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Technical document

SHREDDER

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Summary

This project presents the design and construction of a paper shredding machine (*SHREDDER*), developed entirely by the four students: Sergi, Pau, Gerard and Marcel within the framework of *Integrated Project II* course.

The main objective was to build a functional system capable of shredding a sheet of paper, starting completely from scratch and without using any preassembled commercial components.

The development included the design and fabrication of gears, the selection of a suitable motor for the required torque, the manufacturing of the cutting elements, and the creation of an extraction mechanism using a worm screw. Additionally, a fan was integrated to assist in ejecting shredded paper.

The construction of the prototype required a combination of knowledge in mechanics, electronics, and industrial design, as well as careful management of resources and the fabrication process. The result is a compact and efficient machine capable of performing its main function successfully, demonstrating the feasibility of a fully custom-made project within an educational environment.

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1. Introduction

Our project consists of the design and development of a functional prototype of a mechanical shredder. Although our prototype currently uses paper as its shredding material, its conceptual purpose is to simulate a small-scale woodchipper, with the goal of producing organic mulch that can be used as a nutrient to support the growth of trees and plants. This project responds to a growing environmental need for sustainable waste management and circular use of natural resources, especially in urban and semi-urban settings.

Figure 1: *Example of a woodchipper.*

1.1. Background and State of Art

Shredders and chippers are mechanical devices used to reduce the size of materials such as paper, plastic, and wood for purposes like recycling, composting, or waste volume reduction. Industrial woodchippers are designed to process large volumes of branches and trunks into chips that can be used for soil enrichment or as biomass fuel. These machines typically use rotating shafts equipped with sharp blades or interlocking teeth to pull in and tear apart the material **[1][2]**.

Over time, shredding systems have evolved to become more efficient, incorporating safety mechanisms, automated control systems, and energy-saving motors. Modern designs often use dual-shaft mechanisms for higher torque and reliability, as well as sensors to prevent motor overloads and detect jams **[3]**.

Our prototype was inspired by these systems but scaled down and adapted for low-power environments. Instead of using wood, which would require industrial-grade strength and materials, we used paper to simulate the shredding process. This approach allowed us to focus on key mechanical challenges, such as blade design, torque transmission, and jam prevention, without the need for heavy-duty materials or motors.

1.2. Motivation and Justification

Our motivation for developing this shredder prototype stems from an interest in sustainability, engineering design, and the potential for community impact. Organic shredders are useful in urban gardening, composting initiatives, and ecological waste management. However, commercial machines are often too expensive or oversized for personal or small-community use.

Figure 2: *A woodchipper working.*

By designing a smaller, cost-effective shredder system, we are exploring the possibility of providing communities with a low-cost, low-energy solution for turning organic waste (such as twigs, leaves, and paper) into usable mulch. The use of a wooden structure and 3D-printed components further emphasizes the importance of accessible and sustainable materials in our design process.

1.3. Research and Comparison with Existing Work

Before starting the design, we conducted research into different types of shredders and cutting systems. Based on our study, we identified two main mechanisms: strip-cut shredders, which use parallel rotating discs to produce long paper strips; and cross-cut or industrial shredders, which use interlocking teeth on two shafts to grind material into smaller, irregular pieces **[4]**.

We chose to replicate the dual-shaft, interlocking-tooth mechanism due to its versatility and higher efficiency in breaking down tougher materials. Unlike many existing prototypes, we also integrated a custom Arduino-based control system that detects motor overloads and triggers automatic reversal to clear jams—an advanced feature typically seen in commercial shredders.

Additionally, we introduced a novel solution for jam prevention by including servo-controlled cleaning brushes that sweep debris from between the cutting teeth, a feature inspired by maintenance issues noted in small-scale shredding applications **[5]**.

2. Objectives

At the beginning of the project, we set a series of objectives that guided the entire design and development process of the shredder. These objectives were closely linked to the overall purpose of creating a functional, safe, and sustainable machine capable of improving waste management and recycling efficiency in a domestic or small industrial environment.

The main objectives were focused on the impact and utility of the shredder. First, the product had to reduce the number of times the user had to take out the trash by at least three times, by significantly reducing the volume of waste. Second, it aimed to optimize the recycling process by providing more compact and better-prepared materials, facilitating easier handling and classification of waste for reuse or disposal. These goals helped ensure that the machine was not only technically functional but also practical and beneficial in a real-life context.

To reach these main goals, we also established a set of specific objectives that defined the design requirements and technical characteristics the machine had to meet. One of the most important was ensuring user safety by implementing measures to minimize hazards during operation. This included adding a sensor on the lid that automatically stops the motor when the cover is open, enclosing electronic components, and making the fan inaccessible to prevent contact with moving parts. Another key objective was to make the shredder as autonomous as possible, allowing it to work with minimal human intervention. This led to the implementation of an automatic jam detection system and servo-controlled cleaning brushes.

Durability and maintenance were also central concerns. The machine was designed to be robust and reliable, with a target of requiring only one general maintenance every three years. For that reason, we chose a reinforced wooden structure and designed easily replaceable components. The shredder was also built to handle different materials, not only paper, which guided our decision to adopt an industrial type cutting mechanism with metal blades shaped and assembled manually. Additionally, we made sure that the machine would be easy to transport and manipulate, which we achieved by keeping the total weight around 13 kg, adding wheels to the base, and using a compact, modular design. Finally, we established clear dimensional limits for the finished product: 30 x 40 x 40 cm, a size that balances functionality and portability, and which the final prototype successfully meets.

At an early stage of the project, we also considered adding a classification system that could automatically separate different materials before or after shredding. However, as the development progressed and the complexity of the mechanical and electronic systems increased, we decided to discard this feature. Instead, we focused on refining the shredder's core functionalities—such as reliable cutting, jam handling, and safe operation—since these already required considerable effort and time. This decision allowed us to concentrate our resources on achieving a robust, working prototype within the expected scope and deadlines.

3. Development of the project

The development of our shredder project began with extensive research, experimentation, and iterative improvement. To start, we needed to understand how shredders operate, so we spent time doing research and watching how different types of shredders cut paper. We identified two main types of shredders. The first type cuts paper into long strips, using two round cutting discs that spin in opposite directions and touch each other. When paper passes between them, it gets sliced into rows. The second type, which is often used in more industrial machines, is more powerful and works differently. It uses sharp pieces, like little blades or teeth, that are connected to two turning shafts. As the shafts spin, the teeth pull the material into the center and break it apart. This second type was the one we decided to build, because it seemed more efficient and closer to the kind of shredders used for not only paper but also plastic or other stronger materials.

After deciding on the industrial-style shredding method, we had to build the cutting system ourselves. We used long threaded rods as the main shafts. Then, from long steel strips, we cut square metal pieces that would become the "teeth" of the shredder. Each square was shaped by hand. We used a grinder to sharpen each corner so that they would act like small cutting points. This way, when the rods turned, the teeth could catch the paper and drag it into the center, just like in real industrial shredders. We placed the squares on the threaded rods, one after another, and separated them with metal washers to leave a space between each one. This gap was important so that the teeth from one rod could fit into the spaces of the other rod while both turned at the same time. However, this part was not easy. Many times, we found that the squares would touch each other too closely or get stuck. Often, the squares were positioned too closely or became misaligned, causing the rods to jam. We made repeated adjustments using grinding tools until all components rotated smoothly with minimal friction.

A major challenge was choosing the motor and designing the gears. At first, we planned to use a small motor and increase the torque using large gears. Our idea was to place a small gear on the motor and a larger gear on the shredder shafts to make them turn more slowly but with more force. We even thought about making the two gears on the shredder slightly different sizes so that one would spin faster than the other. But after several tests and many hours of discussion, we realized this idea wasn't working well. The small motor didn't have enough power, and the gears were complicated to design and print. In the end, we decided to change the plan completely. We chose a new motor that already had a built-in reduction gearbox. This motor was stronger and slower, and it allowed us to use two equal-sized gears for the shredder shafts. That way, both shafts turned at the same speed and with the same amount of torque as the motor provided.

After building the shredder, we started testing it, and we quickly noticed another problem. Sometimes, the paper would get stuck between the teeth and wouldn't shred properly. The machine would stop, and the motor couldn't turn anymore. To solve this, we added two helpful features. First, we programmed the motor using Arduino to detect when the current went too high, which meant the shredder was jammed. When that happened, the motor would automatically reverse for a short time to free the paper. Then it would go back to normal rotation and keep shredding. Second, we added small metal brushes, also made from rods, that were controlled by a servo motor. These brushes would move between the teeth to remove any bits of paper that were stuck between the squares. This idea worked very well and helped prevent jams from happening too often.

Once we had a working shredder, we moved on to the next phase, which was to find a way to remove the shredded paper. We designed and 3D-printed a plastic worm screw (or auger), which we placed under the shredder to carry the paper pieces away. The screw was mounted on a hexagonal rod that spun when driven by a motor. Initially, we thought of using a strong metal rod, but it was expensive, and since we were still working on a prototype, we used a plastic one printed in 3D. The first motor we used for the auger was too weak and couldn't turn the screw properly, so we had to replace it with a stronger one. At the end of the auger, we placed a fan that would blow the shredded paper to the side. To allow the paper to exit, we cut an opening in the wooden frame so the fan could push the material out easily.

The main frame of the shredder was made entirely out of wood. This was a sustainable material, strong enough to support all the forces inside the machine, and it was also available in our workshop. We spent many hours designing and building the wooden structure. We had to plan where every component would go, making sure they wouldn't block or interfere with each other. Since we didn't have professional tools, many holes had to be drilled and polished by hand, using files to adjust every part until it fit perfectly. We even added three small wheels to the bottom of the structure so the whole machine could be moved easily. The electronic parts were all carefully placed inside the frame and protected, to avoid any damage or safety risks.

Safety was one of our biggest concerns throughout the project. We knew this type of machine could be dangerous, especially with the sharp teeth and spinning parts. So, we added several safety features. The shredder was covered by a wooden lid with a narrow slot where paper could be inserted. We installed a sensor on the lid so that if it was opened, the shredder would stop working immediately. This prevents anyone from putting their hand inside while the machine is running. We also hid the fan inside the wooden frame, behind a series of small holes, to make sure fingers couldn't reach the spinning blades. Everything was built with safety in mind to reduce the risk of accidents as much as possible.

All electronics, including motors, servos, and sensors, were controlled using Arduino boards. Arduino was the perfect choice for this kind of project because it is easy to use and works well for quick experiments and changes. The control code we wrote includes logic to detect when the shredder is jammed, to reverse the motor, and to move the cleaning brushes when needed. It also manages the safety sensors. The full code is available on GitHub, with comments that explain how everything works. We also created detailed mechanical drawings and diagrams to explain how all the parts are connected and how the machine was built. These documents include calculations and justifications for the design decisions we made during the whole process.

In conclusion, the project required a lot of time, testing, adjustments, and creative solutions. We learned how to design and build a complex system step by step, solving problems as they appeared. From building custom cutting teeth to programming intelligent motor control, every part of the shredder was developed with care and teamwork, and we are proud of the result.

3.1. Description of the design

The shredder is composed of a robust wood structure, engineered to ensure stability and resistance during heavy-duty operation, also the design makes possible the different maintenance operations because the structure is fixed in a proper way to make possible and easy to disassemble all that is necessary.

The design integrates a pair of counter-rotating shafts equipped with multiple cutting blades, optimized for the efficient reduction of paper. Then when it is finally shredded it goes to a designed space enabled to throw it out.

The key components included in the design are:

- Cutting Mechanism: Dual-shaft system with interlocking blades for the torque shredding required.
- Housing Frame: Reinforced frame ensuring mechanical integrity under possible dynamic loads.
- Transmission System: That includes shafts, bearings, and couplings designed to transfer power efficiently from the motor.
- Cleaning Mechanism: To combs are located with the cutting mechanism to remove the remaining paper from between the blades.

3.1.1. Mechanical design

To ensure the paper was shredded correctly, a series of calculations had to be made to determine both the torque and the speed required for this.

Calculations:
Source: [6]

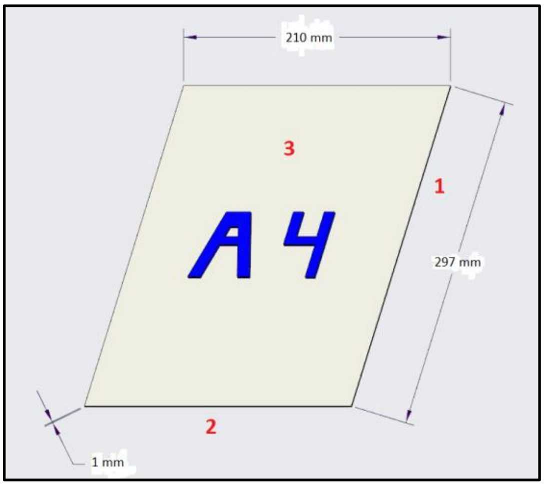


Figure 3: *Dimensions of a sheet of paper.*

$$A1 = 0{,}297 \cdot 0{,}001 = 0{,}000297 m^2$$
$$A2 = 0{,}210 \cdot 0{,}001 = 0{,}000210 m^2$$
$$A3 = 0{,}297 \cdot 0{,}210 = 0{,}06237 m^2$$
$$At = (0{,}000297 \cdot 2) + (0{,}000210 \cdot 2) + (0{,}06237 \cdot 2) = 0{,}1257 m^2$$

Total effort:

Shear force of a sheet of paper: $F = 0{,}7 N$

$$\sigma = \frac{F}{A} = \frac{0{,}7}{0{,}1257} = 5{,}57 Pa$$

Work required to cut a sheet of paper:

Displacement: $s = 0{,}001 m$

$$W = F \cdot s = 0{,}7 \cdot 0{,}001 = 0{,}0007 \frac{N}{m} = 0{,}0007 J$$

Minimum torque to shred a sheet of paper:

$$T = \sigma \cdot r = 5{,}568 \cdot 0{,}015 \rightarrow \boxed{T = 0{,}084 Nm}$$

Torque of each blade:

$$Tg = \frac{T}{nb} = \frac{0{,}167}{21} = 0{,}008 Nm$$

Total system torque:

$$Axis\ 1 (10) \rightarrow T1 = 10 \cdot 0{,}008 = 0{,}08 Nm$$
$$Axis\ 2 (11) \rightarrow T2 = 11 \cdot 0{,}008 = 0{,}088 Nm$$

$$Tt = 0{,}08 + 0{,}088 \rightarrow \boxed{Tt = 0{,}168 Nm}$$

Necessary speed:

$$Blade\ perimeter \rightarrow P = 2\pi \cdot r = 2\pi \cdot 0{,}015 = 0{,}094 m$$

$$Roller\ length \rightarrow L = 0{,}1685 m$$

$$Number\ of\ turns \rightarrow n = \frac{L}{P} = \frac{0{,}1685}{0{,}094} = 1{,}79 turns$$

$$W = \frac{n}{t} = \frac{1{,}79\ turns}{1 min} \rightarrow \boxed{W = 1{,}79 rpm}$$

3.1.2. Electrical design

Even though the project is much more focused on the mechanical aspect, electronics also play an important role in it.

First of all, the project works with various voltage levels, the Shredder is plugged to the electrical grid (220V) and it has to transform the 220V to the voltage every component needs, for doing this there is a power supply with a transformer that lows the voltage from 220V to 24V and it transforms it to DC, once the voltage is 24V it is plugged to the printed circuit board and two different voltage regulators reduce the voltage to 12V and 5V once the three voltages are available the motor driver can be plugged in with 5V in VCC and connected the three pins (INI1,INI2,ABL) to the Arduino, then the 24V coming from the power supply are connected to the motor driver and form it to the motor, in second place all the servos are plugged into 5V and the fan is plugged to 12V the servos and the fan are controlled with the Arduino Mega which it uses PWM to control every motor on its own, in third place the two sensors are incorporated, the current sensor is connected to the Arduino with SDA and SCL and is plugged to 5V then the closing door sensor is connected to the pin 17 of the Arduino and to the ground and when the door is closed it closes the circuit and the pin detects that the door is closed. Finally, the Arduino is connected to 12V with the Vin pin and all the grounds are united.

3.1.3. Control and software

Although heavily mechanical in nature, the Shredder project relies on software instructions and management to work the way the original idea envisioned, as several receptors and actuators make it function harmoniously, a central hub for all control oversees the entirety of the shredding process.

The go-to choice for this project is the well-established Arduino Mega 2560 (**7.3.1.[1]**), a powerful and versatile microcontroller capable of a wide range of possibilities, with high number of pins support, multiple internal programmable timers and sufficiently capable framework built around including an endless amount of third-party peripheral libraries. The extensive plethora of possibilities the Arduino environment offers makes it an easy choice for our cause.

- Programmed working modes:

The Shredder enters different working statuses depending on the user's commands or the sensor inputs, adapting to the current situation or necessity. The working modes consist in the following:

a. **FORWARD** status: Normal working status of the Shredder, activated by default when the door is closed and the user releases the emergency button.

    i. Shredder cutters working in **FORWARD** mode (Shredding mode)

    ii. Fan (Table 9.12) and Spiral (motors activated

    iii. Servomotors in **RECLINED** position (de-clogging OFF)

b. **BACKWARD** Status: Inverse mode of the Shredder, it is only activated during de-clogging routine.

    i. Shredder cutters working in **BACKWARD** mode (non-shredding mode)

    ii. Fan and Spiral motors activated

    iii. Servomotors in **ENGAGED** position (de-clogging ON)

c. Anti-Clogging Routine: Activated when the current sensor detects a peak in current beyond 1 Amp, it will activate in any working status (**FORWARD/BACKWARD**) with the intent to avoid clogging and any derivative effect it may cause. Adapts to current working status, will activate in the opposite direction of the current working status, and will recline de-clogging system if working status is set to **BACKWARD**.

    i. **FORWARD** mode: activates backward, re-engages **FORWARD** mode when done.

    ii. **BACKWARD** mode: activates forward, reclines de-clogging system, and reactivates in **BACKWARD** mode when done, re-engages de-clogging system.

- Controllable actuators:

As mentioned, the Arduino is responsible of controlling all the actuators that are required to make the shredder viable, here is a list of all the output peripherals that are used, their intended function and modes of use.

a. Main Motor: The main motor is the motor that turns the shredder mechanism which is in contact with the paper. It is controlled via Pulse-Width Modulation (PWM), the Arduino is responsible for determining the motor's speed and direction. The main motor cannot be directly controlled via the Arduino, and a driver is used for this task

b. XY160D Driver (**7.3.1.[4]**): Main motor control driver, which enables the Arduino board to take control of the otherwise incompatible 24V DC main motor. It does not require a library, it is controlled through 3 control pins, each determining: rotation direction and speed

Arduino Pin and Function:

Control pin / digital PWM pin 3	Main motor driver speed control (ENA)
Control pin / digital pin 10	Main motor driver direction 1 (IN1)
Control pin / digital pin 11	Main motor driver direction 2 (IN2)

Table 1: *Control and software Pin and Function 1*

c. SG90 Servomotors(**7.3.1.[2]**): Servomotors destined for de-clogging system. These motors are modified in position when the anti-clogging routine is activated. They make use of the “Servo.h” (**7.2.1.[3]**) library and instructions, which are called strategically throughout the code

Arduino Pin and Function:

Control pin / digital PWM pin 6	Servo 1 position control
Control pin / digital PWM pin 7	Servo 2 position control

Table 2: *Control and software Pin and Function 2*

d. Spiral DC Motor: Responsible for collecting the paper and depositing it internally within the shredder. Does not use a library and it is controlled via PWM, speed being the only programable parameter for it.

Arduino Pin and Function:

Control pin / digital PWM pin 5	DC spiral motor speed control

Table 3: *Control and software Pin and Function 3*

e. 12V DC fan: Responsible for ejecting the paper out of the shredder once collected. Due to its 12V nature it cannot be directly implemented into the Arduino, and it is controlled through a voltage regulator electronically. Does not require from libraries and its speed is the only controlled parameter

Arduino Pin and Function:

Control pin / digital PWM pin 4	Fan motor speed control

Table 4: *Control and software Pin and Function 4*

- Sensors and inputs:

Similarly, the Arduino requires from sensory inputs to work properly, reading the status of different processes and parts of the shredder to adapt its actions and make it secure and reliable.

a. Door sensor: This door sensor consists of an open circuit that gets closed whenever the protective door is fully in position. The low value of this input indicates that the door is open, and the program cannot proceed. This state is not controlled by a sensor per-se, but rather the voltage feedback the Arduino gives itself. As a digital input it only reads 2 values.

Arduino Pin and Function:

Control pin / digital pin 17	Door status pin - HIGH value: the door is closed and allows the code to proceed - LOW value: the door is open, and the code cannot proceed

Table 5: *Control and software Pin and Function 5*

b. INA219 current sensor (**7.3.1.[3]**): The INA219 is a current / power sensor that is set up within the circuitry and reads the current value passing through it, returning this value. It is used to control and limit the amount of current being received by the main motor to avoid current spikes, which may translate to clogging. Detection of this current spike allows for quick activation of anti-clogging routine and de-clogging measures. The sensor sends the data through I2C communication protocol, requiring the use of I2C wire library (**7.2.1.[1]**)(**7.2.1.[2]**) and SDA/SCL pins

Arduino Pin and Function:

Integrated SDA pin	Connected directly to INA219 SDA pin to enable I2C communication
Integrated SCL pin	Connected directly to INA219 SCL pin to enable I2C communication

Table 6: *Control and software Pin and Function 6*

Arduino Pin and Function:

Control pin / digital pin 22	GO button activates FORWARD or BACKWARD working mode alternatively when pressed
Control pin / digital pin 24	STOP button stops all modes except Anti-clogging routine
Control pin / digital pin 9	Emergency button: stops all processes, needs to be rearmed to proceed

Table 7: *Control and software Pin and Function 7*

The entirety of the project has been programmed using Arduino's own IDE, which is compatible by default with the applied Arduino Mega 2560 (**7.3.1.[1]**), alongside the specified libraries to support the use of the peripherals.

The actual implemented code accompanies this document

1. Miscellaneous declarations and variables.

   a. Import libraries required for the peripherals.
      i. "Wire.h" I2C library (**7.2.1.[1]**): required for I2C protocol communication.
      ii. "Adafruit_INA219.h" (**7.2.1.[2]**): Required to declare and start/stop sensor communication.
      iii. "Servo.h" (**7.2.1.[3]**): Required to actuate servomotors.

   b. Declare control variables
      i. "current_ina": numerical variable that stores the sensor readings.
      ii. "starter": controls if the initial sequence has already been completed, not to repeat the linear speed engagement of the main motor loop.
      iii. "i": iteration variable for loops.

c. Pin assignation
    i. "p_spd": Analog PWM value, controls motor speed.
    ii. "p_vent": Analog PWM value, controls fan speed.
    iii. "p_spir": Analog PWM value, controls spiral motor speed.
    iv. "p_dir_1": Boolean value, establishes main motor direction alongside "p_dir_2".
    v. "p_dir_2: Boolean value, establishes main motor direction alongside "p_dir_1".
    vi. "p_drc_1": Boolean value, determines whether the door is open or closed.
    vii. "p_srv_1": Analog PWM value, controls the position of servo 1.
    viii. "p_srv_1": Analog PWM value, controls the position of servo 2.

d. Peripheral declaration
    i. "Servo servo_x": creates 2 servos to be controlled via "p_srv_x" pins respectively, servo 3 corresponds to spiral servo.
    ii. "Adafruit_INA219 ina219": creates virtual "INA219" controller.

2. Setup
    a. "Serial.begin(115200)": Starts port communication with the Arduino at 115200 BAUDS.
    b. "ina219.begin()": Starts virtual INA219 controller.
    c. "servo_x.attach(p_srv_x)": Attaches defined pin to respective servo control input.
    d. "pinMode()": Defines previously declared pins to INPUT/OUTPUT.
    e. Timer definition: Defines internal timer control mode, used for main motor's PWM output correction.

3. Loop
    a. First "IF" instruction: Reads if the conditions are met (door being closed).
        i. Sets spinning direction to FORWARD
        ii. Starts motor speed in a linear manner (increasing for loop)
        iii. Turns on spiral motor and fan motor.
        iv. Sets "starter" control variable to TRUE

    b. Following "ELSE IF": Reads if the conditions are met (door being open) if first conditions are not met.
        i. Reduces speed in a linear manner
        ii. Sets main motor direction to OFF.
        iii. Stops fan motor and spiral motor.
        iv. Sets "starter" control variable to FALSE

c. Anti-clogging procedure: Constantly reads value from current sensor and compares it with a predefined threshold.
   i. “ina219.getCurrent_mA()”: Gets milliamp readings from “INA219” sensor.
   ii. “IF” statement: compares sensor reading with value “1600” equivalent to 1.6 Amps (or –700 milliamps).
      1. Stops main motor turning.
      2. Engages servomotors in de-clogging position
      3. Gradually increases main motor speed in the opposite direction.
      4. Stops main motor turning.
      5. Reclines servomotors
      6. Gradually increases main motor speed in the original direction.
      7. Re-engages servomotors if BACKWARD mode was active.

3.2. Functional testing of the prototype

The functional testing phase of our shredder prototype was focused on validating the performance of its core mechanical and electronic components, as well as identifying areas for improvement. Each subsystem was evaluated individually and then as part of the integrated system to ensure the machine functioned as intended.

Mechanical Functionality:

All mechanical parts of the prototype worked successfully during testing. The dual shaft cutting system, manufactured with sharpened square steel piece, demonstrated effective shredding performance when tested with various types of paper. The interlocking teeth were able to pull in, grip, and tear the paper reliably.

We also tested the 3D-printed auger responsible for removing shredded material from the inside of the machine. Once powered by the correct motor, the auger efficiently transported the paper scraps to the exit point. Additionally, the wooden frame structure proved strong and stable enough to support all moving components without significant vibration.

Electronic System Testing:

The main issue founded during the functional testing phase was related to the electronics. While the Arduino control system performed correctly in initial tests: detecting jams, reversing the motor, and activating the cleaning brushes even some components required different voltage levels. Specifically, the fan operated at 12V, while most other components, including the Arduino and servos, required 5V. During a test, powering from a shared power supply led to a voltage mismatch that caused the Arduino board to become damaged.

This failure highlighted an important design limitation: the lack of voltage regulation and electrical isolation between components. We learned that proper separation of power sources or the inclusion of a step-down voltage regulator is critical to protecting low-voltage electronics. This incident triggered a design review and reinforced the need for clearer electrical planning in future iterations.

Performance Observations and Limitations:

- Shredding Efficiency: The machine was able to continuously shred standard paper sheets without jamming under normal operation. The automatic reversal system activated when a jam was simulated, and the servo-driven cleaning brushes successfully cleared build-up between the teeth.

- Power Limitations: The choice of motors was critical. Early testing showed that underpowered motors led to inconsistent performance, especially in the auger system. Replacing these with more powerful alternatives resolved the issue.

- Electrical Reliability: The only significant functional limitation was the lack of a robust electrical protection system, which led to the failure of the Arduino. This will be addressed in future iterations.

4. Cost of the project

Calculations of the costs of the project

- Table with the per-member man-hours dedicated to the project. Specify at least:

This document presents a summary of the hours worked on the project by our team of four engineers. Each team member was responsible for a different part of the project: planning, mechanical design, programming, and electronics.

The goal of this report is to show the time and effort invested in each area, and to calculate the total cost based on a standard hourly rate. This helps give a clear view of the work done and the value it represents. Below is a table with the detailed breakdown of hours.

SPRINT	SERGI BUSQUETS	PAU CAPDEVILA	GERARD SÁNCHEZ	MARCEL SÁNCHEZ
	(Electrical hours)	(Management hours)	(Programming hours)	(Mechanical hours)
0	7	7	7	7
1	9	9	9	9
2	15	12	12	14
3	16	14	16	16
4	16	15	16	16
5	16	16	16	16
6	16	16	16	16
7	16	16	16	16
TOTAL PER MEMBER:	111	105	108	110
TOTAL:	**434 hours**			

Table 8: *Breakdown of hours*

On the other hand, the following table shows the materials that were needed for this project, along with their corresponding costs. This includes all components and resources used during the development process.

Item number	Description of the material	Quantity	Price [€]	Cost [€]	Provider
1	Arduino UNO R3 ATmega328 CH340, 5V, Digital I/O Pins: 14, Analog Input Pins: 6	1	5,99	5,99	Leantec
2	DSLRKIT AC 100-240V to DC 24V 5A 120W Power Adapter DC Port 5.5mm x 2.5mm		22.00	22,00	Amazon
3	Chapa 100cm * 100cm steel 1mm thickness				
4	Bearings 10x15x4, 10 Piece Metal Shielded Ball Bearing, Mini Bearings 10x15x4 Mm, 6700zz Thin Section Ball Bearing, 10mm Inner Bearings	1	8,94	8,94	Amazon
5	ECSiNG 20 PCS M10 Manganese Steel Washers with Wedge Double Pile Lock Washers Outer Diameter 16.6mm Thickness 2.5mm	1	13,09	13,09	Amazon
6	Alberts 477752 Threaded shaft | Blue galvanized | Length 1000 mm | M10 threaded	1	11,22	11,22	Amazon
7	PD® Nuts M10 (DIN 934 / ISO 4032) | Hexagon nuts made of stainless steel A2 V2A | Hexagon nut for screws, threaded studs and threaded rods | 25 pieces	2	13,19	26,38	Amazon
8	Dual DC Motor Drive Module, 7A, 160W, Industrial Grade negative positive PWM speed, XY-160D logic L298	1	4,79	4,79	AliExpress
9	L7812ABV		0,68	0,68	Mouser
10	Emergency stop button	1	5,61	6,61	Mouser
11	Fan	1	25,56	25,56	Farnell
12	Servo motor	2	4,85	9,70	RS
13	Arduino push button	1	1,38	1,38	Amazon
14	Perfboard	1	3,73	3,73	Mouser
1	*5V voltage regulator*	1	5,99	5,99	Amazon
	Total:			146,06	

Table 9: *Components required for the project*

- The total budget of the project.

This document provides a complete overview of the total cost of the project, including both the engineering work and the materials required. The overall budget combines the man-hours invested by the team and the cost of the components used throughout the development.

The following sections present a detailed breakdown of these two main cost elements

BUDGET No. 001 – Technical Development Project
Date: June 6, 2025
Client: —
Project: Design and construction of an electromechanical prototype.
Team: Sergi Busquets, Pau Capdevila, Gerard Sánchez, Marcel Sánchez

Labor Cost (434 total hours)

Engineer	Hours Worked	Rate/hour (€)	Subtotal (€)
Sergi Busquets	111	25	2,775.00
Pau Capdevila	105	25	2,625.00
Gerard Sánchez	108	25	2,700.00
Marcel Sánchez	110	25	2,750.00
Total Labor	**434 h**		**10,850.00**

Materials Cost

Number	Material Description	Quantity	Unit Price (€)	Total (€)	Supplier
1	Arduino UNO R3 ATmega328 CH340	1	5.99	5.99	Leantec
2	AC-DC Adapter 24V 5A	1	22.00	22.00	Amazon
3	Steel plate 100×100 cm, 1 mm thick	—	—	—	—
4	Bearings 10×15×4 mm (10 pcs)	1	8.94	8.94	Amazon
5	M10 manganese steel washers (20 pcs)	1	13.09	13.09	Amazon
6	Threaded rod M10, 1000 mm	1	11.22	11.22	Amazon
7	M10 Hex Nuts, stainless steel (25 pcs)	2	13.19	26.38	Amazon
8	Dual DC Motor Driver Module 7A	1	4.79	4.79	AliExpress
9	Voltage regulator L7812ABV	1	0.68	0.68	Mouser
10	Emergency stop button	1	6.61	6.61	Mouser
11	Fan	1	25.56	25.56	Farnell
12	Servo motors	2	4.85	9.70	RS
13	Arduino push button	1	1.38	1.38	Amazon
14	Perfboard	1	3.73	3.73	Mouser
15	5V voltage regulator	1	5.99	5.99	Amazon
Total Materials			**146.06**		

Budget Summary

Item	Cost (€)
Labor cost (434 hours)	10,850.00
Materials cost	146.06
TOTAL BUDGET	**10,996.06**

Notes:
This budget includes VAT. Prices are estimates and may vary slightly. Valid for 30 days from the issue date.

5. Conclusions

The development of the SHREDDER prototype allowed us to successfully design and build a fully functional paper shredding system from zero, using only custom-made components. The project shows our ability to integrate mechanical, electrical, and software systems in a compact and safe product that fulfils its main function. The dual-shaft cutting mechanism, combined with the custom torque transmission and jam-prevention features, provided reliable and efficient shredding performance.

One of the key achievements was the implementation of an Arduino-based control system capable of detecting jams and triggering automatic reversal and cleaning operations. These features, often found only in commercial devices, added autonomy to our prototype. Furthermore, the wooden frame and modular design highlighted our commitment to sustainability, accessibility, and ease of maintenance.

However, the project also revealed several limitations. The most significant was the vulnerability of the electronic components due to some problems with regulation. A shared power supply between 5V and 12V components caused damage to the Arduino board, pointing to the need for better electrical isolation and protection in future iterations.

Looking ahead, future enhancements should focus on improving electrical safety using dedicated voltage regulators or isolated power circuits. Furthermore, incorporating a more robust classification or separation system could expand the prototype's functionality, although this would require more complex mechanical and software integration. Continued refinement of the mechanical assembly for smoother operation and easier alignment of cutting components would also benefit performance and durability.

In summary, this project proved the feasibility of building a custom electromechanical shredder and provided valuable experience in multidisciplinary engineering, collaborative design, and iterative problem-solving.

6. Bibliography and Webography

This bibliography and webography contains all the external documentation that has been used along the project:

[1] R. A. McDonald, *Recycling and Waste Management*, Springer, 2018.A. P. Vesilind, *Waste Treatment and Disposal*, CRC Press, 2002.

[2] "Industrial Shredders – How Do They Work?" UNTHA Shredding Technology. [https://www.untha.com].

[3] S. L. Chang, et al., "Design and Fabrication of a Paper Shredder," *International Journal of Mechanical Engineering*, 2021.

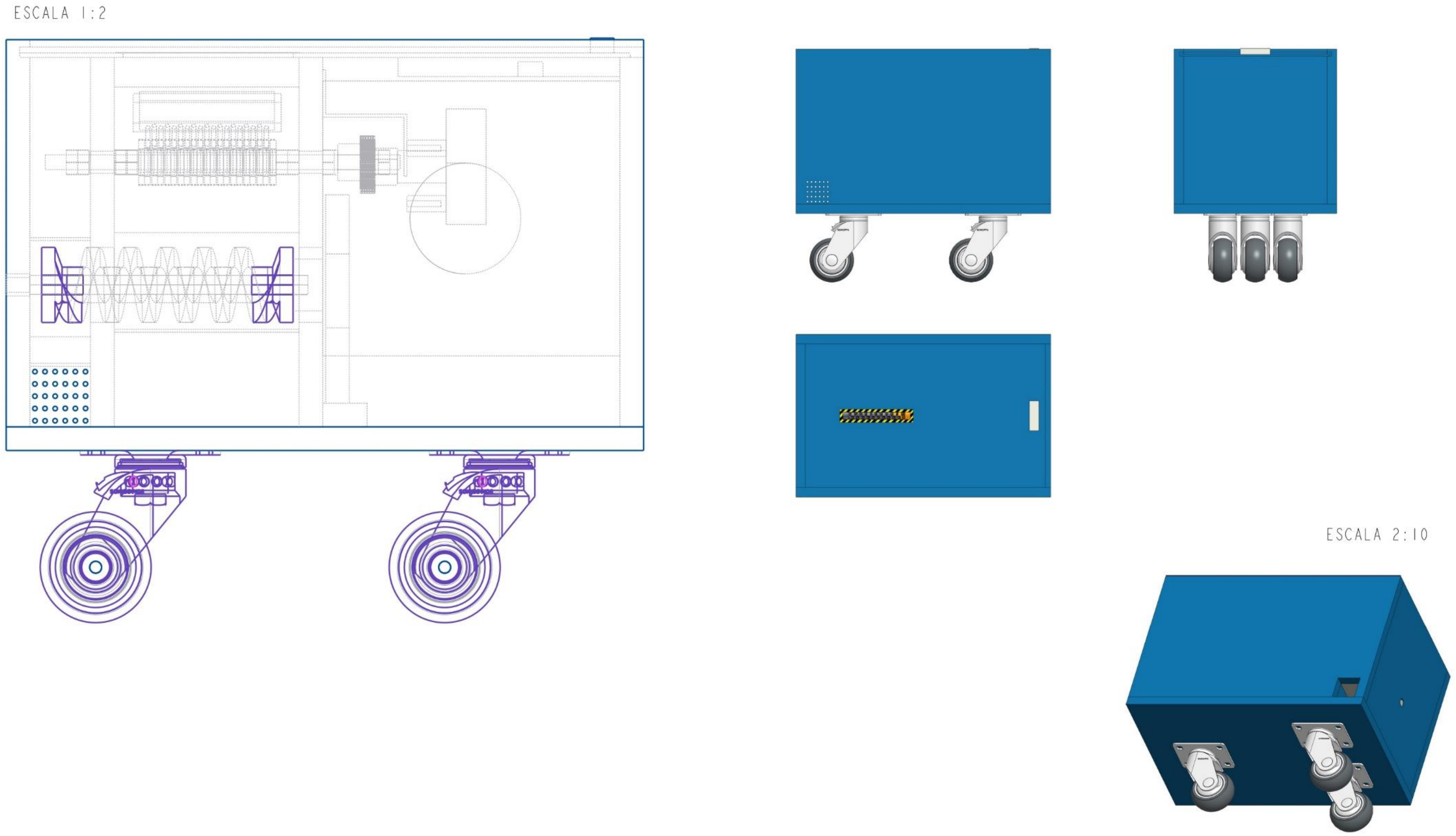
[4] "How to carry out simple maintenance work on your shredder yourself," Vecoplan, 2021. [bit.ly/3Fq2BkN].

[5] Robert L. Norton. (2011). Diseño de máquinas – Un enfoque integrado, Pearson, 4th edn. MÉXICO: Pearson Educación.

[6] David Alejandro Castaño Gutiérrez, Emile Sebastián Sierra Pregonero. (2020). Cálculos y diseño de una trituradora de papel. BOGOTÁ: Universidad Distrital Francisco José de Caldas, Facultad Tecnológica, Tecnología en Mecánica, pp. 79-90.

7. Appendix

7.1. Mechanical design



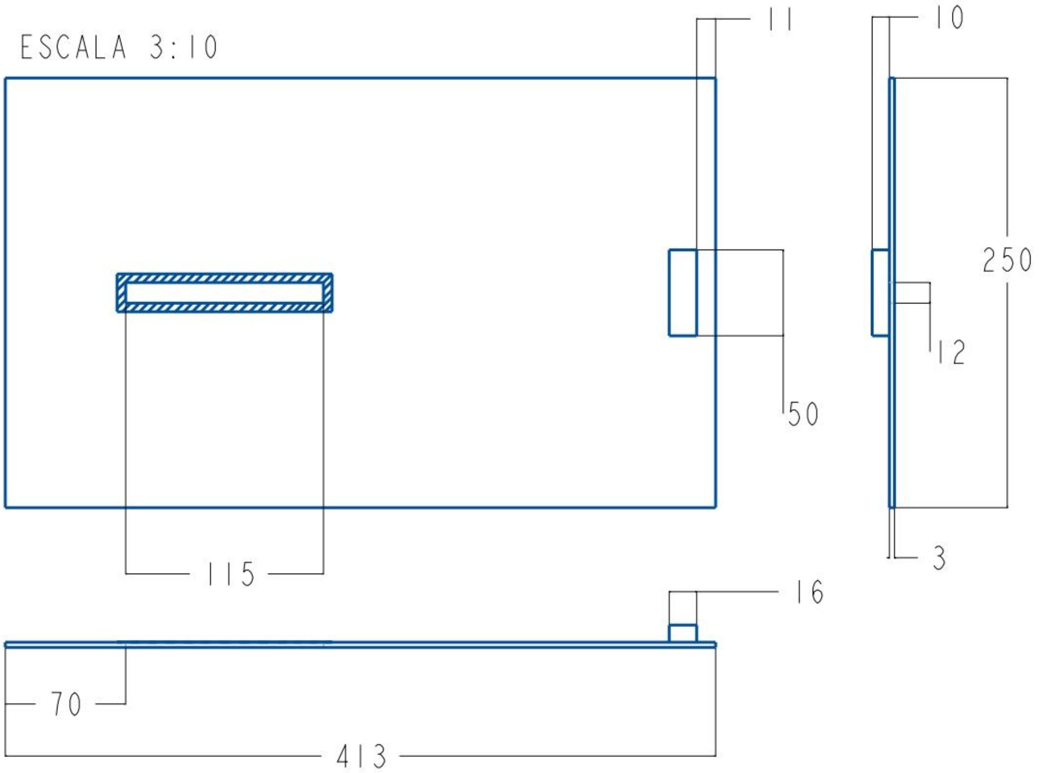
Número de plànol	Denominació peça	Quantitat
T_0.1	Cargol d'Arquímedes	1
T_1.1	Tapa	1
T_1.2	Tapa Interior	1
T_1.3	Pinta A	1
T_1.4	Pinta B	1
T_1.5	Xapa 1	1
T_1.6	Xapa 2	1
T_1.7	Xapa 3	1
T_2.4	Suport Espiral	1
T_3.1	Terra	1
T_3.2	Paret Gran	1
T_3.3	Paret Entrada	1
T_3.4	Paret Interior	2
T_3.5	Paret Final	1
T_3.6	Parte Gran 2	1
T_3.7	Suport Motor	1
T_4.1	Trituradora 1	1
T_4.2	Trituradora 2	1

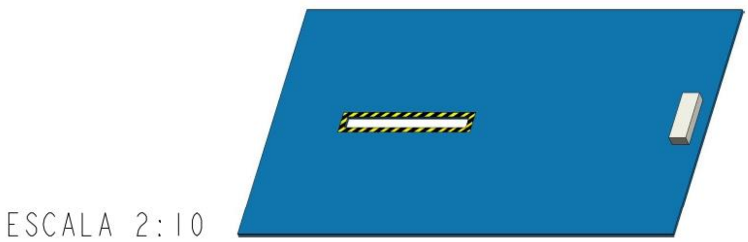
Material	
Xapa de 100x100x2mm	1
Fusta MDF cru 60x120x1,6cm	3
Cargols d'unió 7x50mm	20
Cargols hexagonals M10	6
Femelles M10 (DIN 934 / ISO 4032)	6
Volanderes M10	6
Rodes	3
Coixinets de boles Secció Prima 6700zz, 10mm	5

UVIC UNIVERSITAT DE VIC UNIVERSITAT CENTRAL DE CATALUNYA	PROJECTE INTEGRAT II	
	T_0 – SCHREDDER	
Alumnes: Sergi Busquets - Pau Capdevila Gerard Sánchez - Marcel Sánchez	GRUP 5	
03/06/2025	Plànol segons ISO 2768-89-m	
Professors: Moises Garín i Clara Sandino	**Nº de plànol:** 1	**Nº de plànols:** 23

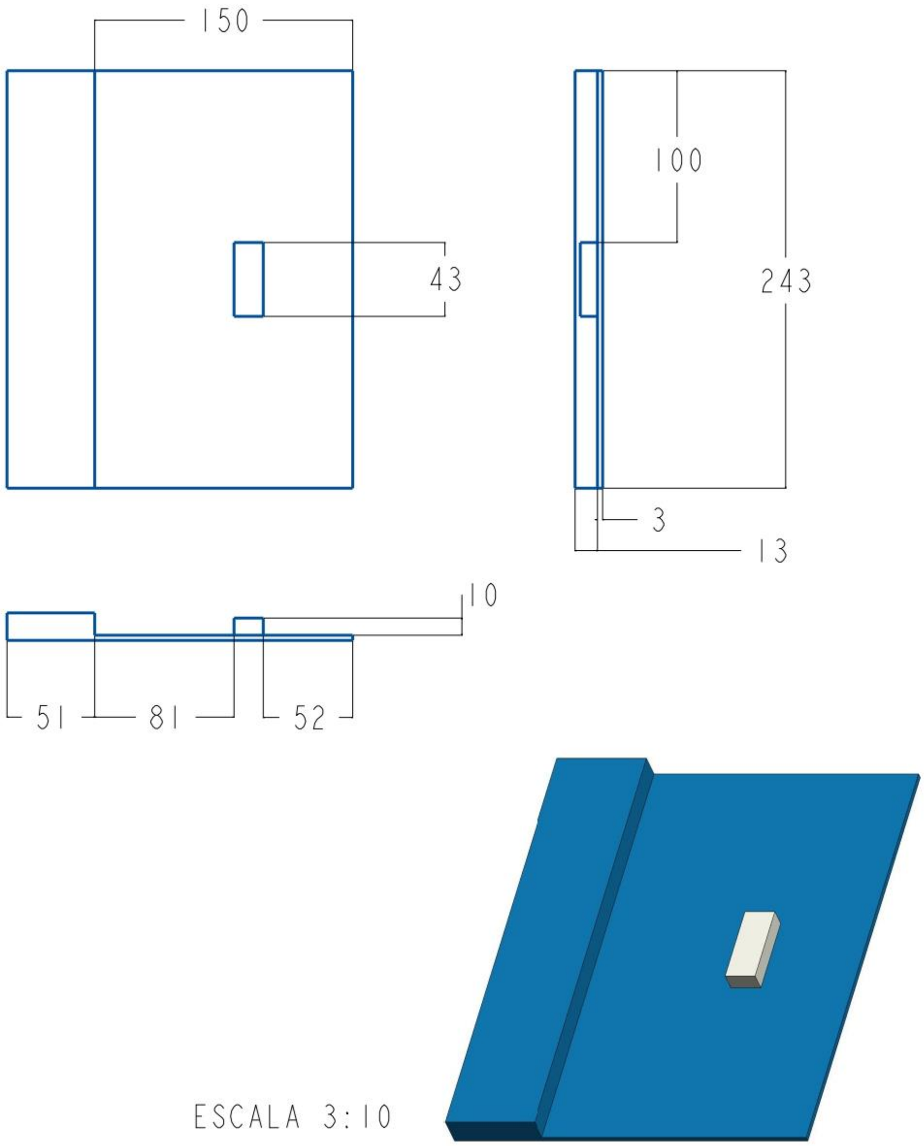
Número de plànol	Denominació peça	Quantitat
T_2.1	Extrem Cargol	2
T_2.2	Interior Cargol	5
T_2.3	Eix Hexagonal	1

UVIC UNIVERSITAT DE VIC UNIVERSITAT CENTRAL DE CATALUNYA	**PROJECTE INTEGRAT II**	
	T_0.1 – Cargol d'Arquímedes	
Alumnes: Sergi Busquets - Pau Capdevila Gerard Sánchez - Marcel Sánchez	GRUP 5	
03/06/2025	Plànol segons ISO 2768-89-m	
Professors: Moises Garin i Clara Sandino	**Nº de plànol:** 2	**Nº de plànols:** 23

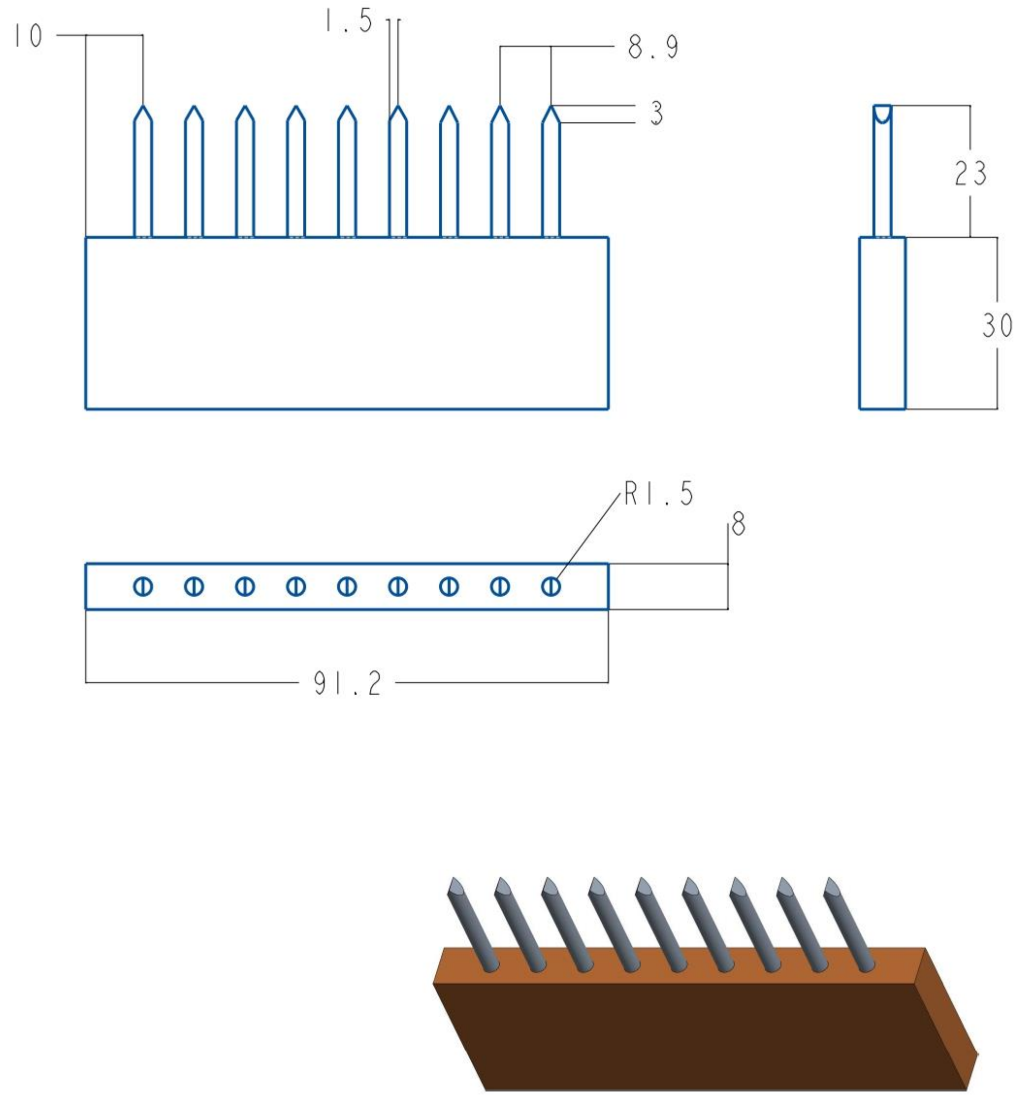




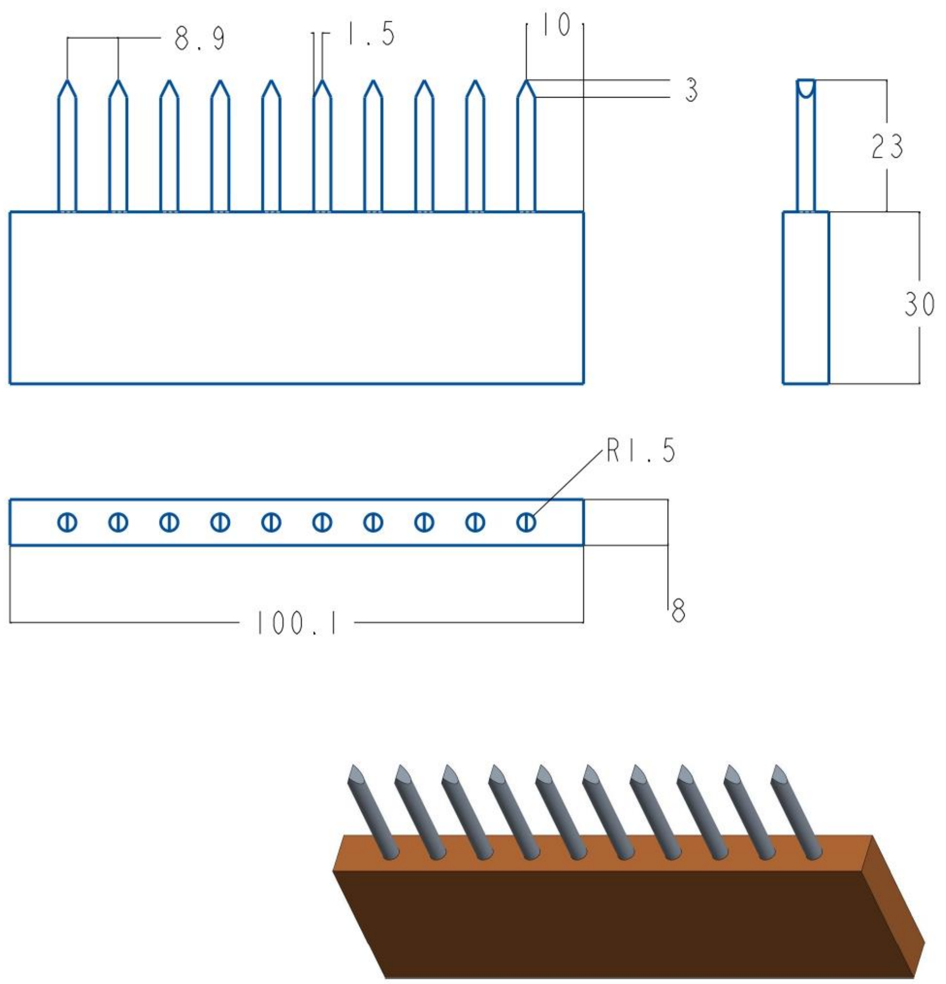
UVIC UNIVERSITAT DE VIC UNIVERSITAT CENTRAL DE CATALUNYA	**PROJECTE INTEGRAT II**
	T_1.1 – Tapa
Alumnes: Sergi Busquets - Pau Capdevila Gerard Sánchez - Marcel Sánchez	GRUP 5
03/06/2025	Plànol segons ISO 2768-89-m
Professors: Moises Garín i Clara Sandino	**Nº de plànol:** 3	**Nº de plànols:** 23



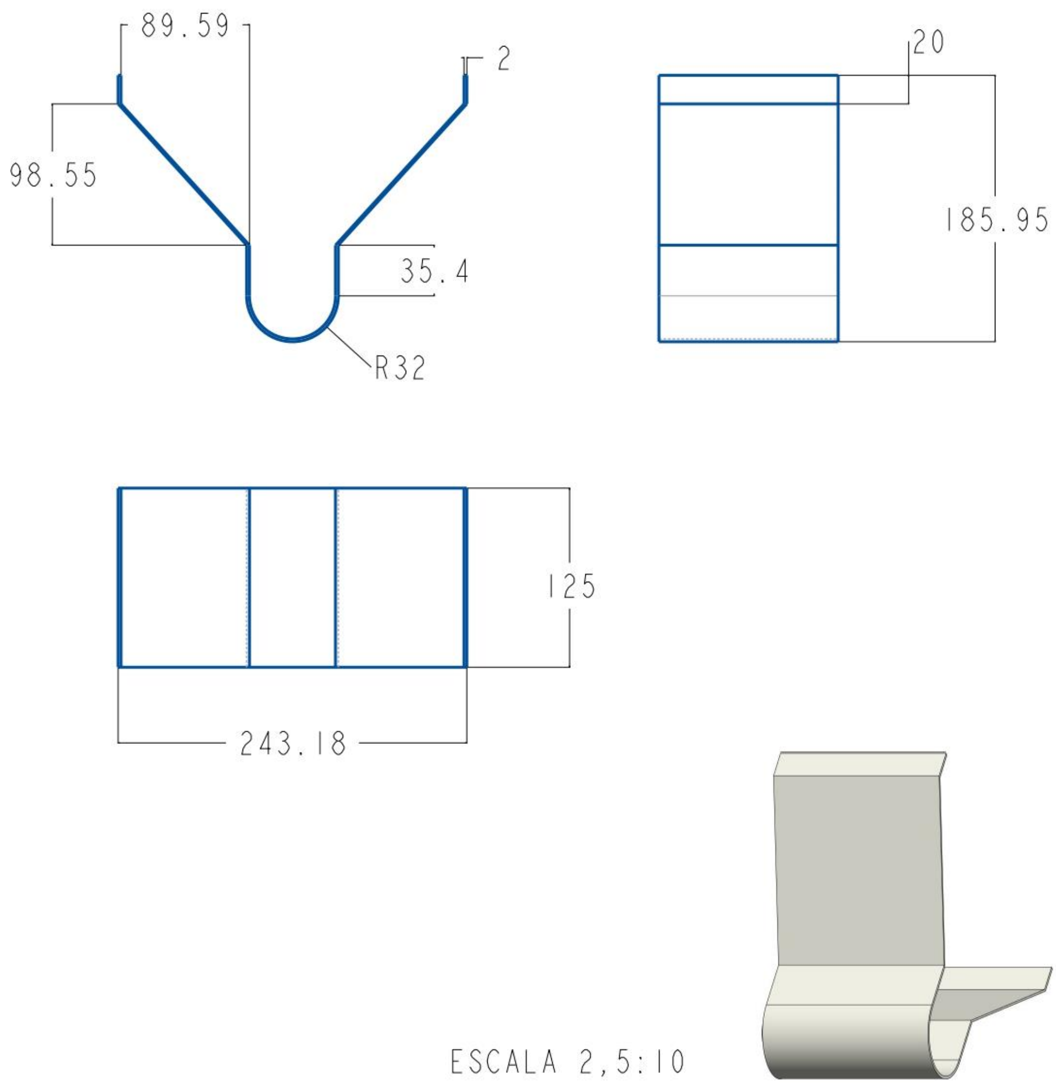
UVIC UNIVERSITAT DE VIC UNIVERSITAT CENTRAL DE CATALUNYA	**PROJECTE INTEGRAT II**	
	T_1.2 – Tapa Interior	
Alumnes: Sergi Busquets - Pau Capdevila Gerard Sánchez - Marcel Sánchez	GRUP 5	
03/06/2025	Plànol segons ISO 2768-89-m	
Professors: Moises Garín i Clara Sandino	**Nº de plànol:** 4	**Nº de plànols:** 23



UVIC UNIVERSITAT DE VIC UNIVERSITAT CENTRAL DE CATALUNYA	**PROJECTE INTEGRAT II**	
	T_1.3 – Pinta A	
Alumnes: Sergi Busquets - Pau Capdevila Gerard Sánchez - Marcel Sánchez	GRUP 5	
03/06/2025	Plànol segons ISO 2768-89-m	
Professors: Moises Garín i Clara Sandino	**Nº de plànol:** 5	**Nº de plànols:** 23



UVIC UNIVERSITAT DE VIC UNIVERSITAT CENTRAL DE CATALUNYA	PROJECTE INTEGRAT II	
	T_1.4 – Pinta B	
Alumnes: Sergi Busquets - Pau Capdevila Gerard Sánchez - Marcel Sánchez	GRUP 5	
03/06/2025	Plànol segons ISO 2768-89-m	
Professors: Moises Garín i Clara Sandino	Nº de plànol: 6	Nº de plànols: 23



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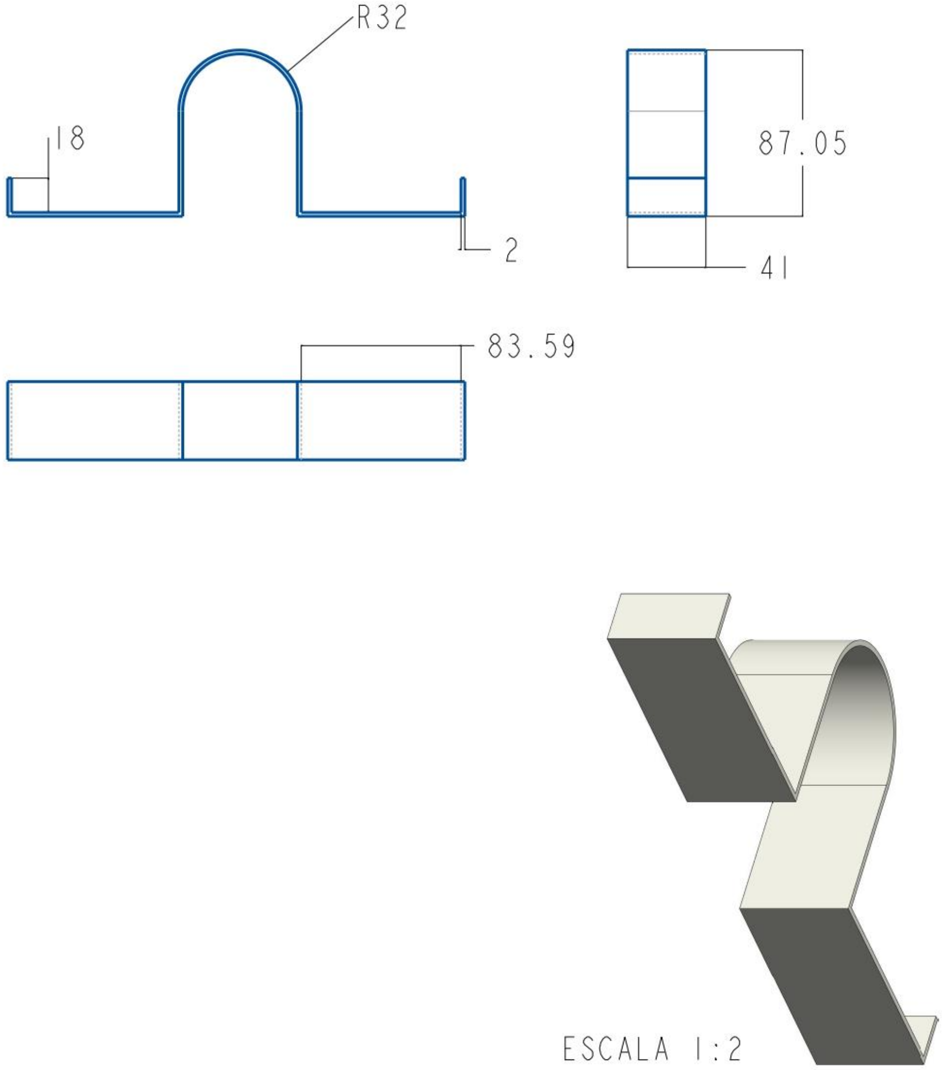
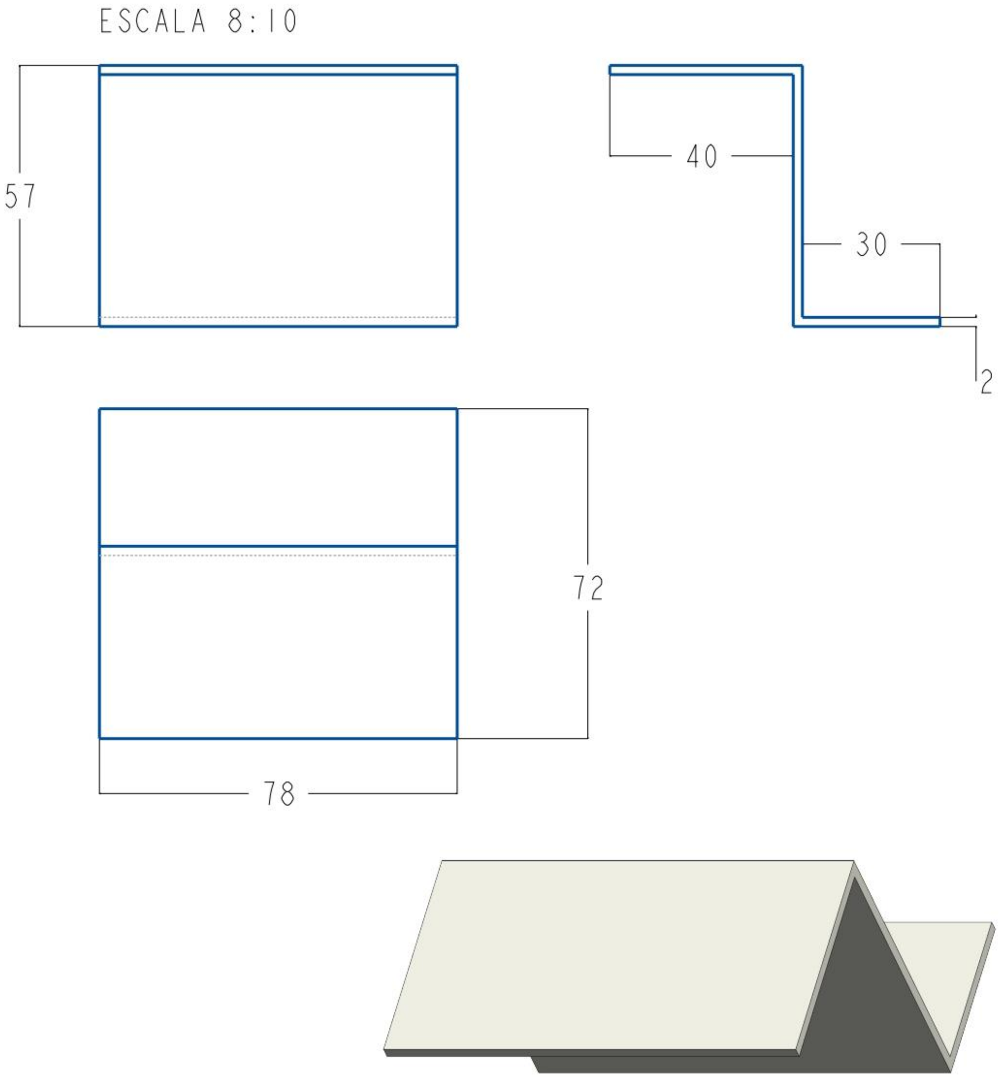
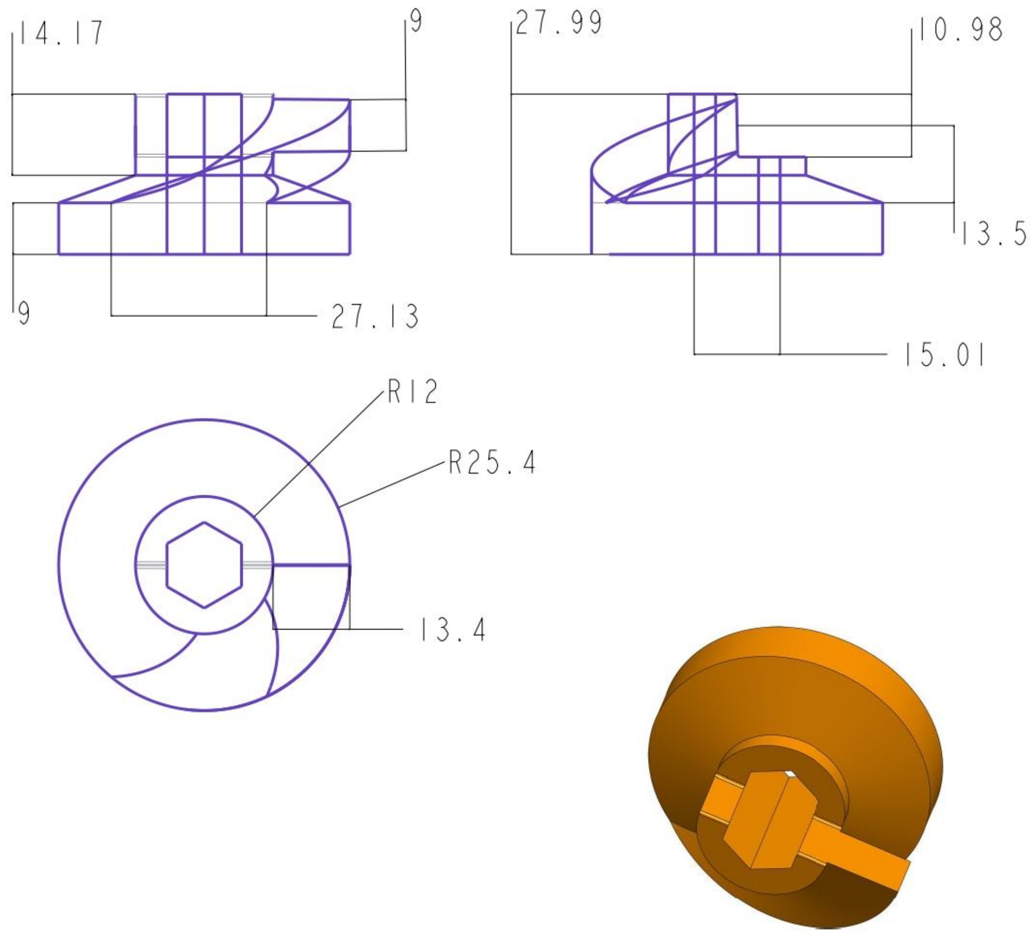
	T_1.5 – Xapa 1
Alumnes: Sergi Busquets - Pau Capdevila Gerard Sánchez - Marcel Sánchez	GRUP 5
03/06/2025	Plànol segons ISO 2768-89-m
Professors: Moises Garín i Clara Sandino	**Nº de plànol:** 7 / **Nº de plànols:** 23



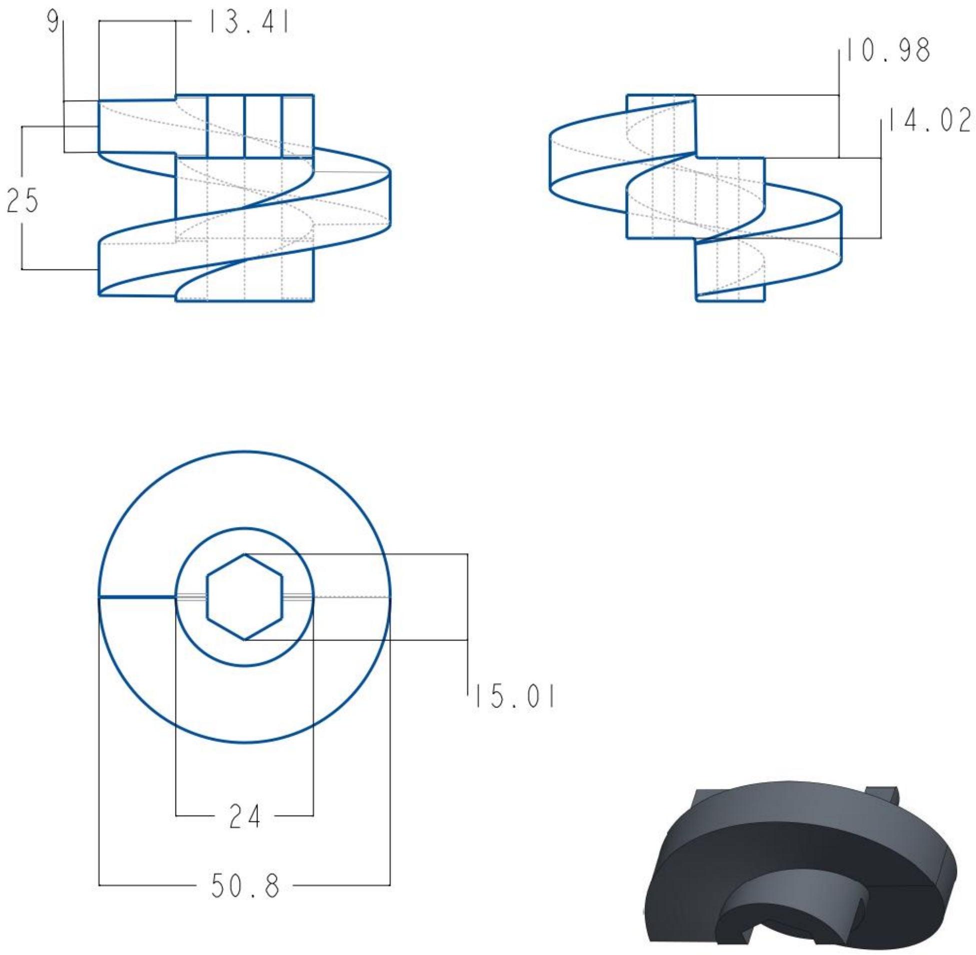
UVIC UNIVERSITAT DE VIC UNIVERSITAT CENTRAL DE CATALUNYA	**PROJECTE INTEGRAT II** **T_1.6 – Xapa 2**
Alumnes: Sergi Busquets - Pau Capdevila Gerard Sánchez - Marcel Sánchez	GRUP 5
03/06/2025	Plànol segons ISO 2768-89-m
Professors: Moises Garín i Clara Sandino	**Nº de plànol:** 8	**Nº de plànols:** 23



UVIC UNIVERSITAT DE VIC UNIVERSITAT CENTRAL DE CATALUNYA	**PROJECTE INTEGRAT II**	
	T_1.7 – Xapa 3	
Alumnes: Sergi Busquets - Pau Capdevila Gerard Sánchez - Marcel Sánchez	GRUP 5	
03/06/2025	Plànol segons ISO 2768-89-m	
Professors: Moises Garín i Clara Sandino	**Nº de plànol:** 9	**Nº de plànols:** 23



UVIC UNIVERSITAT DE VIC UNIVERSITAT CENTRAL DE CATALUNYA	**PROJECTE INTEGRAT II**	
	T_2.1 – Extrem Cargol	
Alumnes: Sergi Busquets - Pau Capdevila Gerard Sánchez - Marcel Sánchez	GRUP 5	
30/05/2025	Plànol segons ISO 2768-89-m	
Professors: Moises Garín i Clara Sandino	**Nº de plànol:** 10	**Nº de plànols:** 23



UVIC UNIVERSITAT DE VIC UNIVERSITAT CENTRAL DE CATALUNYA	**PROJECTE INTEGRAT II**
	T_2.2 – Interior Cargol
Alumnes: Sergi Busquets - Pau Capdevila Gerard Sánchez - Marcel Sánchez	GRUP 5
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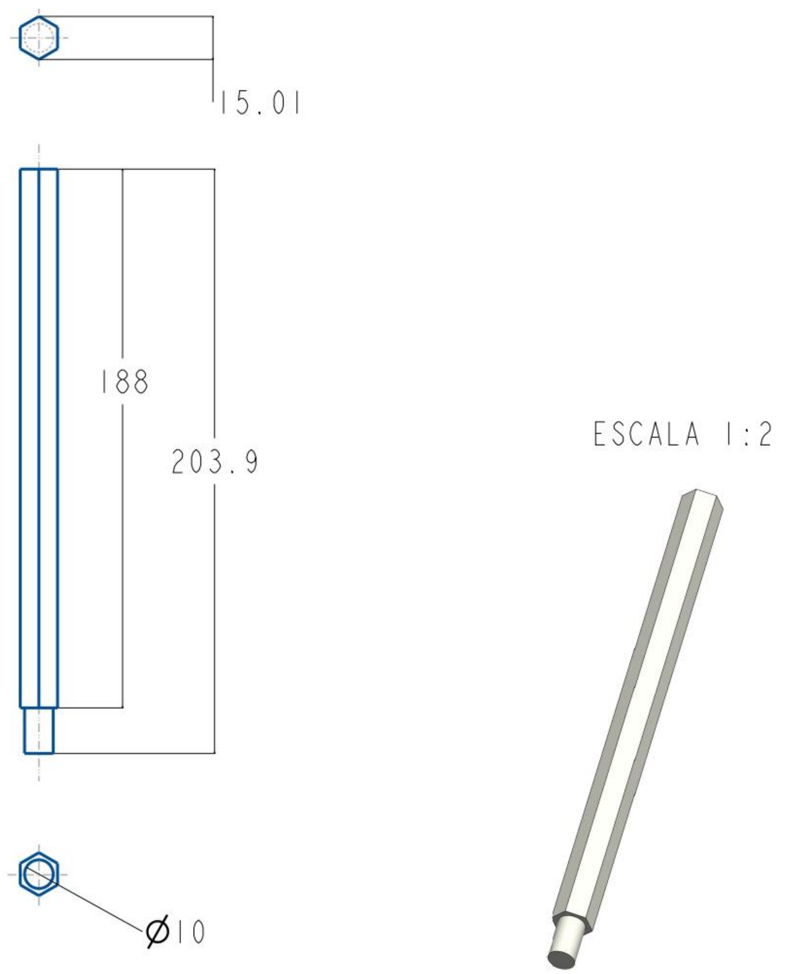
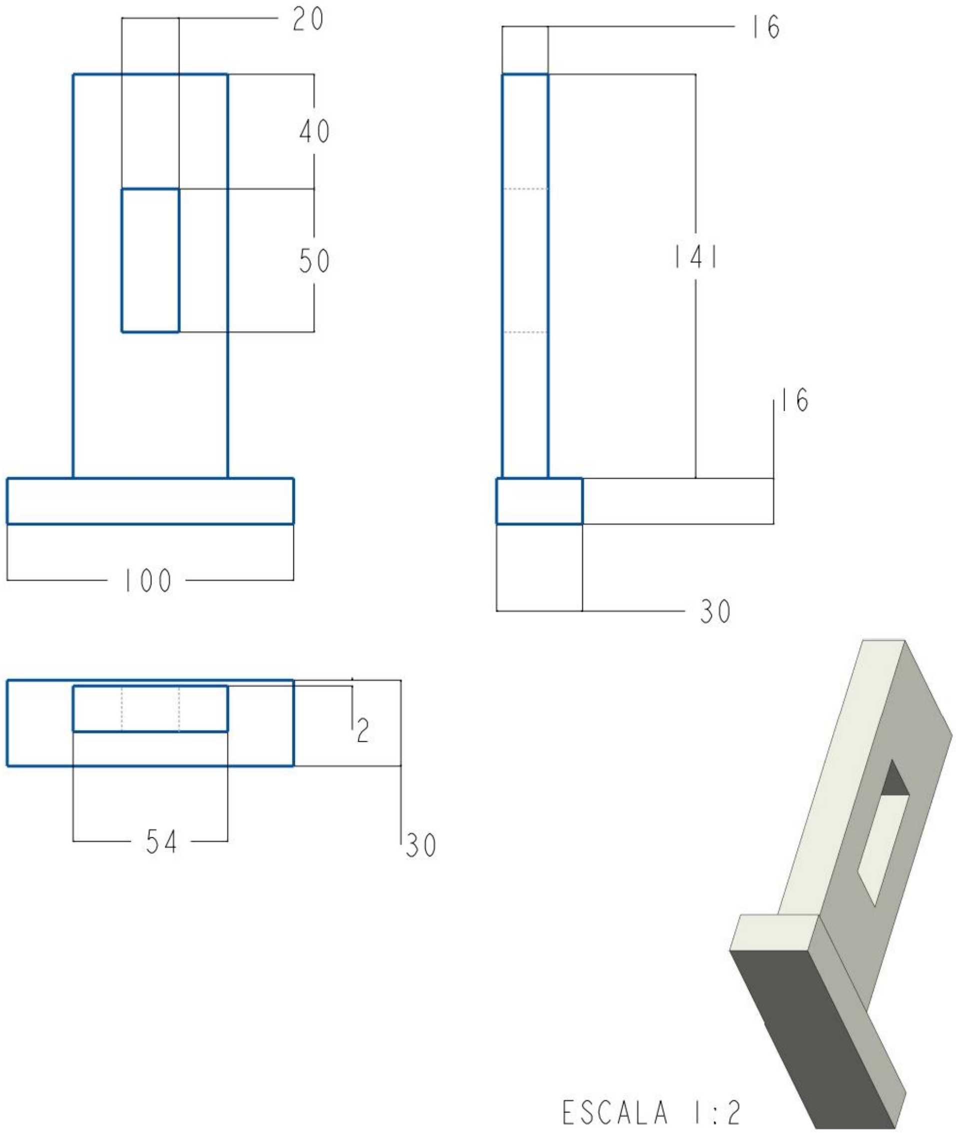
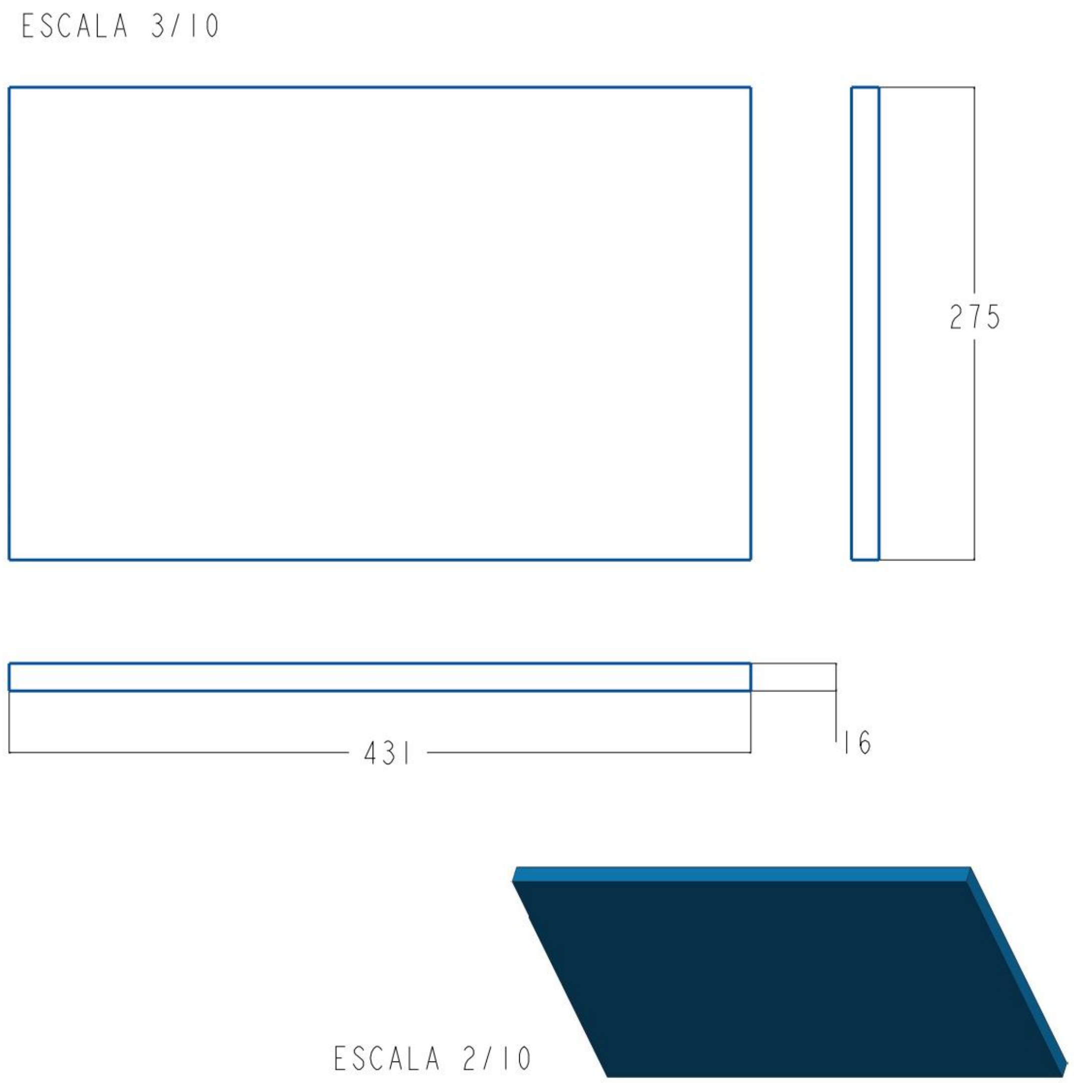
Professors: Moises Garín i Clara Sandino	**Nº de plànol:** 11	**Nº de plànols:**



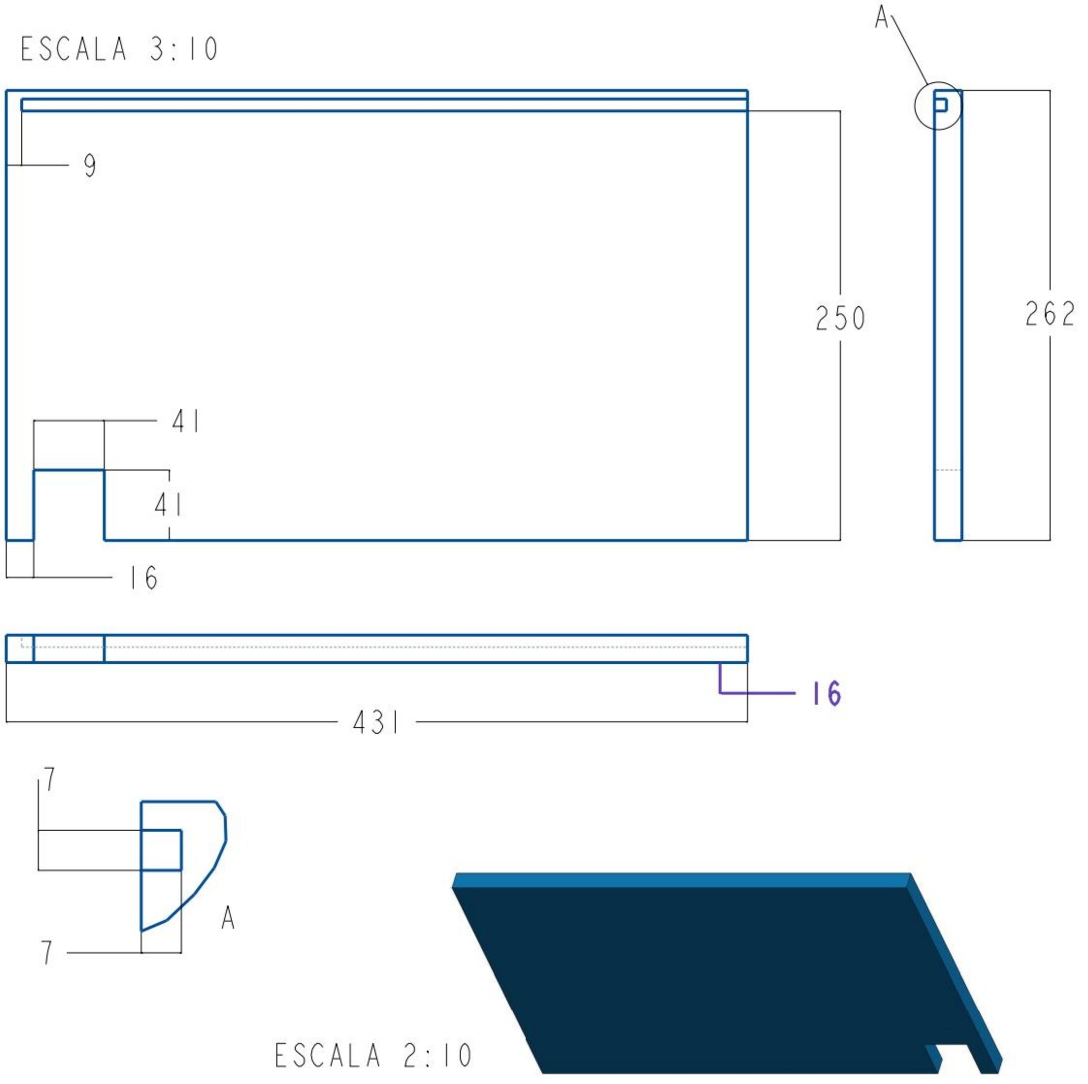
UVIC UNIVERSITAT DE VIC UNIVERSITAT CENTRAL DE CATALUNYA	**PROJECTE INTEGRAT II** **T_2.3 – Eix Hexagonal**
Alumnes: Sergi Busquets - Pau Capdevila Gerard Sánchez - Marcel Sánchez	GRUP 5
30/05/2025	Plànol segons ISO 2768-89-m
Professors: Moises Garín i Clara Sandino	**Nº de plànol:** 12 / **Nº de plànols:** 23



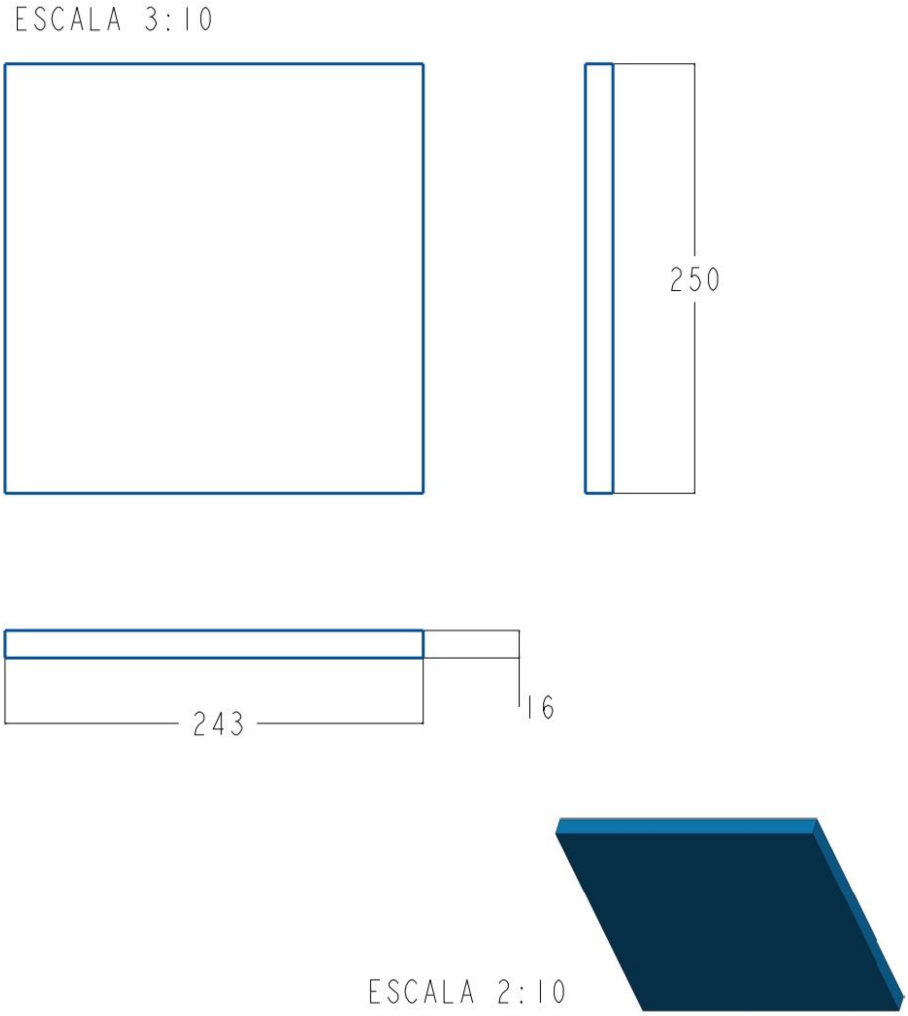
UVIC UNIVERSITAT DE VIC UNIVERSITAT CENTRAL DE CATALUNYA	**PROJECTE INTEGRAT II**	
	T_2.4 – Suport Espiral	
Alumnes: Sergi Busquets - Pau Capdevila Gerard Sánchez - Marcel Sánchez	GRUP 5	
03/06/2025	Plànol segons ISO 2768-89-m	
Professors: Moises Garín i Clara Sandino	**Nº de plànol:** 13	**Nº de plànols:** 23



UVIC UNIVERSITAT DE VIC UNIVERSITAT CENTRAL DE CATALUNYA	**PROJECTE INTEGRAT II**	
	T_3.1 - Terra	
Alumnes: Sergi Busquets - Pau Capdevila Gerard Sánchez - Marcel Sánchez	GRUP 5	
06/05/2025	Plànol segons ISO 2768-89-m	
Professors: Moises Garín i Clara Sandino	**Nº de plànol:** 14	**Nº de plànols:** 23



UVIC UNIVERSITAT DE VIC UNIVERSITAT CENTRAL DE CATALUNYA	**PROJECTE INTEGRAT II**	
	T_3.2 – Paret gran	
Alumnes: Sergi Busquets - Pau Capdevila Gerard Sánchez - Marcel Sánchez	GRUP 5	
08/05/2025	Plànol segons ISO 2768-89-m	
Professors: Moises Garín i Clara Sandino	**Nº de plànol:** 15	**Nº de plànols:** 23



UVIC UNIVERSITAT DE VIC UNIVERSITAT CENTRAL DE CATALUNYA	**PROJECTE INTEGRAT II**	
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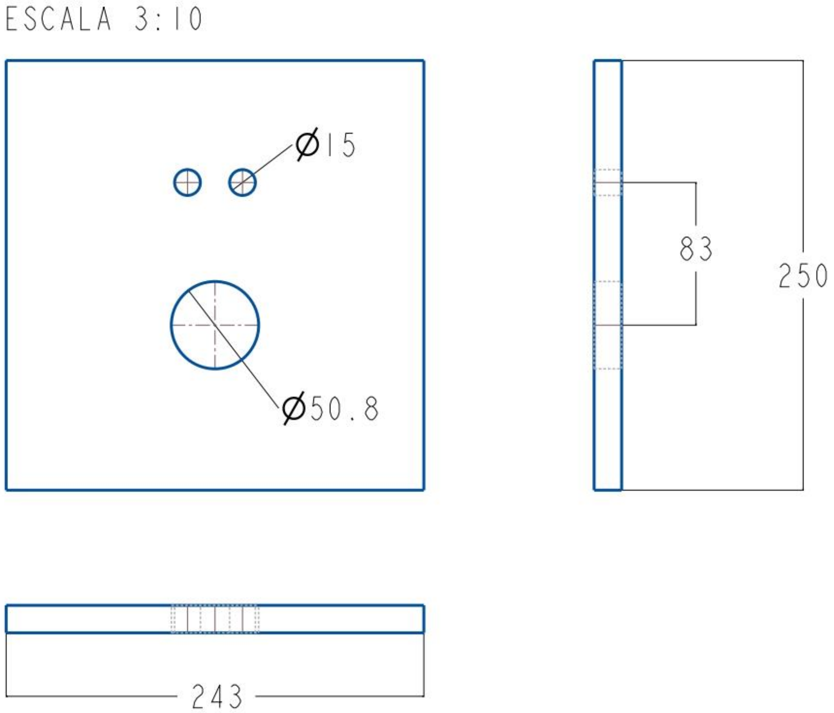
Alumnes: Sergi Busquets - Pau Capdevila Gerard Sánchez - Marcel Sánchez	GRUP 5	
08/05/2025	Plànol segons ISO 2768-89-m	
Professors: Moises Garín i Clara Sandino	**Nº de plànol:** 16	**Nº de plànols:** 23



UVIC UNIVERSITAT DE VIC UNIVERSITAT CENTRAL DE CATALUNYA	PROJECTE INTEGRAT II	
	T_3.4 – Paret Interior	
Alumnes: Sergi Busquets - Pau Capdevila Gerard Sánchez - Marcel Sánchez	GRUP 5	
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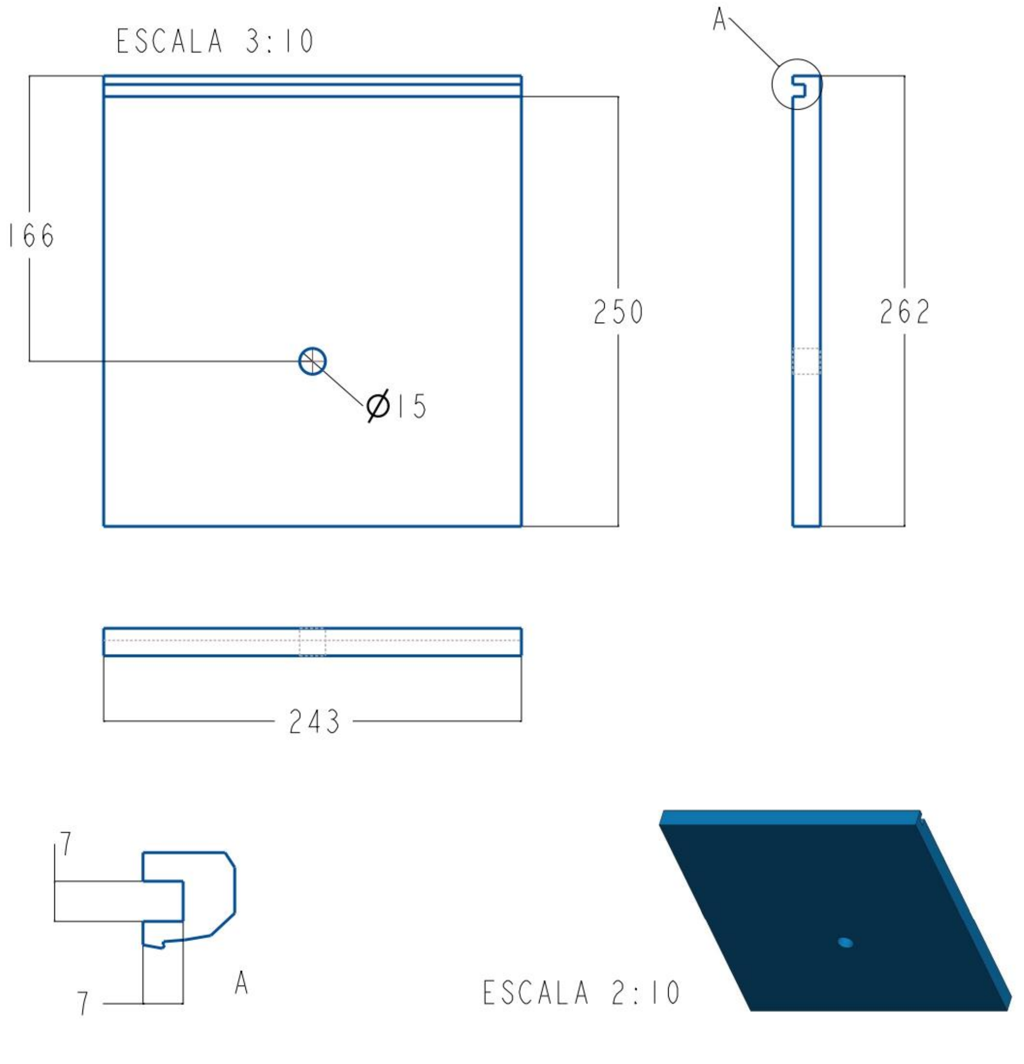
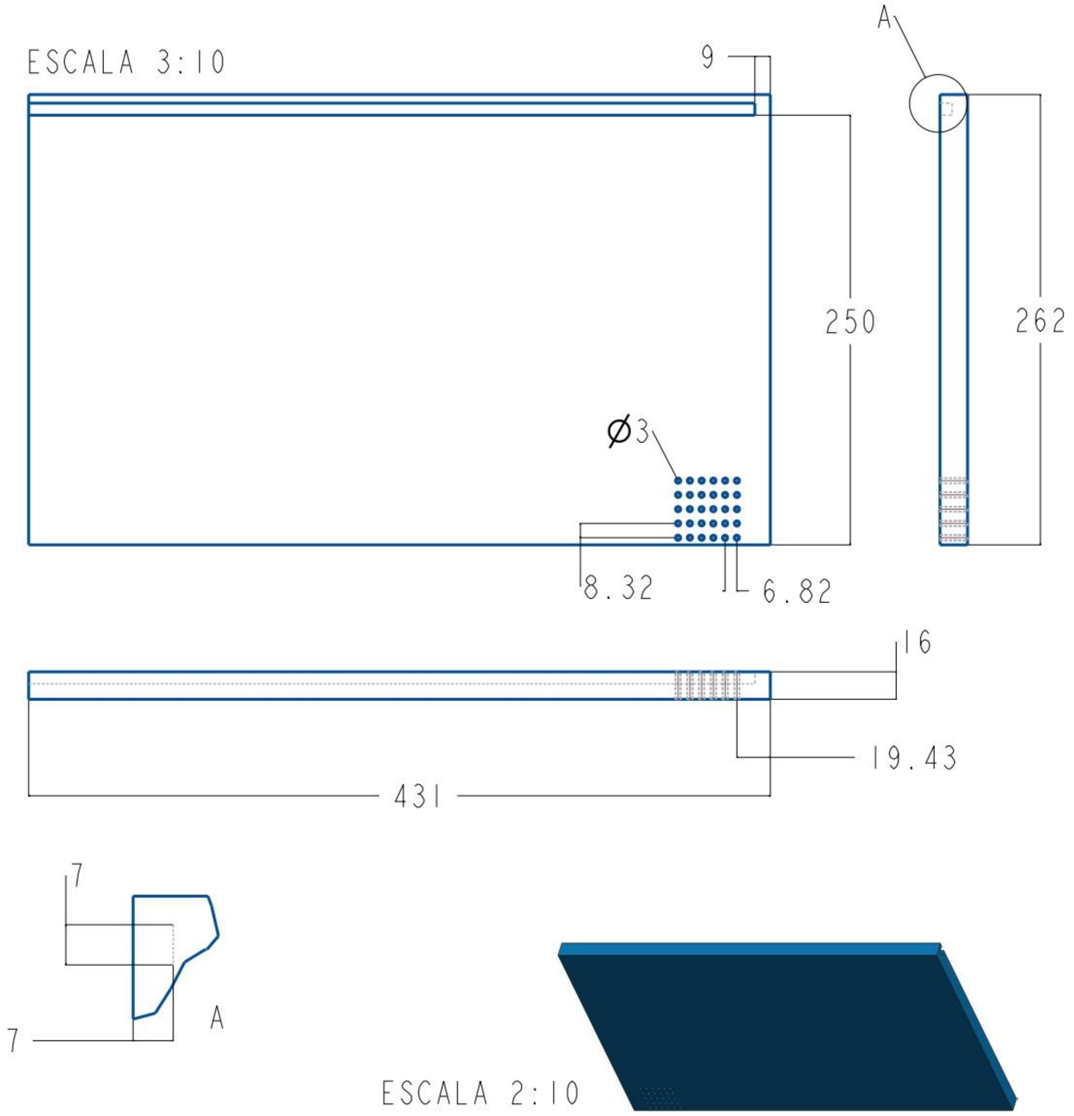
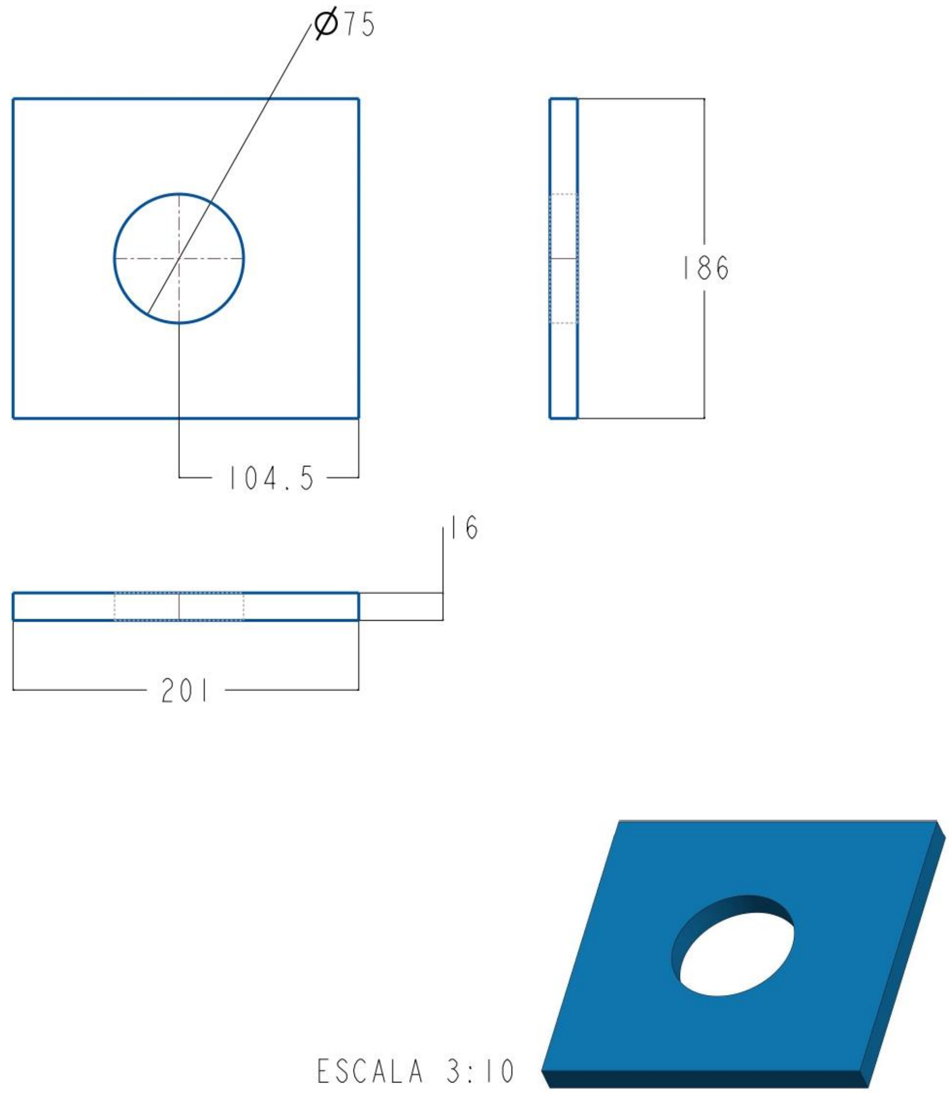
Professors: Moises Garín i Clara Sandino	Nº de plànol: 17	Nº de plànols: 23



UVIC UNIVERSITAT DE VIC UNIVERSITAT CENTRAL DE CATALUNYA	**PROJECTE INTEGRAT II**	
	T_3.5 – Paret final	
Alumnes: Sergi Busquets - Pau Capdevila Gerard Sánchez - Marcel Sánchez	GRUP 5	
08/05/2025	Plànol segons ISO 2768-89-m	
Professors: Moises Garín i Clara Sandino	**Nº de plànol**: 18	**Nº de plànols:** 23



UVIC UNIVERSITAT DE VIC UNIVERSITAT CENTRAL DE CATALUNYA	**PROJECTE INTEGRAT II**
	T_3.6 – Paret Gran 2
Alumnes: Sergi Busquets - Pau Capdevila Gerard Sánchez - Marcel Sánchez	GRUP 5
30/05/2025	Plànol segons ISO 2768-89-m
Professors: Moises Garín i Clara Sandino	**Nº de plànol:** 19 / **Nº de plànols:** 23

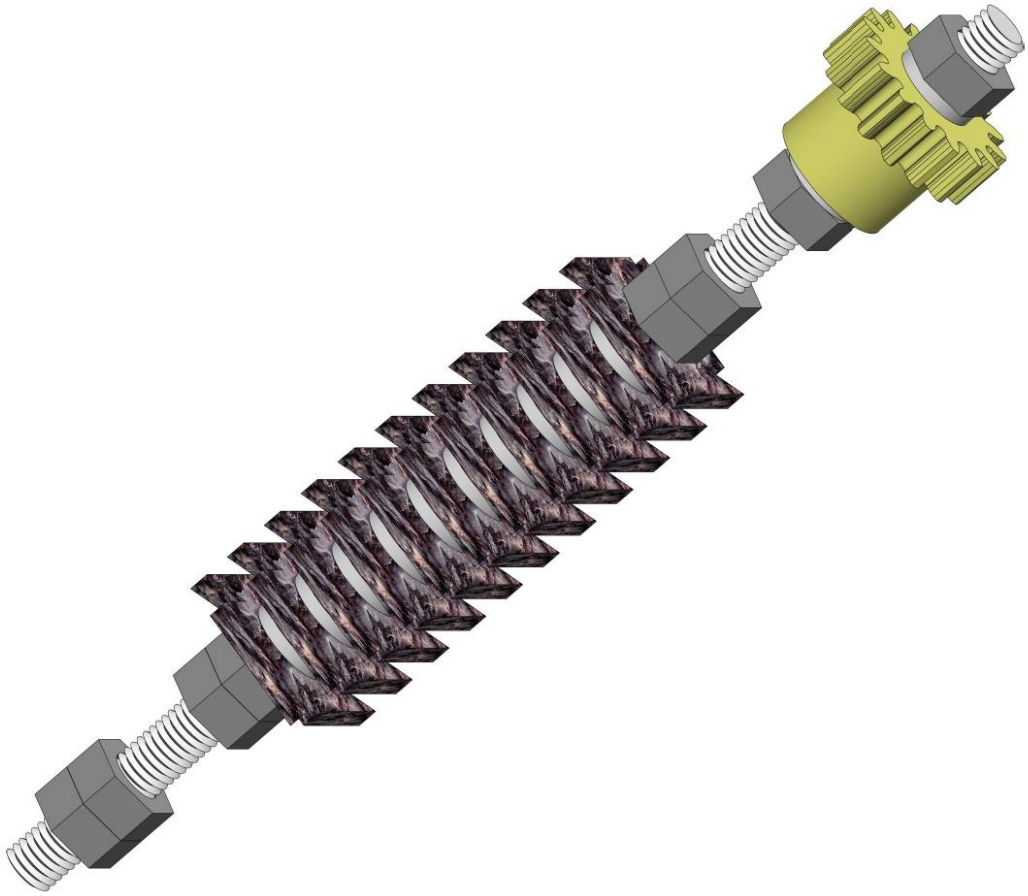


UVIC UNIVERSITAT DE VIC UNIVERSITAT CENTRAL DE CATALUNYA	**PROJECTE INTEGRAT II**	
	T_3.7 – Suport Motor	
Alumnes: Sergi Busquets - Pau Capdevila Gerard Sánchez - Marcel Sánchez	GRUP 5	
03/06/2025	Plànol segons ISO 2768-89-m	
Professors: Moises Garín i Clara Sandino	**Nº de plànol:** 20	**Nº de plànols:** 23

Material	
Eix roscat M10x240mm	1
Femelles M10 (DIN 934 / ISO 4032)	8
Volanderes ECSiNG M10	24
Engranatge Mòdul 2, Z16	1

Número de plànol	Denominació peça	Quantitat
T_4.3	Ganiveta	10

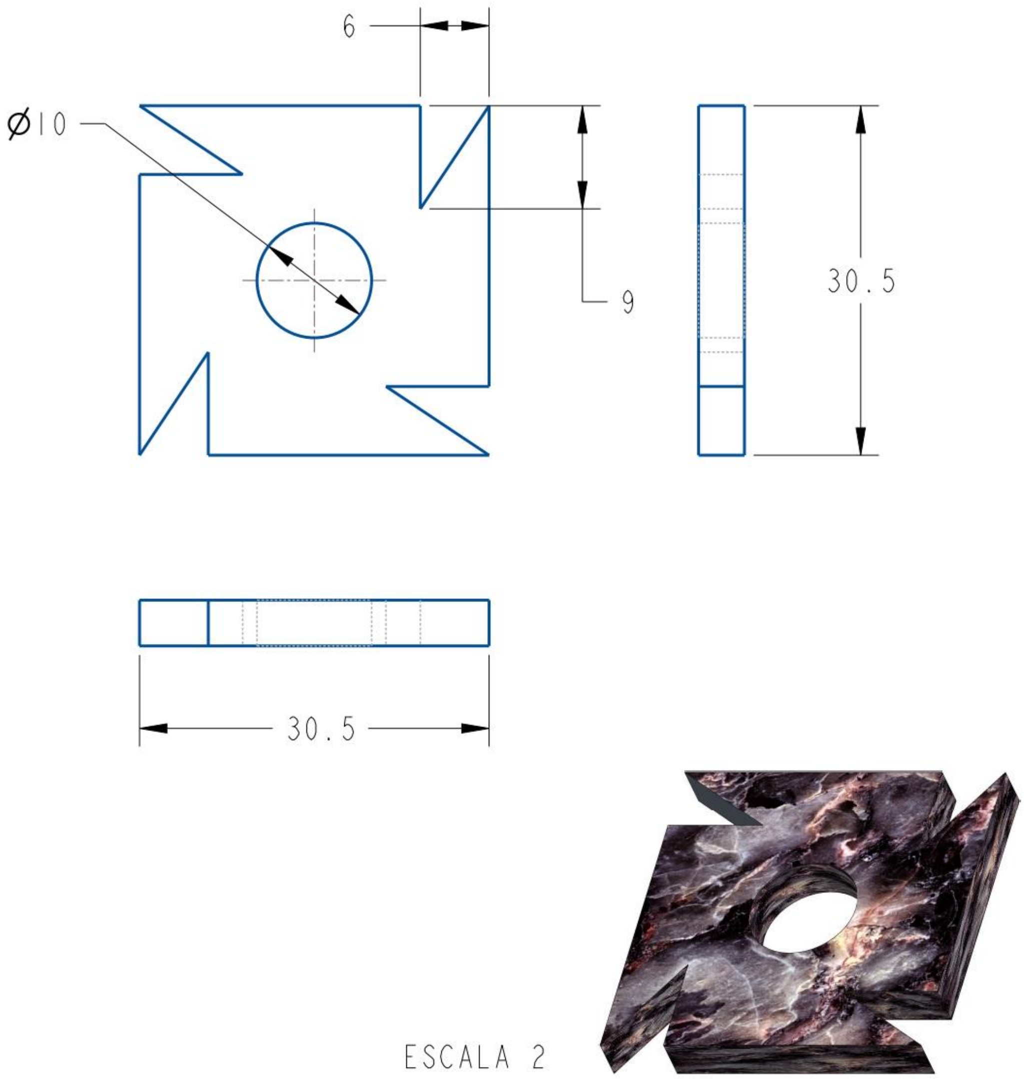
UVIC UNIVERSITAT DE VIC UNIVERSITAT CENTRAL DE CATALUNYA	PROJECTE INTEGRAT II	
	T_4.1 – Trituradora 1	
Alumnes: Sergi Busquets - Pau Capdevila Gerard Sánchez - Marcel Sánchez	GRUP 5	
03/06/2025	Plànol segons ISO 2768-89-m	
Professors: Moises Garín i Clara Sandino	**Nº de plànol:** 21	**Nº de plànols:** 23



Material	
Eix roscat M10x240mm	1
Femelles M10 (DIN 934 / ISO 4032)	8
Volanderes ECSiNG M10	22
Engranatge Mòdul 2, Z16	1

Número de plànol	Denominació peça	Quantitat
T_4.3	Ganiveta	11

UVIC UNIVERSITAT DE VIC UNIVERSITAT CENTRAL DE CATALUNYA	**PROJECTE INTEGRAT II**
	T_4.2 – Trituradora 2
Alumnes: Sergi Busquets - Pau Capdevila Gerard Sánchez - Marcel Sánchez	GRUP 5
03/06/2025	Plànol segons ISO 2768-89-m
Professors: Moises Garín i Clara Sandino	**Nº de plànol:** 22 / **Nº de plànols:** 23



UVIC UNIVERSITAT DE VIC UNIVERSITAT CENTRAL DE CATALUNYA	**PROJECTE INTEGRAT II**	
	T_4.3 – Ganiveta	
Alumnes: Sergi Busquets - Pau Capdevila Gerard Sánchez - Marcel Sánchez	GRUP 5	
03/06/2025	Plànol segons ISO 2768-89-m	
Professors: Moises Garín i Clara Sandino	**Nº de plànol:** 23	**Nº de plànols:** 23

7.2. Software Appendix

```
#include <Wire.h>             // I2C LIBRARY FOR SENSOR COMMUNICATION
#include <Adafruit_INA219.h>  // INA219 CURRENT SENSOR LIBRARY
#include <Servo.h>            // SERVO CONTROL LIBRARY

bool starter;
int current_ina, i;                   // CONTROL VARIABLES, CURRENT READING AND LOOP INDEX

int p_spd = 3;      // MAIN MOTOR SPEED
int p_vent = 4;     // FAN SPEED
int p_spir = 5;     // SPIRAL SPEED
int p_dir_1 = 10;   // MAIN MOTOR DIRECTION CONTROL
int p_dir_2 = 11;   // MAIN MOTOR DIRECTION CONTROL
int p_drc_1 = 17;   // DOOR SENSOR
int p_srv_1 = 6;    // SERVO 1 CONTROL
int p_srv_2 = 7;    // SERVO 2 CONTROL

Servo servo_1;            // SERVO DECLARATION
Servo servo_2;
Servo servo_3;            // SPIRAL SERVO DECLARATION
Adafruit_INA219 ina219;   // CURRENT SENSOR DECLARATION
```

```
void setup() {
  Serial.begin(115200);

  ina219.begin();             // CURRENT SENSOR INITIALITATION
  servo_1.attach(p_srv_1);    // ATTACH SERVOS TO CONTROL PINS
  servo_2.attach(p_srv_2);
  servo_3.attach(p_spir);

  pinMode(p_spd, OUTPUT);             // PWM MAIN MOTOR SPEED
  pinMode(p_vent, OUTPUT);            // PWM FAN SPEED
  pinMode(p_spir, OUTPUT);
  pinMode(p_dir_1, OUTPUT);           // DIRECTION 1 PIN
  pinMode(p_dir_2, OUTPUT);           // DIRECTION 2 PIN
  pinMode(p_drc_1, INPUT_PULLUP);     // DOOR CLOSED SENSOR 1
  pinMode(p_grn, INPUT_PULLUP);       // GREEN BUTTON PIN
  pinMode(p_red, INPUT_PULLUP);       // RED BUTTON PIN
  pinMode(p_srv_1, OUTPUT);           // SERVO 1 CONTROL PIN
  pinMode(p_srv_2, OUTPUT);           // SERVO 2 CONTROL PIN
  pinMode(p_seta, INPUT);             // EMERGENCY BUTTON PIN

  TCCR3A = ( TCCR3A & B11111000 | B00000001 );    // MAIN MOTOR PWM TIMER CONTROL
  TCCR3B = ( TCCR3B & B11111000 | B00000010 );    // PWM PHASE CORRECT 9-BIT MODE / PRESCALER CLK/8

  analogWrite(p_vent, 0);     // START FAN AND SPIRAL OFF
  analogWrite(p_spd, 0);
  servo_1.write(90);          // RECLINE SERVO MOTORS
  servo_2.write(90);
  servo_3.write(90);
  starter = false;
}
```

```
void loop(){
  if(!digitalRead(p_drc_1) && starter == false){  // IF DOOR IS CLOSED, MACHINE CAN PROCEED
    digitalWrite(p_dir_1, LOW);          // SET SELECTED DIRECTION TO DIRECTION CONTROL PINS
    digitalWrite(p_dir_2, HIGH);
    for(i=50;i<250;i++){                 // ENGAGE WORKING SPEED IN LINEAR MANNER TO AVOID CURRENT PEAKS
      analogWrite(p_spd, i);
      delay(10);
    }
    analogWrite(p_vent, 80);             // TURN ON FAN
    servo_3.write(180);                  // TURN ON SPIRAL
    starter = true;                      // INITIAL SEQUENCE STARTED
  }
  else if(digitalRead(p_drc_1)){         // IF DOOR IS OPEN, STOP ALL ACTIONS
    digitalWrite(p_dir_1, LOW);          // SET SELECTED DIRECTION TO DIRECTION CONTROL PINS
    digitalWrite(p_dir_2, LOW);
    for(i=200;i>50;i--){                 // ENGAGE WORKING SPEED IN LINEAR MANNER TO AVOID CURRENT PEAKS
      analogWrite(p_spd, i);
      delay(10);
    }
    analogWrite(p_vent, 0);              // TURN OFF FAN
    servo_3.write(90);                   // TURN OFF SPIRAL
    starter = false;                     // INITIAL SEQUENCE READY TO REPEAT
  }
```

```
  current_ina = ina219.getCurrent_mA();         // READ CURRENT SENSOR STATUS
  if(current_ina > 1600 || current_ina < -700){ // IF PEAK CURRENT SURPASSES THRESHOLD, ENGAGE ANTI-CLOGGING PROCEDURE
    digitalWrite(p_dir_1, LOW);                 // FORCE MOTOR DRIVER TO STOP
    digitalWrite(p_dir_2, LOW);
    delay(500);
    servo_1.write(110);                  // ENGAGE SERVO MOTORS IN DECLOGGING POSITION (ONLY IN BACKWARD MODE)
    servo_2.write(50);
    digitalWrite(p_dir_1, HIGH);         // SWAP MOTOR DIRECTION
    digitalWrite(p_dir_2, LOW);
    for(i=50;i<101;i++){                 // ENGAGE WORKING SPEED IN LINEAR MANNER TO AVOID CURRENT PEAKS
      analogWrite(p_spd, i);
      delay(10);
    }
    delay(500);
    digitalWrite(p_dir_1, LOW);          // SWAP MOTOR DIRECTION TO ORIGINAL DIRECTION
    digitalWrite(p_dir_2, HIGH);
    analogWrite(p_spd,100);
    delay(500);
    for(i=50;i<101;i++){                 // ENGAGE WORKING SPEED IN LINEAR MANNER TO AVOID CURRENT PEAKS
      analogWrite(p_spd, i);
      delay(10);
    }
    servo_1.write(90);                   // RECLINE SERVO MOTORS
    servo_2.write(90);
    starter = false;
  }
}
```

7.2.1. Software libraries

[1] "Wire.h":
https://docs.arduino.cc/language-reference/en/functions/communication/wire/

[2] "Adafruit_INA219":
https://github.com/adafruit/Adafruit_INA219

[3] "Servo.h": https://docs.arduino.cc/libraries/servo/

7.3. Electronical Appendix

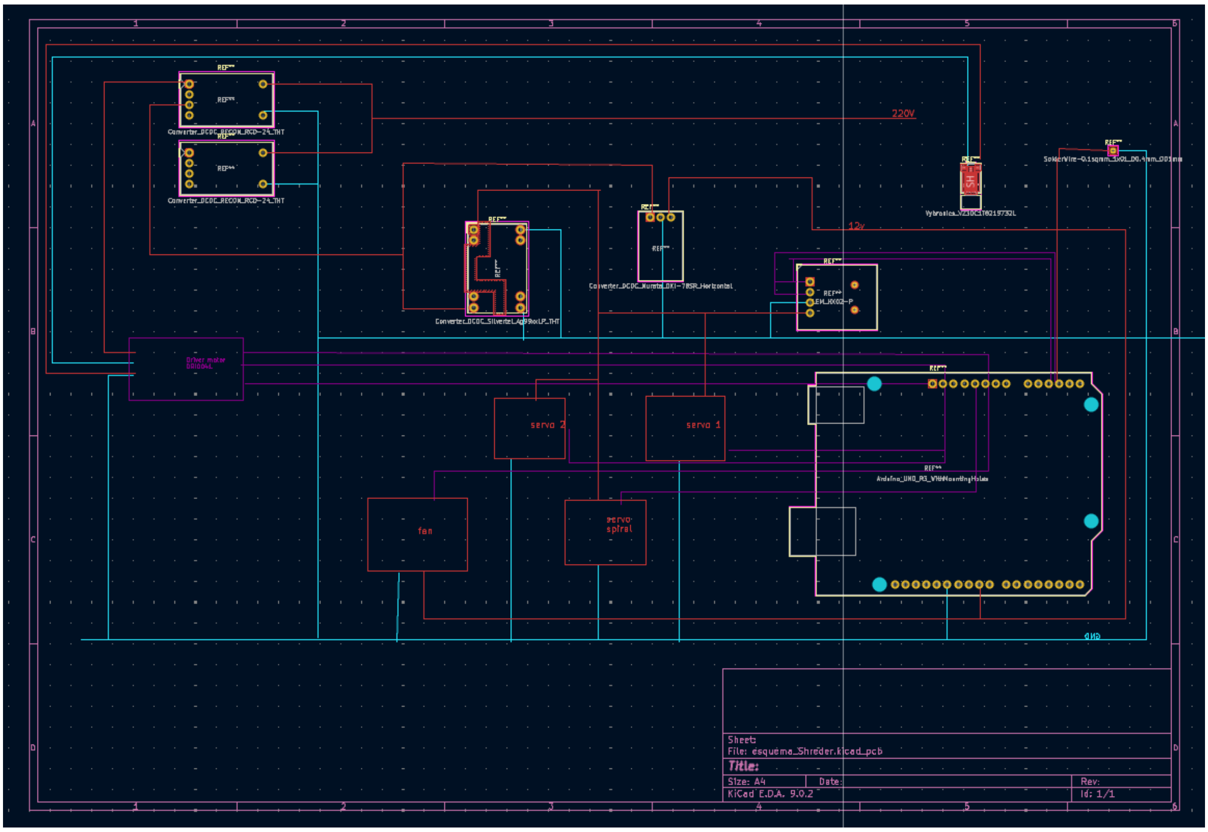


Figure 4: Connection's schematic

7.3.1. Electronical devices and peripherals

[1] Arduino Mega 2560:
https://store.arduino.cc/products/arduino-mega-2560-rev3

[2] SG90 Servomotor:
http://www.ee.ic.ac.uk/pcheung/teaching/DE1_EE/stores/sg90_datasheet.pdf

[3] INA219 Current/Power sensor:
https://www.ti.com/lit/ds/symlink/ina219.pdf?ts=1749082885825&ref_url=https%253A%252F%252Fwww.google.com%252F

[4] XY160D DC Motor driver:
https://www.handsontec.com/dataspecs/module/7A-160W%20motor%20control.pdf