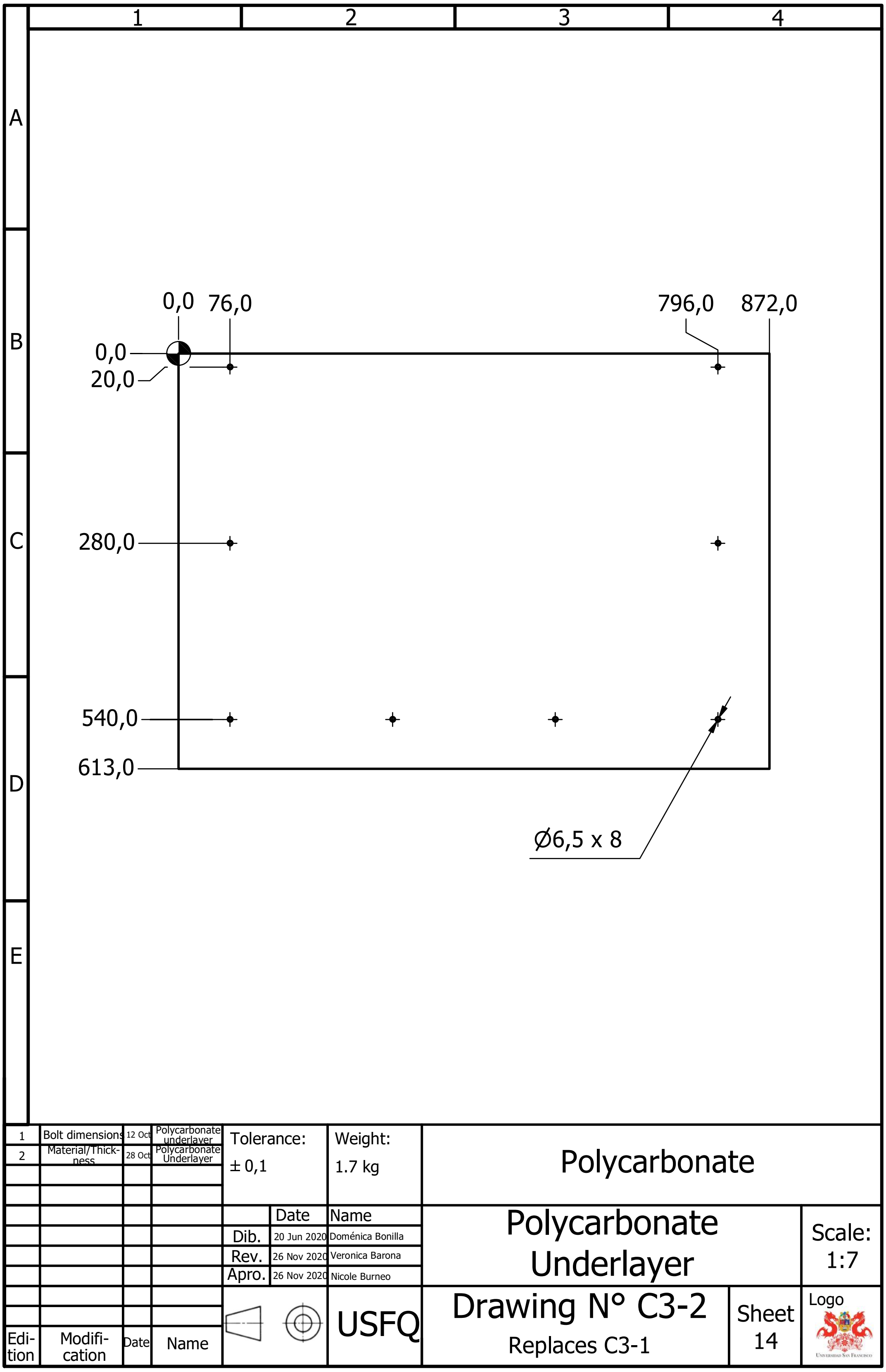
Drawing N° C1-2

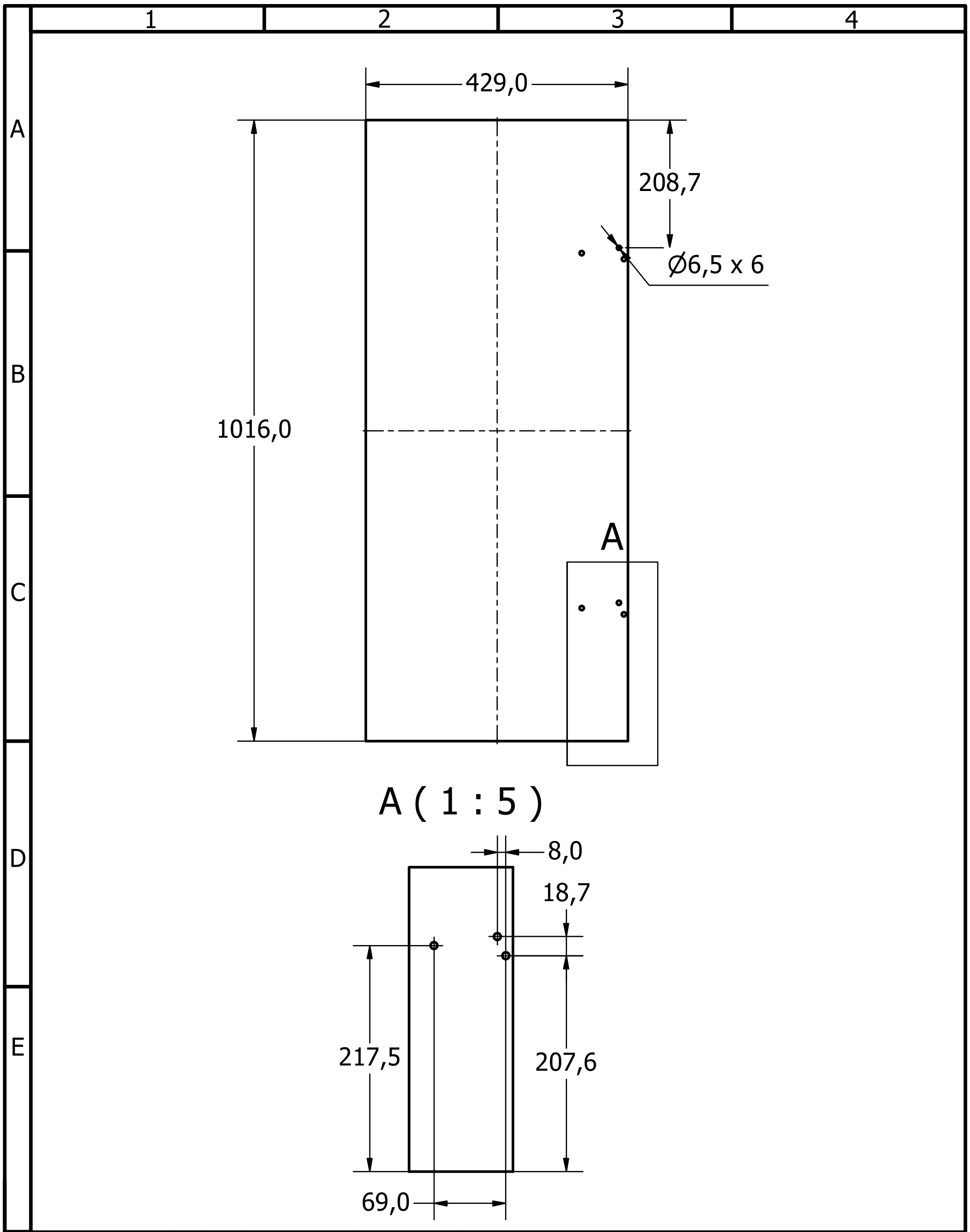
Replaces C1-1

Sheet 12

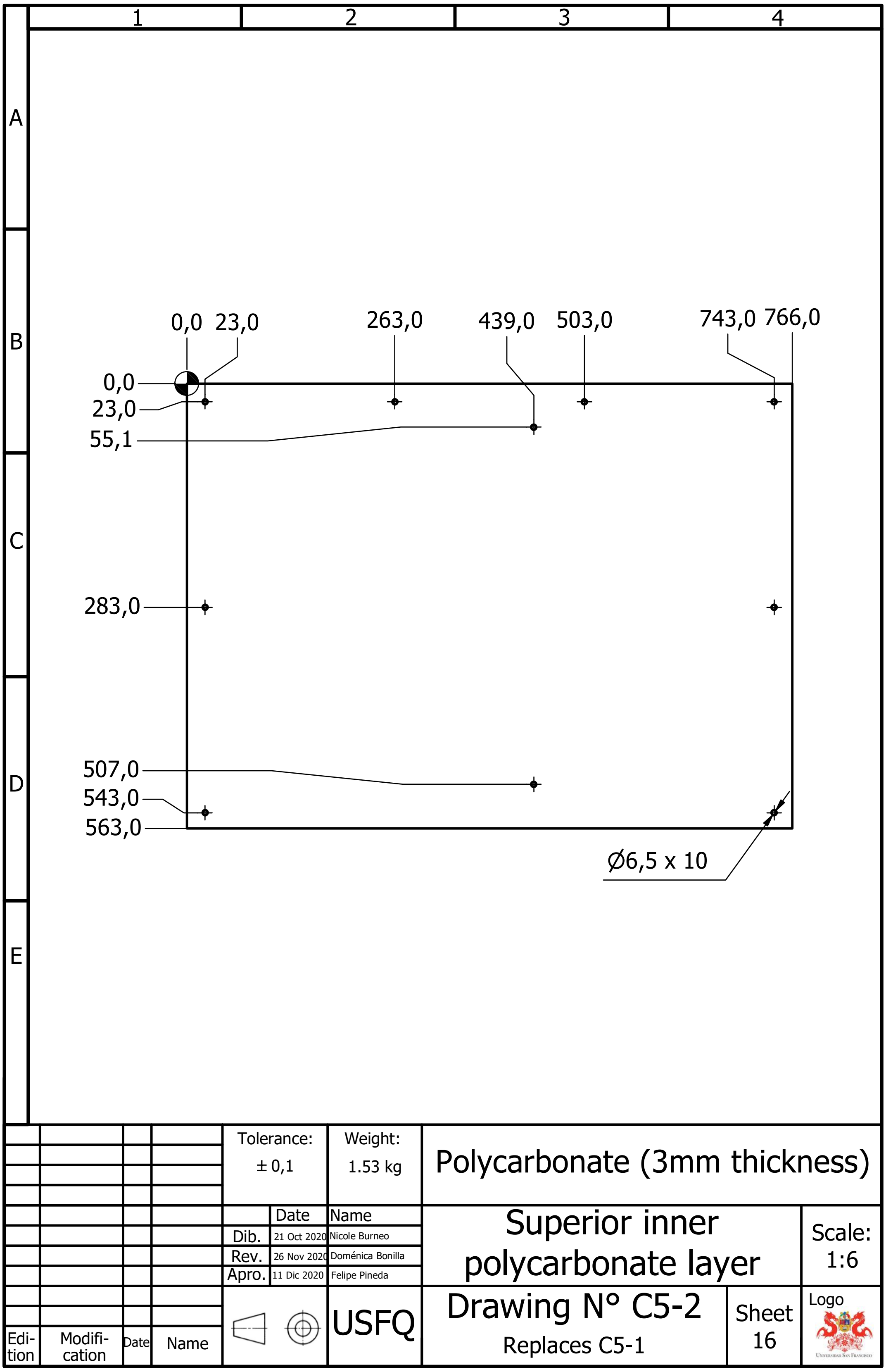
Logo


1
2
3
4
A
B
C
D
E
560,0
Ø6,5 x 6
133,0
910,0
B
A
B (1 : 3)
3,0
Ø6,5 x 6
31,5
31,5
133,0
A (1 : 4)
60,0
50,0 x 9
50,0
20,0
280,0
20,0
Tolerance:
± 0,1
Weight:
1.9 kg
Polycarbonate (3mm thickness)
Date
Name
Dib.
20 Jun 2020
Doménica Bonilla
Rev.
26 Nov 2020
Veronica Barona
Apro.
26 Nov 2020
Nicole Burneo
Lateral polycarbonate inner layer
Scale:
1:8
Edi-tion
Modifi-cation
Date
Name
USFQ
Drawing N° C2-2
Replaces C2-1
Sheet
13
Logo

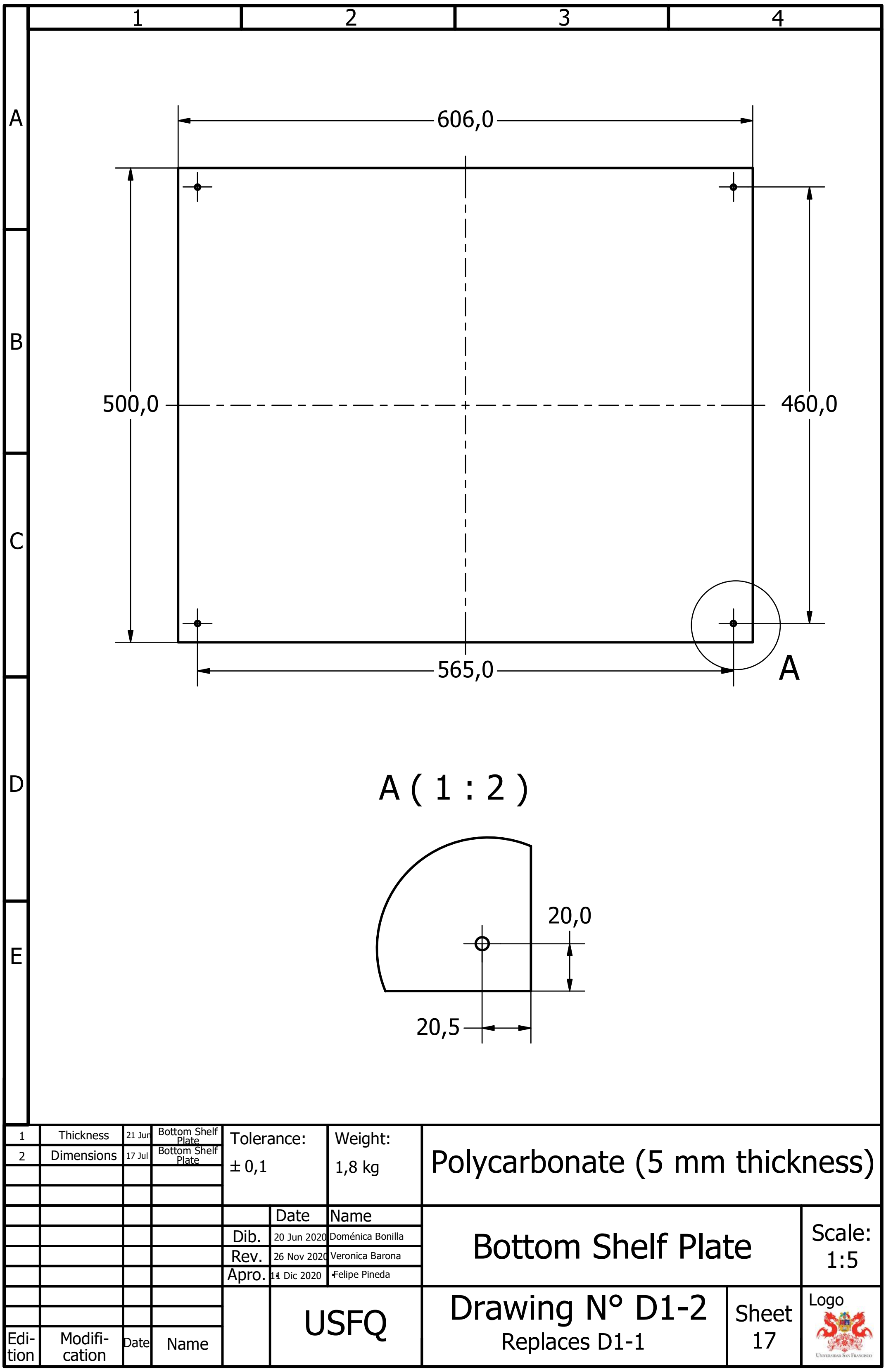

1
2
3
4
A
B
C
D
E
0,0
76,0
796,0
872,0
0,0
20,0
280,0
540,0
613,0
Ø6,5 x 8
1 Bolt dimensions 12 Oct Polycarbonate underlayer
2 Material/Thickness 28 Oct Polycarbonate Underlayer
Edition
Modification
Date
Name
Tolerance:
± 0,1
Weight:
1.7 kg
Polycarbonate
Date
Name
Dib. 20 Jun 2020 Doménica Bonilla
Rev. 26 Nov 2020 Veronica Barona
Apro. 26 Nov 2020 Nicole Burneo
Polycarbonate Underlayer
Scale:
1:7
USFQ
Drawing N° C3-2
Replaces C3-1
Sheet
14
Logo

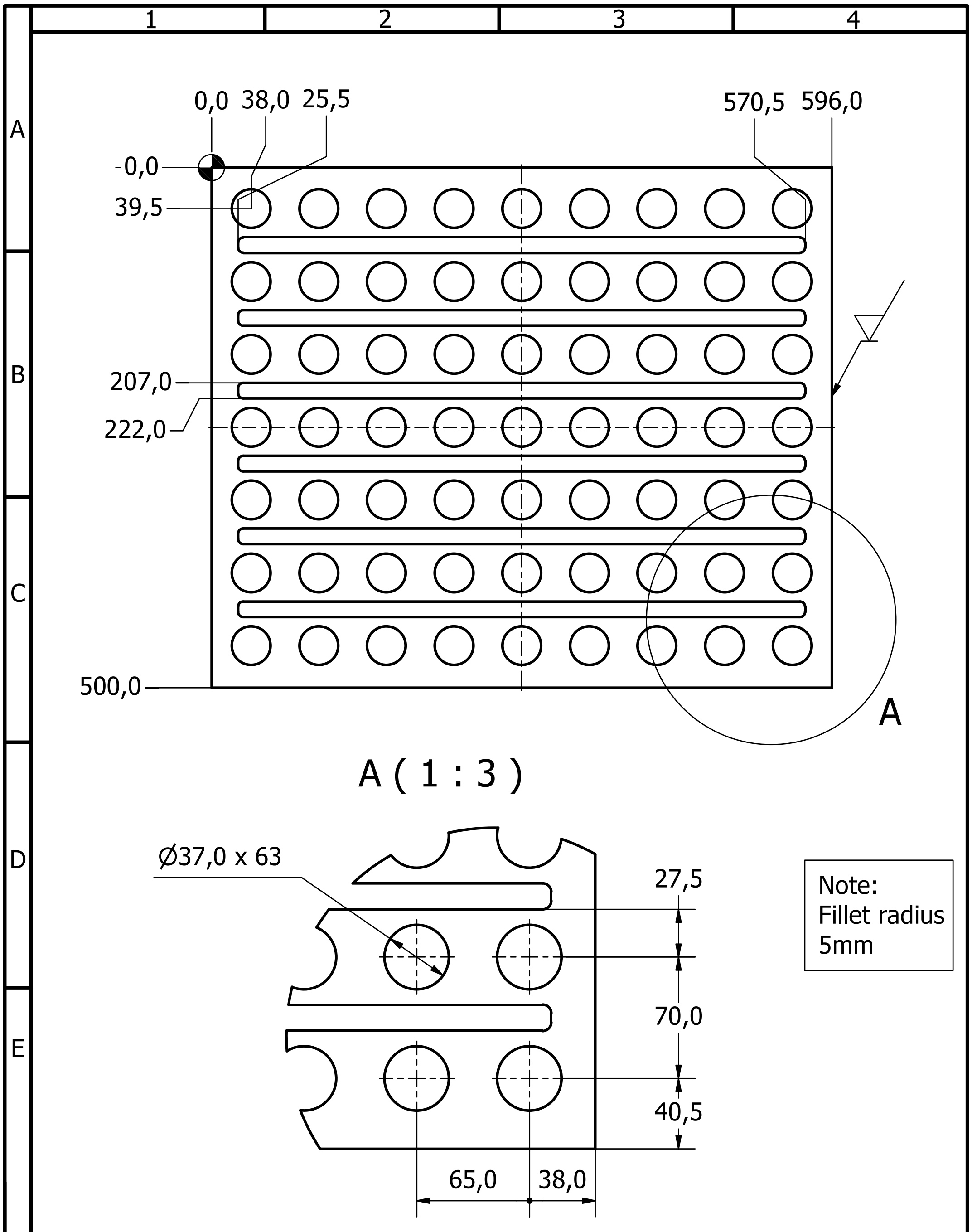


1	Air flux holes	21 Jun	Holder	Tolerance ±0.1	Weight 1.5 kg	Polycarbonate (3mm thickness)	
				Date	Name	Polycarbonate inner door	Scale: 1:9
				Dib. 20 Jun 2020	Domenica Bonilla		
				Rev. 20 Nov 2020	Veronica Barona		
				Apro.			
Edi-tion	Modifi-cation	Date	Name		USFQ	Drawing N° C4-2 Replaces C4-1	Sheet 15 / Logo

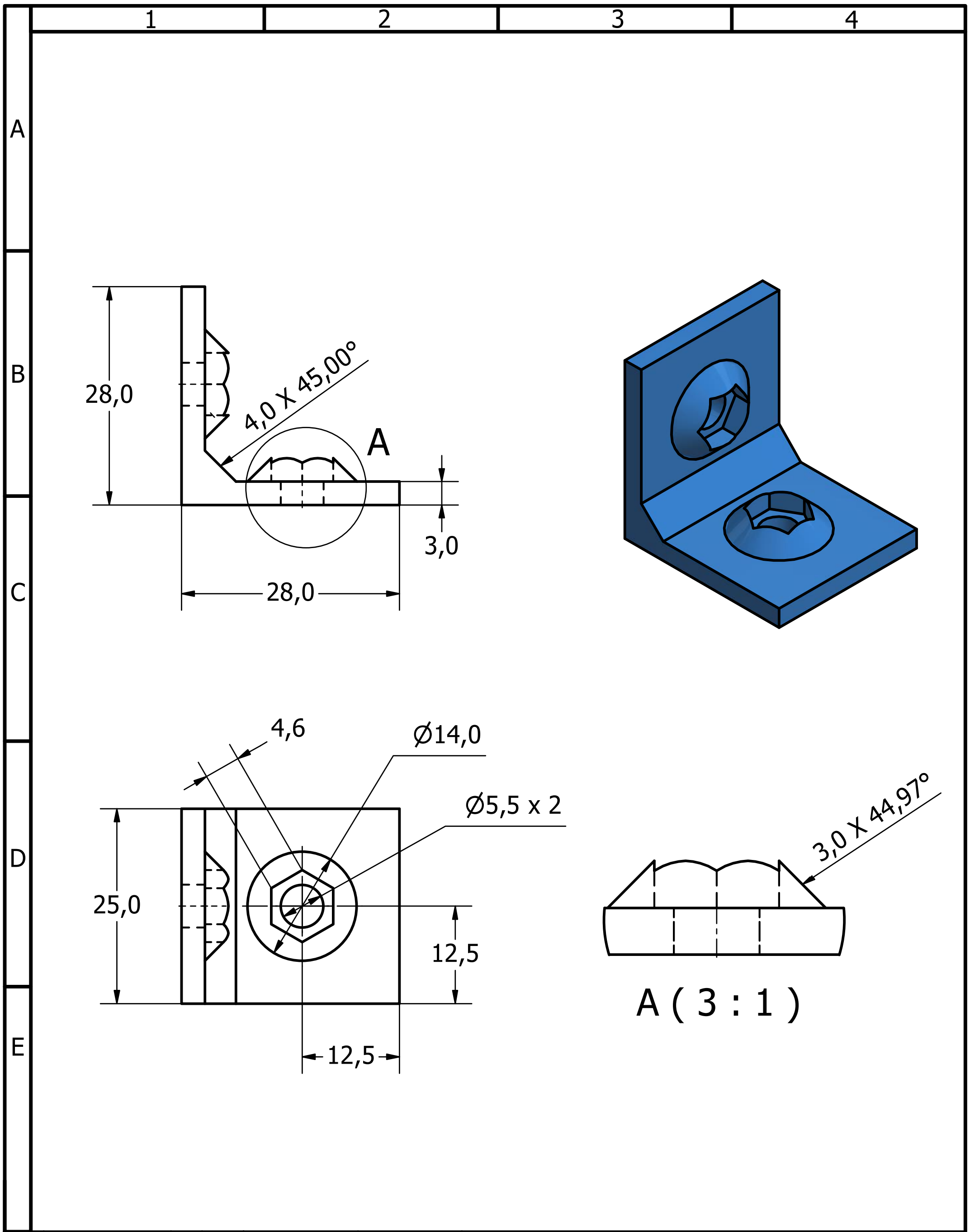

1
2
3
4
A
B
C
D
E
0,0 23,0
263,0
439,0 503,0
743,0 766,0
0,0
23,0
55,1
283,0
507,0
543,0
563,0
Ø6,5 x 10
Tolerance:
± 0,1
Weight:
1.53 kg
Polycarbonate (3mm thickness)
Date
Name
Dib. 21 Oct 2020 Nicole Burneo
Rev. 26 Nov 2020 Doménica Bonilla
Apro. 11 Dic 2020 Felipe Pineda
Superior inner polycarbonate layer
Scale: 1:6
USFQ
Drawing N° C5-2
Replaces C5-1
Sheet 16
Logo
Edi-tion
Modifi-cation
Date
Name

Shelf structure





1	Air Flux holes	21 Jun	Egg container 1	Tolerance ±0.1	Weight 1.09kg	Polycarbonate (5 mm thickness)	
2	Egg container diameter	17 Jul	Egg container 1				
3	Thickness	25 Nov	Egg container 1				
					Date	Name	Egg container 1	Scale: 1:5
				Dib.	20 Jun 2020	Domenica Bonilla		
				Rev.	20 Nov 2020	Veronica Barona		
				Apro.				
Edition	Modification	Date	Name		USFQ	Drawing N° D1-2 Replaces D2-1	Sheet 18	Logo



Edition	Modification	Date	Name
1	Bolt holes	21 Jun	Holder

Tolerance ±0.1

Weight 0.004kg

PLA

	Date	Name
Dib.	20 Jun 2020	Domenica Bonilla
Rev.	20 Nov 2020	Veronica Barona
Apro.		

Holder

Scale: 1.5:1

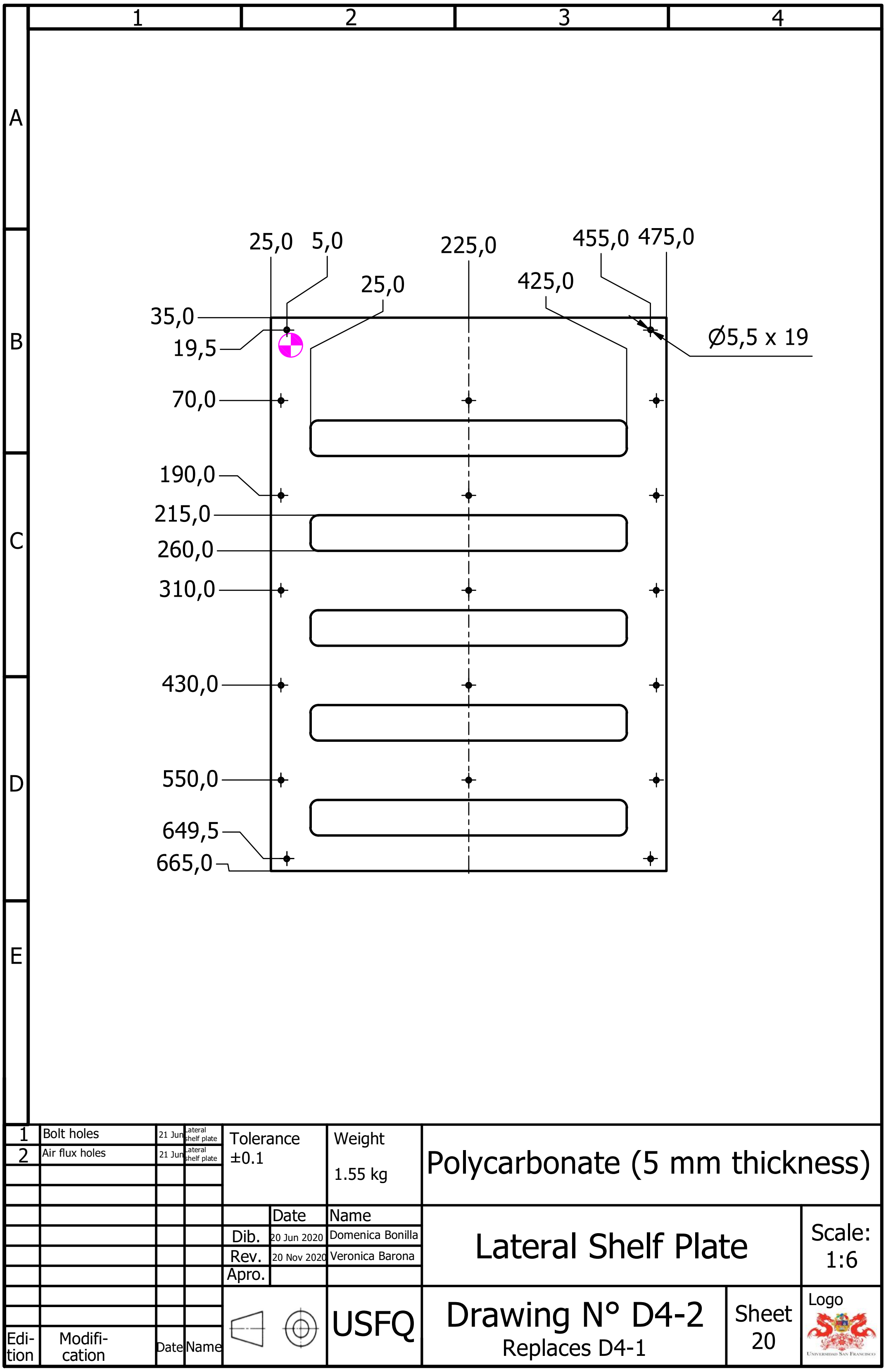
USFQ

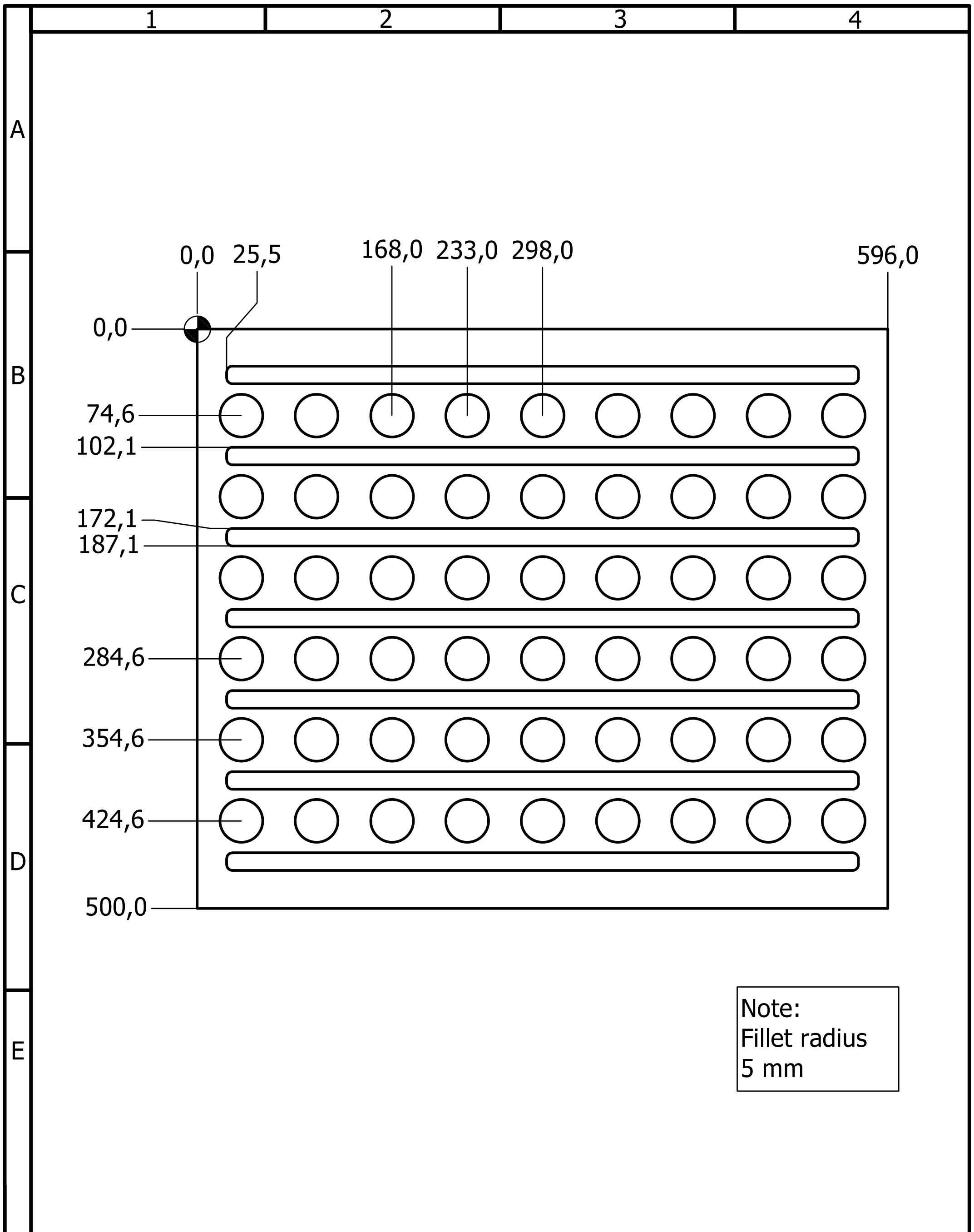
Drawing N°D3-2

Replaces D3-1

Sheet 19

Logo


1
2
3
4
A
B
C
D
E
25,0
5,0
225,0
455,0
475,0
25,0
425,0
35,0
19,5
Ø5,5 x 19
70,0
190,0
215,0
260,0
310,0
430,0
550,0
649,5
665,0
1 Bolt holes 21 Jun Lateral shelf plate
2 Air flux holes 21 Jun Lateral shelf plate
Edi-tion
Modifi-cation
Date
Name
Tolerance
±0.1
Weight
1.55 kg
Polycarbonate (5 mm thickness)
Date
Name
Dib. 20 Jun 2020 Domenica Bonilla
Rev. 20 Nov 2020 Veronica Barona
Apro.
Lateral Shelf Plate
Scale:
1:6
USFQ
Drawing N° D4-2
Replaces D4-1
Sheet
20
Logo



Edi-tion	Modifi-cation	Date	Name
1	Air Flux holes	21 Jun	Egg container 2
2	Egg container diameter	17 Jul	Egg container 2
3	Thickness	25 Nov	Egg container 2

Tolerance: ± 0,1

Weight: 1,1 kg

Polycarbonate (5 mm thickness)

	Date	Name
Dib.	20 Jun 2020	Doménica Bonilla
Rev.	26 Nov 2020	Veronica Barona
Apro.	.	.

Egg container 2

Scale: 1:5

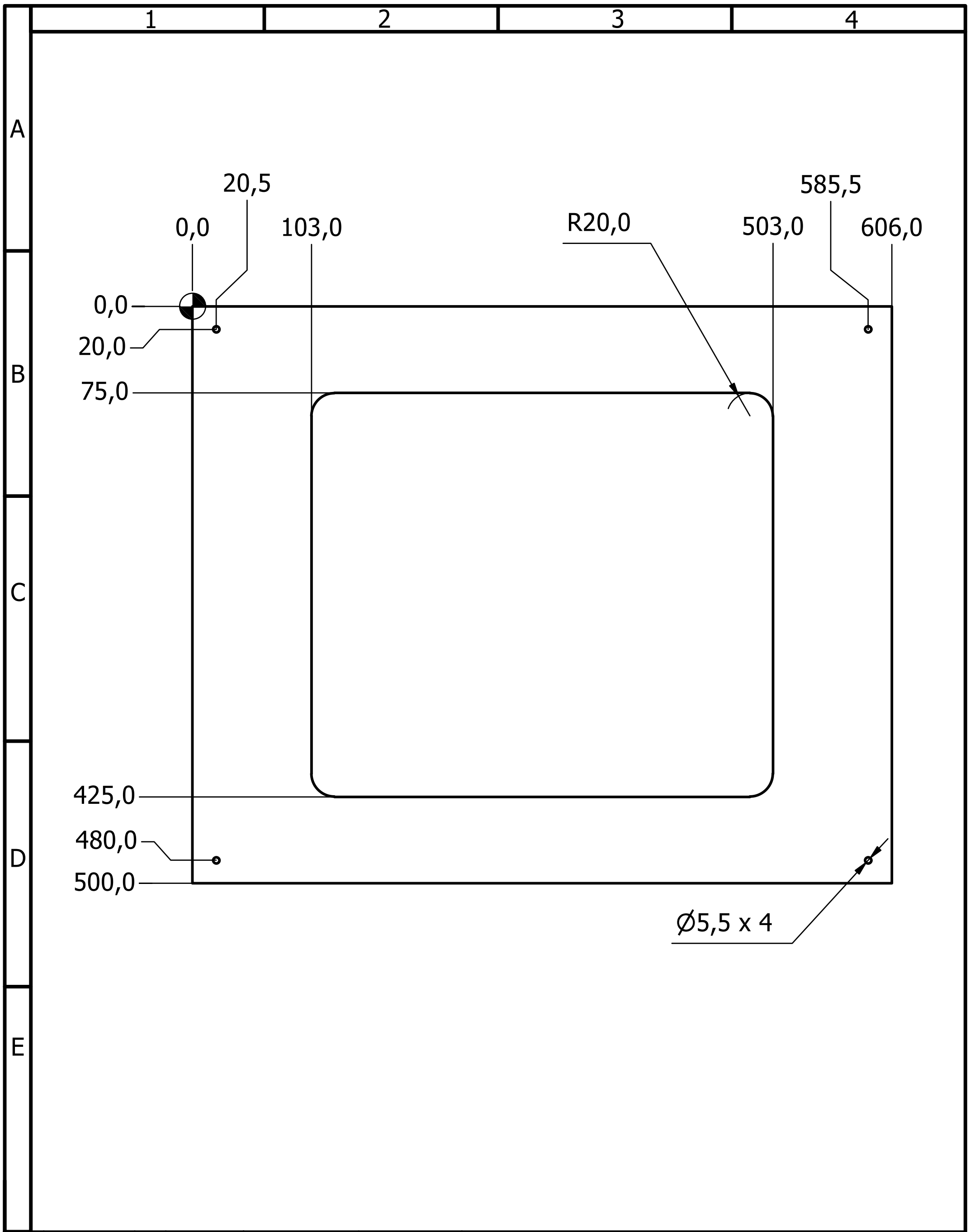
USFQ

Drawing N° D5-2

Replaces D5-1

Sheet 21

Logo



Edition	Modification	Date	Name
1	First design	20 Jun	Top shelf plate
2	Thickness	12 Ag	Top shelf plate
3	Bolt diameter	25 Nov	Top shelf plate

Tolerance: ± 0,1

Weight: 0.97 kg

Polycarbonate (5 mm thickness)

	Date	Name
Dib.	20 Jun 2020	Doménica Bonilla
Rev.	26 Nov 2020	Veronica Barona
Apro.	.	.

Top shelf Plate

Scale: 1:4,5

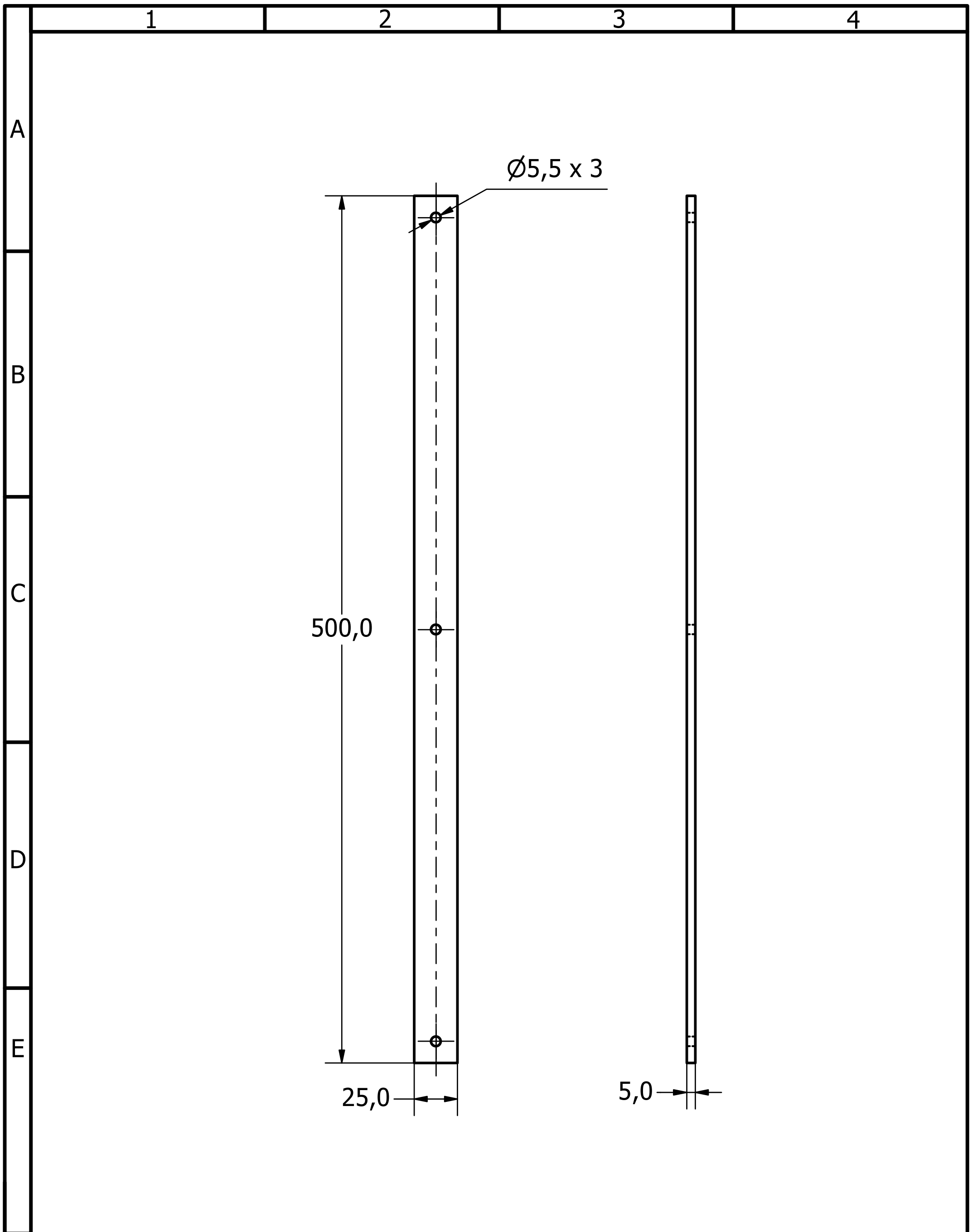
USFQ

Drawing N° D6-2

Replaces D6-1

Sheet 22

Logo



Edition	Modification	Date	Name
1	Bolt dimensions	21 Jun	Bottom Shelf Plate
2	Material/Thickness	28 Jul	Bottom Shelf Plate

Tolerance: ± 0,1

Weight: 0.07 kg

Polycarbonate (5 mm thickness)

	Date	Name
Dib.	20 Jun 2020	Doménica Bonilla
Rev.	26 Nov 2020	Veronica Barona
Apro.	.	.

Shelf Suport

Scale: 1:3

USFQ

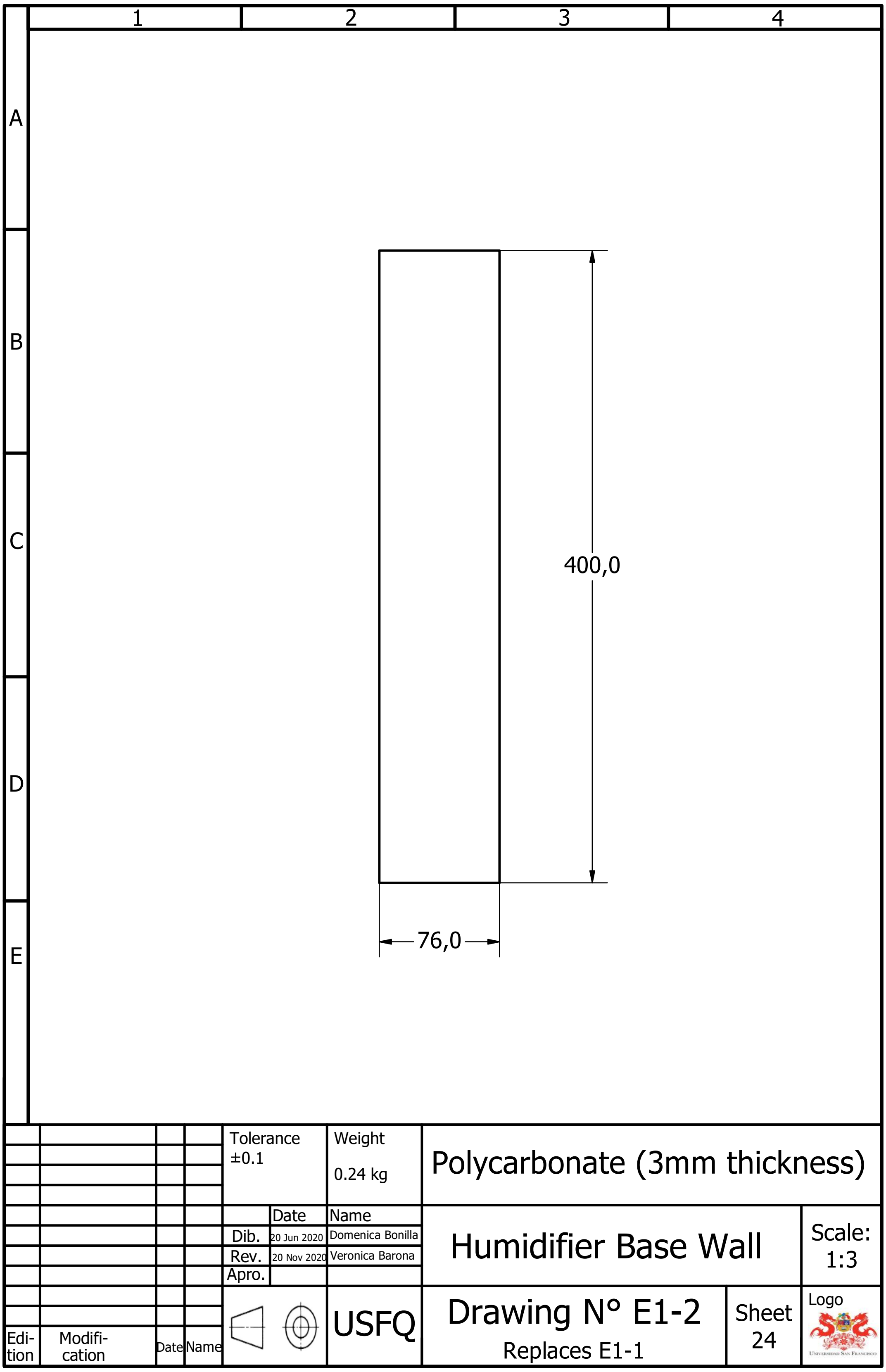
Drawing N° D7-2

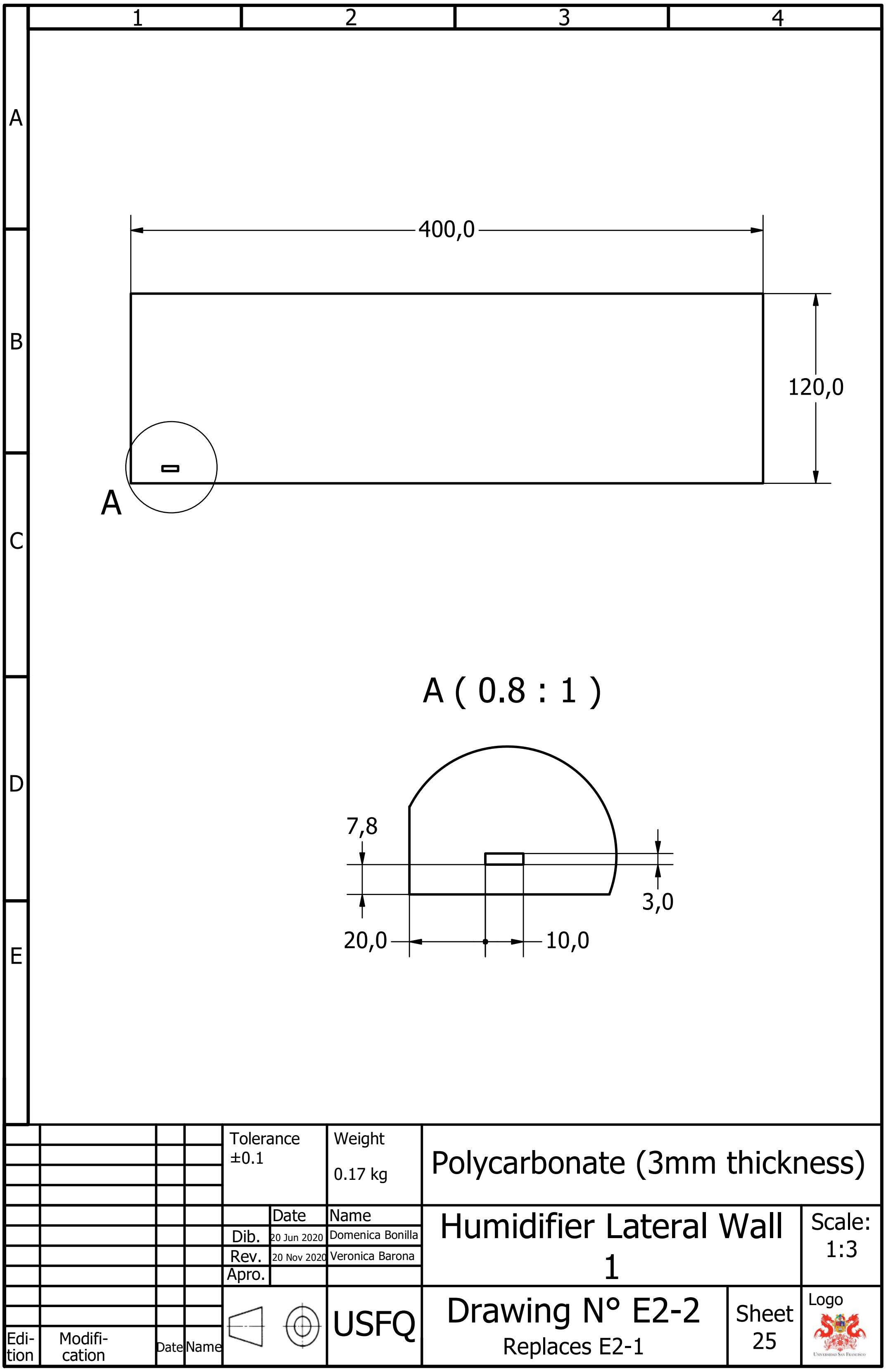
Replaces D7-1

Sheet 23

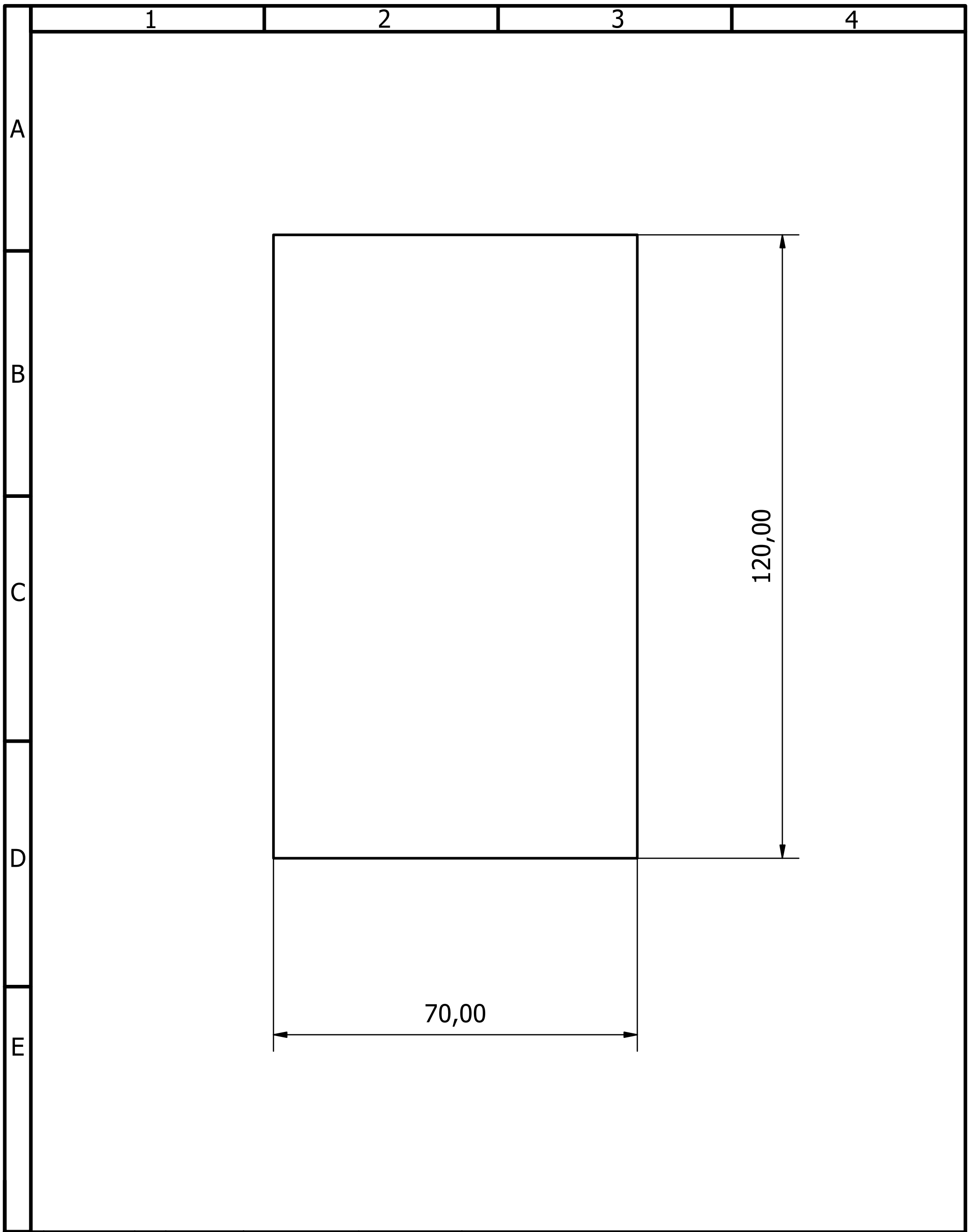
Logo

Humidifier structure





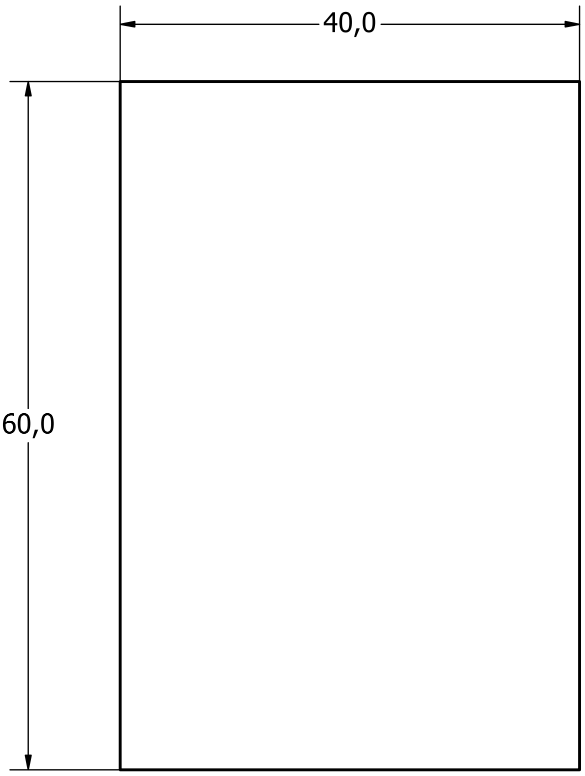
1
2
3
4
A
B
C
D
E
400,0
120,0
A
A (0.8 : 1)
7,8
3,0
20,0
10,0
Tolerance
±0.1
Weight
0.17 kg
Polycarbonate (3mm thickness)
Date
Name
Dib.
20 Jun 2020
Domenica Bonilla
Rev.
20 Nov 2020
Veronica Barona
Apro.
Humidifier Lateral Wall 1
Scale:
1:3
Edi-tion
Modifi-cation
Date
Name
USFQ
Drawing N° E2-2
Replaces E2-1
Sheet
25
Logo



Tolerance: ± 0,1	Weight: 0.03 kg	Policarbonate (3mm thickness)	
	Date / Name	Lateral humidifier layer 2	Scale: 1:1
Dib.	20 Nov 2020 / Doménica Bonilla		
Rev.	26 Nov 2020 / Veronica Barona		
Apro.	26 Nov 2020 / Nicole Burneo		
	USFQ	Drawing N° E3-2 Replaces E3-1	Sheet 26

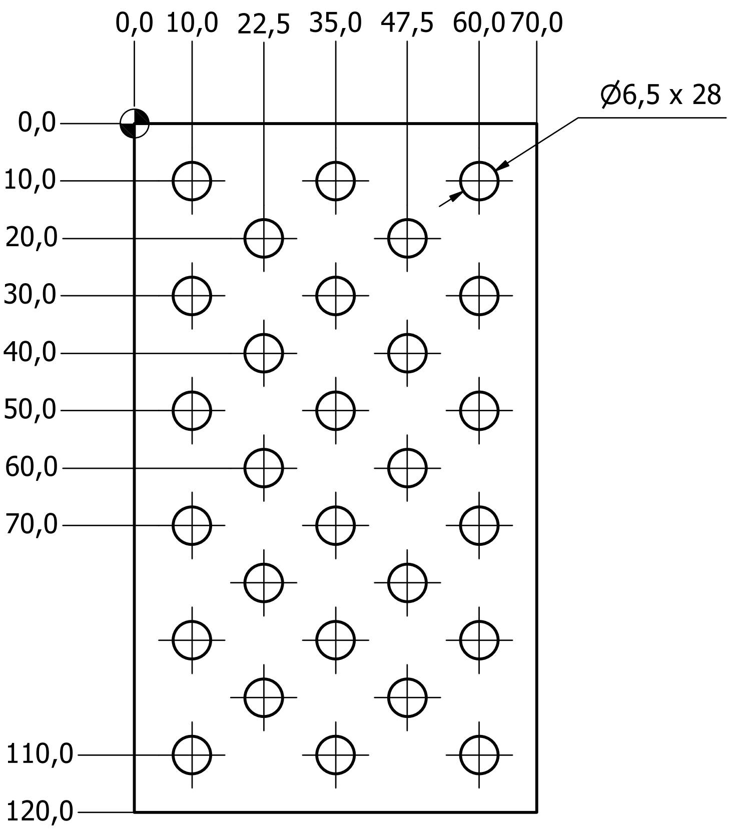
Edi-tion	Modifi-cation	Date	Name

Universidad San Francisco



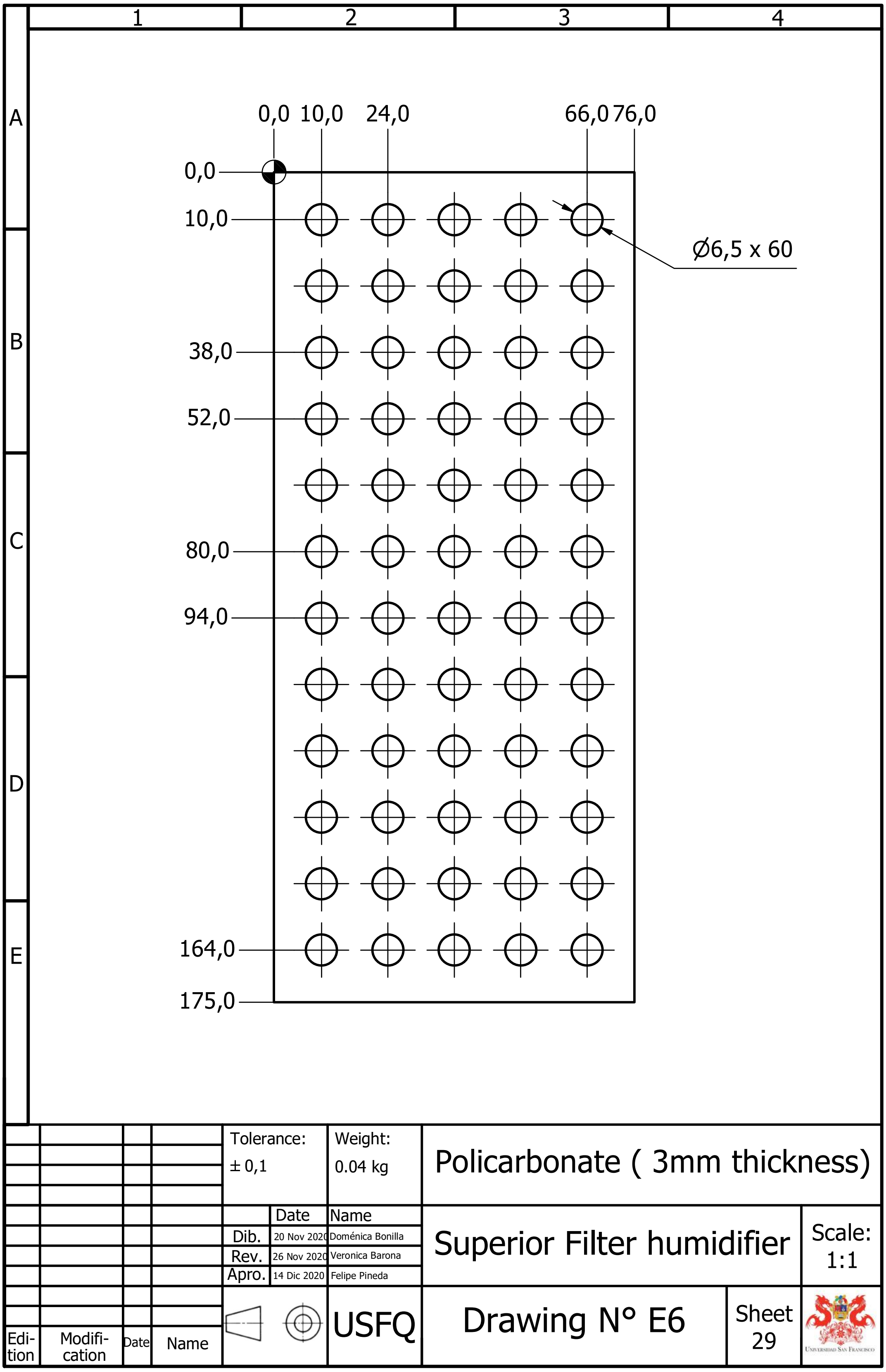
Tolerance ±0.1	Weight 0.008 kg	Aluminium (2.5 mm thickness)	
	Date	Name	Peltier aluminiun sheet	Scale: 2:1
Dib.	20 Jun 2020	Domenica Bonilla		
Rev.	20 Nov 2020	Veronica Barona		
Apro.				
	USFQ	Drawing N° E4-2 Replaces E4-1	Sheet 27	Logo

Edi-tion	Modifi-cation	Date	Name

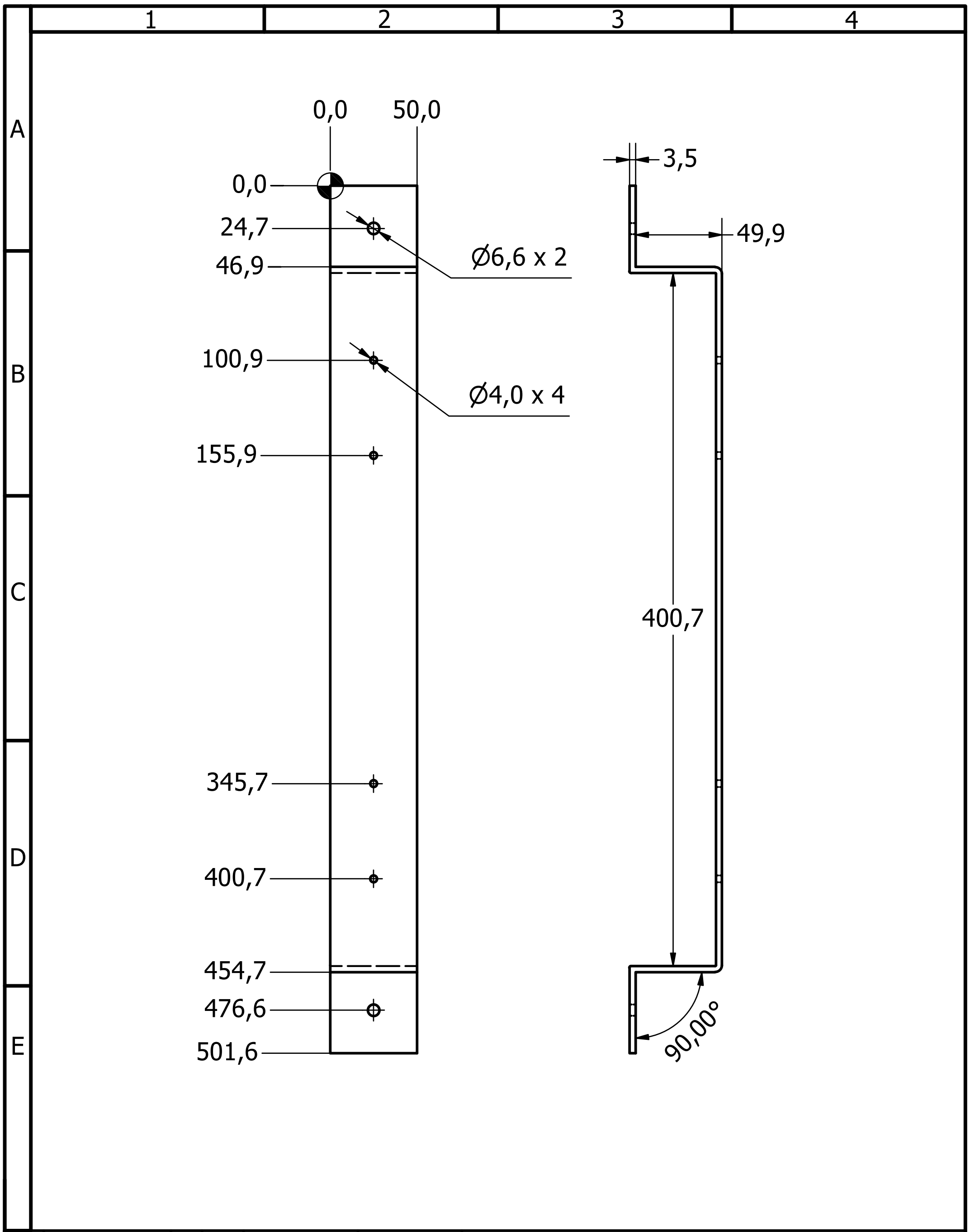


Tolerance: ± 0,1	Weight: 0.027 kg	Policarbonate (3mm thickness)			
	Date	Name	Filter humidifier		Scale: 1:1
Dib.	20 Nov 2020	Doménica Bonilla			
Rev.	26 Nov 2020	Veronica Barona			
Apro.	14 Dic 2020	Felipe Pineda			
		USFQ	Drawing N° E5	Sheet 28	

Edi-tion	Modifi-cation	Date	Name


1
2
3
4
A
B
C
D
E
0,0
10,0
24,0
66,0
76,0
0,0
10,0
38,0
52,0
80,0
94,0
164,0
175,0
Ø6,5 x 60
Tolerance:
± 0,1
Weight:
0.04 kg
Policarbonate (3mm thickness)
Date
Name
Dib.
20 Nov 2020
Doménica Bonilla
Rev.
26 Nov 2020
Veronica Barona
Apro.
14 Dic 2020
Felipe Pineda
Superior Filter humidifier
Scale:
1:1
Edi-
tion
Modifi-
cation
Date
Name
USFQ
Drawing N° E6
Sheet
29

Ceramic bulbs structure



Tolerance ±0.1	Weight 0.83 kg	Stainless Steel (3.5 mm thickness)				
	Date	Name	Lightbulb Socket Holder		Scale: 1:3	
Dib.	20 Jun 2020	Domenica Bonilla				
Rev.	20 Nov 2020	Veronica Barona				
Apro.						
Edi-tion	Modifi-cation	Date	Name	USFQ	Drawing N° F1-2 Replaces F1-1	Sheet 30	Logo

Detailed calculations

Subsystem components selection was carried out by implementing selection matrices method. Detailed process is described on materials and methods section and considered elements are presented.

Heating System

Heating system selection

Solutions
Solution A: Kit Fan + Resistance
Solución B: Ceramic Bulbs
Solución C: 3D printing warming beds

Selection criteria
a) Temperature control
b) Power consumption
c) Price
d) Conection
e) Acquisition

1.- Evaluation of each criterion weight

temperature control> power consumption >acquisition>price>conection

Criteron	Temperature control	Power consumption	Acquisition	Price	Conection	S+1	Weighted value
Temperature control		1	1	1	1	5	0.333333
Power consumption	0		1	1	1	4	0.266667
Acquisition	0	0		1	1	3	0.2
Price	0	0	0		1	2	0.133333
Conection	0	0	0	0		1	0.066667
					Suma	15	1

Evaluation of specific weight for each solution criteron

2.-Evaluation of speficic weight for temperature control criteron kit fan + resistance > ceramic bulbs > 3D printing warming beds

Criteron	A Solution	B Solution	C Solution	S+1	Weighted value
A Solution		1	1	3	0.5
B Solution	0		1	2	0.33333333
C Solution	0	0		1	0.16666667
			Sum	6	1

3.-Evaluation of speficic weight for power consumption criteron

ceramic bulbs> kit fan + resistance > 3D printing warming beds

Criteron	A Solution	B Solution	C Solution	S+1	Weighted value
A Solution		0	1	2	0.33333333
B Solution	1		1	3	0.5
C Solution	0	0		1	0.16666667
			Suma	6	1

4.-Evaluation of speficic weight for price criteron

ceramic bulbs > kit fan + resistance > 3D printing warming beds

Criteron	A Solution	B Solution	C Solution	S+1	Weighted value
A Solution		0	1	2	0.33333333
B Solution	1		1	3	0.5
C Solution	0	0		1	0.16666667
			Suma	6	1

5.-Evaluation of speficic weight for conection criteron

ceramic bulbs > kit fan + resistance > 3D printing warming beds

Criteron	A Solution	B Solution	C Solution	S+1	Weighted value
A Solution		0	1	2	0.33333333
B Solution	1		1	3	0.5
C Solution	0	0		1	0.16666667
			Suma	6	1

5.-Evaluation of speficic weight for Adquisition criteron ceramic bulbs = kit fan + resistance > 3D printing warming beds

Criteron	A Solution	B Solution	C Solution	S+1	Weighted value
A Solution		0.5	1	2.5	0.41666667
B Solution	0.5		1	2.5	0.41666667
C Solution	0	0		1	0.16666667
			Suma	6	1

Table A1 Heating system matrix selection options

Option	Heating system	Sketch - photo	Power	Price	Volume [m3]	EASE OF ACCESS	Facts
1	Fan and resistance kit		60W 2m 230Vac 45W 1,5m 230Vac 75W 2,5m 230Vac 90W 3m 230Vac 105W 3,5m 230Vac 120W 4m 230Vac 135W 4,5m 230Vac 150W 5m 230Vac	\$56 - \$100 Depends on power and size	80x80x25mm Bolas 92x92x25mm Bolas 120x120x25mm Bolas 150x150x50mm Bolas 200x200x60mm Bolas	ELEKTROPUNTO ESPAÑA - AMAZON -EBAY	Good temperature control and distribution
2	Black light lamp		25 - 150 W	\$ 5 - \$20 Depends on the power (Does not include shipping)	0.000213	ESPAÑA – Ebay - Amazon	Temperature control difficulty. Excellent for keeping eggs warm
3	3D printer warming beds		90 W	\$40 - \$70 Depends on the brand	0.00009252	Mercado libre Ec	Difficulty in temperature control and connection

Humidification System

Solutions
A Solution: kit
B Solution: Ultrasonic
C Solution: for incubator

Selection criteria
a) Price
b) Weight
c) Dimensions
d) Power Consumption

1.- Evaluation of each criterion weight

dimensions > power consumption > price > weight

Criteron	Price	Weight	Dimensions	Power Consump	S+1	Weighted
Price		1	0	0	2	0.2
Weight	0		0	0	1	0.1
Dimension	1	1		1	4	0.4
Power Consumption	1	1	0		3	0.3
				Sum	10	1

2.-Evaluation of speficic weight for Price criteron

incubator> kit> ultrasonic	

Criteron	A Solutio	B Solution	C Solution	S+1	Weighted value
A Solution		0	1	2	0.33333
B Solution	0		0	1	0.16667
C Solution	1	1		3	0.5
			Sum	6	1

3.-Evaluation of speficic weight for Weight criteron

incubator= kit> ultrasonic	

Criteron	A Solutio	B Solution	C Solution	S+1	Weighted value
A Solution		1	0.5	2.5	0.41667
B Solution	0		0	1	0.16667
C Solution	0.5	1		2.5	0.41667
			Sum	6	1

4.-Evaluation of speficic weight for Dimensions criteron

incubator > kit > ultrasonic

Criteron	A Solutio	B Solution	C Solution	S+1	Weighted value
A Solution		1	0	2	0.33333
B Solution	0		0	1	0.16667
C Solution	1	1		3	0.5
			Sum	6	1

5.-Evaluacion del peso especifico del criterio **Consumo energetico**

incubator = kit > ultrasonic

Criteron	A Solutio	B Solution	C Solution	S+1	Weighted value
A Solution		1	0.5	2.5	0.41667
B Solution	0		0	1	0.16667
C Solution	0.5	1		2.5	0.41667
			Sum	6	1

Table A2 Humidity control system matrix selection options

Humidifiers specs									
Option	**Component**	**Price**	**Dimensions**	**Volume**	**Weight**	**Power consumption**	**Measuring rate**	**Picture**	**Brand**
1	Humidity kit control	$53,11	70,5mmx28,5mmx51mm	102471,75	35g	10W	1%-99% (±3%) 0-50°C(0,6°C)		KITHUME DADECO
2	Ultrasonic humidifier	$24,99	76,2mmx111,76x116,84mm	995022,526	725,75 g	20W	1%-98% (±3%) 0-50°C(0,6°C)		Homedics
3	Incubator's humidifier	$14,50	51mm diameter	40,0553063	35g	10W	1%-99% (±3%) 0-50°C(0,6°C)		Tesla

External Wall

Soluciones:
A Solution: Asbestos cement
B Solution: Acrilyc
C Solution: Polycarbonate
D Solution: Stainless Steel

Selection Criteria:
a) Thermal conductivity
b) Low price
c) Density
d) Assembly

1.- Evaluation of each criterion weight

price > assembly = density > thermal conductivity

Criteron	Price	Assemb	Density	Thermal Conductivity	S+1	Weighted value
Price		1	1	1	4	0.4
Assembly	0		0.5	1	2.5	0.25
Density	0	0.5		1	2.5	0.25
Thermal Conductivity	0	0	0		1	0.1
				sum	10	1

Evaluation of specific weight for each solution criteron

2.-Evaluation of speficic weight for Thermal Conductivity criteron

Acrylic>Polycarbonate>Abestos Cement>Stainless Steel

Criteron	A Solution	B Solut	C Solution	D Solution	S+1	Weighted value
A Solution		0	0	1	2	0.2
B Solution	1		1	1	4	0.4
C Solution	1	0		1	3	0.3
D Solution	0	0	0		1	0.1
				Sum	10	1

3.-Evaluation of speficic weight for Price criteron

Asbestos Cement > Polycarbonate > Acrylic > Stailess Steel

Criteron	A Solution	B Solut	C Solution	D Solution	S+1	Weighted value
A Solution		1	1	1	4	0.4
B Solution	0		0	1	2	0.2
C Solution	0	1		1	3	0.3

4.-Evaluation of speficic weight for Density criteron

Polycarbonate>Acrylic>Asbestos Cement>StainlessSteel

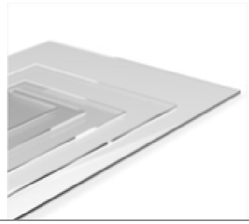
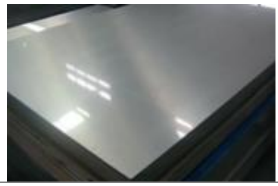
Criteron	A Solution	B Solut	C Solution	D Solution	S+1	Weighted value
A Solution		0	0	1	2	0.2
B Solution	1		0	1	3	0.3
C Solution	1	1		1	4	0.4
D Solution	0	0	0		1	0.1
				Suma	10	1

5.-Evaluation of speficic weight for Assembly criteron

Polycarbonate=Acrylic=StainlessSteel>AsbestosCement

Criteron	A Solution	B Solut	C Solution	D Solution	S+1	Weighted value
A Solution		0	0	0	1	0.1
B Solution	1		0.5	0.5	3	0.3
C Solution	1	0.5		0.5	3	0.3
D Solution	1	0.5	0.5		3	0.3
				Suma	10	1

Table A3 External wall material matrix selection options

Option	External material	Picture	Thermal conductivity	Price	Price / Volume [$/m3]	Density	Quotation place	Assembly / Machining
1	Asbestos Cement		0.23 W/m K	$17.71 Thickness: 8 mm Dimensions: 1.22 x 2.44	743.67	1.25 g/cm3 - 1250 kg / m3	PROMAC	Fiberglass tape + screws. Steel profiles required for the structure. No accurate cut.
2	Acrylic		0.18 W/m K	$77.25 Thickness: 3 mm Dimensions: 1.20 x 2.80	7663.69	1190 kg / m3	ACRILUX	Laser cut required
3	Polycarbonate		0.20 W/m K	$266.58 Thickness: 3 mm Dimensions: 5.80 x 2.05	7473.51	1200 kg / m3	ACIMCO	CNC cutting
4	Stainless Steel		16.3 W/m K	$80 Thickness: 2 mm Dimensions: 0.62 x 0.56	115207.37	8111 kg / m3	Marketplace	It can be cut with laser or oxy-fuel cutting.

Insulating Material

Solutions
A Solution: Polyurethane Foam
B Solution: Fiberglass
C Solution: Cork

Selection Criteria:
a) Thermal conductivity
b) Low price
c) Density
d) Assembly

1.- Evaluation of each criterion weight

thermal conductivity > price > assembly = density

Criteron	Price	Assembly	Density	Thermal Conductivity	S+1	Weighted value
Price		1	1	0	3	0.3
Assembly	0		0.5	0	1.5	0.15
Density	0	0.5		0	1.5	0.15
Thermal Conductivity	1	1	1		4	0.4
				Sum	10	1

Evaluation of specific weight for each solution criteron

2.-Evaluation of speficic weight for Thermal Conductivity criteron

Polyurethane Foam>Fiber glass = Cork

Criteron	A Solution	B Solution	C Solution	S+1	Weighted value
A Solution		1	1	3	0.5
B Solution	0		0.5	1.5	0.25
C Solution	0	0.5		1.5	0.25
			Sum	6	1

3.-Evaluation of speficic weight for Price criteron

Polyurethane > fiberglass > Cork

Criteron	A Solution	B Solution	C Solution	S+1	Weighted value
A Solution		1	1	3	0.5
B Solution	0		1	2	0.333
C Solution	0	0		1	0.167

4.-Evaluation of speficic weight for Density criteron

Polyurethane > fiberglass > Cork

Criteron	A Solution	B Solution	C Solution	S+1	Weighted value
A Solution		1	1	3	0.5
B Solution	0		1	2	0.333
C Solution	0	0		1	0.167
			Sum	6	1

5.-Evaluation of speficic weight for Assembly criteron

Polyurethane foam > cork > fiberglass

Criteron	A Solution	B Solution	C Solution	S+1	Weighted value
A Solution		1	1	3	0.5
B Solution	0		0	1	0.167
C Solution	0	1		2	0.333
			Sum	6	1

Table A4 Insulating materials option characteristics

Option	Insulating Material	Picture	Thermal conductivity	Price	Price / Volume [$/m3]	Density	Assembly
1	Polyurethane Foam		0.026 W/ m K	$8.12	203	30 kg / m3	Spray itself over the desired surface
2	Fiberglass		0.040 W/ m K	$12.26 Thickness: 5 cm Dimensions: 1.22 x 0.61	329.48	48 kg / m3	Cut it out with stiletto
3	Cork		0.040 W/ m K	$7.50 Thickness: 5 mm Dimensions: 0.9 x 0.6 m	2777.78	240 kg / m3	Cut it out with saw or stiletto

Energy Source

Solutions
A Solution: pv paneles + batteries
B Solution: batteries
C Solution: Diesel generator

Selection Criteria
a)Price
b)Sustentability
c)Dimensions

1.- Evaluation of each criterion weight

sustentability > price > dimensions

Criterion	Price	Sustentability	Dimensions	S+1	Weighted value
Price		0	1	2	0.33333
Sustentability	1		1	3	0.5
Dimensions	0	0		1	0.16667
			Sum	6	1

2.-Evaluation of speficic weight for Price criteron

batteries > diesel generator > pv panels

Criteron	A Solutio	B Solution	C Solution	S+1	Weighted value
A Solution		0	0	1	0.16667
B Solution	1		1	3	0.5
C Solution	1	0		2	0.33333
			Sum	6	1

3.-Evaluation of speficic weight for Sustentability criteron

pv panels> disel generator > batteries

Criteron	A Solutio	B Solution	C Solution	S+1	Weighted value
A Solution		1	1	3	0.5
B Solution	0		0	1	0.16667
C Solution	0	1		2	0.33333
			Sum	6	1

4.-Evaluation of speficic weight for Dimensions criteron

batteries > pv panels = disel generator

Criteron	A Solutio	B Solution	C Solution	S+1	Weighted value
A Solution		0	0.5	1.5	0.25
B Solution	1		1	3	0.5

Table A5 Energy source option characteristics

ENERGY SOURCE						
OPTION	**Name**	**Sketch**	**Price**	**Dimensions or weight**	**Dimensions or weight**	**Extra features**
1	Solar Panels + batteries		Kit. -$999 1.- $47.50 2.- $89.99 3.-138.99 4.-209.99	Kit. -16.3x67x3.5cm 1.- 70x50x3 cm 2.-120x52x3.5 cm 3. -16.3x67x3.5cm 4.-200x100x4cm	Kit. -200W 1.- 50W 2.-100W 3.- 200W 4.-300W	no need electrical source
2	Batteries		$125	33x23.8x17.3 cm	135Ah	no need electrical source
3	Diesel Generator		$537	100kg	3.8 KWA	110/220 V

Additionally, detailed calculations that support results and discussion are presented below. For this purpose, the incubator was divided into two main concerns: structural and biological conditions.

Structural

Walls

```
"Caso Final: Policarbonato + Fibra de vidrio+Policarbonato con Ventilador Encendido"

" Uso de Focos Ceramicos: 150 W
              Ventilador 230 Vac: 120 x 120 x 38 mm
  Dimensiones incubadora: 76 x 56.3 x 91 cm
  Temperatura de Incubacion= 33 C"

"Temperatura, Presion y densidad del aire a las condiones ambientales"

    rh_amb=0.946
    T_amb=22.1
    P_o= 101.325 [kPa]
    rho_air=Density(AirH2O,T=T_amb,r=rh_amb,P=P_o)
    cp_amb=Cp(AirH2O,T=T_amb,r=rh_amb,P=P_o)
    k_amb=Conductivity(AirH2O,T=T_amb,r=rh_amb,P=P_o)
    mu_amb=Viscosity(AirH2O,T=T_amb,r=rh_amb,P=P_o)
    alpha_amb=k_amb/(rho_air*cp_amb)
    nu_amb=mu_amb/rho_air
    Pr_amb=Prandtl(Air_ha,T=T_amb,P=P_o)

"Temperatura de incuabacion"

    T_inc= 33 [C]
    rh_inc= 0.94
    dp=DewPoint(AirH2O,T=T_inc,r=rh_inc,P=P_o)
    rho_inc=Density(AirH2O,T=T_inc,r=rh_inc,P=P_o)
    cp_inc=Cp(AirH2O,T=T_inc,r=rh_inc,P=P_o)

"Volumen total incubadora"

    Vol = (0.76*0.91*0.563) [m^3]

"Tiempo en que la incubadora debe alcanzar la temperatura deseada"

    Tiempo= 5*Convert(min,s)

"Flujo de aire dado por el ventilador"

    Q_v=105.5*Convert(ft^3/min,m^3/s)

"Altura Incubadora"

    L=  0.91 [m]
```

```
"Propiedades"

    cp_air=Cp(Air_ha,T=T_amb,P=P_o)
    mu_air=Viscosity(AirH2O,T=T_inc,r=rh_inc,P=P_o)
    Pr_air=Prandtl(Air_ha,T=T_inc,P=P_o)
    k_air=Conductivity(AirH2O,T=T_inc,r=rh_inc,P=P_o)
    epsilon_poli= 0.94
    sigma=0.0000000567 [W/m^2 K^4]

" Flujo masico proporcionado por el ventilador"

    m_dot= rho_air*Q_v
    Q_dot=m_dot *(h_2-h_1)

    h_1=Enthalpy(AirH2O,T=T_amb,r=rh_amb,P=P_o)
    h_2=Enthalpy(AirH2O,T=T_inc,r=rh_inc,P=P_o)

" a) Cantidad de calor para la incubadora"

    m_air=Vol*rho_air
    Q=m_air*cp_air* 1000*(T_inc-T_amb)
    Q_dot_cont=Q/Tiempo

" b) Perdida de potencia en la incubadora"

    " Velocidad del aire en la incubadora"

    A_ventilador= (pi/4*110^2)*Convert(mm^2,m^2)
    vel_air= Q_v/A_ventilador

    " Reynolds"

    Re1= (rho_air*vel_air*L)/mu_air
    Nus_L1=0.664*Re1^(1/2)*Pr_air^(1/3)
    h_c1=(Nus_L1*k_air)/L

    T_film=(T_poli1+T_amb)/2
    mu_film=Viscosity(AirH2O,T=T_film,r=rh_inc,P=P_o)
    rho_film=Density(AirH2O,T=T_film,r=rh_amb,P=P_o)
    nu_film=mu_film/rho_film
    Pr_film=Prandtl(Air_ha,T=T_film,P=P_o)
    k_film=Conductivity(AirH2O,T=T_film,r=rh_inc,P=P_o)
    cp_film=Cp(AirH2O,T=T_film,r=rh_inc,P=P_o)
    alpha_film=k_film/(rho_film*cp_film)

    Re=(vel_air*L)/nu_film
    Nus_L=0.664*Re^(1/2)*Pr_film^(1/3)
    h_c=(Nus_L*k_film)/L


    "Radiacion"

    h_r=epsilon_poli*sigma*(T_poli+T_amb+546.3)*((T_poli+273.15)^2+(T_amb+273.15)^2)

    "Temperatura superficie capa exterior de policarbonato"

    Q_dot_perdidas1=(T_inc-T_poli1)/(((1/h_c1)+(L_gfiber/k_gfiber)+(2*L_poli/k_poli))*(1/A_paredes))
    Q_dot_perdidas=(T_inc-T_poli)/(((1/h_c)+(L_gfiber/k_gfiber)+(2*L_poli/k_poli))*(1/A_paredes))
```

"Resistencias"

```
A_paredes= 3.264 [m^2]
L_poli= 3*Convert(mm,m)
L_gfiber= 50*Convert(mm,m)
k_poli= 0.20 [W/m K]
k_gfiber=0.040 [W/m K]

Q_dot_perdidas1=(T_inc-T_amb)/(((1/h_c1+L_gfiber/k_gfiber+2*L_poli/k_poli)*(1/A_paredes))+((1/(h_r*A_paredes))*(1/((h_cvo1)*(A_L1+2*A_L2))))/((1/(h_r*A_paredes))+(1/((h_cvo1)*(A_L1+2*A_L2)))))
Q_dot_perdidas=(T_inc-T_amb)/(((1/h_c+L_gfiber/k_gfiber+2*L_poli/k_poli)*(1/A_paredes))+((1/(h_r*A_paredes))*(1/((h_cvo)*(A_L1+2*A_L2))))/((1/(h_r*A_paredes))+(1/((h_cvo)*(A_L1+2*A_L2)))))
Q_dot_perdidas=(T_inc-T_supInt)/((1/h_c)*(1/A_paredes))

Q_dot_total=Q_dot+Q_dot_perdidas+Q_dot_cont
```

"Coeficiente conveccion natural externa"

```
Fluid$='Air_ha'
Call FC_plate_vertical(Fluid$, (T_amb+1), T_amb, P_o, L : h_cvo1, Nusselt_v_o1, Ra_v_o1)
Call FC_plate_vertical(Fluid$,T_poli1, T_amb, P_o, L : h_cvo, Nusselt_v_o, Ra_v_o)
```

Photovoltaic Panels

1. Determinación de la demanda de Energía		
Demanda diaria de Energía AC	307.2	Wh
Demanda diaria de Energía DC (Wh)	49.12	Wh
Pérdida del Sistema	0.3	0.2-0.3
Demanda Energía Requerida para el Sistema	**534**	**Wh/dia**

2. Selección del Inversor		
Voltaje del Inversor	12	V
Eficiencia del Inversor	0.85	
Potencia Continua	500	W

3. Dimensionamiento del Banco de Baterías		
Amperios.hora diarios	44.5	Ah
Límite de Descarga	0.7	
Diás de Autonomía	2	
Amperio.hora requeridos por la batería	127.1	Ah
Capacidad de la Batería Seleccionada	33	Ah
Voltaje del la Batería Seleccionada	12	V
Eficiencia de la Batería	0.9	
Número de Baterías en Paralelo	4	
Número de Baterías en Serie	1	

Total de Baterías	**4**	

4. Dimensionamiento del Arreglo de Paneles		
Energía de salida Requerida para el Arreglo	593.0	Wh/dia
Voltaje máximo STC Panel	15.3	V
Potencia STC Panel	100	W
Factor de Perdidas	0.9	
Potencia Corregida Panel	90	
Horas Pico de Sol	4.731	
DF	0.9	
Energía de salida del Panel	383.2	Wh/dia
Número de Paneles necesarios	**2**	
Número de Paneles en Serie	1	
Número de Paneles en Paralelo	2	

5. Dimensionamiento del Controlador		
Corriente de Corto Circuito Panel	5.99	A
Corriente de Corto Circuito Arreglo	15	A
Corriente del Controlador	**80**	**A**

Biological Conditions

Humidification / Dehumidification System

```
"Plate condensation"
"vertical plate"
Fluid$='Water'
P=101.325 [kPa]
T_inc=(33+273.15)[K]
rh_inc=0.94

T_w=dewpoint(AirH2O,T=T_inc,r=rh_inc,P=P)
T_sat=T_sat(Water,P=P)
L=0.06[m]
W=0.04[m]


Call Cond_vertical_plate(Fluid$, L, W, T_w, T_sat :h_m, Re_L, q_dot, m_dot)

"critical relativ humidity]"
rh=1
"critical volume"
V=0.389 [m^3]

"Properties/constants"
R=0.4615[kPa*m^3/(kg*K)]
P_g=Pressure(Water,T=T_inc,x=1)

"Resolution"
```

```
rh=P_v/P_g
m_v=(P_g*V)/(R*T_inc)

"mass that represents de 6% to be condensated"
m_6=m_v*0.06

"Time thar requires to condensate 6% of humidity"
t=m_6/m_dot
```

APPENDIX B

Project Management

This appendix section will present project management concerns, referring specifically to Gantt full diagram, detailed budget and expenses report.

Gantt Diagram

ITEM	DESCRIPTION	% COMPLETED	START	END	DURATION
1	**Scheduling**	**100%**	**Wed 2/9/2020**	**Thu 10/9/2020**	**8**
1.1	Member recognition meeting	100%	Wed 2/9/2020	Thu 3/9/2020	1
1.2	Requirement recopilation	100%	Tue 8/9/2020	Wed 9/9/2020	1
1.3	Member role assignation	100%	Wed 9/9/2020	Thu 10/9/2020	1
2	**Design**	**100%**	**Thu 10/9/2020**	**Sat 12/12/2020**	**93**
2.1	Initial design proposals	100%	Thu 10/9/2020	Tue 15/9/2020	5
2.2	Second design proposal	100%	Wed 16/9/2020	Sun 11/10/2020	25
2.3	Final design	100%	Sun 11/10/2020	Mon 30/11/2020	50
2.4	Calculations	100%	Mon 28/9/2020	Sat 12/12/2020	75
3	**Construction**	**35%**	**Sun 15/11/2020**	**Thu 7/1/2021**	**53**
3.1	Quotations	100%	Sun 15/11/2020	Mon 23/11/2020	8
3.2	Materials acuisition	40%	Mon 30/11/2020	Sun 20/12/2020	20
3.3	Prototype construction	0%	Mon 21/12/2020	Thu 31/12/2020	10
3.4	Plans and prototype consistency revision	0%	Mon 4/1/2021	Thu 7/1/2021	3
3.5	Prototype assembly	20%	Fri 11/12/2020	Mon 21/12/2020	10
4	**Experimentation**	**0%**	**Mon 4/1/2021**	**Sat 9/1/2021**	**5**
4.1	First prototype tests	0%	Mon 4/1/2021	Thu 7/1/2021	3
4.2	Prototype corrections	0%	Thu 7/1/2021	Sat 9/1/2021	2
5	**Portfolio**	**98%**	**Sat 3/10/2020**	**Fri 18/12/2020**	**76**
5.1	Individual plans elaboration	100%	Tue 10/11/2020	Tue 15/12/2020	35
5.2	Operations manual	100%	Fri 20/11/2020	Wed 25/11/2020	5
5.3	Assembly manual	100%	Fri 20/11/2020	Sat 28/11/2020	8
5.4	Assembly drawings elaboration	100%	Sat 28/11/2020	Thu 3/12/2020	5
5.5	Final presentation	50%	Mon 14/12/2020	Fri 18/12/2020	4
5.6	Final report	100%	Sat 3/10/2020	Wed 16/12/2020	74

Figure B1 Full Gantt diagram general work

The figure presented above contemplates all work required for the equipment design in general terms. The total time required for this project contemplates a total of 18 weeks. Detailed diagrams for calculations and assembly are presented below.

ITEM	DESCRIPTION	% COMPLETE	START	END	DURATION
1	**Structural System**	**100%**	**Mon 12/10/2020**	**Mon 7/12/2020**	**56**
1.1	Heat transfer, heat loss through walls calculation	100%	Mon 12/10/2020	Thu 22/10/2020	10
1.2	Heat transfer transcient simulation	100%	Mon 30/11/2020	Mon 7/12/2020	7
2	**Humidification / Dehumidification System**	**100%**	**Sun 1/11/2020**	**Wed 4/11/2020**	**3**
2.1	Total mass condensed in peltier, time required for dehumidification	100%	Sun 1/11/2020	Wed 4/11/2020	3
3	**Heating System**	**100%**	**Mon 5/10/2020**	**Mon 12/10/2020**	**7**
3.1	Determine critical temperature scenarios troughout incubation periods	100%	Mon 5/10/2020	Mon 12/10/2020	7
4	**Structural Egg Container System**	**100%**	**Thu 22/10/2020**	**Thu 3/12/2020**	**42**
4.1	Total deflection egg container calculus	100%	Thu 22/10/2020	Thu 29/10/2020	7
4.2	Vibration simulation	100%	Mon 30/11/2020	Thu 3/12/2020	3
5	**Photovoltaic Panels**	**100%**	**Tue 1/12/2020**	**Fri 4/12/2020**	**3**
5.1	Total power required by system calculation	100%	Tue 1/12/2020	Thu 3/12/2020	2
5.2	Amount of photovoltaic panels and betteries required calculations	100%	Wed 2/12/2020	Fri 4/12/2020	2
6	**Air flow**	**100%**	**Sun 15/11/2020**	**Sat 5/12/2020**	**20**
5.1	Simulations on air flow and determine amount of air renovation per day	100%	Sun 15/11/2020	Sat 5/12/2020	20

Figure B2 Gantt diagram for calculations and simulations

ITEM	DESCRIPTION	STORE / RESPONSIBLE	% COMPLETED	DURATION [DAYS]
1	**Material Acquisition**		**79%**	**25**
1.1	Electronics purchase	Import from US	100%	25
1.2	Bolts, nuts, hinges purchase	La casa del perno	0%	1
1.3	Structure materials purchase	ACIMCO / Mercado Libre	70%	5
1.4	Photovoltaic and batteries purchase	AlfaSolar	0%	5
2	**Manufacture**		**14%**	**8**
2.1	CNC Cutting Polycarbonate	ACIMCO	70%	2
2.2	3D printing	USFQ	40%	2
2.3	CNC Milling		0%	6
2.4	Utility knife cut	Felipe Pineda	0%	
2.5	Saw cutting		0%	6
3	**Construction**		**0%**	**10**
3.1	Electronic assembly	Group Members	0%	10
3.2	Walls paste / assembly	Group Members	0%	7
3.3	Incubator structure assembly	Group Members	0%	9
3.4	PV Panels structure assembly	Group Members	0%	4
4	**Experimentation**		**0%**	**7**
4.1	Functionality tests	Group Members	0%	7
4.2	Assembly corrections	Group Members	0%	7
5	**Storage for transportation**		**0%**	**6**
5.1	Disassembly	Group Members	0%	2
5.2	Packaging	Group Members	0%	4

Figure B 3Gantt diagram for assembly / construction

From figure B2 it can be concluded that the calculation and simulation process took a total of 10 weeks. In contrast, Figure B3 presents the expected chores in terms of assembly and construction. It can be determined that a total of 7 weeks are required for this task. It is expected, according to the general Gantt diagram that the incubator will be ready for January 10, 2021.

Budget

This section presents a detailed budget for the components and manufacturing costs. It is important to stand out that labor force costs are included, since the group members are expected to do this task.

ITEM	DESCRIPTION	UNIT PRICE	QUANTITY	TOTAL	WEIGHTED VALUE
1.1	Dehumidifier (Peltier 12706 + Fan + heat sink)	$ 19.99	1	$ 19.99	1.1%
1.2	Temperature controller + sensor	$ 29.99	1	$ 29.99	1.6%
1.3	Humidifier / Dehumidifier controller + sensor	$ 41.99	1	$ 41.99	2.2%
1.4	Ceramic Bulbs	$ 13.99	1	$ 13.99	0.7%
1.6	Humidifier	$ 22.00	1	$ 22.00	1.2%
1.7	Ceramic Bulbs socket	$ 0.50	2	$ 1.00	0.1%
1	ELECTRONICS			$ 128.96	6.8%
2.1	Bolt M5x16	$ 0.07	16	$ 1.12	0.1%
2.2	Bolt M5x20	$ 0.08	30	$ 2.40	0.1%
2.3	Bolt M6x70	$ 0.25	66	$ 16.50	0.9%
2.4	Nut M5	$ 0.06	46	$ 2.76	0.1%
2.5	Nut M6	$ 0.07	66	$ 4.62	0.2%
2.7	Washer M5	$ 0.03	76	$ 2.28	0.1%
2.8	Washer M6	$ 0.02	66	$ 1.32	0.1%
2.9	Stainless Steel Hinges	$ 8.00	4	$ 32.00	1.7%
2.10	Extra bolts, nuts and washers	$ 6.00	1	$ 6.00	0.3%
2	SUBJECTION ELEMENTS			$ 69.00	3.6%
3.1	Egg holder (5mm thickness)	$ 70.00	2	$ 140.00	7.4%
3.2	Walls structure, water holder (3mm thickness)	$ 267.00	1	$ 267.00	14.1%
3	POLYCARBONATE			$ 407.00	21.5%
4.1	Fiberglass (50 mm thickness)	$ 72.50	1	$ 72.50	3.8%
4	FIBERGLASS			$ 72.50	3.8%
5.1	Manufacturing expenses	$ 116.45	3	$ 349.35	18.5%
5	MANUFACTURE			$ 349.35	18.5%
6.1	Printing service	$ 39.00	1	$ 39.00	2.1%
6.2	Material	$ 4.55	1	$ 4.55	0.2%
6	3D PRINTING			$ 43.55	2.3%
7.1	Cables	$ 40.00	1	$ 40.00	2.1%
7	CABLES			$ 40.00	2.1%
8.1	Panels	$ 156.80	2	$ 313.60	16.6%
8.2	Batteries	$ 115.00	3	$ 345.00	18.2%
8.3	Structure	$ 114.90	1	$ 114.90	6.1%
8	PHOTOVOLTAIC PANELS			$ 773.50	40.9%
9.1	Loctite sealant	$ 3.57	1	$ 3.57	0.2%
9.2	Loctite heat silicon	$ 4.93	1	$ 4.93	0.3%
9	EXTRA			$ 8.50	0.4%
			TOTAL	**$ 1,892.36**	

Figure B4 Detailed Budget incubator assembly and construction

Following budget presented in Figure B4 and procedures to access funding from Mechanical Engineering Department (MED) and Tiputini Biodiverse Station (TBS), expenses at the moment correspond to the following:

Table B1 Current expenditures by budget precedence

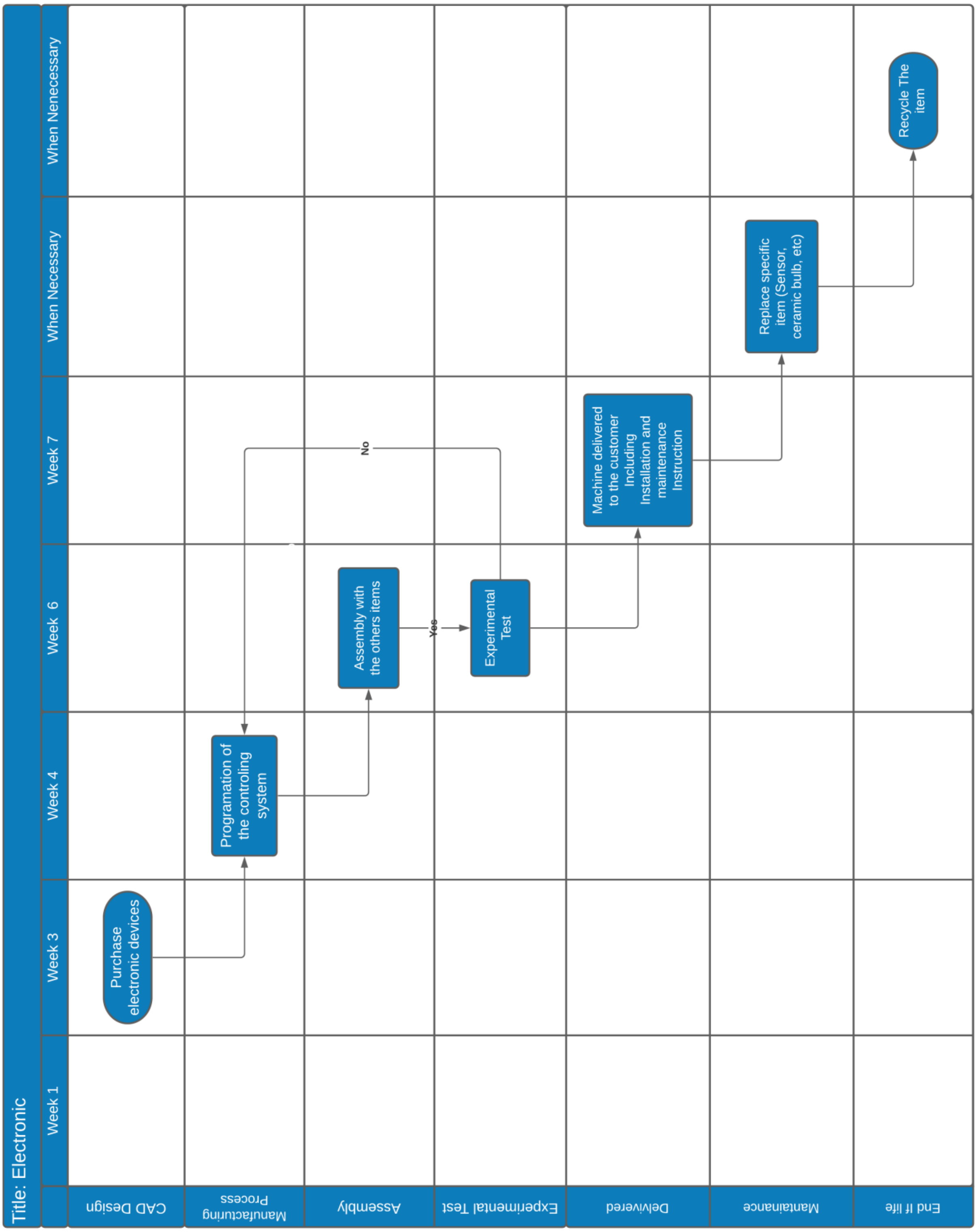
Item	Warehouse	Price	Payment Responsible
Polycarbonate 3 mm thickness	ACIMCO	$ 266.58	MED
Polycarbonate CNC cutting	ACIMCO	$	MED
Ceramic Bulbs	Amazon	$ 27.98	TBS
Temperature controller + thermostat	Inkbird (Amazon)	$ 29.99	TBS
Humidity controller + hygrostat	Inkbird (Amazon)	$ 41.99	TBS
3D Printing parts			TBS

Missing expenditures are expected to be carried out through December. Corresponding receipts are presented in Appendix C.

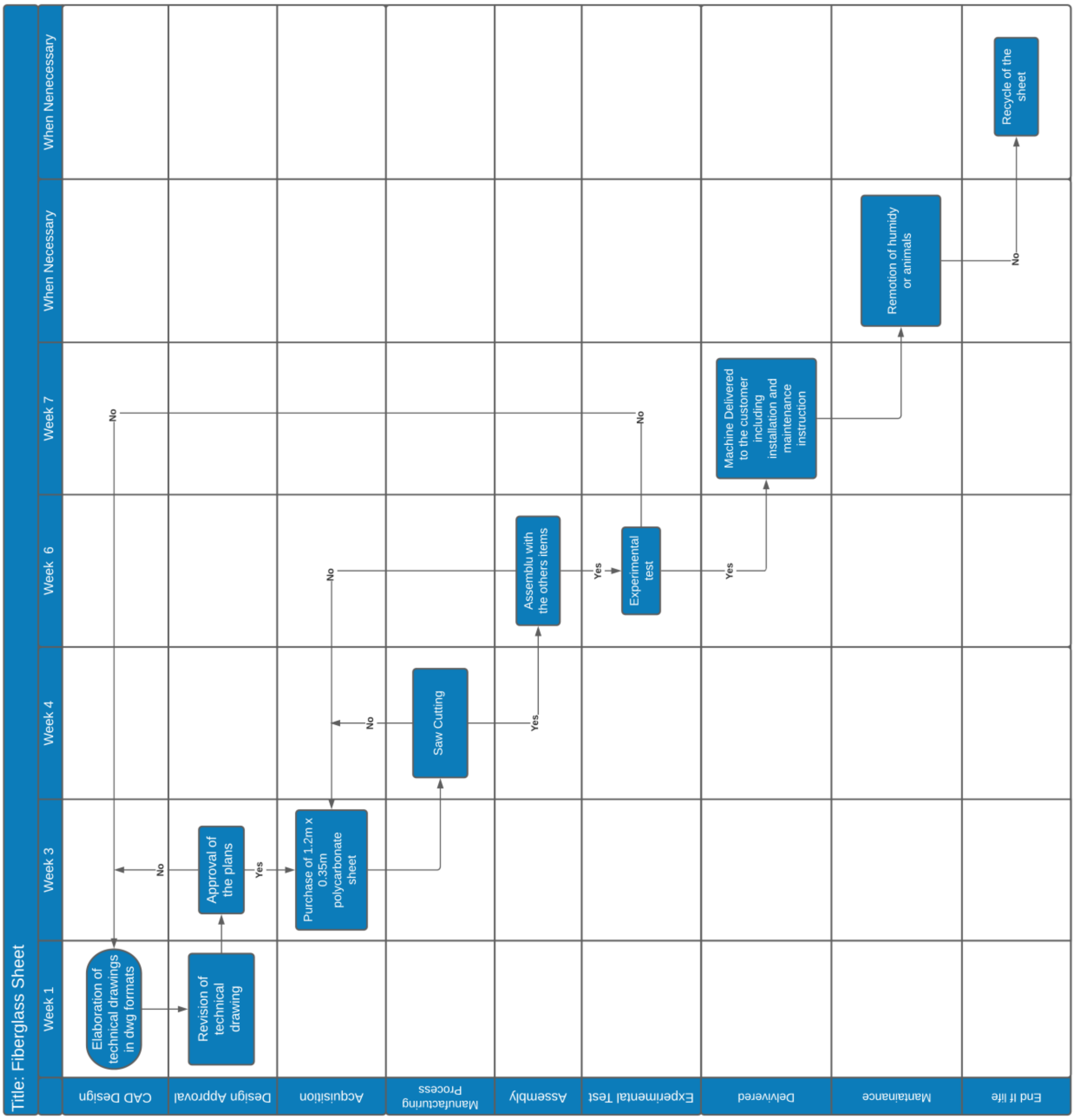
Flow Diagram manufacturing process

This section includes manufacturing process required by incubator assembly and flow diagrams per material.

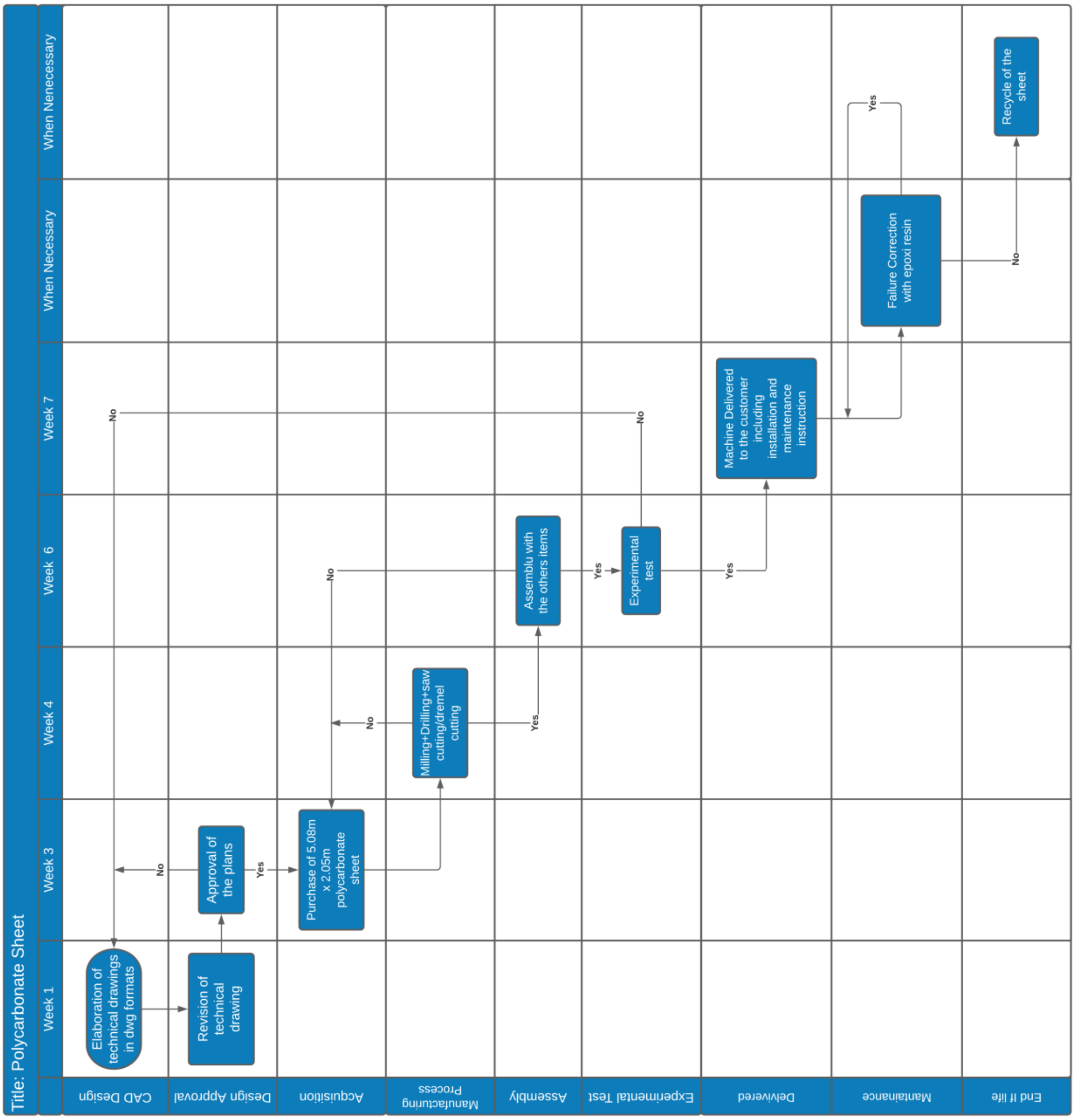
Electronic components



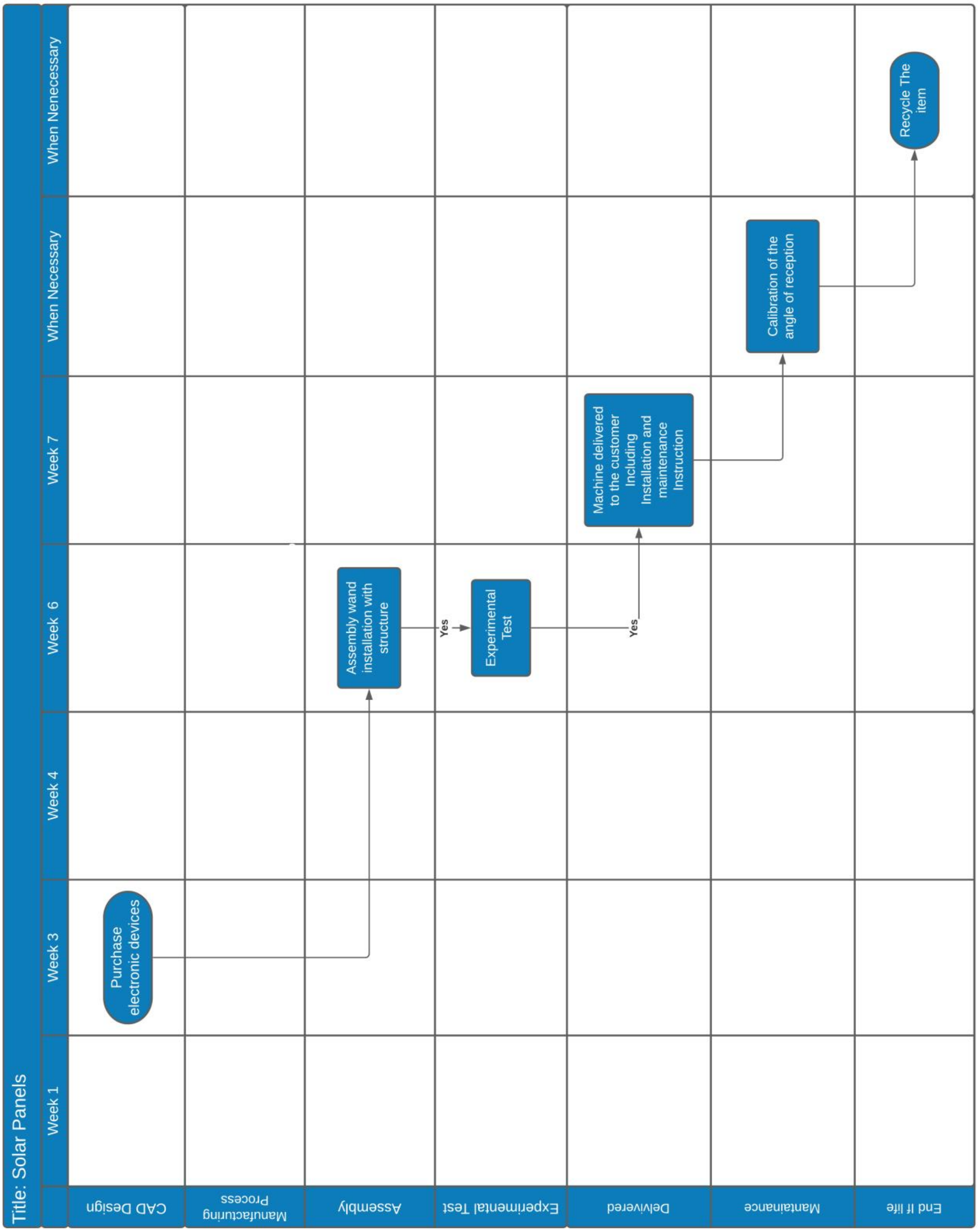
Fiberglass sheet



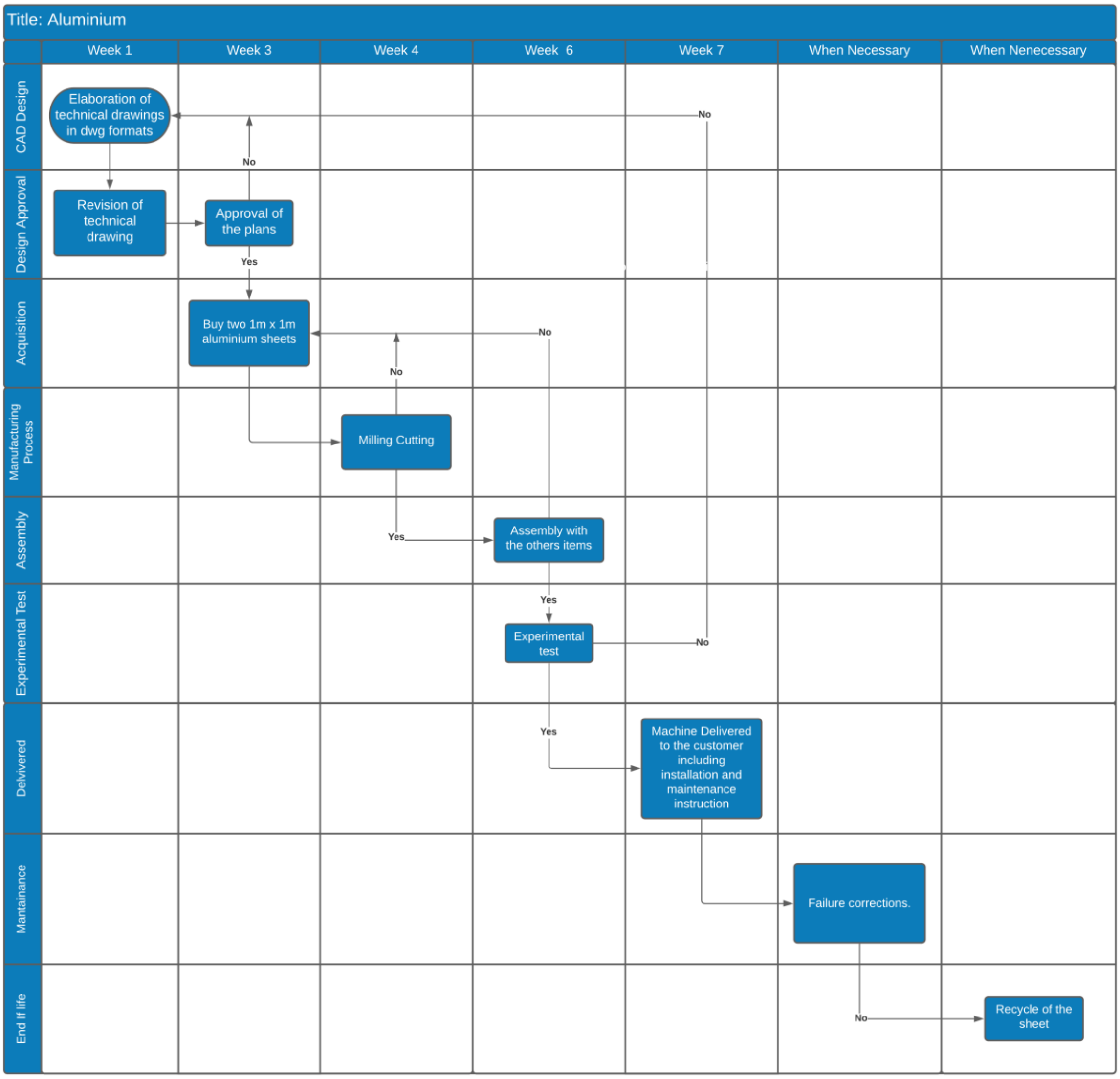
Polycarbonate sheet



Solar panels



Aluminium



Title: Aluminium
Week 1
Week 3
Week 4
Week 6
Week 7
When Necessary
When Nenecessary
CAD Design
Design Approval
Acquisition
Manufacturing Process
Assembly
Experimental Test
Delvivered
Mantainance
End If life
Elaboration of technical drawings in dwg formats
Revision of technical drawing
Approval of the plans
No
Yes
Buy two 1m x 1m aluminium sheets
No
Milling Cutting
No
Yes
Assembly with the others items
Yes
Experimental test
No
Yes
Machine Delivered to the customer including installation and maintenance instruction
Failure corrections.
No
Recycle of the sheet