GRADO EN INGENIERÍA EN TECNOLOGÍAS INDUSTRIALES

TRABAJO FIN DE GRADO

# Connected Frame. Diseño de un sistema antirrobo conectado para cuadros.

Autor: Loreto Bohigues Flores

Director: Álvaro Pérez Bello

Madrid, Julio 2021

Declaro, bajo mi responsabilidad, que el Proyecto presentado con el título

Diseño de un sistema antirrobo para cuadros

en la ETS de Ingeniería - ICAI de la Universidad Pontificia Comillas en el

curso académico 2020/2021 es de mi autoría, original e inédito y

no ha sido presentado con anterioridad a otros efectos.

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tomada de otros documentos está debidamente referenciada.

Fdo.: Loreto Bohigues Flores Fecha: 18/ 07/ 2021

Autorizada la entrega del proyecto

EL DIRECTOR DEL PROYECTO

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# CONNECTED FRAME. DISEÑO DE UN SISTEMA ANTIRROBO CONECTADO PARA CUADROS

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Director: Pérez Bello, Álvaro.
Entidad Colaboradora: Altair

## RESUMEN DEL PROYECTO

A lo largo de este proyecto, se ha llevado a cabo el diseño y fabricación de un producto conectado, en concreto un marco para cuadros, además del desarrollo de un plan de negocio en torno a dicho producto. De este modo, tras la fase de diseño se ha construido el prototipo, empleando la impresión 3D como método de fabricación. Dicho prototipo se ha conectado a la nube a través de la tecnología del Internet de la cosas, para así ser monitorizado a través de una sencilla aplicación.

**Palabras clave**: Arte, Marco, Conservación, Seguridad, IoT, Impresión 3D, Empresa

### 1. Introducción

Aunque en los últimos años los avances tecnológicos han permitido disponer de sistemas que protegen mucho más las obras de arte, sólo los museos pueden permitirse este tipo de seguridad, mientras que los propietarios particulares de obras de arte no disponen de un sistema adecuado para ellos. Los productos disponibles hoy en día en el mercado, como los marcos microclimáticos (SIT, 2016) y los detectores de movimiento (Bea Sensors, s.f.) están enfocados a la protección del arte dentro de los museos.

Con el fin de preservar y proteger estas pinturas y el patrimonio que representan, es necesario proporcionar a estos coleccionistas de arte privados un producto que integre la seguridad y la conservación que requieren. Por ello, este proyecto tendrá como objetivo dar una solución a este problema utilizando la tecnología del Internet de las Cosas (IoT). Esta tecnología permitirá al propietario de la obra de arte tener más conectividad y, como consecuencia, aumentará la inmediatez de la información a la hora de monitorizar el cuadro.

La idea principal del proyecto es enfocarlo como la creación de una start-up que se centra en un cuadro conectado. El objetivo es diseñar y construir un prototipo del producto, tanto la parte mecánica como la electrónica, así como una plataforma a través de la cual se controlará la obra de arte. Por último, se llevará a cabo un plan de negocio.

### 2. Diseño del prototipo

La primera sección del proyecto consiste en el diseño del producto que más tarde se fabricará, como se ha mencionado anteriormente. De este modo, el diseño del prototipo se ha dividido en tres bloques principales: el diseño del hardware, el diseño en 3Dpor ordenador del marco y el diseño del software.

Para diseñar el hardware apropiadamente se ha utilizado el programa Fritzing y se han escogido los distintos elementos. La placa Arduino nano 33 IoT se ha considerado la más apropiada debido a su reducido tamaño y a que incluye un módulo Wifi y un acelerómetro. Asimismo, se ha elegido el sensor DHT22 para medir la humedad y la temperatura del medio y el sensor BH1750 (GY30) para medir la intensidad lumínica. El diagrama del diseño del hardware se muestra a continuación en la Ilustración 1.

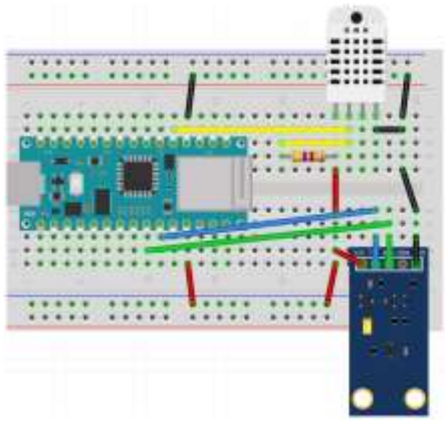

*Ilustración 1. Diseño del hardware*

Por otra parte, para al diseño de las piezas del marco, se ha utilizado el programa Altair Inspire Studio. El marco se ha dividido en cuatro piezas principales que irán ensambladas entre sí mediante cuñas. Además, se han diseñado tres piezas donde se insertarán los distintos sensores y la placa, y una chapa que ocultará la parte trasera del cuadro.

En cuanto al software, tendrá tres funciones principales, la lectura de las variables a medir, el procesamiento de dicha información y la activación de las alarmas tanto para la conservación como para la parte de seguridad del marco, como puede observarse en la siguiente ilustración (Ilustración 2).

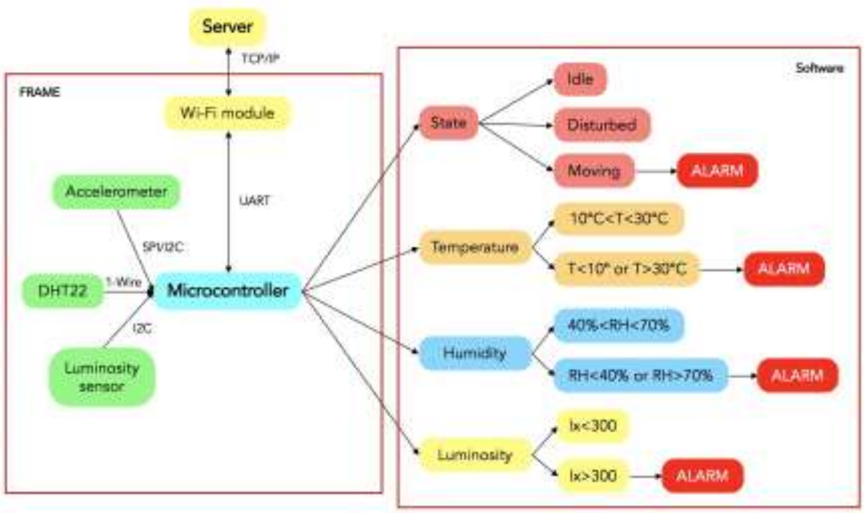


*Ilustración 2. Diagrama del funcionamiento del dispositivo*

## 3. Fabricación del prototipo

El segundo bloque del proyecto consiste en la fabricación del prototipo, partiendo del diseño realizado anteriormente. Al igual que en la sección anterior, la fase de fabricación se ha dividido en distintas partes: la fabricación del marco, el ensamblaje del hardware, el desarrollo del software y la validación del prototipo final.

Para la construcción de las piezas del marco diseñadas se han sopesado distintos métodos de fabricación posibles entre aquellos disponibles en el laboratorio de ICAI y de acuerdo a las recomendaciones del profesorado, se ha escogido la impresión 3D. De este modo, tras analizar los distintos métodos de impresión 3D disponibles (FDM, SLA y MJF) y sus características, se ha escogido el método de impresión de FDM debido al tamaño de las piezas y a la posibilidad de utilizar materiales similares a la madera. Luego, tras escoger un material de este tipo, se ha procedido a la impresión de las piezas diseñadas y su post-procesado. A continuación, se ha cortado, limado y pulido una la chapa de aluminio de 1mm de grosor, de acuerdo al diseño.

En cuanto al ensamblaje del hardware, se ha llevado a cabo al igual que en el diseño, a excepción del circuito diseñado para el sensor DHT22, para el cual se ha necesitado una alimentación mayor de la prevista, que se ha realizado de manera externa, a través de tres pilas de 1,5V. La placa y la resistencia del circuito se han soldado a una PCB, a la cual se han conectado los sensores DHT22 y BH1750 mediante cables largos debido a que es necesario situarlos en partes distintas del marco.

Finalmente, se ha desarrollado el software mediante el programa Arduino IDE a través de distintas librerías preestablecidas y se ha creado una aplicación mediante Blynk para poder monitorizar de manera sencilla la información recibida desde el dispositivo. Una vez completadas todas las partes, se ha ensamblado el marco final y se ha validado el correcto funcionamiento de este.

## 4. Plan de negocio

Basándose en las secciones desarrolladas anteriormente, se ha llevado a cabo un plan de negocio en torno al Connected Frame, con el objetivo de analizar la rentabilidad de lanzar dicho producto al mercado.

Por una parte, es necesario definir un modelo de negocio basándose en una investigación tanto del mercado del arte tanto español (McAndrew, 2017) como del mercado del arte global (McAndrew, 2021), de modo que se conozca la situación actual y las características de sus coleccionistas (Arteinformado, 2019). De este modo, se han podido establecer las características del público objetivo, a partir de lo cual se ha llevado a cabo un estudio de los competidores existentes en el mercado y se han definido las distintas partes concretas de dicho modelo de negocio.

Por otra parte, se han definido un plan financiero y un plan de precios, con el objetivo de evaluar el rendimiento de la start-up en los primeros años de vida de cara a proporcionar información para potenciales inversores. En primer lugar, el plan de precios ha permitido establecer un precio de venta aproximado del producto, que se ha basado en los costes de producción estimados a partir del prototipo construido. Dado que los marcos son productos que varían en precio y tamaño, se ha establecido una estructura de precios con una parte fija y otra variable, basándose en los tamaños estándar de las obras de arte hasta un cierto perímetro debido a la baja rentabilidad de utilizar la impresión 3D para productos de gran tamaño. Asimismo, se ha definido una tasa a pagar por los servicios IoT en los primeros años y un servicio opcional de instalación del cuadro enmarcado.

En cuanto al plan financiero, este se ha llevado a cabo con el objetivo de realizar una predicción de la situación de la empresa en los próximos cinco años. De este modo, se ha llevado a cabo una previsión de crecimiento, en el cual se ha basado la cuenta de resultados. Los costes se han estimado en base a los ingresos anuales y se ha obtenido que en el primer año la empresa tendrá unas pérdidas de unos 11.000 €, sin embargo, a partir del siguiente año, se comenzará a obtener beneficios cada vez mayores hasta alcanzar un beneficio antes de impuestos de 975.500 € en el quinto año. Asimismo, el balance de situación, aunque no sea tan preciso, da una idea tanto de la situación de la empresa al inicio de sus actividad, como de los recursos necesarios para llevar el proyecto a cabo.

Finalmente, se ha estimado el valor actual neto de la empresa si se cumplen las predicciones a 5 años, es decir, el valor que tendrá en cinco años el dinero invertido hoy. De este modo, el valor actual de la empresa a cinco años, será de aproximadamente 1,2 millones de euros, lo cual es una buena predicción, teniendo en cuenta que la inversión inicial es de tan solo 110.000 €.

## 5. Conclusiones

Este proyecto se concluye de manera muy positiva, habiendo cumplido todos los objetivos propuestos. El producto diseñado se ha desarrollado satisfactoriamente, utilizando la tecnología IoT para implementar en un solo producto tanto un sistema para la conservación de los cuadros como un sistema de alarma.

Por último, cabe destacar que la importancia y utilidad de este proyecto no sólo radica en encontrar un método de fabricación adecuado para realizar un producto conectado y rentable de forma que cumpla los objetivos, sino que va más allá y contribuye a la Industria 4.0 a través de la fabricación de un prototipo innovador y conectado y el desarrollo de una empresa en torno a él.

## 6. Referencias

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# CONNECTED FRAME. DESIGN OF AN ANTI-THEFT CONNECTED SYSTEM FOR PAINTINGS

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Supervisor: Pérez Bello, Álvaro.
Collaborating Entity: Altair

## ABSTRACT

Throughout this project, the design and manufacture of a connected product has been carried out, specifically a connected frame, as well as the development of a business plan around this product. Thus, after the design phase, the prototype was built, using 3D printing as a manufacturing method. This prototype has been connected to the cloud through the Internet of Things technology, in order to be monitored through an easy-to-use application.

**Keywords**: Art, Framework, Conservation, Security, IoT, 3D Printing, Business

### 1. Introduction

Although in the last years the technological advances have make it possible to have systems that protect the works of art a lot more, only museums can afford this kind of security, while particular art owners don't have a system suited for them. The products available in the market nowadays, such as microclimatic frames (SIT, 2016) and movement detectors (Bea Sensors, s.f.) are all focused on protecting art within museums.

In order to preserve and protect this paintings and the heritage they represent, it is necessary to provide this private art collectors with a product that integrates the security and conservation that they require. Therefore, this project will have the purpose of giving a solution to this problem by using the technology of the Internet of Things (IoT). This technology will allow the owner of the artwork to have more connectivity and, as a consequence, the immediacy of the information when monitoring the painting will increase.

The main idea of the project is to approach it as the creation of a start-up that focuses on a connected frame. The objective is to design and build a prototype of the product, both the mechanical and the electronical parts, as well as a platform through which the artwork will be controlled. Finally, a business plan will be carried out.

### 2. Design of the prototype

The first section of the project consists of the design of the product that will later be manufactured, as mentioned above. Thus, the design of the prototype has been divided into three main blocks: the hardware design, the 3D computer design of the frame and the software design.

In order to design the hardware properly, the Fritzing program has been used and the different elements have been chosen. The Arduino nano 33 IoT board has been considered the most appropriate due to its small size and the fact that it includes a Wifi module and an accelerometer. Likewise, the DHT22 sensor was chosen to measure the humidity and temperature of the medium and the BH1750 (GY30) sensor to measure the light intensity. A diagram of the hardware design is shown in Illustration 1.

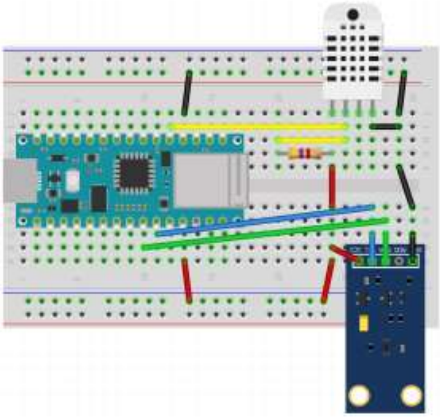

*Illustration 1. Hardware design*

The Altair Inspire Studio software was used to design the frame parts. The frame has been divided into four main parts that will be assembled together using wedges. In addition, three pieces have been designed where the different sensors and the plate will be inserted, and a plate that will hide the back of the frame.

As for the software, it will have three main functions, the reading of the variables to be measured, the processing of this information and the activation of the alarms for both the conservation and the security part of the frame, as can be seen in the following illustration (Illustration 2).

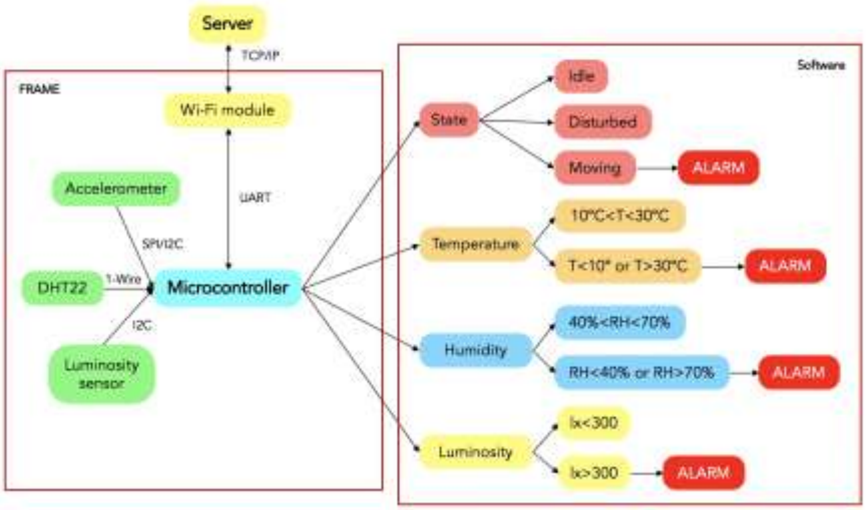


*Illustration 2. Diagram of the functioning of the device*

## 3. Manufacturing of the prototype

The second block of the project consists of the manufacture of the prototype, starting from the design made previously. As in the previous section, the manufacturing phase has been divided into different parts: the manufacture of the frame, the assembly of the hardware, the development of the software and the validation of the final prototype.

For the construction of the designed frame parts, different possible manufacturing methods were weighed up among those available in the ICAI laboratory and, in accordance with the recommendations of the teaching staff, 3D printing was chosen. Thus, after analysing the different 3D printing methods available (FDM, SLA and MJF) and their characteristics, the FDM printing method was chosen due to the size of the parts and the possibility of using materials similar to wood. Then, after choosing such a material, the designed parts were printed and post-processed. Next, a 1mm thick aluminium sheet was cut, filed and polished according to the design.

The assembly of the hardware was carried out in the same way as in the design, with the exception of the circuit designed for the DHT22 sensor, for which a larger power supply than expected was required, which was provided externally by means of three 1.5V batteries. The circuit board and resistor were soldered to a PCB, to which the DHT22 and BH1750 sensors were connected by means of long cables, as they needed to be placed in different parts of the frame.

Finally, the software has been developed using the Arduino IDE program through different pre-established libraries and an application has been created using Blynk to be able to easily monitor the information received from the device. Once all the parts were completed, the final framework was assembled and its correct functioning was validated.

## 4. Business plan

Based on the sections developed above, a business plan has been drawn up for the Connected Frame, with the aim of analysing the profitability of launching this product on the market.

On the one hand, it is necessary to define a business model based on research into both the Spanish art market (McAndrew, 2017) and the global art market (McAndrew, 2021), so that the current situation and the characteristics of its collectors (Arteinformado, 2019) are known. In this way, it has been possible to establish the characteristics of the target public, on the basis of which a study of the existing competitors in the market has been carried out and the different specific parts of the business model have been defined.

On the other hand, a financial plan and a pricing plan have been defined, with the aim of evaluating the performance of the start-up in the first years of its life in order to provide information for potential investors. Firstly, the pricing plan has made it possible to establish an approximate selling price for the product, which has been based on the production costs estimated on the basis of the prototype built. Since the frames are products that vary in price and size, a pricing structure has been established with a fixed and a variable part, based on standard artwork sizes up to a certain perimeter due to the low profitability of using 3D printing for large products. A fee has also been defined for IoT services in the first years and an optional framing installation service.

As for the financial plan, this was carried out with the aim of predicting the company's situation over the next five years. In this way, a growth forecast was carried out, on which the profit and loss account was based. The costs have been estimated on the basis of the annual income and it has been obtained that in the first year the company will make a loss of around €11,000, however, from the following year onwards, it will start to make increasing profits until it reaches a pre-tax profit of €975,500 in the fifth year. Likewise, the balance sheet, although not as precise, gives an idea of both the company's situation at the start of its activity and the resources necessary to carry out the project.

Finally, the net present value of the company has been estimated if the 5-year predictions are fulfilled, i.e. the value that the money invested today will have in five years. Thus, the present value of the company in five years will be approximately 1.2 million €, which is a good prediction, taking into account that the initial investment is only 110,000 €.

## 5. Conclusions

This project is concluded in a very positive way, having fulfilled all the proposed objectives. The product designed has been developed satisfactorily, using IoT technology to implement in a single product both a system for the conservation of paintings and an alarm system.

Finally, it should be noted that the importance and usefulness of this project lies not only in finding a suitable manufacturing method to make a connected and cost-effective product in a way that meets the objectives, but that it goes further and contributes to Industry 4.0 through the manufacture of an innovative and connected prototype and the development of a company around it.

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# 1. INTRODUCTION

Traditionally, thefts and vandalism have been one of the main issues that museums have had to face in terms of security. Specially during the 20$^{th}$ century, there has been a lot of relevant robberies such as the theft of La Gioconda (1911) or The Scream (1994, 2004). Although in the last years the technological advances have make it possible to have systems that protect the works of art a lot more, only museums can afford this kind of security, while particular art owners don't have a system suited for them.

Therefore, a lot of paintings and works of art don't have the protection that they require. In contrast to what many people think, some of the most valuable paintings in history, belong to particular owners. For example, the Salvator Mundi, whose author is believed to be Leonardo Da Vinci, was sold to a private art collector for more than 450 million dollars in 2017 (Rodríguez, 2017). Furthermore, in Spain, the House of Alba has in its possession paintings of renowned artists such as Goya, Tiziano or Rubens (Fundación Casa de Alba, s.f.); and Sorolla's family owns nowadays, most of the painter's collection.

In order to preserve and protect this paintings and the heritage they represent, it is necessary to provide this private art collectors with a product that integrates the security and conservation that they require. Therefore, this project will have the purpose of giving a solution to this problem by putting the technology of the Internet of Things (IoT) at the service of art. This technology will allow the owner of the artwork to have more connectivity and, as a consequence, the immediacy of the information when monitoring the painting will increase. This aspect of the product is extremely relevant, because a delayed reaction when it comes to security and conservation, can mean irreparable damage or losing the artwork.

The main idea of the project is to approach it as the creation of a start-up that focuses on a connected frame. The objective is to design and build a prototype of the product, both the mechanical and the electronical parts, as well as a platform through which the artwork will be controlled. Finally, a business plan will be carried out.

# 2. STATE OF THE ART

## *2.1 SOLUTIONS TO THEFTS IN MUSEUMS AND ART GALLERIES*

Currently, the market offers different kinds of solutions to security problems in the art sector. Nevertheless, none of the devices attached to the artwork offers the connectivity of the Internet of Things. Most of the solutions that exist nowadays are mainly devices that either activate an alarm or send the data to the alarm centre. In the best cases, this means the client doesn´t have the information immediately and the reaction time is longer than it should be. There are different types of devices that are now being used to protect art in museums.

First of all, dual technology and antimasking sensors are used to identify the presence of people when detecting variations of temperature and microwaves in a room (Risco Group, s.f.). In addition, the antimasking system, sends a warning if the detector is covered. For example, the company Bea Sensors® offers a product called EYE-TECH that detects the presence of active infrared by measuring the distance to the device. It has a maximum range of 2,5 m and it is thought to be installed in doors, however, it can be used in other places, for example near the artwork, to detect the presence of people (Bea Sensors, s.f.).

Another type of sensors that are often used to protect the artwork are seismic sensors. This sensors, can detect any vibration on the object that is under surveillance and are usually used to protect works of art that are protected by a showcase such as sculptures and some paintings. In addition to this seismic sensors, showcases usually have glass break detectors, which can identify the presence of cracks when the glass is being shattered. For example, the company Ajax Systems, offers a device called GlassProtect that uses a microphone to identify the specific sound of the glass breaking and falling, while ignoring other external sounds such as those of a truck, a thunder or a dog barking (Ajax Systems, s.f.).

Furthermore, the most frequently used sensors to avoid people or burglars from coming near the artwork are curtain motion detectors. This sensors can detect the movement near the object by creating an imaginary curtain which makes the alarm go off when trespassed and they are external to the artwork. For example, the company Bea Sensors®, offers the LZR-600, an anti-theft device that consists of a LASER based security device with high precision and a detection range of 25m x 25m. If anything reaches the protected zone, an alarm is set, with a maximum response time of 80ms. The battery duration is 5 years and each sensor costs around 1735€ (Bea Sensors, s.f.). On the other hand, the company Ajax Systems produces the Motion Protect Curtain (Ajax Systems, s.f.). This curtain motion detector is cheaper than the previous on mentioned, however, the response time is higher (150 ms) and the detection range is of 3 to 15 meters, which is lower.

Moreover, to identify the movement of the artwork itself, in order to protect it from thefts, it is sometimes used a wireless multi-axis detector, more commonly known as an accelerometer. This device, generates an alarm when the object is moved, so it has to be placed on the object to be able to detect its movement correctly. The company Visonic, offers a product called the SPD-1000, which is a device that is placed out of sight and has the function of detecting the movement in different levels, being able to distinguish between the touch of the artwork or the lifting of the object, indicating the different levels of alarm, depending on the seriousness of the event (Visonic, s.f.).

## *2.2 MAINTENANCE AND PREVENTIVE CONSERVATION*

The awareness of our society when it comes to the conservation of our cultural heritage, has increased over the years. Technology has been an ally for institutions and restorers and has helped to improve significantly, the conservation of the works of art. One of the main advances that technology has provided us with, is the climatization of museums, which has been recently implanted in places such as the Louvre or the Sistine Chapel (Hitachi Cooling & Heating, 2018).

The main threat when it comes to the deterioration of the works of art, is the environment around them. High temperatures, humidity or light intensity, can deteriorate a painting as much as a corrosive substance would, this is the reason why this three parameters should always be controlled in order to preserve the paintings. The ideal value of humidity and temperature would be around 58% and 17ºC respectively. An excess of humidity and temperature could cause the non-adhesion of the materials. On the contrary, the lack of humidity and low temperatures, could produce the cracking of the structure and the materials (Hitachi Cooling & Heating, 2018).

Nowadays, there are companies that put technology at the service of restorers and museums in order to help them prevent the deterioration of the artwork. Testo and SIT are the main companies in this sector.

First of all, Testo is a company that offers a variety of products to measure and control the environmental conditions of the artwork. This devices are independent from the paintings and they register constantly the values of temperature and humidity. They can create reports of a certain period of time automatically and they send an alarm to the owner in case of exceeding the parameters of humidity and temperature are not in the appropriate interval. This solutions are often used when the artwork is being either displayed, transported or restored (Testo, s.f.).

On the other hand, the microclimatic frame MCFrame, is a product of the company SIT. They are specifically designed for the transportation of paintings or temporary exhibitions in order to prevent and minimize excessive fluctuations of humidity and temperature. Each McFrame is designed for a concrete artwork and it has a datalogger that registers the parameters of humidity and temperature inside the frame. To access this information, the data has to be downloaded. This product can also control the air exchange and measure the air quality to localize the presence of pollution (SIT, 2016).

Finally, the main goal of this project is to integrate in the same product, the conservation and security of the painting and improve the immediacy with which the information is available with the technology of the IoT.

# 3. OBJECTIVES OF THE PROJECT

In this section, the global objectives will be described, in order to clarify the main idea of the product and the problems to be solved throughout the project.

1. Design of a connected product that works through the technology of the Internet of Things as a new solution to art thefts, integrating an antitheft system in the frame of the painting as well as a preservation unit.
2. Construction of a prototype, including the structure of the frame, as well as the hardware and the software, with the objective of analysing the functioning and performance of the product previously designed.
3. Analysis of the market in order to launch the product at a competitive price and to a certain target audience.

# 4. DESCRIPTION OF TECHNOLOGIES

In each phase of the project, certain programs will be used in order to develop the different tasks.

The first phase, will consist in the design of the prototype, for which Altair Inspire Studio will be used. On one hand, Altair Inspire Studio will be the tool used for the mechanical part of the project, the 3D design of the frame and its blueprints. On the other hand, the hardware will be designed with the program Fritzing. Fritzing is an open source software for the design of electronics hardware (Fritzing, s.f.). It allows the user to simulate the prototype of the hardware and it has a very user-friendly interface. Also, it offers a lot of different components in its database and it allows the user to import new components that can be easily found online.

The second phase of the project consists on the coding and assembling of the prototype. In this phase, the development of the software will be made through the program Arduino, which uses C++ as a programming language. Also, Blynk will be the IoT platform used to connect the product to the cloud. Blynk is a platform that has been designed with the objective of facilitating the development of products related to the Internet of Things. Thus, this application is a tool used to design the interface through the use of different widgets provided (Blynk, s.f.) in order to control a device.

# 5. PROJECT PLANNING

After having stated the objectives of this project, the different tasks to be achieved will be described in the table below (Table 1). Each task will be assigned to a certain period of time, and some extra time will be left in case it is needed to solve additional problems. The distribution of the tasks throughout the available time can be found in Table 2.

| | Tasks | |
|---|---|---|
| **Design** | 1.1 | Research on similar projects and possible competitors |
| | 1.2 | 3D Design of the frame |
| | 1.3 | Design of hardware |
| | 1.4 | Design of algorithms |
| **Coding and assembling of prototype** | 2.1 | Purchase of hardware material for prototype |
| | 2.2 | Assembly of hardware |
| | 2.3 | Coding of algorithm |
| | 2.5 | Validation of hardware and software design |
| | 2.6 | Construction of frame and integration of electronical device in it |
| | 2.7 | Validation of complete model |
| **Business plan** | 3.1 | Study of competitors |
| | 3.2 | Pricing strategy |
| | 3.3 | Costs and sales model. Three year projection |

*Table 1. Description of tasks*

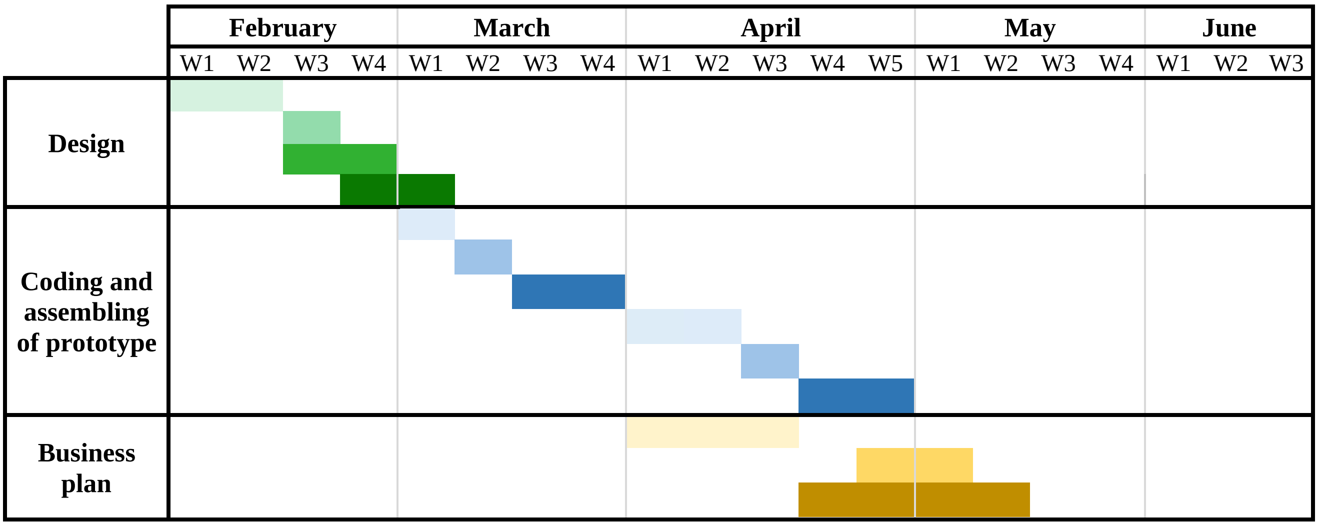


*Table 2. Distribution of tasks throughout the time available*

# 6. SUSTAINABLE DEVELOPMENT GOALS (SDGS)

The Sustainable Development Goals (SDGs), represent an urgent call by all members of the United Nations in order preserve the planet and improve the lives of everyone in it (United Nations [UN], s.f.). This project, will help to achieve some of the 17 SDGs (**¡Error! No se encuentra el origen de la referencia.**). It will be focused mainly in goals 4, 9, 12 and 16 which will be explained more exhaustively in the following paragraphs.

*Image 1. Sustainable development goals of the United Nation's 2030 Agenda (United Nations [UN], s.f.)*

First of all, art has always been one of the main sources to study the evolution of humanity throughout history. After all, some of the most ancient evidence of human existence are cave paintings. Therefore, by helping to the preservation of art, this project contributes to improve the **quality of education** (SDG 4). This connected frame protects the paintings from being stolen and helps to preserve them despite damaging environmental conditions.

Moreover, the technology used to build the product is one of the most innovative ones at the moment, which contributes to SDG number 9 (**industry, innovation and infrastructure)**, specially by promoting innovation. The internet of things has the purpose of making our lives easier by allowing people to be connected with the world they live in.

As a consequence, this Connected Frame simplifies the task of taking care of a valuable painting and it gives the owner the opportunity to control the conditions of the painting in real time.

In addition, the main material used for the production of the frame is 100% biodegradable, which contributes to the preservation of the environment. Furthermore, the business developed with the Connected Frame as the main axis, revolves around a customized product with a long life. Therefore, it avoids scale productions with large amounts of waste, opting for responsible production and consumption and thus contributing the fulfilment of SDG number 12 (**responsible consumption and production**)

Finally, in terms of peace and justice, this product provides the customer with the protection that they need for their paintings. On one hand, the Connected Frame contributes to establish peace in society because of the prevention of thefts and vandalism and, as a consequence, of chaotic and violent situations. On the other hand, achieving justice is also one of the main objectives of this product. Not only does it prevent the painting from being stolen, but in case of theft, the alarm warns the owner. For this reasons, this device certainly helps to achieve SDG number 16 (**Peace, justice and strong institutions**).

# 7. DESIGN OF THE PROTOTYPE

Once the general idea of the product has been described, to begin with the design of the prototype, the main tasks the device will have to carry out will be explained below:

- **Reading data**: The main variables that will have to be read are the temperature, the humidity and the light intensity for the conservation of the painting as well as the acceleration of the three axis (x, y, z) for the alarm system. This variables will be read by different sensors, which is why we will need a **temperature and humidity sensor**, a **light intensity sensor** and an **accelerometer** (IMU).
- **Data treatment**: The data read by the sensor of the hardware will be received by a microcontroller that will have the function of treating this data in order to simplify the information that will be sent later on to the cloud. This **microcontroller** is where all the software and algorithms will be executed.
- **Sending and receiving data from the cloud**: Once the data has been treated, this simplified information will be sent to the cloud through a wireless technology to a platform that will store and display this data. The most common available technologies are Wi-Fi and Bluetooth, but knowing that the frame will be in a house, the most appropriate technology to use would be Wi-Fi, which is why a **Wi-Fi module** will be the most suitable sensor for this task.

The functions described above will be performed by the hardware and the software of the prototype. However, to make a connected frame, the frame itself will have to be designed, taking into account that the hardware will have to be integrated into the framework. Also, when designing the frame, it will be necessary to pay attention to the aesthetic component, given that a frame is a product whose main function is to display the painting that it houses.

Therefore, the design of the product will be divided in three main blocks that will be executed in the following order: design of the hardware, 3D design of the frame and design of the software. The first step will be to design the hardware because it is necessary to know the electronic components that are going to be used, in order to do the 3D design of the frame and to design the algorithms.

The diagram in Figure 1, shows the information flows and the diagram of the prototype that will be designed and built in this project.

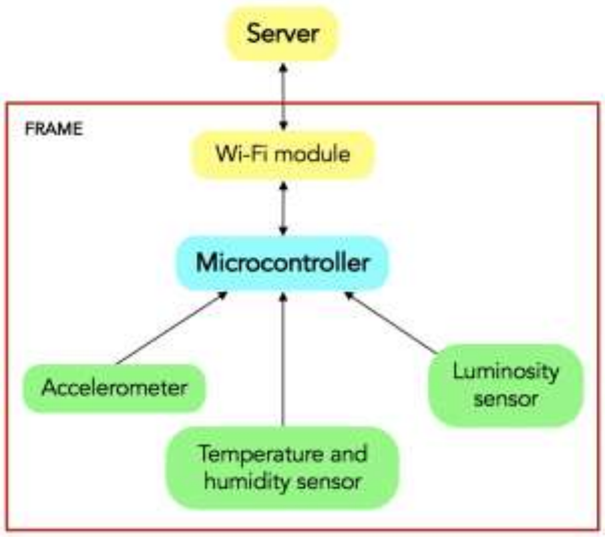


*Figure 1. Diagram of the prototype and information flows*

## 7.1 HARDWARE DESIGN

The first step that has been taken in order to design the prototype is the design of the hardware of the frame, in order to have the measurements of the different electronic components. This way, we will be able to make the 3D design of the frame later and integrate the electronic part in it.

### 7.1.1 CHOICE OF COMPONENTS

To carry out the design of the hardware and fulfil all the requirements for the design of the electronic part, it is required a microcontroller, a wifi module, an accelerometer, a temperature and humidity sensor and a light intensity sensor.

- **Board**

The Arduino NANO 33 IoT was considered to be the best board to build the prototype because it includes a microcontroller, a wifi module and an accelerometer, but also because of its reduced size. The Arduino NANO 33 IoT is a board of 45x18mm, which includes Wi-Fi and Bluetooth modules as well as a 6-axis IMU (LSM6DS3), a 3-axis accelerometer and a 3-axis gyroscope. All these characteristics make this board very suitable for IoT products and specially for the prototype of this project. The price of this board with headers included is of 18€, and all the specifications (Arduino, s.f.) can be found in Anex I.

The microcontroller will have the function of collecting the data of the sensors, treating the data received and sending this data to the cloud. Also, the wifi module will communicate with the cloud and the accelerometer will collect the data of the acceleration in the three axis, that will be treated in order to send to the platform the state of the frame (idle or moving) in order to create an alarm system for the painting.

- **Temperature and humidity sensor**

In addition to the board, a temperature and humidity sensor and a light intensity sensor will be required to measure the variables related to the conservation of the painting. There is a wide range of temperature and humidity sensors in the market, but the ones that stand out among the others are the DHT11 and the DHT22. The main difference between this two sensors is the range of temperature and humidity they measure.

- The DHT11 sensor is a more simple sensor that has a temperature range of 0 to 50 ºC and a humidity range of 20-80%. It is also less precise than the DHT22 sensor, with an error of +/- 2 ºC and +/-5% for temperature and humidity respectively.
- On the other hand, the DHT22 sensor has a temperature range of -40 to125 ºC with an error of +/- 0.5 ºC and a humidity range of 0-100% with an error of +/- 2.5%. Both sensors can work in a voltage range between 3V and 5V (Adafruit industries, 2020).

As the device will be designed to be inside a house, the temperature range of sensor DHT11 would be enough, however, the error might be too high and the humidity range might not be enough for places with very high humidity. Given this, the sensor DHT22 will be the one chosen for this project as its characteristics are more suitable for the connected frame.

- **Light intensity sensor**

The last component that will be required for the hardware of the prototype is a light intensity sensor. The most simple option available in the market for measuring light intensity is the photoresistor, which is a component that varies its resistance depending on the light intensity received. However, this component does not provide a numerical value of the light measured. Given that it will be necessary to establish a light limit for the system to warn the owner, we will need a numerical value to be measured by the sensor.

The light is commonly measured in two different units, lumens and lux. The lumens measure the luminous flux, the amount of light emitted per second (Enciclopaedia Britannica, 2017), whereas the lux measure the light intensity, that is the quantity of light per area (Encliclopaedia Britanicca, 2012; Formlabs, s.f.; Formlabs, s.f.). The most interesting variable to measure in this case is the light intensity as it is more accurate to measure the damage that the light causes in paintings. For instance, if a painting is constantly receiving a flow of light at a very low intensity (lumens are high and lux are low), the light will not cause any damage. However, if the intensity of the light received by the painting is high but the luminous flow is low, the light will cause damage the painting.

The most common sensor available for measuring this variable is the BH1750FVI, which measures the lux received (light intensity) and sends this information to the microcontroller. This sensor is more commonly sold in module GY302, but in this case, the most suitable option is the GY30 because it will be easier to integrate it in the frame due to its dimensions.

The sensor BH1750FVI can measure a light intensity range of 0-65535lx at a high resolution, and the measurement variation is of +/-20%. It measures accurately any light source (Sun light, incandescent, fluorescent, white led…) and the spectral response is of approximately the human eye (400-700 nm). Also, no external parts are needed for the connexion to the board, which makes it a very intuitive sensor to use. The supply voltage can be of between 3V to 5V (Rohm, 2011) and the price is of around 7€. Given this specifications, this sensor fulfils all the requirements needed for this project.

### 7.1.2 CONNEXION OF COMPONENTS

The connexion of the components of the hardware was simulated with Fritzing. Fritzing is an open source software for the design of electronics hardware (Fritzing, s.f.). It allows the user to simulate the prototype of the hardware and it has a very user-friendly interface. Also, it offers a lot of different components in its database, however, the main advantage of this program is that it allows the user to import new components that are not in the platform and that can be easily found online. For instance, Arduino provides the fritzing file of all their boards in case it is not available in the Fritzing database. The licence to download the program has a cost of 8€ as a donation to the organization in order to ensure the future development of the source code.

- **Temperature and humidity sensor. DHT22**

The DHT22 sensor has 4 pins (1-4 from left to right as seen in Image 2), which have the following functions (Adafruit industries, 2020):

- Pin 1(VDD) is where the supply voltage is connected and it can go from 3.3V to 5.5V.
- Pin 2 (DATA) is the pin through which the information is send to the microcontroller and it is connected to a digital pin of the board.
- Pin 3 (NULL) has  no connection.
- Pin 4 (GND) in connected to ground.

For carrying out the connection of this sensor to the board, it is required a pull up resistor to read the measurements correctly. Even though the Adafruit datasheet indicates that no extra components are needed for the connection of this sensor, it is commonly used a 4,7 kΩ or a 10 kΩ pull up resistor to make the measurements more accurate. The pull up resistor will be placed between the VDD and the DATA pins and in this case, it will have a value of 4,7 kΩ. The diagram of the connection of sensor DHT22 is included in Figure 2.

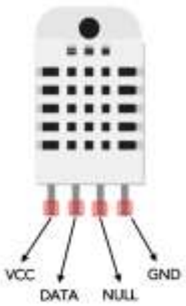


*Image 2. Pin distribution in DHT22*

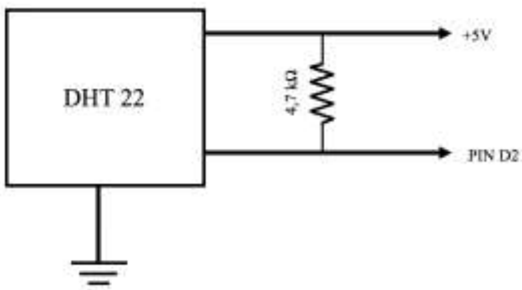


*Figure 2. Connection diagram of DHT22*

- **Light intensity sensor. BH1750 GY30**

The BH1750 GY30 has 5 pins (1-5 from bottom to top as shown in Image 3), which have the following functions (Rohm, 2011):

- Pin 1 (GND) is connected to ground.
- Pin 2 (ADD) has no connection, but it indicates the address of the component (master or slave).
- Pin 3 (SDA) is the serial data pin, which is the pin through which the information is send to the microcontroller and it is connected to the analog pin A5, the SDA pin of the Arduino NANO 33 IoT board.
- Pin 4 (SCL) is the serial clock pin, which is the pin that sends the clock signal. This pin is connected to analog pin A4, which is the SCL pin of the Arduino NANO 33 IoT board.
- Pin 5 (VCC) is the power supply terminal.

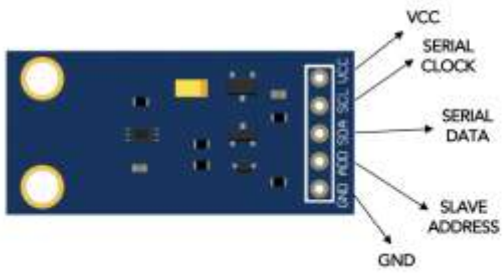


*Image 3. Pin distribution in BH1750 GY30*

The BH1750 sensor communicates with the microcontroller though the I2C communication protocol for which it is required the SDA and SCL pins, as well as the ADD pin to define the address of the sensor. The connection of this sensor to the board does not require any external components, which makes it very simple.

- **Board**

The Arduino NANO 33 IoT board includes the Wi-Fi module and the accelerometer, thereby they are connected internally and no external connection is needed.

- The **Wi-Fi module** contained by the Arduino board selected, is the **NINA W-102**. This is a multi-radio module which includes Wi-Fi connection among other features and can communicate with other devices via different communication protocols such as UART, SPI or I2C. It is ideal for devices that work through the Internet of Things (u-blox, 2019).
- The **accelerometer** included in the Arduino NANO 33 IoT board is in the **LSM6DS3** sensor, an IMU (inertial motion unit) which contains a 3D digital accelerometer and a 3D digital gyroscope. It uses SPI and I2C as communication protocols and offers an always-on low-power feature. This sensor has significant motion and tilt functions, as well as indoor navigation, vibration monitoring and compensation and the creation of connected devices as main applications. (ST, 2017)

The board will receive the information related to the light intensity sensor through analog pins A4 and A5, and the data from the temperature and humidity sensor through digital pin D2. Also, the board the Wi-Fi module and the accelerometer will communicate internally with the microcontroller.

A diagram of the final design of the hardware, including the connection of all the components, is shown in Image 4.

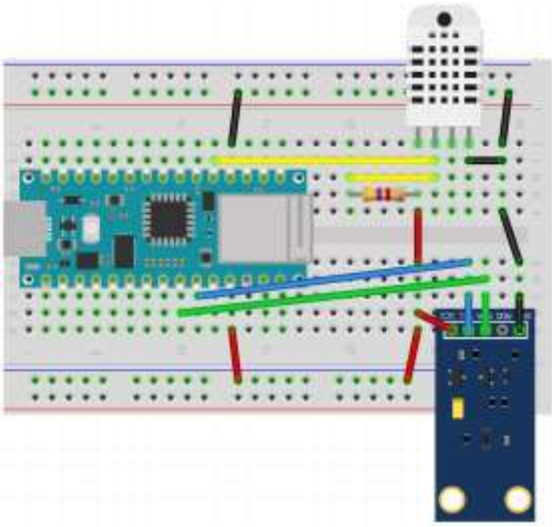

*Image 4. Diagram of the hardware of the prototype*

### 7.1.3 POWER SUPPLY

As for how to power the prototype to be developed, the ideal would be a long-life battery that would have to be changed or recharged at most once a year. However, since the product will be permanently located in a house, the least expensive and most feasible way would be to power the product from the mains. Due to the aesthetic component of the product, it would be ideal to install a plug on the back of the panel to prevent the cable from being visible. This will also allow the cable to be hidden so that it cannot be cut without moving the frame and the owner will be alerted that the frame is in danger. Also, if the frame is disconnected from the power supply, the customer will be notified.

## *7.2 3D DESIGN OF THE FRAME*

Once the hardware has been designed, and the functions of each component have been defined, the 3D design of the frame will be carried out. Given that the frame has a very important aesthetic component, the external appearance of the design will be specially relevant, while, on the other hand, it is required to have a functional frame where all the tasks can be fulfilled according to the design of the hardware.

All frames, are usually composed by four different pieces of wood. This pieces are manufactured starting from a wood strip where the excess wood is cut with different machinery, in order to achieve the section designed, which has a gap for placing the painting as well as the external design of the frame, which is completely decorative. The pieces that compose the frame are often assembled with glue, as well as with nails or even stapled in the back part of the frame with square staples. Once the frame is assembled, the back is finished with nails or paper, to secure the frame.

In this case, in addition to the four main pieces of the frame, there is a piece for each sensor and for the board, that will be placed strategically in the frame. The main parts will be assembled together through a joint, in addition to them being glued together. The drawings of the different parts of the frame can be found in Annex II.

### 7.2.1 ELEMENTS OF THE FRAME

The four main pieces of the frame will be placed as seen in Image 5, and have the following functions.

- **Top piece**

The top piece of the frame, will have the luminosity sensor integrated in it. Given that in a house, the light source usually comes from the ceiling, this piece is the most optimal to measure the light that receives the painting as the sensor will be receiving more light if it is placed on the top. Therefore, it will be necessary to make a groove for the light to reach the luminosity sensor properly.

- **Bottom piece**

The bottom piece of the frame will have the board placed in it. The board is the part of the hardware where the accelerometer is located, therefore it has to be placed in a part of the frame where the movement can be measured the accurately. As paintings are normally hung from the top, the bottom part of the frame is the one that moves the most in case the position of the painting is changed. As a consequence, this is where the board will be located.

- **Right piece**

This piece of the frame will have the function of housing the temperature and humidity sensor. This sensor requires for the air to pass freely into the sensor to measure the temperature and humidity of the air correctly, therefore, the right piece will have a series of grooves where the sensor is located. Also, this sensor could be placed anywhere as long as the air enters the sensor, however, it will be placed in the lower part of the right piece in order to be near the board and use shorter cables. Furthermore, this piece of the frame will also have a channel from bottom to top for the cables to be guided from the board to the external sensors.

- **Left piece**

This piece of the frame will be the most simple, as it will have no electronic components or cables. Consequently, the left piece will be the part of the frame that is removed in case the painting has to be separated from the frame for maintenance or other motives.

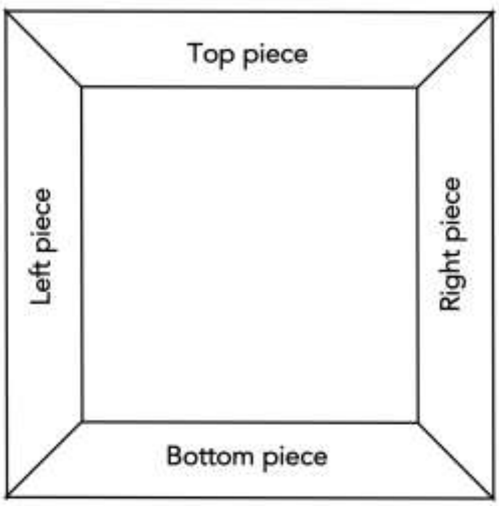


*Image 5. Positioning of the main pieces of the frame as seen from the front*

This four main pieces of the frame will all have a channel for the painting to fit in the frame. For this part of the design, a canvas of 240x330x20mm was taken as a reference.

In addition to the main pieces of the frame, there will be three different pieces for the sensors and the board, which will be located into the main pieces as mentioned before. This pieces will have the functions described below.

- **Temperature and Humidity sensor piece**

This piece will be specifically made to place the DHT22 into the frame. The sensor will be screwed to this piece, which at the same time will be screwed to the right piece, where the sensor will match the corresponding grooves for the air to reach the sensor. This piece will be removable from the frame, in case there is a problem and the sensor has to be replaced.

- **Light intensity sensor piece**

The light intensity sensor piece, will be the part of the frame where the sensor BH1750 will be located. The sensor will be screwed to this piece through the corresponding assembly holes. At the same time, the light intensity sensor piece will be screwed to the top piece of the frame, where it will meet the matching groove in order for the light to reach the sensor. This piece will also be removable in case the sensor needs to be replaced for a new one.

- **Board piece**

This piece will have the function of hosting the board and other elements of the hardware that are neither of the sensors. The board will be screwed to this piece and, at the same time, the board piece will be screwed to the bottom piece of the frame because of the accelerometer. As well as the two previous pieces described, this piece will be removable in case there is an average and the board or other components of the hardware have to be replaced.

Once the main pieces of the frame and the pieces of the sensors have been designed to be assembled together, the frame requires a piece to close and hide the back part of the product, as well as for security reasons.

- **Back piece**

The back piece will be designed with the objective of manufacturing it with sheet metal. Therefore, it will be a thin piece with rounded corners that will have four holes, which will be used to screw the back piece to the right and left pieces of the frame.

### 7.2.2 SELECTION OF MANUFACTURING METHOD

In addition to knowing the different pieces that will be designed and their functions, it is necessary to select a manufacturing method. The frame will be designed according to this, as it may condition the design because the tools and resources available may be limited.

Taking into account the resources, tools and machines available in ICAI, there are three possible manufacturing methods that could be used for this project as described below.

- **Buy a frame and adapt it**

The idea of this manufacturing procedure would be to buy a frame and adapt it to meet the requirements of the project. Thus, a frame large enough would have to be purchased to be able to integrate the hardware with the board and the various sensors. Then, the necessary holes, slots and grooves would be made with the milling machine in the fabrication lab for the adaptation of the frame. Finally, the additional pieces for the sensors would be manufactured either with the milling machine or with 3D printing.

- **Traditional manufacturing**

This procedure is the most common one as this is how frames are traditionally made. This manufacturing method would consist of starting from a wooden strip and using a milling machine to carry out the necessary operations to obtain the desired profile with the required hollows, grooves and slots. Likewise, a radial milling machine would be used to obtain the main parts of the frame with the necessary measurements, starting from the wooden strip. Also, in order to make the holes for the screws, a drilling machine would be needed.

- **3D printing**

3D printing would be the most innovative way to manufacture a frame, as they are traditionally made of wood and handcrafted. The use of this method requires the 3D design of the different pieces to obtain the files in stl format, which are required by the 3D printers to carry out the printing. This way, both the working time and the number of machines to be used would be reduced, as only the 3D printer would be necessary. Furthermore, the main advantage of 3D printing is the great flexibility it offers, allowing the creation and fabrication of all kinds of complex geometry.

Therefore, the optimal method to carry out the manufacturing of the frame will be 3D printing, whose main disadvantage is the material with which the frame will be printed, as it cannot be pure wood due to the nature of the technology used. To this end, an attempt will be made to choose a material with the maximum percentage of wood available so that both the finish and the properties are as similar to wood as possible.

This manufacturing method will be the one chosen for all parts of the device except for the back piece, as it is considered a more suitable method in this case due to the cost, time and low complexity of the part to be manufactured.

### 7.2.3 SELECTION OF JOINTS

Once the manufacturing process for the product has been chosen, the joints between the parts will be selected. Since the different pieces will be made with 3D printing, and the materials used for this are usually thermoplastics, the optimal joining method will be threaded inserts. This type of connection is chosen because when threaded holes are made in thermoplastic materials, they deform over time and the screws cannot be easily removed or inserted.

As mentioned previously, the pieces for the sensors and the board will be bolted to the main parts of the frame. In addition to this, the back sheet will also be bolted to the right and left pieces of the frame and the sensors will be screwed to their corresponding pieces.

Therefore, for the connection of the pieces of the sensors and the board to the frame, metric 4 inserts and countersunk screws will be used so that they do not protrude and the back piece can be positioned correctly. Likewise, metric 4 inserts will also be used for the back piece, however, the screws used will have rounded heads so that the sheet metal is properly secured to the frame. In addition to this, the sensors and the board will also be attached to their corresponding pieces, for which metric 2,5 inserts and rounded head screws will be used in order for the sensors and the board to be attached correctly.

As mentioned before, the four main parts of the frame will be glued together, however, to reinforce this union, the pieces will be assembled by using wedges as shown in Image 6. Thus, the surface of the joint will be increased and the joint will be stronger.

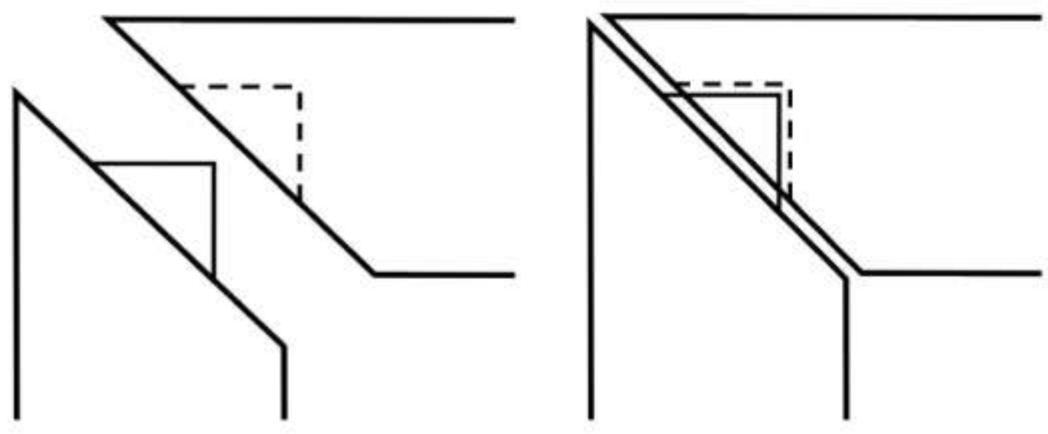

*Image 6. Assembly of the main parts of the frame with wedges*

## 7.3 SOFTWARE DESIGN

Once the different elements to be used in the hardware have been chosen, the software operation will be designed as a previous step to its development. Thus, the operation of the device is divided into 3 main and independent blocks: Movement control, light intensity monitoring and humidity and temperature measurement. For each of these blocks, a state diagram will be developed, and both the variables involved and the interactions of these variables with the platform will be explained in each diagram. Likewise, wifi will be used as the communication technology between the device and the platform since paintings are generally located in a house, which is a place where this type of technology is usually available.

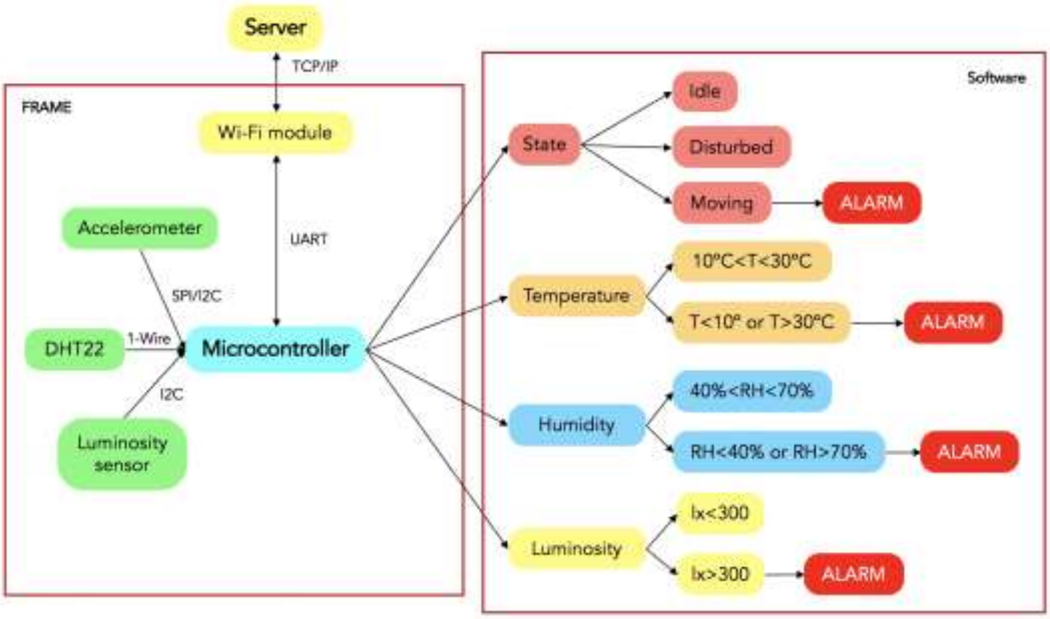


*Figure 3. Diagram of the hardware and software of the prototype including communication protocols*

## 7.3.1 STATE DIAGRAMS

### *7.3.1.1 Accelerometer*

First of all, the functioning of the motion detector that will be placed inside the product will be explained through the following state diagram, shown in Figure 4. This way, the motion detector can be in four possible states: Off, idle, disturbed and moving. The accelerometer will be used to obtain the different states. Once it has been turned on, it will be used to read the accelerations in the three axes and after processing the information read, the idle, disturbed and moving states will be obtained.

When the device is idle it means that the frame will be in its natural position, hanging on the wall. However, when the frame is disturbed, this will imply that although the frame is still hanging, vibrations are being detected on the wall, however, this will not trigger any alarm. Lastly, if the frame is in a moving state, this indicates that the frame is being moved and therefore an alarm will be triggered. Thus, as inputs from the accelerometer we will receive the variable Acc_on, which can take as values 0 and 1, being 1 when the accelerometer is measuring and 0 when it is off. In addition, through the values of the disturbed and moving variables the three states of the frame will be obtained, being Idle=00, Disturbed=10 and Moving=01, the first number corresponding to the disturbed state and the second to the moving state, so that if both are 0 the idle state is obtained.

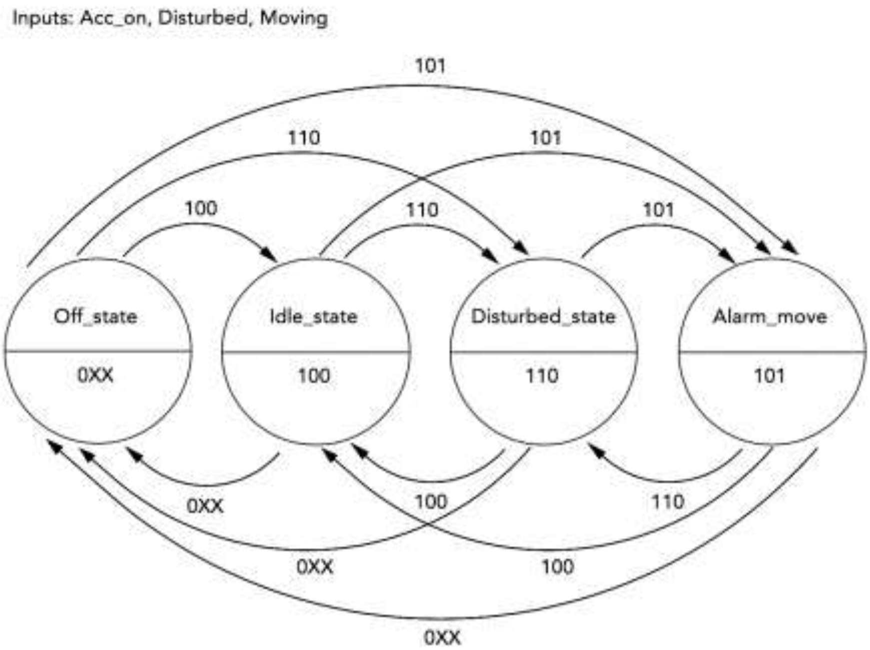


*Figure 4. State diagram of the accelerometer*

### *7.3.1.2 Temperature and humidity*

Next, the functioning of the temperature and humidity sensor that will be part of the prototype will be explained. Through this sensor, the humidity and temperature variables will be measured and the corresponding alarms will be activated when they enter the range of undesired values. Thus, as can be seen in the status diagram in Figure 5, the DHT22 sensor can be in 4 possible states: off, on, in temperature alarm state and in humidity alarm state. Then, when the sensor is not operating, it will be in the off state. Likewise, when it is operating within the desired range of values, it will be in the on state. On the other hand, the sensor will be in the temperature alarm state when the temperature variable enters the risk range. The same will occur with the humidity alarm state and the humidity variable. It should be noted that these two alarms can be activated at the same time since the temperature and humidity variables are independent of each other.

Thus, the inputs received will be three variables: DHT22_on, temperature_warning and humidity_warning. The three variables will take values 0 and 1, so that when the sensor is on, DHT22_on will be equal to 1, when the temperature is between 10ºC and 30ºC temperature_warning will be equal to 0, and humidity_warning will be equal to 0 when the humidity is between 40% and 70%.

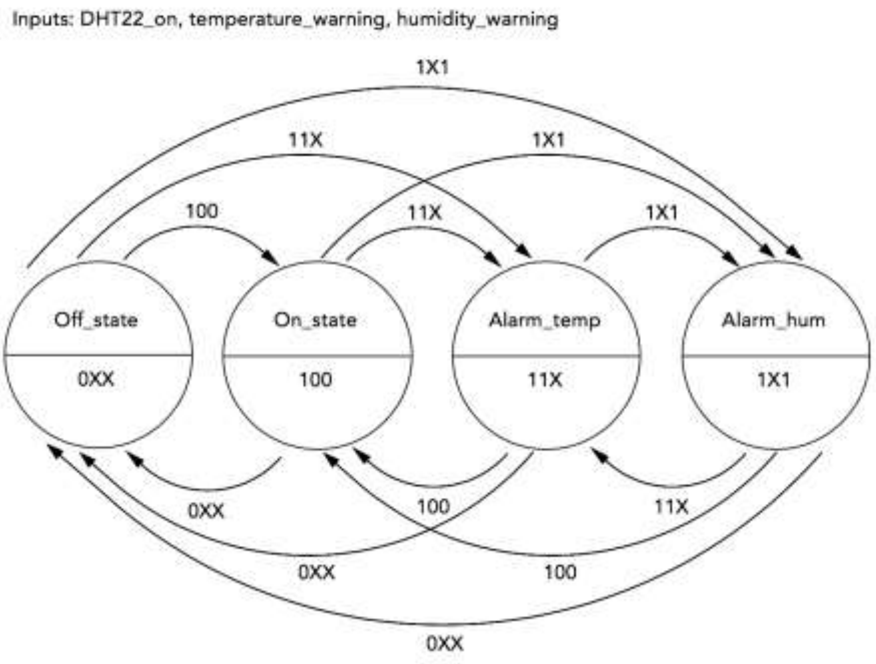


*Figure 5. State diagram of the temperature and humidity sensor*

### *7.3.1.3 Light intensity*

Finally, the operation of the BH1750 sensor inside the prototype will be explained. Through this sensor, the light intensity will be measured and the corresponding alarm will be activated when the measured variable has an undesired value. Thus, for the proper conservation of the paintings, the limit of light intensity that is considered adequate is usually between 150 and 250 lux, however, to give some margin, the limit chosen for the device will be 300 lux.

On the one hand, as can be seen in the status diagram in Figure 6, the sensor can be in 4 possible states: off, on and in light alarm state. Thus, if the sensor is out of operation, it will be in the off state, while if it is on and in the appropriate light intensity range (<300 lx) it will be in the on state. Likewise, if the sensor measures a light intensity greater than 300 lux, it will be in the alarm state.

On the other hand, two inputs will be received regarding the brightness sensor: BH1750_on and light_warning. Both inputs can take values 0 and 1. The BH1750_on input will indicate if the sensor is on, so that if it is on it will take the value of 1 and otherwise it will be 0. The input light_warning will indicate if the sensor measurement is within the desired range, therefore, if it is greater than 300 lux, it will take the value of 1 and otherwise it will be 0.

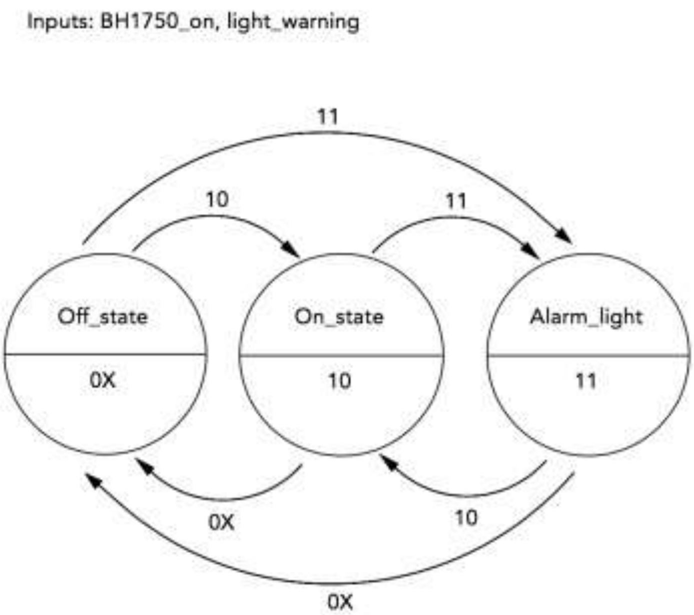


*Figure 6. State diagram of the light intensity sensor*

# 8. MANUFACTURING OF THE PROTOTYPE

After having carried out the design of the prototype and each of its different parts, this section will analyse the process of building the prototype as well as the different problems encountered in this process. This way, an in-depth explanation of the different phases in the construction of the prototype will be given, starting with the manufacture of the frame, the assembly and connection of the hardware, as well as the development of the software. Finally, the functioning of the prototype as a whole will be validated.

Then, once the design phase has been carried out, all the elements that will be required in principle for the manufacture of the prototype are known. These elements are listed below.

- Arduino nano 33 IoT board
- USB to microUSB cable
- Temperature and humidity sensor DHT22
- Light intensity sensor BH1750 (GY30)
- Resistor of 4,7 kΩ
- Jumper cables
- Protoboard
- Batteries
- Battery case
- Welding board 4x6 cm
- Long cables for welding
- Spool of thread for 3D printing
- M4 screws with countersunk head and with rounded head
- M2,5 screws with rounded head
- M4 and M2,5 threaded inserts

For the development of the software, the program Arduino IDE will be used.

## *8.1 MANUFACTURING OF FRAME*

This section will include the different steps followed to obtain the different parts of the frame. After having designed the parts, 3D printing has been chosen as the most suitable manufacturing method for the Connected Frame. Given that the device to be manufactured is a first prototype, this method has been considered the most accessible and least expensive. Then, for the execution of the printing process, the ICAI manufacturing laboratory was contacted and the most suitable method was chosen from among the available options, with the advice of Professor Mariano Jiménez, who is in charge of the laboratory.

Firstly, as a step prior to 3D printing, it is necessary to design the parts using 3D design software for the items to be printed. This has been carried out in the product design section using the Altair Inspire Studio software. Once the 3D computer design has been completed, the pieces to be printed will be selected, that is, all of them except the back plate. Then, these files have been converted to stl format, which will be the file read by the printer. In addition, it is also important to highlight the importance of the tolerances when converting the file to stl format, as a poor choice of these tolerances can result in a low quality print that is useless. The two main variables to be taken into account to avoid printing errors are the chord tolerance and the angular tolerance.

- **Chord tolerance**: Maximum accepted error between the theoretical surface of the geometry and the triangulated face of the stl adaptation. Thus, the smaller this tolerance is, the higher the accuracy of the adapted model. Ideally, it should be between 0.02 and 0.01 or less, however, the larger the part, the higher the minimum tolerances allowed by the program.
- **Angular tolerance**: maximum sweep angle between triangles when adapting to a curved surface when the part is converted to stl format. Therefore, as for chord tolerances, the smaller the angular tolerance, the higher the accuracy of the parts. The ideal value for this tolerance is around 3º or less, however, it can vary depending on the size and geometry of the part.

Table 3 shows the tolerances chosen for the different parts to be printed when carrying out the conversion to stl format. It should be pointed out that the largest tolerances are those of the largest parts of the frame, the right piece and the left piece.

| Part of the frame | Chord Tolerance (mm) | Angular Tolerance (º) |
|---|---|---|
| Top piece | 0,017 | 3 |
| Bottom piece | 0,017 | 3 |
| Right piece | 0,022 | 3 |
| Left piece | 0,022 | 3 |
| Temperature and humidity sensor piece | 0,01 | 3 |
| Light intensity sensor piece | 0,01 | 3 |
| Board piece | 0,01 | 3 |

*Table 3. Tolerances for conversion to stl format*

### 8.1.1 3D PRINTING PROCESS

Once the files have been converted to stl format with the appropriate tolerances, we will proceed to analyse the different printing methods available in the ICAI laboratory, in order to choose the most suitable method and material for the prototype to be manufactured.

Therefore, among the many kinds of 3D printers available on the market, the printing methods available at ICAI are FDM (Fused deposition modelling), SLA (Stereolithography) and MJF (Multi jet fusion). The first two methods (FDM and SLA) are very common and important in the 3D printing industry, however, MJF is a less commonly used method. Below, the functioning of each technique will be explained, as well as their advantages and disadvantages regarding the prototype to be manufactured.

- **FDM**

FDM is an additive manufacturing process that uses the principle of material extrusion to produce the part by layers. This technology enables accurate production of feature details and has an excellent strength-to-weight ratio. Thus, the manufacturing process begins with the slicing of the layered 3D CAD data, which will be used by the machine to manufacture the part on a platform. The creation of each layer will be carried out using spools of thermoplastic material and support material, which will later be removed. This way, the material, heated to a certain temperature to make it malleable, is extruded through nozzles that place the material precisely on the platform, or on the previous layer until the part is finished. Once the part is completed, it is removed from the platform and cleaned from its support material. However, depending on the desired finish of the part, additional post-processing is sometimes required (Solid Concepts, 2013). The materials most commonly used in this type of 3D printing are thermoplastics (ABS, PLA, Ulthem...) or variations of these, although there are also FDM printers that work with other materials such as metals.

There are several FDM printers available for use in the ICAI lab, however, the largest is the DT600+ model from Dynamic Tools. This printer model has a build volume of 600x450x450 mm and a maximum extruder temperature of 500ºC. In addition, it can print on thermoplastic materials such as ABS, as well as on carbon fibre, Flex, conductive or magnetic materials and wood (Dynamical Tools, s.f.).

- **SLA**

Stereolithography or SLA was one of the first 3D printing techniques to appear on the market. This type of additive manufacturing is popularly known as resin 3D printing because its working principle is based on the hardening of liquid resins through a light source such as a laser or projector. Thus, this technique consists of the extrusion of the part layer by layer from the liquid resin. At the start of the printing process, the machine immerses the platform in the liquid resin and the laser solidifies the required parts. The platform is then moved a few microns upwards and the process is repeated successively until the part is complete. Due to the popularity of this technique, the resins used are particularly versatile and have a wide range of optical, mechanical and thermal properties comparable to those of thermoplastics. In addition, the parts produced using this technology have a high resolution, precision and sharpness, as well as a smooth surface finish (Formlabs, s.f.).

Regarding the SLA printing devices available in the ICAI laboratory, there are two models from Formlabs, the Form 2 and Form 3. Both models are very similar, however, the Form 3 model offers a larger build volume of up to 145x145x185 mm. In addition, this printer has an accuracy of up to 25 microns, however, the range of materials available is not very wide as the operating principle of these machines requires the material to be a thermosetting resin (Formlabs, s.f.).

- **MJF**

This 3D printing technique involves the use of an ink-jet matrix that applies materials that can be selectively melted onto a bed of nylon powder. The whole is then heated to solidify the layer of the applied material and the process is repeated, forming a new layer until the required piece is finished. Once the process is finished, the piece obtained is removed and the remaining nylon powder is eliminated (Protolabs, s.f.).

In addition, MJF method is characterised by the excellent quality of the surface finish of the pieces, their fine resolution and an improvement in the homogeneity of the mechanical properties compared to methods such as SLS (selective laser sintering). Moreover, it is a fast technique that can be used with different materials such as resins, thermoplastics or metals (Protolabs, s.f.).

As for the MJF printers available, ICAI only has the HP Jet Fusion 580C, which is known for its fast part construction and high precision. However, the maximum build volume is 332x190x248mm, although it has the advantage of being able to print parts across the entire colour spectrum. In addition, HP printers use very specific thermoplastics, in this case HP 3D High Reusability CB PA 12, a rigid polymer (HP Development Company, 2021).

#### *8.1.1.1 Choice of printing technique and material*

Having analysed the three types of printing available, it should be noted that the material to be used will be a very important factor in the choice of the printing method. This is because frames for paintings are commonly made of wood, a material that cannot be melted and is not malleable, one of the principles on which the techniques discussed above are based. Therefore, it will not be possible to use wood, but it will be necessary to look for a material as similar as possible.

On the other hand, the size of the pieces will also be relevant in the choice of the technique to be used. Thus, the smaller parts have dimensions suitable for any of the available machines, however, the main parts of the frame, having larger dimensions, can only be printed on the FDM machine (Dynamic Tools DT600+). Also, as FDM is the most widespread 3D printing technology on the market, the range of materials available is very broad. Thus, the production of filaments with special properties is quite frequent. These filaments are manufactured by mixing thermoplastics such as PLA with other materials like metal powder or wood powder, which will be the most interesting for the prototype to be manufactured. Therefore, as all the pieces will be manufactured in the same material, FDM will be the most suitable technique for the prototype of this project.

- **Material: Timberfill**

Then, once FDM was chosen as the technique to be used, we looked for a filament made of a material with the highest possible percentage of wood. Thus, it was decided to use a Timberfill filament, commercialised in Spain by the company Filament2print. This material is composed of a mixture of bioplastics and natural wood fibres, making it 100% biodegradable (Fillamentum, s.f.).

This material can be used for 3D printing in a similar way to PLA, however, it is important to take into account some indications for the correct use of this material. Firstly, due to the high percentage of wood fibres, this material is particularly fragile due to its low elongation at break (2%). Therefore, a certain amount of supervision is required when printing with this material, as the thread can easily break. As for the printing temperature, this should be between 170 and 185 ºC and the base should be heated to about 40ºC (Fillamentum, s.f.). Taking these indications into account, the printing of all the pieces in the Timberfill material in Rosewood colour has been carried out, as can be seen in Image 7.

For the printing of all the parts, two 750 g spools of thread were ordered, since one spool of thread was not enough due to the dimensions of the device. Even so, in order to save material and make the prototype lighter, the inside of the piece has been printed with a lower density.

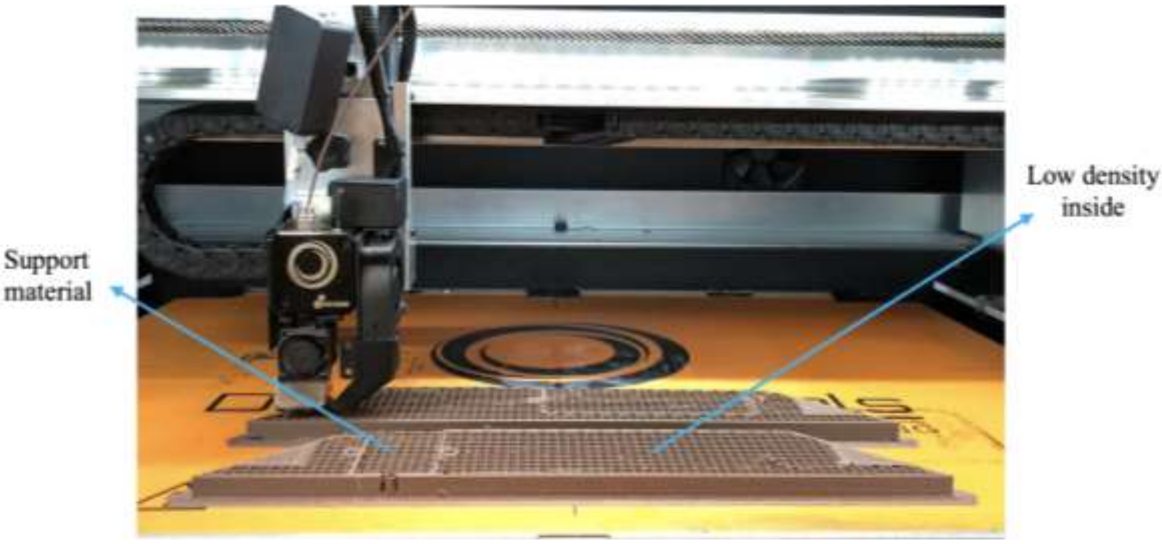


*Image 7. Printing process of top and bottom pieces*

#### *8.1.1.2 Post-processing and finishing*

After printing, the parts were post-processed. This way, the support material used by the machine during printing process was removed. It is worth noting the big difference between the time required for post-processing on small and large parts. After removing the support material, the holes in the large pieces corresponding to the sensors were filed out so that the small parts could be inserted and removed more easily. In addition, the parts of the pieces corresponding to the assembly of the different of the frame have also been filed to facilitate joining by means of an adhesive.

Finally, it is very common for defects to appear on the part due to the printing process, such as threads that have not been properly bonded to the surface or parts where the desired finish has not been achieved. This defects must be corrected during post-processing. Thus, a soldering iron has been used to achieve the desired finish in the parts where defects have been found, generally loose threads, which are softened and joined to the surface of the part using the soldering iron. The outer surface of the left-hand part was also smoothed using a soldering iron, as the aesthetic appearance of the frame is particularly important. The surface was then filed and sanded to achieve a smooth finish similar to that of the other parts. Once the printing defects had been corrected on all the printed parts, the frame was varnished for a brighter finish.

#### *8.1.1.3 Assembly of the inserts*

After having printed all the parts and having completed the post-processing phase of all of them, the assembly of the different inserts was carried out by means of the process that will be explained below.

In the larger parts, that is, in the four main parts of the frame, M4 size inserts will be installed to join these pieces with the back plate using four inserts. The assembly of the three smaller parts, namely the two parts for the sensors and the part for the board, will be done by assembling two inserts of size M4 for each part. Thus, a total of ten M4 size inserts will be installed. On the other hand, in the part for the temperature and humidity sensor, an M2.5 size sensor will be installed for attaching the DHT22 sensor to the part. Likewise, two sensors of the same size will be placed on the part for the light intensity sensor in order to secure the BH1750 GY30 sensor.

To install the inserts, a soldering iron suitable for thermoplastic materials will be heated up to 200°C. Before heating the soldering iron, the most suitable tip should be chosen to introduce the insert into the soldering iron. Once the soldering iron is heated, it will be introduced into the insert and the insert will be placed over the previously designed hole where it is to be installed. The soldering iron will heat the insert, which will move inside the hole as the surrounding material heats up. Once the insert reaches the surface’s level, the soldering iron will be removed and the material of the part will cool down so that the insert is completely integrated and fastened in the part.

#### *8.1.1.4 Possibilities for improvement through other methods*

Given the limitations encountered in carrying out this project, and the fact that the product to be manufactured is a prototype, it has not been possible to use the optimum material or manufacturing process that would be required for the final product.

The most suitable alternative would be to make a product using wood rather than the material used, which is a mixture of wood and thermoplastic materials. Given the advantages of 3D printing, wood printing would be preferable to traditional frame construction. This technology is available on the market through printers that print using wood powder, with exceptional finishes. For example, Forust is a company that exclusively prints wooden parts using a technology that reuses sawdust, a waste product derived from wood (Forust, s.f.). In this way, Forust uses binder jetting technology to process this sawdust, which is joined using a glue activated by a liquid binder, obtaining 3D printed parts made entirely from wood (3D natives, 2020).

### 8.1.2 MANUFACTURING OF THE BACK PLATE

For the fabrication of the back piece that will complete the frame, an aluminum sheet with a thickness of 1 mm provided by the ICAI fabrication laboratory has been used, on which a series of operations have been carried out until the final piece is obtained.

First of all, the initial sheet was taken and cut to the appropriate dimensions (33 x 27 cm) using an hydraulic shear. On this piece, the corner radiuses were cut using a corner cutter and the specific tool for rounding the corners. Then, the edges of the whole piece have been filed to smooth them, preventing them from cutting. In this way, only the four holes that will be used to assemble the piece remain to be drilled. These holes were drilled with an M4 drill bit and then countersunk.

Although the part is now complete, it needs to be polished and cleaned as aluminum is a material that scratches easily. Thus, using a piece of alumina, the surface of the sheet was polished on both sides repeatedly until the desired finish was achieved. Finally, the part was cleaned with alcohol.

## *8.2 HARDWARE ASSEMBLY*

As for the hardware, it should be noted that it has been very similar to the design previously made, however there have been some slight modifications.

First, the circuit was assembled as shown in the design (Image 4) on a 400-contact breadboard. To verify that both the board and each of the sensors worked correctly, each sensor was assembled separately and different examples of the libraries corresponding to each sensor were tested. As for the Arduino board, the correct connection of the board to the computer and the operation of the IMU were verified using the SimpleAccelerometer example, included in the Arduino_LSM6DS3.h library.

Secondly, after verifying that the board was working correctly, the assembly of the BH1750 GY30 sensor was performed. To check its correct operation, the library recommended by Arduino for this sensor was used; however, after trying different libraries, it was found that none of them was compatible with the microcontroller of the board (SAMD21). Then, after resorting to the direct and more usual programming of the sensor, it was verified that it worked correctly.

Finally, the DHT22 sensor was assembled and the DHTtester example of the DHT.h library was used to verify its correct operation. However, it was verified that the information received from the sensor was equivalent to that of a disconnected sensor. After numerous verifications, it was concluded that the 3.3V power supply on the board was not sufficient to power the temperature and humidity sensor, so it was necessary to use an external power supply that provides 4.5V by means of 3 AA rechargeable batteries of 1.5V each.

## *8.3 DEVELOPMENT OF SOFTWARE*

Once the hardware has been validated and it has been verified that everything works correctly, the development of the algorithm has been carried out. This algorithm will be used to control the prototype by reading and processing data, as well as sending information to the cloud. Thus, this section will explain the functioning of the different parts that constitute the software developed for the Connected Frame, as well as the app with which the client will have access to the information.

### 8.3.1 BLYNK

For the design of the app through which the client will have access to the information related to the framework, Blynk will be used. Blynk is a platform that has been designed with the objective of facilitating the development of products related to the Internet of Things. Thus, it is divided into three main parts: the Blynk app, the Blynk server and the Blynk libraries (Blynk, s.f.).

The application is the tool used to design the interface through the use of different widgets provided, the libraries allow the communication with the server through the use of different commands and the server is the part responsible for the communication between the hardware and the application (Blynk, s.f.). The operation of the communications through the Blynk platform can be observed in the Image 8.

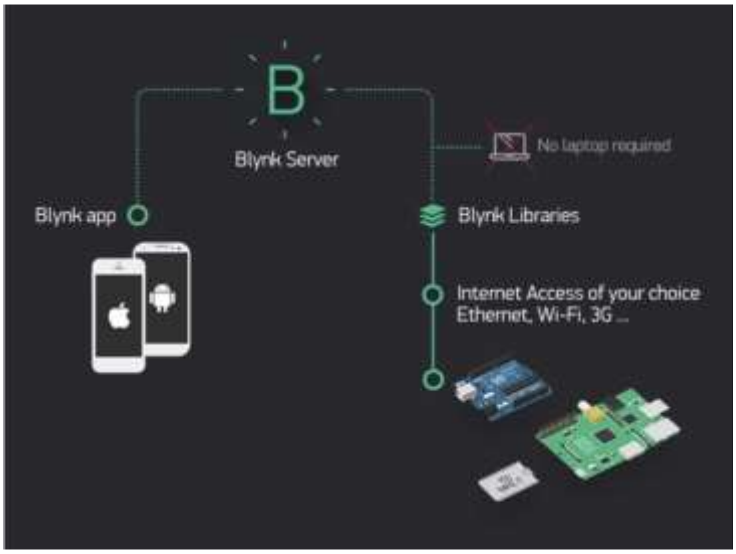


*Image 8. Functioning of Blynk communications (Blynk, s.f.)*

### 8.3.2 FUNCTIONS OF THE SOFTWARE

The algorithm that will be associated with the Connected Frame has been developed using the Arduino IDE software, due to the fact that the board used within the product is an

Arduino nano 33 IoT. For the development of this algorithm, modular programming has been used by creating several functions for each differentiated part of the code, in order to make it easier to understand and execute. Thus, the tasks performed by the different functions that constitute the code, which can be consulted in Annex III, will be explained below.

#### *8.3.2.1 Connected_Frame*

Firstly, there is the Connected Frame function, which is the main function, where the necessary libraries are imported, the variables are declared and the different sensors and functions are initialized. In addition, within this function the rest of the functions are called to be executed.

Therefore, the different libraries necessary for the programming of the temperature sensor, the accelerometer, for the Wifi connection of the product to the cloud and for obtaining the credentials (Auth token, Wifi name and Wifi password), defined in a separate library, are imported. Next, the pins and variables necessary for the correct operation of the functions and sensors are defined, in addition to defining the virtual pins that will correspond to the widgets of the application. The rest of the function is divided into the void setup() and void loop() functions.

- **Void setup ():** The different sensors are initialized, besides making the connection to the Blynk server through wifi and defining the repetition interval of the myTimerEvent function, which will be in charge of sending the information to the Blynk server.
- **Void loop ():** Within this function, the Blynk.run() function and the timer.run() function are executed to send the information to the Blynk server every certain time interval previously selected (1 second).

#### *8.3.2.2 DHT22_data*

This part of the code is divided into two functions whose objective is to read the data coming from the DHT22 sensor, using the commands provided by the DHT.h library and by using of the previously defined sensor (dht).

- **Temp ():** Measures and returns the temperature value measured by the DHT22 sensor in ºC, and in case of not receiving data, displays the message "Failed to read temperature from DHT sensor!" in the serial monitor.
- **Hum ():** Measures and returns the percentage of relative humidity measured by the DHT22 sensor, and in case of not receiving data, displays the message "Failed to read humidity from DHT sensor!" on the serial monitor.

#### *8.3.2.3 BH1750_GY30*

This section of the code has the objective of managing the operations regarding the BH1750 light intensity sensor, therefore, it is divided in two functions. There are several libraries available for the development of the code of this sensor, however, none of them is compatible with the microcontroller of the board used in the project (SAMD21), thus, the general programming of this sensor has been implemented by using the Wire.h library, which allows us to communicate with I2C devices such as the BH1750 sensor.

- **BH1750_init ()**: Initializes sensor BH1750_GY30, so when this function is called, the Wire.h library is initialized and the previously defined address of the sensor (ADDR) is sent in order to start the transmission and start reading data.
- **Lux ()**: Measures and returns the light intensity value measured in lux through a series of communications with the sensor BH1750 GY30. The variable that returns the value of light intensity is initialized to 0, therefore, in case of not receiving data from the sensor, the value of light intensity will be of 0 lux.

#### *8.3.2.4 Accelerometer*

This module contains the different functions used to measure the accelerometer data and process this information in order to obtain all the possible states in which the device can be found (static, disturbed or moving). In addition, several auxiliary functions are also developed in this part in order to simplify the execution of different mathematical operations. To develop this part of the code, the library Arduino_LSM6DS3.h has been used in order to read the acceleration of the IMU. Also, this part of the code is based on the algorithm developed by another student within the university (Ayerra Basés, 2020) .

- **Acc_init ()**: Initializes the accelerometer and it case the initialization fails, it displays the message "Failed to initialize IMU!" in the serial monitor. It also initializes to 0 all the elements of the array PREVIOUS_STATES, therefore supposing that the initial state of the frame is idle.
- **State ()**: The objective of this function is to calculate the state of the frame (Idle, disturbed or moving), depending on the accelerations read from the different axis (x, y, z) of the IMU included in the Arduino board. Therefore, it is divided in three main parts: the measurement of the acceleration in the three axis, the calculation of the maximum rms and delta acceleration among all three axis and the estimation and filtering of the state of the frame. Finally, this function return the filtered state of the frame, that is, taking into account the 3 previous states measured.

Auxiliary functions used within function state:

- **Summation (float numbers[], int n, int start)**: This function has three inputs: a vector (numbers[]) and two integer variables, n and start. It calculates the addition of n elements of an array from position start (included) to position start+n (not included).
- **Average (float numbers[], int n, int start)**: This function has the same inputs as the previous one, a vector (numbers []) and two integer variables. It calculates the average of n elements of an array from position start (included) to position start+n (not included).
- **Rms (float numbers[], int n)**: This function calculates the rms value of the first n elements of an array, therefore, it is important to take into account that the length of the array (numbers[]) has to be at least of n elements.

### *8.3.2.5 Blynk_event*

This part of the code is composed of a single function whose objective is to call the different functions that read the information coming from the sensors, to send the information via wifi to the Blynk server. This function will be called from the main function

Connected_Frame () and will be executed every second. For the development of this part of the code, the libraries BlynkSimpleWiFiNINA.h, WiFiNINA.h and SPI.h have been used.

- **myTimerEvent**: This function is divided into three distinct parts. Firstly, the functions in charge of measuring the information coming from the sensors (temperature, humidity, light intensity and frame state) are called. Also, the previous variables are updated, which will be needed later to define the state of the different alarms. Secondly, the data is sent to the Blynk server. This way, humidity, temperature and light intensity will be associated to the virtual pins previously defined in the application (V5, V6 and V7 respectively). Likewise, a different message will be sent for each of the different states of the frame (Idle, disturbed or moving) to the lcd screen of the application, associated to the virtual pin V8. Finally, the ranges in which the alarm will be activated for each of the measured variables will be defined. When the variables go from the optimal range to the risk range, a push notification will be sent to the cell phone warning of the frame state and, in the case of temperature, humidity and light intensity, a red led will be activated in the application while the corresponding variable is in the risk range.

### 8.3.3 CONNECTED FRAME APP

To create an application through the Blynk app, first it will be necessary to create a new project, where it will be required to select a device and a connection type among those available. Since the Arduino nano 33 IoT is not available, the most similar board has been selected, which will be the Arduino MKR1000 since it has the same microcontroller. Also, Wifi will be used as the connection type since the board has a wifi module and the product will be more easily handled.

Therefore, once the new project has been created, the corresponding widgets will be added to the project canvas: An lcd screen to control de movement of the frame, the notification widget for being able to receive push notifications and three gauge widgets to control humidity, temperature and luminosity. Also, a warning led for each one of the gauges will be added in order for it to turn on in case an alarm is triggered. Once the widgets have been included, the virtual pins corresponding to each widget will be selected, as well as the color and other features regarding the app's interface. Next, the different screens that can be found inside the application will be shown and briefly explained.

### *8.3.3.1 Initial screens*

In the following images (Image 10 and Image 9) the initial screens of the app are shown. The home screen will be displayed when the client accesses the app, then, the client will have to login by introducing an email and a password. In case of not having an account already, a new account will have to be created in order to log in.

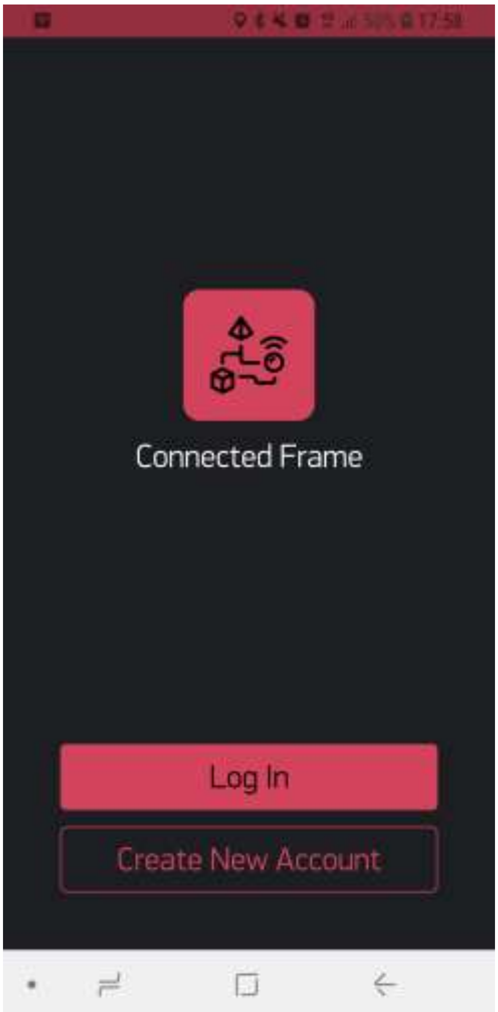


*Image 10. Home screen*

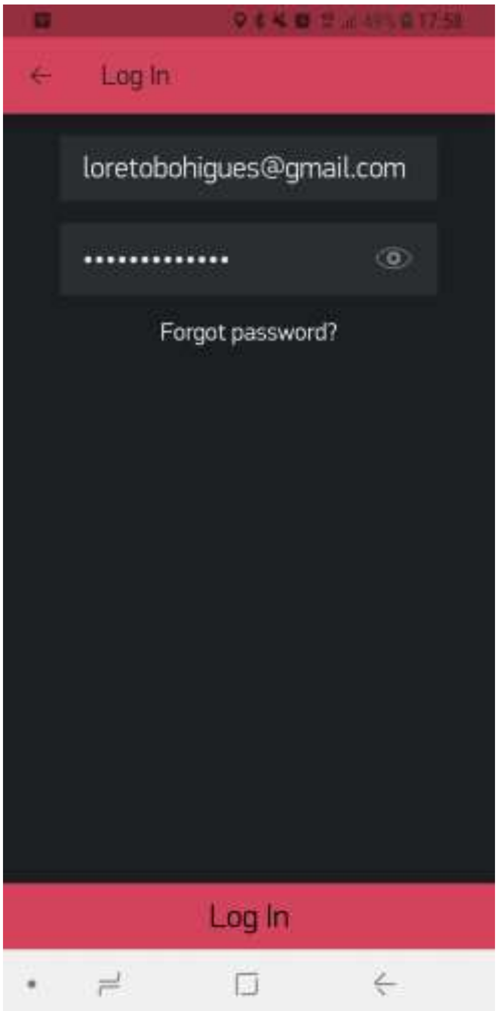


*Image 9. Login screen*

### *8.3.3.2 Humidity alarm*

The following images show the screen of the app when the humidity is not in the optimal range (Image 11) and the push notification received when the alarm is triggered (Image 12). It can be observed below that the value of humidity is 99,9%, which is too high and therefore, the warning led is on as the value of humidity is over 70%. Also, a push notification has been received with the message "Humidity is not in the optimal range. Please check the painting's environment.".

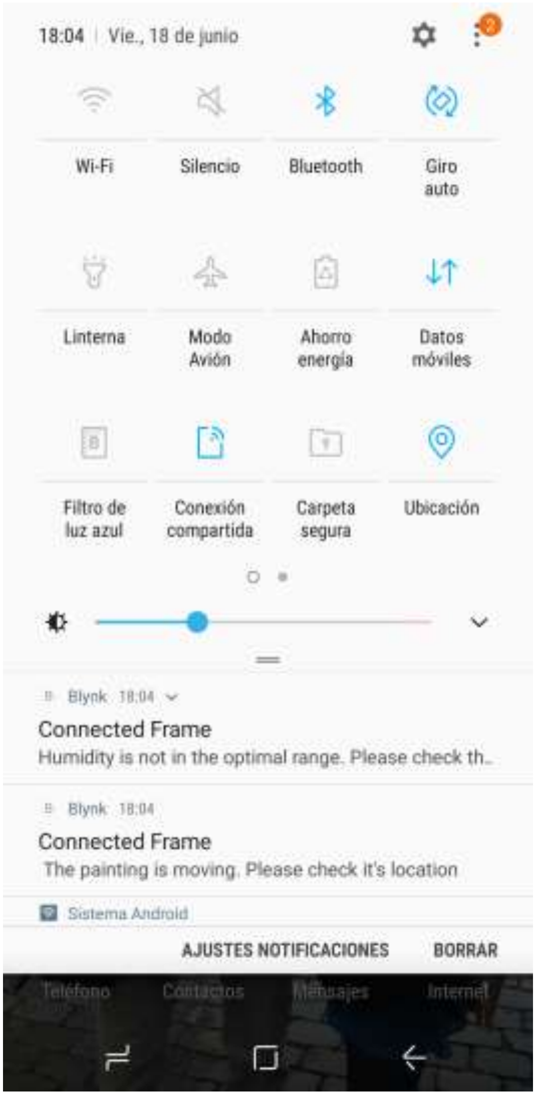


*Image 12. Push notification for humidity alarm*


*Image 11. App screen when humidity alarm is triggered*

#### *8.3.3.3 Temperature alarm*

The following images show the screen of the app when the temperature is not in the optimal range (Image 14) and the push notification received when the alarm is triggered (Image 13). It can be observed below that the value of temperature is 30,4 ºC, which is too high and therefore, the warning led is on, as the value of temperature is over 30 ºC. Also, a push notification has been received with the message "Temperature is not in the optimal range. Please check the painting's environment.".

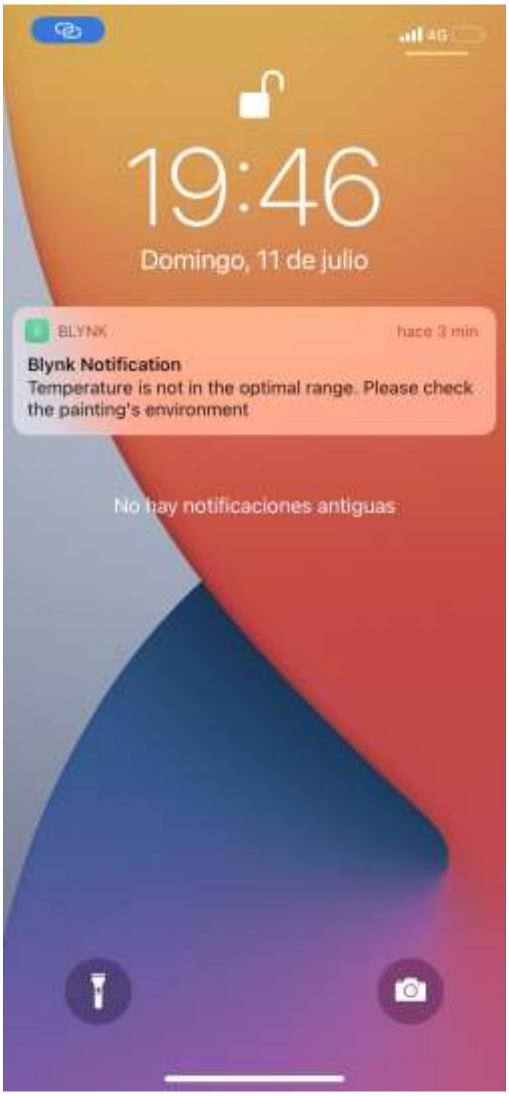


*Image 13. Push notification for temperature alarm*


*Image 14. App screen when temperature alarm is triggered*

### *8.3.3.4 Light intensity alarm*

The following images show the screen of the app when the light intensity is not in the optimal range (Image 15) and the push notification received when the alarm is triggered (Image 16). It can be observed below that the value of light intensity is of 924 lx, which is too high and therefore, the warning led is on as the value of light intensity is over 300 lx. Also, a push notification has been received with the message "Light intensity is not in the optimal range. Please check the painting's environment.".

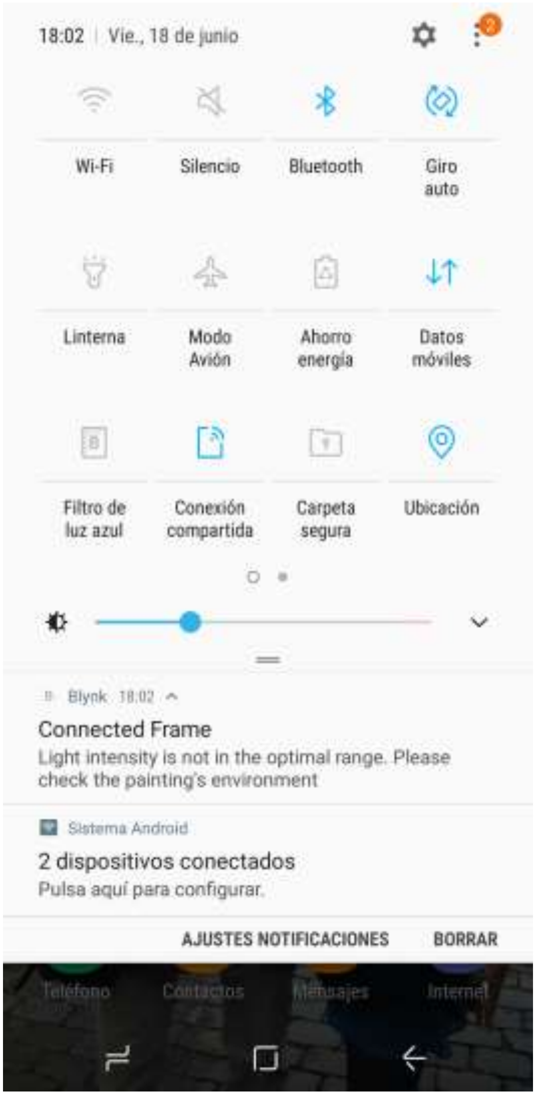


*Image 16. Push notification for light intensity alarm*


*Image 15. App screen when light intensity alarm is triggered*

### *8.3.3.5 Motion alarm*

The following images show the screen of the app when the painting is moving (Image 18) and the push notification received when the movement alarm is triggered (Image 17). It can be observed below that the LCD screen displays the message “The painting is: MOVING”, which is the state that triggers the alarm. The message displayed on the LCD screen varies depending on the state registered by the hardware (Idle, disturbed of moving)). Also, in order to warn the owner, a push notification has been received with the message “The painting is moving. Please check its location.”.

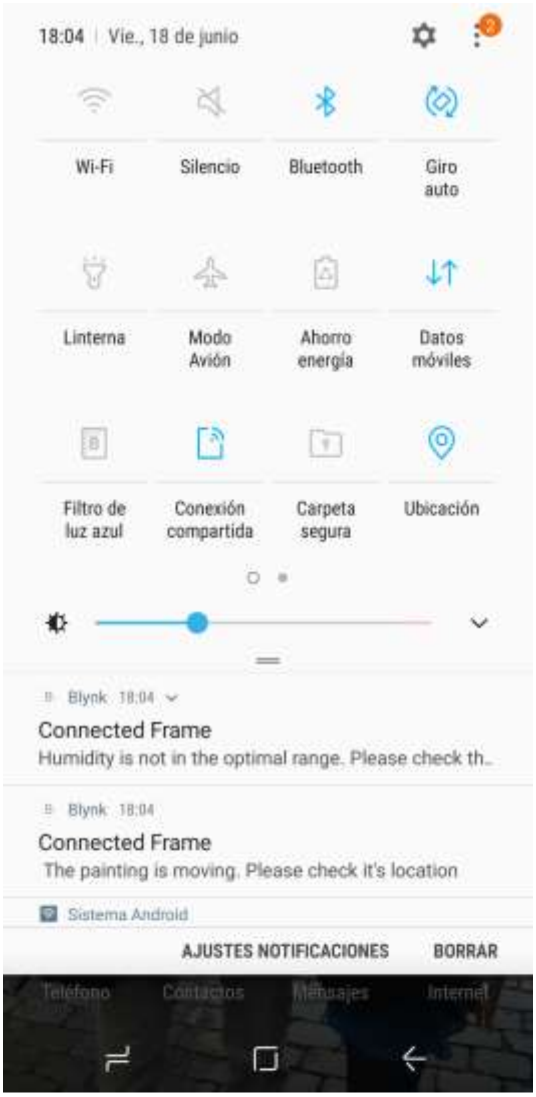


*Image 17. Push notification for movement alarm*


*Image 18. App screen when movement alarm is triggered*

## *8.4 ASSEMBLY OF PROTOTYPE AND VALIDATION*

Once the manufacturing of the parts, the hardware and the development of the software has been complete (MarcadorDePosición1) (MarcadorDePosición1) (Guillén, Saisho, 2019; Guillén, Saisho, 2019)d, the assembly and validation of the complete prototype has been carried out. In this way, first of all, the assembly and union of the different parts of the frame has been carried out by means of the wedges designed for this purpose. They have been properly fixed by applying an appropriate glue and by applying pressure during the drying process.

Next, the hardware was welded. First of all, the sensors have been welded, which will be separated from the main board due to their strategic placement inside the frame. On the one hand, the DHT22 sensor has been soldered on the corresponding pins directly with the three wires that will connect it to the board. On the other hand, the light intensity sensor will be connected to pins from which it can be connected and disconnected. These pins will be soldered in turn to the long wires that connect the sensor to the board. After soldering these sensors, they will be screwed into their corresponding parts and inserted into the frame, leading the wires to the board where the Arduino board, the resistor and the battery wires will be soldered according to the arrangement tested previously in the hardware assembly.

*Image 19. Assembly of light intensity sensor*

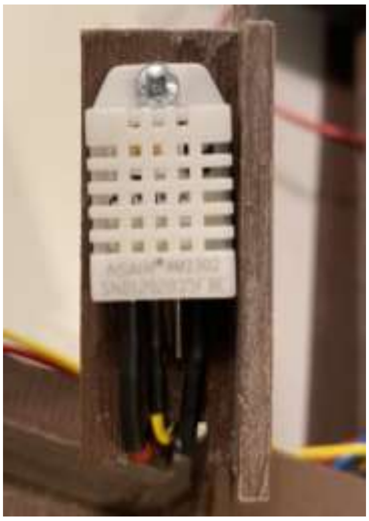

*Image 20. Assembly of temperature and humidity sensor*

After soldering the PCB, it will be installed on the corresponding part, which in turn will be screwed to the frame. Finally, the battery holder will be attached to the inside of the lower right corner of the frame and the frame will be closed by the aluminum plate which will be screwed to the back.

Finally, to verify that the final prototype is working properly, it has been connected to the network and the software developed in Arduino has been uploaded back to the board. Afterwards, it has been verified that the information arrives properly to the designed application. The final prototype is shown in the images below (Image 21 and Image 22).

*Image 22. Front view of the assembled frame*

*Image 21. Back view of the assembled frame*

# 9. BUSINESS PLAN

Once the prototype has been designed and manufactured, the business plan of the start-up that will sell the product will be developed. To do this, we will start by carrying out a market research through which we will try to analyse the market and the competition in depth. In addition, a study of the company's potential customers will be carried out. After having analysed the market, an optimal business model for the company will be proposed and both a financial plan and a pricing model will be carried out.

## *9.1 MARKET RESEARCH*

### 9.1.1 PURPOSE AND OBJECTIVES

Prior to determining the main aspects of the art market both nationally and internationally, as well as the context in which art thefts occur within this sector, we will proceed to define both the purpose and objectives of the research to be carried out. Later on, based on the information gathered, the target audience will be defined based on the group of the population that best suits the product.

**PURPOSE**

The purpose of this investigation is to know the feasibility of launching the Connected Frame within the Spanish market.

**OBJECTIVES**

- ✓ Analyse the profile of art collectors in Spain and internationally to define the target audience
- ✓ Study the situation of the art market in Spain and internationally
- ✓ Define the potential competitors of the company and their characteristics

### 9.1.2 WEB RESEARCH

Prior to defining the benchmark, the target audience and the rest of the business model, an exhaustive information research will be carried out in order to know the sector in which the company is going to operate. In the case of the Connected Frame, the search for information will be focused both on the international art market and the Spanish art market. This research will establish a basic framework of information for the subsequent analysis of the business and the definition of the different aspects of it.

#### *9.1.2.1 THE GLOBAL ART MARKET*

The global art market consists of the set of buyers and sellers who exchange works of art and culture traditionally associated with the various arts, as well as the set of services and companies associated with that exchange.

In 2018, the market ahead reached a figure of more than $67 billion, in contrast to the $64 billion recorded the previous year. However, the global art market value decreased significantly in 2020, due to the Coronavirus pandemic, which caused a 22% decrease compared to the 2019 figures, dropping to a value of $50 billion (Statista Research Department, 2020).

In terms of worldwide sales volume in this market, it peaked in 2019 with 40.5 million transactions compared to 39.8 million the previous year. However, in 2020 this value decreased significantly reaching a value of 31.4 million transactions. Looking at the data provided in Figure 7, it can be seen how a similar value was only reached in 2009, after the impact of the 2008 financial crisis. Therefore, it can be noted how crises affect this sector greatly (Statista Research Department, 2021).

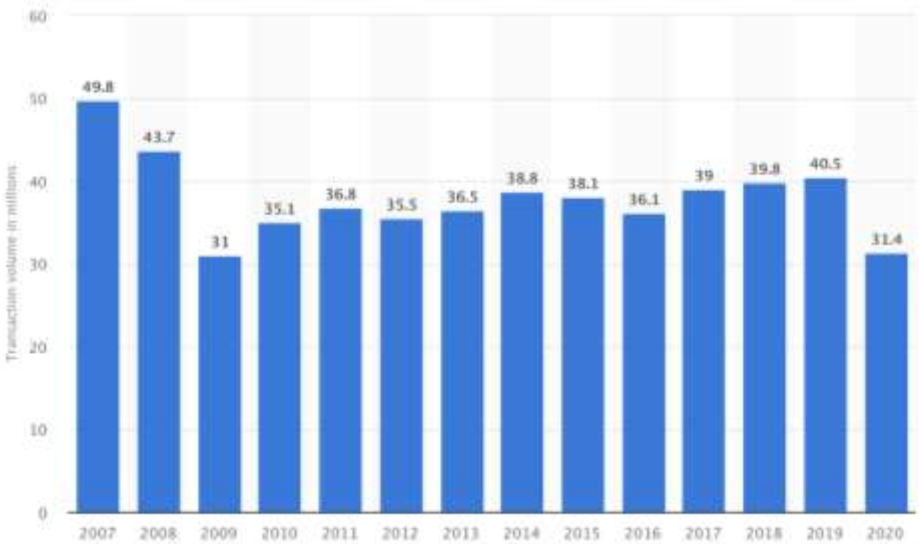


*Figure 7. Global art market value from 2007 to 2020 (Statista Research Department, 2021)*

On the other hand, if we take a closer look at the different regions according to the market share, the United States rank first, with a market share of 42% in 2020, although the country has been consolidated in this position for years. Europe is in second place with 31% of the market share, especially because of countries such as the United Kingdom, France, Switzerland, Germany or Spain. China is also worth mentioning as it is in third place with 20% of the market share as shown in Figure 8 (McAndrew, The art market 2021, 2021).

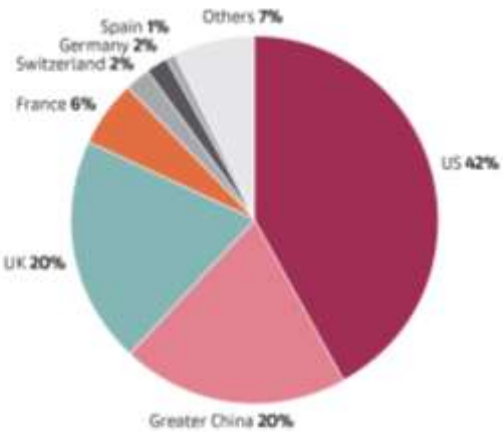


*Figure 8. Global market share by value in 2020 (McAndrew, 2021)*

- **ART COLLECTORS**

Since works of art are goods with a high value, to be part of the art market as a collector it is necessary to have a high income. Therefore, the countries with the highest number of millionaires and wealth are key in this market since they have a larger number of potential buyers. For instance, the United States, which is the country with the largest market share, also has the largest share of millionaires and billionaires as shown in Figure 9 and Figure 10. Thus, a remarkable correlation between the number of billionaires and market share can be observed. In addition, it is worth noting that due to the crisis caused by the coronavirus, inequalities have increased globally, that is, the part of the population with the highest income has increased its wealth globally by 10%. Thus, in 2020 the global number of billionaires increased by 7% and they increased their wealth over the year by 32%. This is partly due to the strong performance of the financial market during the coronavirus crisis, which has led to the preservation and growth of the wealth of many collectors in the art market (McAndrew, The art market 2021, 2021).

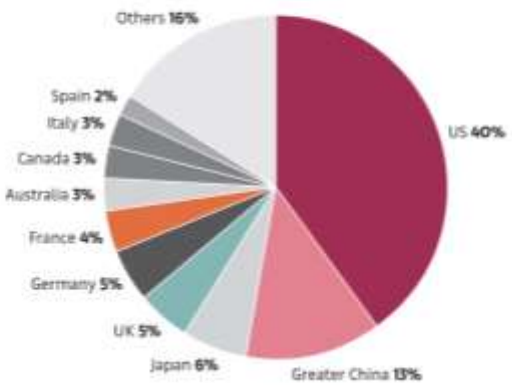


*Figure 9. Global share of the population of dollar millionaires in 2020 (McAndrew, 2021)*

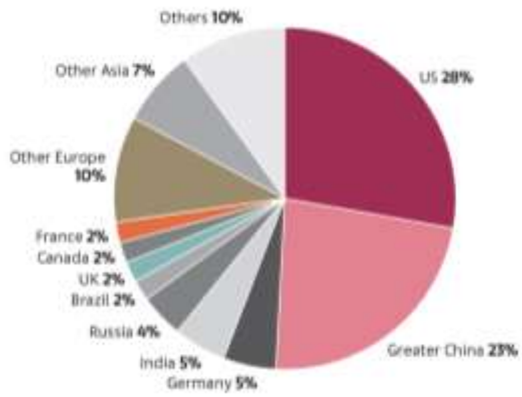


*Figure 10. Global share of the population of billionaires in 2020 (McAndrew, 2021)*

Also, according to the surveys of 2569 high net worth collectors conducted by Arts Economics, despite the pandemic, collectors have retained and increased interest in continuing to collect. This increased interest, while homogeneous across all generations, is most notable among millennials, who also plan to increase their activity in the art market in 2021 (McAndrew, The art market 2021, 2021).

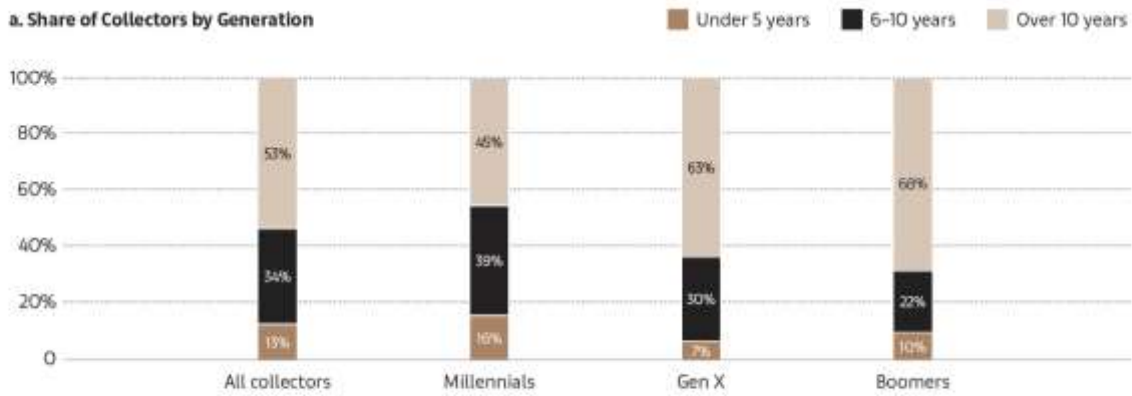


*Figure 11. Length of time collecting. Share of collectors by generation (McAndrew, 2021)*

As shown in Figure 11, more than half of millennials who collect art have been collecting for less than 10 years. Thus, it is worth highlighting the growing presence of a generation of young and wealthy collectors who foresee a promising future for the art market.

Moreover, given the extremely large sample size of the survey mentioned above, it can be considered representative of the global art collecting community. With this in mind, it is worth noting the homogeneity between men and women. As for the generational distribution of collectors, although the questionnaire was distributed over a wide range of ages, the most representative generational segments were the millennials (52%) and generation X (32%), followed by the boomers with 12%, as shown below in Figure 12.

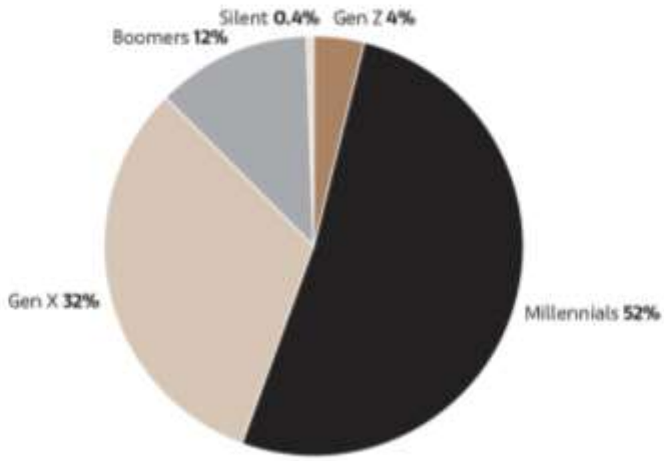


*Figure 12. Market share by generation (McAndrew, 2021)*

- **ONLINE SALES**

In terms of the success of sales channels in the art market, it should be pointed out that although traditional art transactions through galleries, auction houses and fairs continue to predominate, the online art market has experienced a period of significant growth in recent years (Statista Research Department, 2020). This growth has been increased in 2020, primarily because the pandemic has caused to abandon in-person activity, which has accelerated the digital transformation of the art market. As a consequence, the online sales in 2020 reached a record of $12.4 billion, doubling in value the online sales of the previous year and reaching a 25% share of the art market as seen in Figure 13 (McAndrew, The art market 2021, 2021). However, even though most art dealers believe that the online sales will continue to grow in the following years, most of them noted their keenness to return to connecting with clients offline, as usual (McAndrew, The art market 2021, 2021).

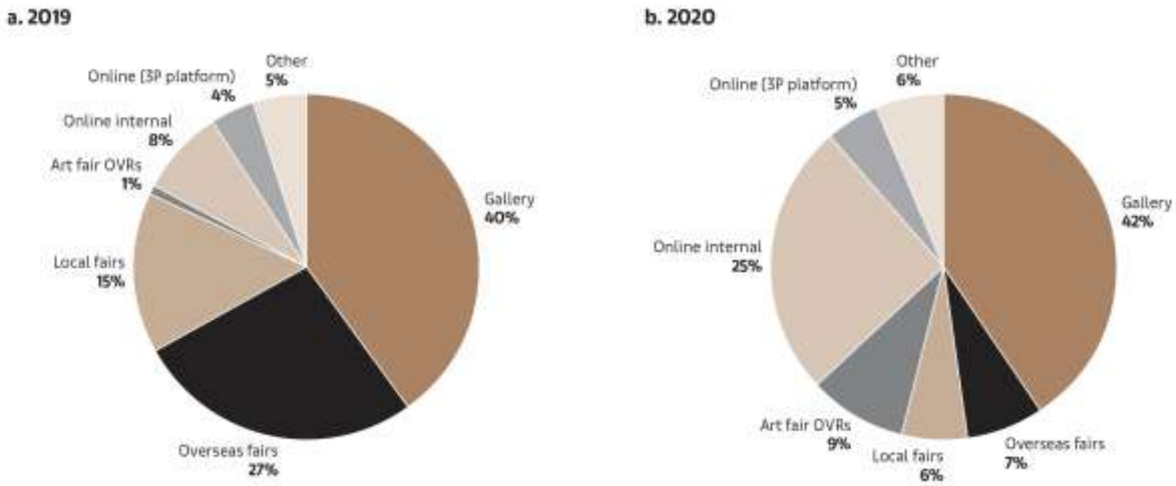


*Figure 13. Share of dealer sales by value by sales channel in 2019 and 2020 (McAndrew, 2021)*

### *9.1.2.2 THE SPANISH ART MARKET*

After analyzing the international art market, we will proceed to further explore the characteristics of the Spanish art market, given that this is a potential market to start commercializing the Connected Frame, with a possible future expansion to more prolific countries in the art world, such as the United Kingdom, the United States or China.

As for the Spanish art market, there is currently no data as recent as that of the global art market, however, in 2017 the organization Fundación "La Caixa" requested a report about the art market in Spain to the consulting firm Arts Economics, coordinated by Dr. Clare McAndrew. This report, studies the situation of the art market in Spain during the past few years, however, it does not take into account the situation caused by the coronavirus crisis in Spain, nevertheless, the consequences of this recent crisis can be inferred from those produced in the international art market.

Thus, and according to the report mentioned above, sales in the Spanish art market reached a minimum in 2009, as did the international market. However, while the international market suffered a drop of 40%, the Spanish market experienced a slightly larger drop in sales, which accounted for 44%. After the financial crisis, the Spanish market began to recover, but at a slower pace than the international market and sales began to flatten out (McAndrew, 2017). According to Dr. Clare McAndrew, the stabilization in Spain after the 2008 financial crisis is mainly due to the fact that Spain is a market for works of art of modest value. This is due to the fugue of the most highly priced works out of Spain as approximately 97% are sold abroad, including millionaire Picassos, Dalís and Mirós (Kunitz, s.f.). Nevertheless, after said period of stagnation, sales began to grow moderately and in 2016 and they reached the figure of 385 million euros, 42% higher than in 2009. This growth continued until, in 2020 it declined significantly due to the coronavirus crisis as did the global art market (McAndrew, 2017). However, it should be pointed out that, as mentioned above, in 2020, the Spanish art market had a global market share by value of 1%, making it the seventh most relevant market in the world in terms of value as shown in Figure 8.

- **SPANISH ART COLLECTORS**

After outlining the evolution and general situation of the Spanish art market in recent years, we will proceed to analyze the general profile of Spanish art collectors by making use of the report *100 Activos coleccionistas de arte españoles* published by the platform Arteinformado, which is currently the most exhaustive document in this regard due to the opacity of the Spanish art market.

Thus, the Spanish market is a modest and less ostentatious market in where, although it is managed a smaller patrimonial capacity than in Latin America, it has a more international character. In addition, it should be noted that the profile described below is that of an active collector, that is, one who is present in the market and buys on a regular basis (Kunitz, s.f.).

In the first place, the Spanish art collector is characterized by being mostly male (48%) as opposed to 24% of women and 28% that collect as a couple (Arteinformado, 2019). In addition, most of the collectors live in Madrid or Catalonia, since the market is mostly located in these places, however, it should be noted that the third region in terms of collectors is Cantabria (Kunitz, s.f.).

Secondly, the age range of the Spanish collector is wide since it goes from those born in the 20's to those born in the 80's, however, the majority of them were born in the 60's and 50's, so they mostly belong to generation X. Likewise, more than half of them were initiated in the art world with the idea of building a collection, which is why both completing their collections and supporting the sector are among their main motivations to continue collecting (Arteinformado, 2019).

As for the collectors' interests, painting stands out as the main artistic discipline in Spain, followed by photography and sculpture. Furthermore, although a large number of collectors claim to have started collecting works of Spanish artists, over the years they have focused more on international and contemporary artists. Also, while the majority (85%) include in their collections pieces by renowned artists, there are also collectors who own artwork by emerging artists (36%) and mid-career artists (38%) (Arteinformado, 2019; Bea Sensors, s.f.).

With regard to the management of their private collections, Spanish collectors are particularly active in the public market. Approximately half of them regularly lend their collections for temporary exhibitions. In addition, they also participate in other types of projects such as the organization of exhibitions focused on their collection, the possession of temporary deposits in museums and national and international centers, as well as other projects and initiatives of their own. Likewise, 24% have organizations dedicated to the management and exhibition of their collection. On the other hand, with respect to where they buy, Spanish collectors prefer national galleries, although they combine their purchases between Spanish and foreign galleries.

- **STRUCTURE OF THE ART MARKET**

The art market in Spain, as well as in the rest of the world, is traditionally divided into auction houses, art fairs and art galleries, in addition to the recent growth in online sales.

On the one hand, auction house are among the most popular sectors in Spain due to the accessibility and transparency of this kind of service towards the customers. For instance, this sector represented a 20% of Spain's art market value in 2016. Auction houses are mainly located in Madrid and Barcelona and the key to their popularity is the low prices within the art market. For example, in 2016 almost half of the acquisitions were done at a price under 1.000€ and 97% of the lots were sold at a price under 50.000€ (MarcadorDePosición1).

On the other hand, galleries are the most direct bond between artists and collectors and in 2016 accounted for 70% of the market sales However, the market price in Spain is still low with respect to other similar countries. For instance, most of the transactions done through galleries in 2016 had a price in between 1.000€ and 5.000€ and only a small part of the transactions were done at prices over 250.000€ (MarcadorDePosición1).

Finally, with regard to art fairs, it is important to highlight that this sector is growing, in fact in 2016 the sales rose up to 41% with respect to the previous year. Also, the importance of ARCO both nationally and internationally is especially relevant as it is the main contact between international collectors and the Spanish art market (MarcadorDePosición1).

### 9.1.3 TARGET AUDIENCE

After having carried out the market research, the target audience will be defined. This step is crucial in the development of an appropriate business model, so that the company can develop and adapt the product to the customer's requirements. In the case of the Connected Frame, this product offers the possibility to approach the business strategy in two possible ways: Business to customer (B2C) and Business to business (B2B). Both alternatives will be studied as follows in order to make a decision.

#### *9.1.3.1 B2B*

The first option involves selling the product directly to other companies that can benefit from the advantages offered by the Connected Frame. Therefore, the product could be sold to galleries, auction houses or art fairs for the protection of works of art when they are exhibited or stored. Likewise, the Connected Frame could also be used for art transportation tasks, being able to collaborate with companies such as SIT or other companies involved in the transportation and logistics of the art sector.

Thus, if the chosen approach is B2B, the company would not have to bear the costs of the retail shops, however, the online sales channel would be necessary. Moreover, as it is a highly customised product, an economy of scale is not considered as it would not have any effect on cost reduction. On the other hand, post-sales maintenance of the product would be necessary as in the B2B strategy. In addition, galleries, auction houses and art fairs often handle works of art with a frame already installed either by the previous owner or by the artist, and sometimes the work is not framed as the choice of the frame is usually a task left to the collector.

On the other hand, collaborating with transport and logistics companies specialised in the art market has its advantages and disadvantages, as there is a lot of competition in this sector compared to a B2B approach. This implies a larger number of potential customers, however, there are few large companies in this sector, which makes it more difficult for them to make a large investment in the product. In addition, the main advantage of working B2B is the large orders, which would not reduce costs significantly as it is a customised product that does not benefit from economies of scale, as mentioned above.

#### *9.1.3.2 B2C*

On the other hand, this second option would focus on selling the product directly to potential customers, that is, to the person who buys and puts frames the artwork, which most of the time is the collector, but sometimes it can also be the artist who frames the artwork directly. Therefore, in this case the product would be used for own consumption and since the product is intended for personal use, it would be better adapted to the customer's requirements more adequately.

If this strategy is chosen, given private collectors often have more than one work of art and acquire pieces on a regular basis, more than one or two pieces could be sold per customer. This way, if the customer is satisfied with the product and service offered, there is the possibility of building customer loyalty. Also, since works of art tend to have a high price compared to other goods and art collectors are usually in an advantageous economic position, the price that the customer would be willing to pay would be high. This implies that the number of customers would not have to be very high to reach the sales target.

As for the marketing strategy, this could be carried out by approaching the client in a personalized way at art fairs or galleries, without the need to reach a very large public through marketing campaigns, but by going to the meeting points where our target public is concentrated. On the other hand, this strategy would imply that the company would have to take care of direct sales to the customer through retail stores and online sales. However, due to the recent increase in online sales in the art market, this would allow the opening of a reduced number of retail stores that are reinforced with the online sales channel, through which the company can stay in touch with customers for the post-sale product support service. On the other hand, it is also important to highlight that the product does not require installation by the company, since once the customer receives the product, the painting would have to be hanged as usual. However, it could be offered as an additional service in case the artwork has very large dimensions.

After having analysed both possible business strategy approaches to choose and their implications, it can be concluded that the most suitable strategy for the Connected Frame is the one aimed directly at customers (B2C). Thus, although the initial investment might be slightly higher than that required for a B2B approach, the difference is not significant due to the absence of the economy of scale effect on costs. Moreover, given that collectors tend to have a high socio-economic level, a slightly higher price should not be a problem. It should also be noted that although the uncertainty of the demand would be lower if the B2B strategy had been chosen, the difficulty of finding customers willing to invest large amounts of money is a very important point in the decision to choose the B2C strategy. Therefore, the product is better adapted to the customer's requirements if the private art collector is chosen as the target audience.

Once the choice of business strategy has been made and the market research has been carried out, the characteristics of the optimal target audience for the Connected Frame will be defined below.

**TARGET AUDIENCE**

- ✓ Residents in Spain
- ✓ Generation X and late Baby Boomers (Born in the 50's)
- ✓ Art collectors and painters
- ✓ Middle-high to high social class

### 9.1.4 BENCHMARK

Once the market in which the product will be launched has been studied and the target audience has been defined, the company's competitive benchmark will be determined in this section. This way, a comparison of the products, services and processes offered by the Connected Frame and similar companies within the sector will be made in order to identify opportunities of improvement. Therefore, by analysing the performance of the different companies within the sector, it will be possible to implement the required changes in order to improve the Connected Frame, as well as the services and processes of the company.

Focusing on the Connected Frame, a secondary information search was carried out in order to find similar products. Thus, we have found two alternatives that are currently available on the market. Thus, the customer has the option to buy different devices separately that offer some of the functionalities also offered by the Connected frame, however, the most similar product found in the market is the microclimatic frames McFrame offered by the company SIT.

These MCFrame microclimatic frames, as previously mentioned in the State of the Art section, are a product developed by SIT, a company dedicated to the conservation and transport of works of art. Thus, MCFrame microclimatic frames are manufactured specifically for each work of art so that it is integrated into the original framing. However, the use of this product is mainly intended for the transport and storage of transit works of art, as well as for temporary exhibitions. As for the functioning of the product, these frames include a latest generation anti-reflective glass that allows the creation of an isolated atmosphere, whose environmental variables are controlled, by measuring the parameters of humidity and temperature. Nevertheless, to obtain these readings it is necessary to access a minidatalogger that the product is equipped with, in order to download them every time a query is required to verify the variables are within the expected range. In addition, due to the creation of an isolated atmosphere, the MCFrame can also measure variables related to air quality and the level of airtightness of the air, in order to achieve a minimum air exchange with the outside (SIT, 2016).

Regarding the commercial approach of both companies with respect to the compared products, the main difference lies in who each product is aimed at.

On one hand, SIT offers a product focused on museums, art galleries and renowned collections such as that the House of Alba. In addition, its products are focused on specific periods, so the service and product offered are designed for the short term in exceptional situations such as the transport and temporary exhibition of the work. Likewise, the McFrame is sold as a frame to protect the work temporarily, therefore, it is installed on top of the frame in which the artwork is usually displayed.

On the other hand, the Connected Frame is a product aimed at private collectors and has the objective of monitoring different variables of the painting in the long term, that is, the frame is designed to be installed directly on the artwork, so that it fulfills the function of a frame at the same time that it records conservation and security variables for the protection of the painting. Thus, the product will be installed in the usual place of display of the work and the owner will be able to access the monitored variables in real time due to the implementation of IoT technology in the product.

Moreover, once the commercial approach of both companies has been mapped out, a more detailed comparison of the functionalities and features of the products in question (Connected Frame and McFrame) will be carried out. Therefore, the main features of the Connected Frame and McFrame can be found in Table 3.

| Features | Connected Frame | MCFrame (SIT) |
|---|---|---|
| Incorporation of the frame into the product | ✓ | ✓ |
| Creation of an isolated atmosphere into the frame | ✗ | ✓ |
| Tracking of variables that affect the conservation of the painting (humidity, temperature, light intensity) | 💧🌡☀ ✓ | 💧🌡 ✓ |
| Real-time monitoring of the movement of the frame for security | ✓ | ✗ |
| IoT technologies implemented | ✓ | ✗ |
| Product accessibility for individuals | ✓ | ✗ |

*Table 4. Comparative table of features and functionalities*

As shown in Table 4, both products share similarities and differences. First of all, the Connected Frame includes a security system that tracks the movement of the artwork, as an additional protective element to the product offered by SIT. It should also be pointed out that in terms of the conservation parameters monitored, the Connected Frame includes the variables of humidity, temperature and light intensity, while the MCFrame does not measure this last one. However, the product offered by SIT creates an isolated atmosphere inside the frame that facilitates the measurement of parameters, a functionality that the Connected Frame does not include, since this product is designed for long periods of exposure, where the atmosphere in which the piece is located is more stable. Likewise, the accessibility of the product to individuals is an advantage for the Connected Frame, taking into account the chosen business strategy.

Finally, it should be noted that the main advantage of the Connected Frame is the implementation of IoT technologies, which represents a considerable increase in value for the product by improving accessibility to real-time information for customers, among other things.

## *9.2 BUSINESS MODEL*

Once an analysis of the market in which the product will be launched has been carried out, the main competitors and the consumer profile has been carried out, we will proceed to look into the details of the business model. First, a Lean Canvas Business Model will be designed to get a general idea of the structure of the company, after which a pricing model and a financial plan will be carried out for the first 5 years of life of the Start-Up to be developed. These last two sections will be especially relevant in order to get investors in the first stages.

### 9.2.1 LEAN CANVAS BUSINESS MODEL

The Lean Canvas Business model consists of a one-page diagram that aims to graphically capture the general idea of the business model to be developed in a start-up. In this way, investors will be able to see the most relevant aspects of the business with a quick glance in order to make a potential investment.

Thus, for the development of the Connected Frame, the Lean Canvas Business Model shown in the following page has been developed. The elements shown in this diagram are listed below together with a brief explanation of each one.

**Key objectives:** Definition of the top-level goals and how they will be measured.

**Vision:** high level introduction to the company and business model.

**Problem**: The problem that the company has been built to overcome.

**Solution**: The main solutions that the product or services of the company offer to the problems mentioned.

**Value Proposition**: The key characteristics that differentiate the product offering.

**Competitive Advantage:** the advantage of the company over the rest of the market.

**Existing alternatives**: Different solutions to the needs and problems that the company satisfies.

**Target audience:** a description of what the company´s ideal customers would be.

**Go-to market:** channels that will be used to reach and sell to customers.

**Cost Structure:** List of the most important costs incurred in the company´s activities.

**Revenue Structure:** sources of revenue of the company.

## The Lean Canvas Business Model

**Designed for:** Connected Frame **Designed by:** Loreto Bohigues **Date:** 08/06/2021 **Version:** 1.0

**Key objectives**
Raising awareness about the importance of preserving works of art properly for posterity.

Adequately protect works of art in private residences as most burglaries take place in these.

Contribute to the progress of the Industry 4.0 by creating a product which is connected to the cloud.

**Problem**
Thefts of works of art from private residences and their consequences, such as low recovery rates.

Deterioration of paintings due to the environmental variables to which they are usually exposed.

**Solution**
Reduction of thefts through an alarm system incorporated in the frame.

Improvement of preventive conservation of paintings by measuring the environmental variables in real time with the Connected Frame.

**Existing alternatives**
Museums and galleries have security systems and devices for preventive conservation, but there are not similar products for the general public.

SIT has a similar product (McFrame) for companies and designed for transport or temporary exhibition. It does not include a security system.

**Target audience**
Private art collectors, residing in Spain and belonging to Generation X and the last baby boomers (born in the 50's).

**Vision**
Product that includes both a security system and a solution for preventive conservation within the frame.

**Value proposition**
Innovative product that integrates a security and conservation system.

Device integrated into the frame of the artwork.

Inclusion of IoT in the product to improve the immediacy of information so that it can be accessed in real time.

**Competitive advantage**
There is no product on the market that integrates a security and conservation system for the artwork.

Added value due to the IoT technologies implemented in the Connected Frame.

**Go-To market**
Few retail stores reinforced with online platform, as well as art fairs where the target audience is usually concentrated.

**Cost Structure**
Production costs: Suppliers, manufacturing, warehouses
Distribution costs: Transportation
Manpower costs

**Revenue Structure**
High-priced product due to the valuable nature of the artwork it protects and the high acquisitive capacity of the target audience
Possibility for one customer to purchase several products
Optional installation service of the artwork
Post-sales service

### 9.2.2 PRICING MODEL

Once the business plan has been defined, a pricing strategy for the Connected Frame will be established. This pricing strategy will be crucial for the future development of the company as it will be its main method of revenue. Since the Connected Frame is a customized product, the price of each product will be unique and will be established depending mainly on the size of the artwork and the services required by the client.

For the implementation of the pricing structure, the frames have been divided into 3 groups according to the standard size of the artwork. Thus, small works will have a size between 12x9 cm and 33x24 cm, with a maximum perimeter of 120 cm, medium works will have a size between 35x27 cm and 92x73 cm, with a perimeter between 120 cm and 330 cm, and large works will be those with a perimeter greater than 330 cm. After making this division, it has been decided not to manufacture frames for large works at the beginning of the start-up since 3D printing technology would be too expensive due to the size of the pieces and the most cost-effective way would be to make the product using other methods that could be studied later.

To establish the price of the frames, it has been separated into two parts according to the costs. On the one hand, a fixed price will be determined since a part of the production costs will be fixed. On the other hand, since the price of the product will depend on the size of the work to be framed, a variable part of the price has been established. Likewise, the price for small works will be 20% higher than the costs of the product, while for medium-sized works it will be 10% higher.

Accordingly, the fixed part of the price will be €89.45 for small works and €81.99 for medium-sized works, taking as a reference the fixed costs of the manufactured prototype, as shown in Annex IV. Likewise, a variable unit price of 2.28 €/cm for small works and 2.09 €/cm for medium works has been established, for which the variable part of the costs per cm of the perimeter of the frame has been taken as a reference.

In addition, the customer will have access to two types of services: IoT and frame installation services. The IoT service will consist of the application developed above, to which the customer will have access at all times from his phone. The storage of the data will be outsourced by the company and will require an annual fee from the customer. Moreover, the customer will be able to have several devices on the same application and will only have to pay a single annual fee that, from the fifth year onwards, will become free of charge in order to reward customer loyalty. This fee will be of 50 € per year and per user regardless the size of the painting framed.

The product installation service will be an optional service offered by the company at an additional cost. This service will include both the installation of the framed painting in the home and the commissioning of the device. This service will cost €10 for small works and €40 for medium-sized works, since the handling and transportation of the work is more complicated and costly.

Taking into account the above, Table 5 shows the pricing structure according to the services offered and the size of the framed works. As can be seen, the price is divided into a fixed and a variable part, in addition to showing how it is calculated according to the perimeter of the artwork.

| Product | Fixed price | Variable price | Selling price | IoT services | Installation fee |
|---|---|---|---|---|---|
| Small paintings (P<120 cm) | 89 € | 2,28 €/cm | 89+2,28*P | 50€/year/user (first 5 years) | 10 € |
| Medium paintings (120<P<330) | 82 € | 2,09 €/cm | 82+2,09*P | 50€/year/user (first 3 years) | 40 € |

*Table 5. Pricing structure*

For a better understanding of the price structure, an example for each of the possible frame sizes is shown below. For this purpose, the size used for the prototype will be taken, which is 24x33 cm, and as a medium size, the measurements for a 61x55 cm frame will be used. Thus, as can be seen in Table 6, the fixed part of the price does not vary according to the size, while the variable part is calculated according to the perimeter of the framed picture, leaving a selling price of 349€ and 545€ for the small and medium frame respectively, to which should be added the IoT service fee of 50€ per year and the installation fee if contracted by the customer.

| Product | P (cm) | Fixed price | Variable price | Selling price | IoT services | Installation fee | Total (with installation) |
|---|---|---|---|---|---|---|---|
| Small paintings (24x33 cm) | 114 | 89 € | 2,28 €/cm | 349 € | 50€/year/user (first 5 years) | 10 € | 409 € |
| Medium paintings (61x50 cm) | 222 | 82 € | 2,09 €/cm | 545 € | 50€/year/user (first 3 years) | 40 € | 635 € |

*Table 6. Pricing example*

Since the pricing structure developed for the frame has been based on unit production costs calculated on the basis of the prototype, it is likely that long-term costs will be optimized so that more competitive prices can be offered with a higher profit margin.

### 9.2.3 FINANCIAL PLAN

After establishing a pricing structure for the company to be developed, a financial plan will be drawn up to forecast the company's growth over the next 5 years if the company meets the defined objectives, in order to provide with financial information to potential investors. Therefore, in this section a growth forecast will be carried out, where the growth objectives for the next 5 years will be established. An income statement will be developed, which will provide a prediction of the profits obtained, and an initial balance sheet will be presented in order to give a general idea of the initial value of the company and the necessary investment at its first stages. Also, the net present value of the company will be calculated taking into account the 5 year forecast.

#### *9.2.3.1 Growth forecast*

Firstly, through the growth forecast, an approximate prediction of the company's growth over the next 5 years will be made, taking into account that the current year (2021) does not represent a prediction. These growth ratios will be the targets on the basis of which the income statement will be predicted later on.

Thus, as shown in Table 7, a prediction of the company's growth with respect to revenue, cost of goods sold (COGS) and total operating expenses has been made. Revenue growth is presented as a percentage of the previous year's revenue, while both COGS and Total operating expenses are shown as a % of revenue.

| | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 |
|---|---|---|---|---|---|---|
| **Revenue growth** | 0% | 90% | 100% | 50% | 40% | 30% |
| **COGS (% revenue)** | 140% | 60% | 60% | 30% | 20% | 20% |
| **TOTAL OP expenses (% revenue)** | **40%** | **15%** | **10%** | **10%** | **10%** | **10%** |
| Marketing expenses | Rest | Rest | Rest | Rest | Rest | Rest |
| Rent | 5.000 | 5.000 | 5.000 | 10.000 | 10.000 | 10.000,00 |
| Distribution | 3% | 2% | 2% | 2% | 2% | 2% |
| Personnel expenses | 6% | 6% | 4% | 4% | 4% | 4% |

*Table 7. Growth forecast*

As for **revenue growth**, it will not grow in 2021 as it will be the year of the company's birth, however, the following two years it will grow significantly (80% and 90%) as it gains customers. In the following three years, however, growth will decrease (50%, 30% and 30%) as the company begins to cover a larger part of the Spanish market and the increasing tendency of entering the market will begin to slow down.

As for the **cost of goods sold**, this refers to the cost of goods sold, which includes raw material costs, transportation costs, production costs and distribution costs. These types of costs will be especially high in the early stages of the company, but, as mentioned above, as production increases and the company grows, they can be optimized, resulting in a higher profit margin.

Finally, the evolution of **operating expenses** in the coming years will also be analysed, which will represent a particularly high percentage of revenue in the year of birth of the start-up. However, in the following years they will be less representative due to the growth of the company. Thus, the most representative operating expenses will be those for marketing, rent and distribution and those for personnel expenses. As shown in the table, distribution expenses will be 3% of revenue on a constant basis over the 5 years. Likewise, 5,000 euros will be dedicated to rent during the first 2 years, while during the last three years this figure will increase to 10,000 euros as a consequence of the company's growth.

In addition, the expenses for the marketing part will be mainly due to the participation in art fairs. Thus, at the beginning the company will have to make itself known, so a larger part of the budget will be invested in the year of creation of the company, in the first two years this budget will decrease slightly, while in the last three years it will increase again as the company will have covered a larger part of the market and it will be more difficult to find new clients. The rest of the operating expenses will correspond to wages and salaries, and therefore, to personnel expenses.

### *9.2.3.2 Income statement and balance sheet*

Through the income statement, we will try to make a prediction of the company's evolution over the next 5 years based on the growth forecast previously made.

| | **2021** | **2022** | **2023** | **2024** | **2025** | **2026** |
|---|---|---|---|---|---|---|
| Revenue | 109.447,41 € | 217.950,09 € | 444.900,17 € | 685.850,26 € | 982.890,36 € | 1.300.707,47 € |
| COGS | -142.281,64 € | -196.155,08 € | -177.960,07 € | -274.340,10 € | -196.578,07 € | -195.106,12 € |
| **Gross profit** | **-32.834,22 €** | **21.795,01 €** | **266.940,10 €** | **411.510,15 €** | **786.312,29 €** | **1.105.601,35 €** |
| MKT | -15.000,00 € | -10.000,00 € | -10.000,00 € | -15.000,00 € | -20.000,00 € | -30.000,00 € |
| Rent and distribution | -8.283,42 € | -11.538,50 € | -18.347,01 € | -30.575,51 € | -39.486,71 € | -49.021,22 € |
| Personnel expenses | -9.550,80 € | -11.154,01 € | -16.143,01 € | -23.009,52 € | -38.802,33 € | -51.049,52 € |
| **Total Op. Expenses** | **-32.834,22 €** | **-32.692,51 €** | **-44.490,02 €** | **-68.585,03 €** | **-98.289,04 €** | **-130.070,75 €** |
| **EBITDA** | **-65.668,45 €** | **-10.897,50 €** | **222.450,09 €** | **342.925,13 €** | **688.023,25 €** | **975.530,60 €** |
| Taxes | 0,00 € | 0,00 € | -33.367,51 € | -51.438,77 € | -172.005,81 € | -243.882,65 € |
| **NET INCOME** | **-65.668,45 €** | **-10.897,50 €** | **189.082,57 €** | **291.486,36 €** | **516.017,44 €** | **731.647,95 €** |

*Table 8. Income statement*

This way, for each year, the Revenue and COGS have been calculated as a percentage of this in order to obtain the Gross profit, from which the operating expenses, calculated as indicated above, will be deducted. Thus, EBITDA (Earnings before interests, taxes, depreciation and amortization) will be obtained, after which the corresponding taxes will be calculated on the basis of current Spanish law. The law states that companies are exempt from taxation if the result of the year is negative and in the case of a positive result, the tax rate is 25%. However, in the case of newly created companies, the tax rate is 15% for the first two years in which profits are made.

Therefore, as shown in Table 8, it is expected to incur losses during 2021 and 2022, however, from 2023 onwards, profits will start to be generated and the company will grow to an EBDITA of €975,530, which is a promising result.

After analysing the forecast for the next 5 years set out in the income statement, an approximate balance sheet will be drawn up for the company at the end of 2020, after the start of its activity. Although the balance sheet is not as precise as the income statement, it can give an idea of both the value of the company at this point in time and the various resources that will be necessary to start up the business.

| **ACTIVE** | | **PASIVE** | |
|---|---|---|---|
| **ASSETS** | **220.000,00 €** | **LIABILITIES** | **200.000,00 €** |
| **ST Assets** | **203.500,00 €** | **ST Liabilities** | **150.000,00 €** |
| Inventory | - € | Suppliers | 150.000,00 € |
| ST Clients | 150.000,00 € | ST Loan | - € |
| Cash and Equivalent | 53.500,00 € | **LT Liabilities** | **50.000,00 €** |
| **LT Assets** | **16.500,00 €** | LT Loan | 50.000,00 € |
| Software and app patents | 1.500,00 € | **EQUITY** | **20.000,00 €** |
| PPE | 15.000,00 € | Common stock | 110.000,00 € |
| | | Retained earnings | - 90.000,00 € |
| | | Accumulated income | - € |
| **TOTAL ASSETS** | **220.000,00 €** | **TOTAL Liabilities + Equity** | **220.000,00 €** |

*Table 9. Balance sheet*

Then, as shown in Table 9, the balance sheet will be divided into assets, liabilities and equity. The equity part will take the rounded data from the income statement, so that the initial investment will be €110,000 and the retained earnings will make up a loss of €90,000. As can be seen, the value of different aspects of the company has been estimated, such as long-term receivables, cash, patents and so on. In this way, it has been approximated that the company at the start of its activity will have a value of around €220,000.

### *9.2.3.3 Net present value*

Finally, to complete the financial plan, the net present value (NPV) of the company will be calculated, in the event that the objectives established in the previously developed forecast are met. The net present value represents the value in the future of the money invested in the present, so that the more time passes, the more the money invested will be worth, and therefore the company, in the event that its profit and loss account has positive values. Thus, through NPV, potential investors can get an idea of what their investment will be worth after a certain period of time, in this case 5 years.

Then, to calculate the NPV, the equation shown in Figure 14 will be used, where i is the discount rate and t indicates the year in which the NPV is being calculated, so that in the numerator is the EBITDA of the year in which the NPV is going to be calculated and t=0 is the present year. The discount rate (i) is a magnitude that indicates the risk of investing in a company, so that the higher the discount rate, the greater the risk, but also the greater the money recovered if the objectives are met. In the case of start-ups, this value is higher than normal due to the higher risk involved and is usually between 15% and 20%. In this case, given that the initial investment required is low, we will use a discount rate of 15% for the calculation of the NPV, as shown in Table 10.

$$NPV = \sum_{t=0}^{t} \frac{EBITDA_t}{(1+i)^t}$$

*Figure 14. Net present value*

Thus, as it is shown in Table 10, taking the EBITDA calculated in the income statement between 2020 and 2026, it is obtained that the initial investment of 110,000 euros will have a value of 1.2 million euros after 5 years, which is a good result considering that the initial investment is low.

| **EBITDA** | -65.668,45 € | -10.897,50 € | 222.450,09 € | 342.925,13 € | 688.023,25 € | 975.530,60 € |
|---|---|---|---|---|---|---|
| **Discount rate (i)** | 15% | 15% | 15% | 15% | 15% | 15% |
| **t** | 0 | 1 | 2 | 3 | 4 | 5 |
| **NPV** | **-65.668,45 €** | **-75.144,54 €** | **93.059,68 €** | **318.538,52 €** | **711.918,05 €** | **1.196.929,17 €** |

*Table 10. Net present value*

# 10. ANALYSIS OF RESULTS

In this section the different results obtained after the completion of the project will be analysed, as well as the difficulties encountered during its execution.

As for the design of the prototype, this was simple in terms of hardware and software because not many sensors were necessary due to the choice of the Arduino board, which already incorporated both the Wifi module and the accelerometer, however, there were certain difficulties in incorporating the hardware into the frame when designing the different parts, as there is not much space within a frame and the pieces had to be designed according to the size of the sensors and the board.

Regarding the manufacturing of the prototype, 3D printing the parts was straightforward but time-consuming, especially because of the post-processing phase. As for the hardware, everything worked as designed, with the exception of the humidity and temperature sensor, which had to be powered externally with 3 batteries of 1,5V as the power supply on the board is 3.3V and was not sufficient for the sensor to work properly, even though it was indicated as so on the datasheet.

Also, the software programming was simple due to the existence of multiple libraries for the different sensors and previous work, however, the library for the light intensity sensor did not work due to incompatibility with the board's microcontroller, so a lower level code had to be used. Difficulties were also encountered when connecting the board to the computer, as on many occasions the USB port was not detected, regardless of the computer used. It should also be noted that the Blynk library used for communication between the device and the server was very easy to use.

Therefore, although this part of the project was the most challenging, the difficulties were overcome and the prototype was built in a functional and aesthetically pleasing way that meets the requirements initially proposed.

Finally, the business plan section allowed an initial analysis to be made of the market in which the product would be launched. It should be noted in this aspect that the search for information for the market analysis was somewhat complex due to the fact that the art market, although large, is a very exclusive and opaque market, especially when it comes to private collectors, who are normally reluctant to share information for security or privacy reasons. Thus, it was decided to resort to studies previously carried out by consultancies or specialized platforms, which have a greater amount of resources and information.

Moreover, for the pricing and financial plan, approximate material costs were used according to the prototype made by using the Ultimaker Cura software for the accurate approximation of the 3D printing subcontracting, which is the most expensive part of the prototype. Therefore, through the predictions made in this section, potential investors could get a general idea of the possible development of the company, which was estimated to be very positive.

# 11. CONCLUSIONS AND FUTURE PROJECTS

After having completed the project, it is concluded in a satisfactory way and all objectives have been met. The design and manufacture of the prototype has been positively completed and a business plan for the manufactured prototype has been outlined. In addition, a preservation system and an alarm system for paintings have been brought together in the same product, with everything integrated within the framework and connected through the technology of the Internet of Things. Although the prototype built would not be ready to be commercialised, it is a good start to evaluate possible improvements and how the product could be positioned in the market.

As for future projects, it could be interesting to make a new prototype with new features by integrating other sensors such a GPS or a proximity sensor with their corresponding alarms. The GPS would have the function of locating the frame so that it can be tracked in case it is stolen. However, the proximity sensor would have the function of preventing spectators from touching the paintings, which will have both a conservation and a safety function. Also, the app could be further developed incorporating the new features and improving the interface and connectivity for the user.

Another option to investigate, could be to analyse different manufacturing methods for the frame, as well as other 3D printing techniques with new materials. As mentioned previously in the project, there are some companies dedicated to printing wooden parts, so the feasibility of this type of technique for the prototype could be studied together with a cost analysis in order to improve the profitability of the product.

Finally, it should be noted that the importance and usefulness of this project lies not only in finding a suitable manufacturing method to make a connected and cost-effective product in a way that meets the objectives, but that it goes further and contributes to Industry 4.0 through the manufacture of an innovative and connected prototype and the development of a company around it.

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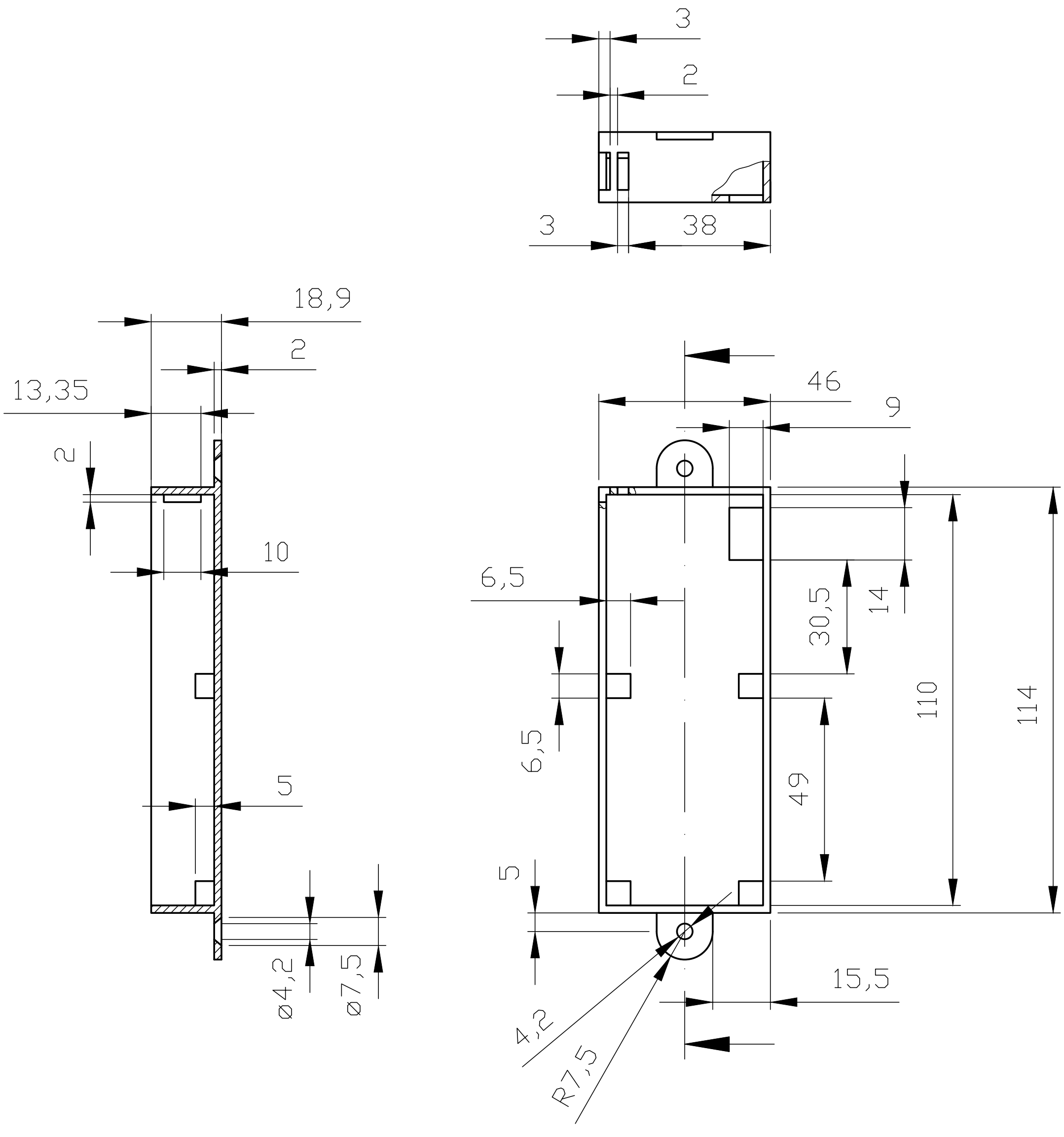
# ANNEX I. ARDUINO NANO 33 IOT TECH SPECS

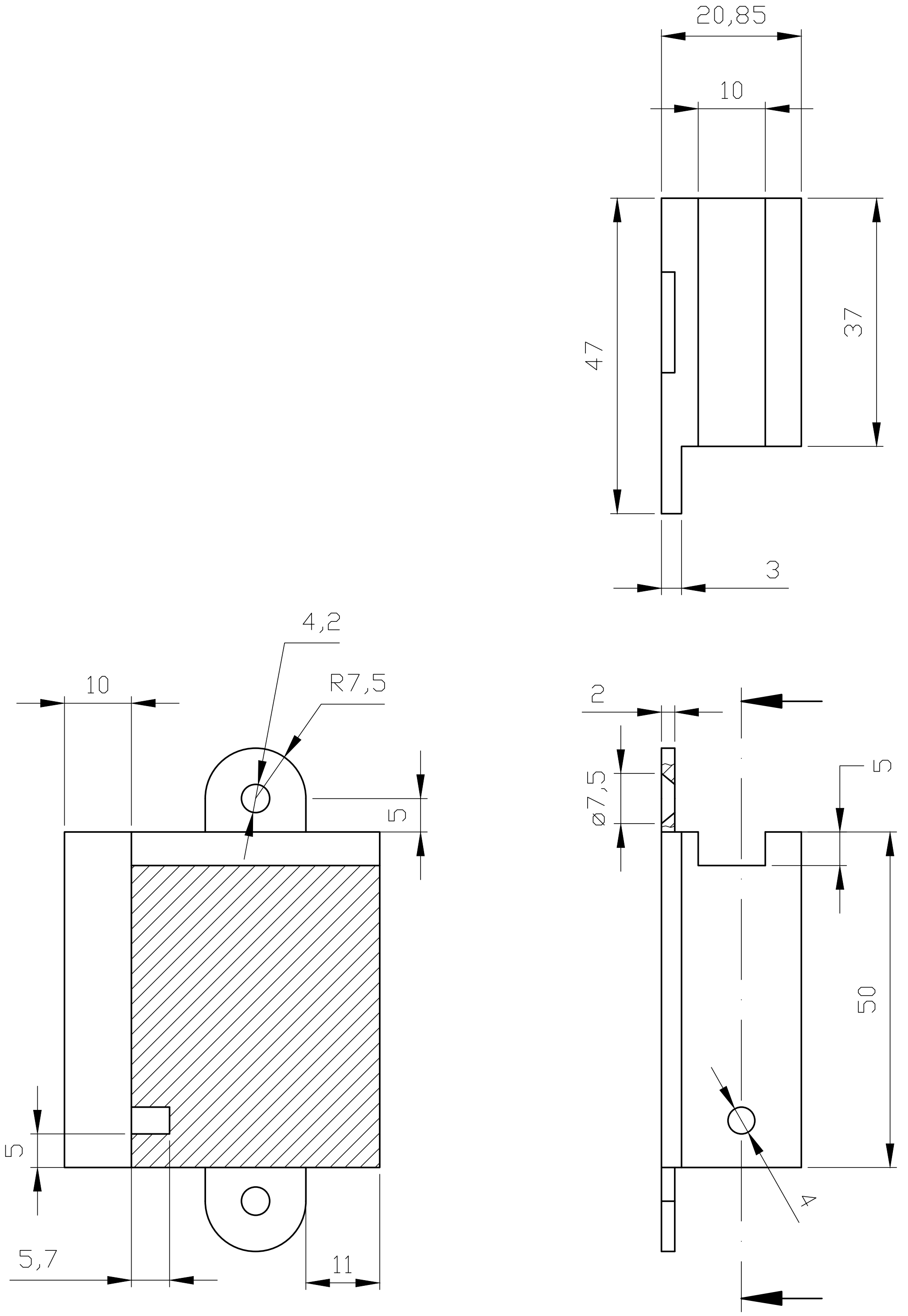
| | |
|---|---|
| **Microcontroller** | SAMD21 Cortex®-M0+ 32bit low power ARM MCU |
| **Radio module** | u-blox NINA-W102 |
| **Secure Element** | ATECC608A |
| **Operating Voltage** | 3.3V |
| **Input Voltage (limit)** | 21V |
| **DC Current per I/O Pin** | 7 mA |
| **Clock Speed** | 48MHz |
| **CPU Flash Memory** | 256KB |
| **SRAM** | 32KB |
| **EEPROM** | none |
| **Digital Input / Output Pins** | 14 |
| **PWM Pins** | 11 (2, 3, 5, 6, 9, 10, 11, 12, 16 / A2, 17 / A3, 19 / A5) |
| **UART** | 1 |
| **SPI** | 1 |
| **I2C** | 1 |
| **Analog Input Pins** | 8 (ADC 8/10/12 bit) |
| **Analog Output Pins** | 1 (DAC 10 bit) |
| **External Interrupts** | All digital pins (all analog pins can also be used as interrput pins, but will have duplicated interrupt numbers) |
| **LED_BUILTIN** | 13 |
| **USB** | Native in the SAMD21 Processor |
| **IMU** | LSM6DS3 |
| **Length** | 45 mm |
| **Width** | 18 mm |
| **Weight** | 5 gr (with headers) |

# ANNEX II. BLUEPRINTS OF THE FRAME

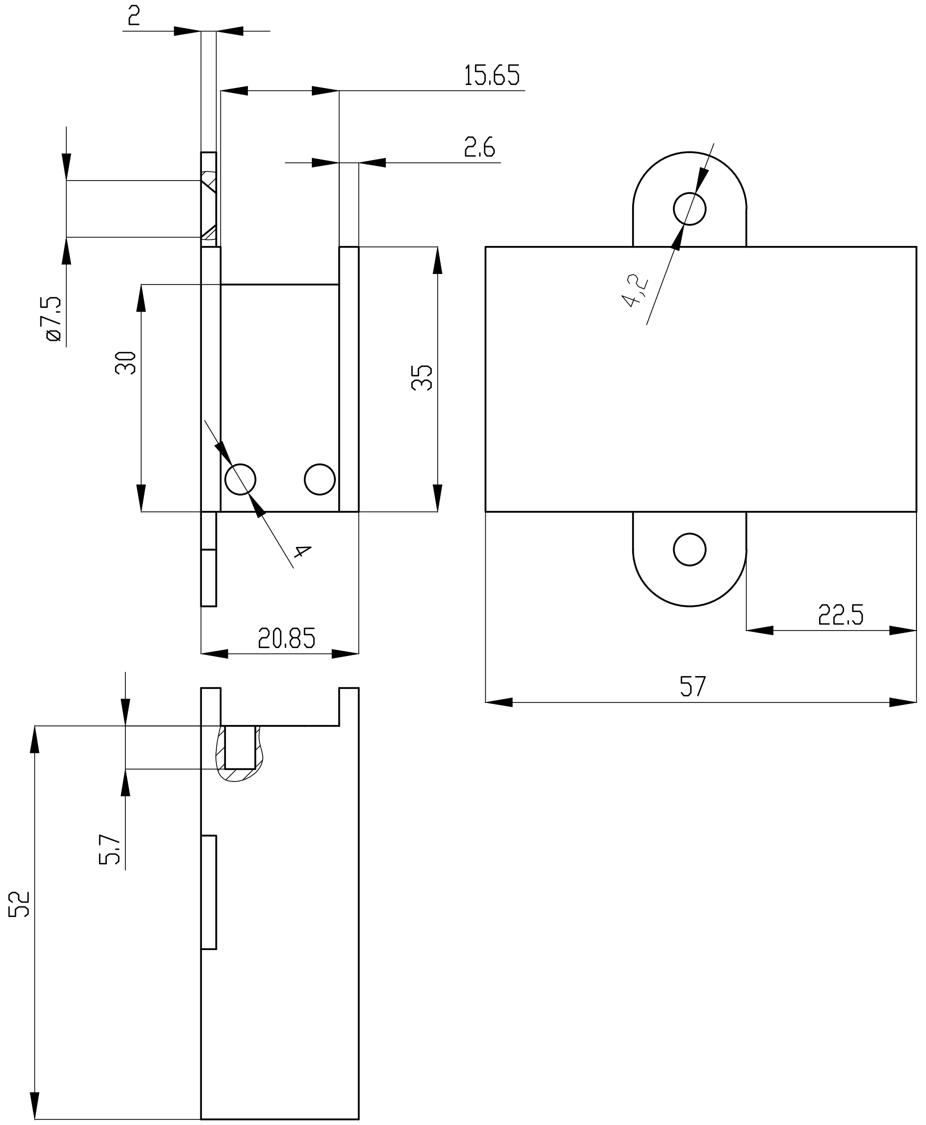
In the following pages, the blueprints of the frame are showed, as designed



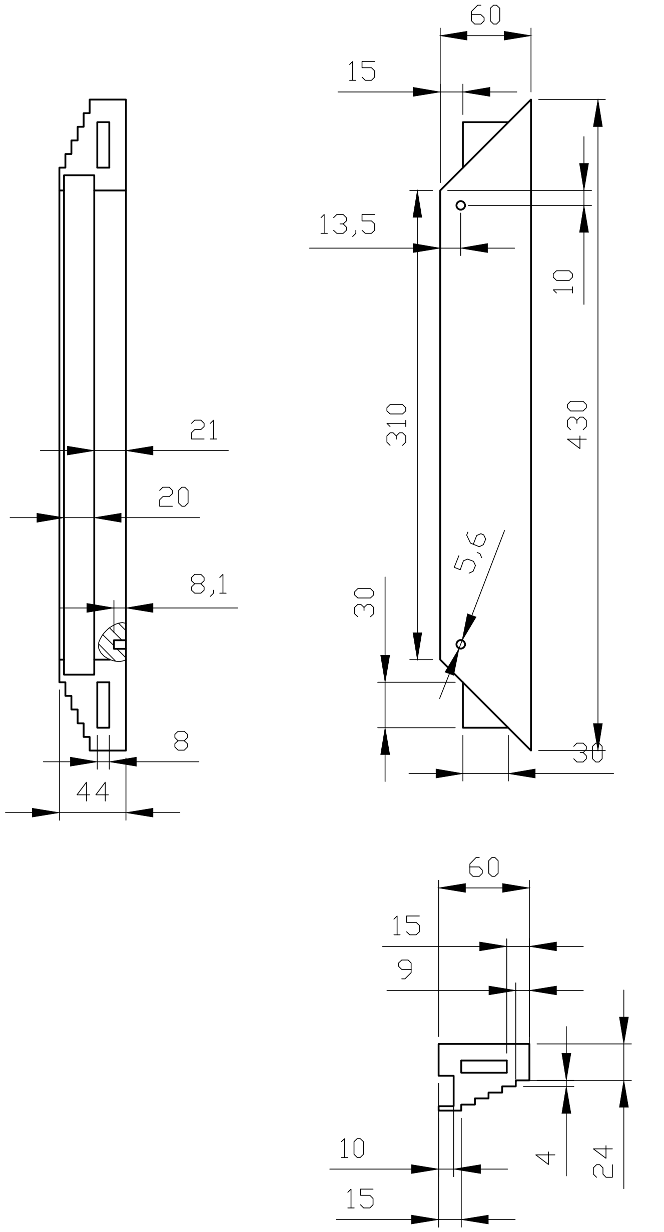

| | | | |
|---|---|---|---|
| MATERIAL | PLA | | Pieza placa |
| TOLERANCIA | ISO 2768 m, K | | |
| | NOMBRE | FECHA | Connected Frame |
| DIBUJADO | L.B.F. | 17/07/2021 | |
| COMPROBADO | | | |
| ESCALA: 1:1 | FIRMA L.B.F. | | ICAI |
| | | | Nº DE LAMINA: 1 |



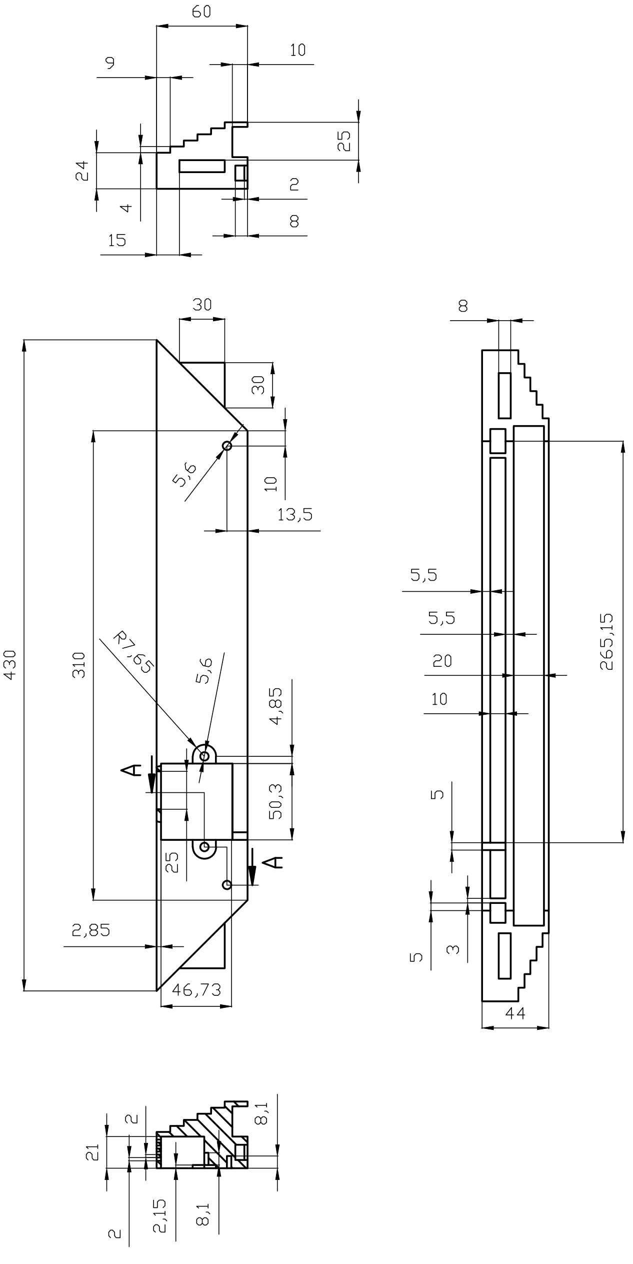

| | | | |
|---|---|---|---|
| MATERIAL | PLA | | Pieza sensor DHT22 |
| TOLERANCIA | ISO 2768 m, K | | |
| | NOMBRE | FECHA | Connected Frame |
| DIBUJADO | L.B.F. | 17/07/2021 | |
| COMPROBADO | | | |
| ESCALA: 1:1 | FIRMA L.B.F. | ICAI | Nº DE LAMINA: 2 |




| | | | | |
|---|---|---|---|---|
| MATERIAL | PLA | | Pieza sensor BH1750 | |
| TOLERANCIA | ISO 2768 m, K | | | |
| | NOMBRE | FECHA | Connected Frame | |
| DIBUJADO | L.B.F. | 17/07/2021 | | |
| COMPROBADO | | | | |
| ESCALA: 1:1 | FIRMA L.B.F. | | ICAI | Nº DE LAMINA: 3 |

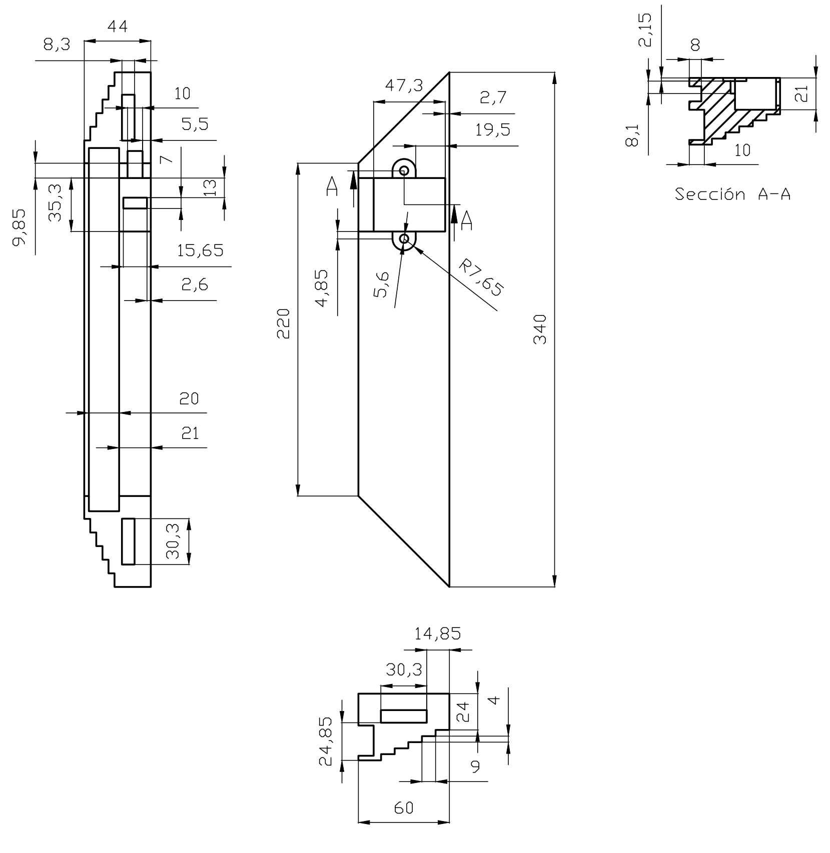



| | | | |
|---|---|---|---|
| MATERIAL | PLA | | Pieza izquierda |
| TOLERANCIA | ISO 2768 m, K | | |
| | NOMBRE | FECHA | Connected Frame |
| DIBUJADO | L.B.F. | 17/07/2021 | |
| COMPROBADO | | | |
| ESCALA: 1:5 | FIRMA L.B.F. | | ICAI |
| | | | Nº DE LAMINA: 4 |

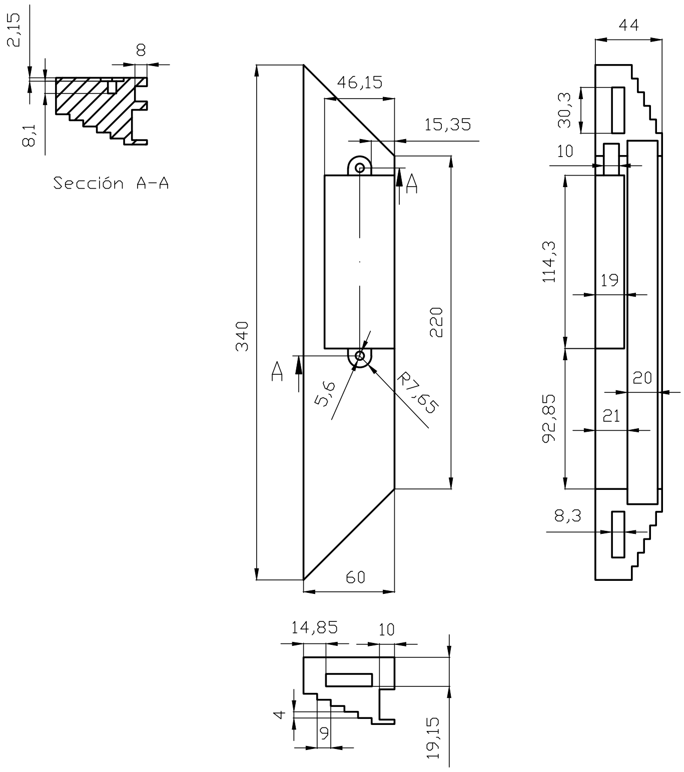



Sección A-A

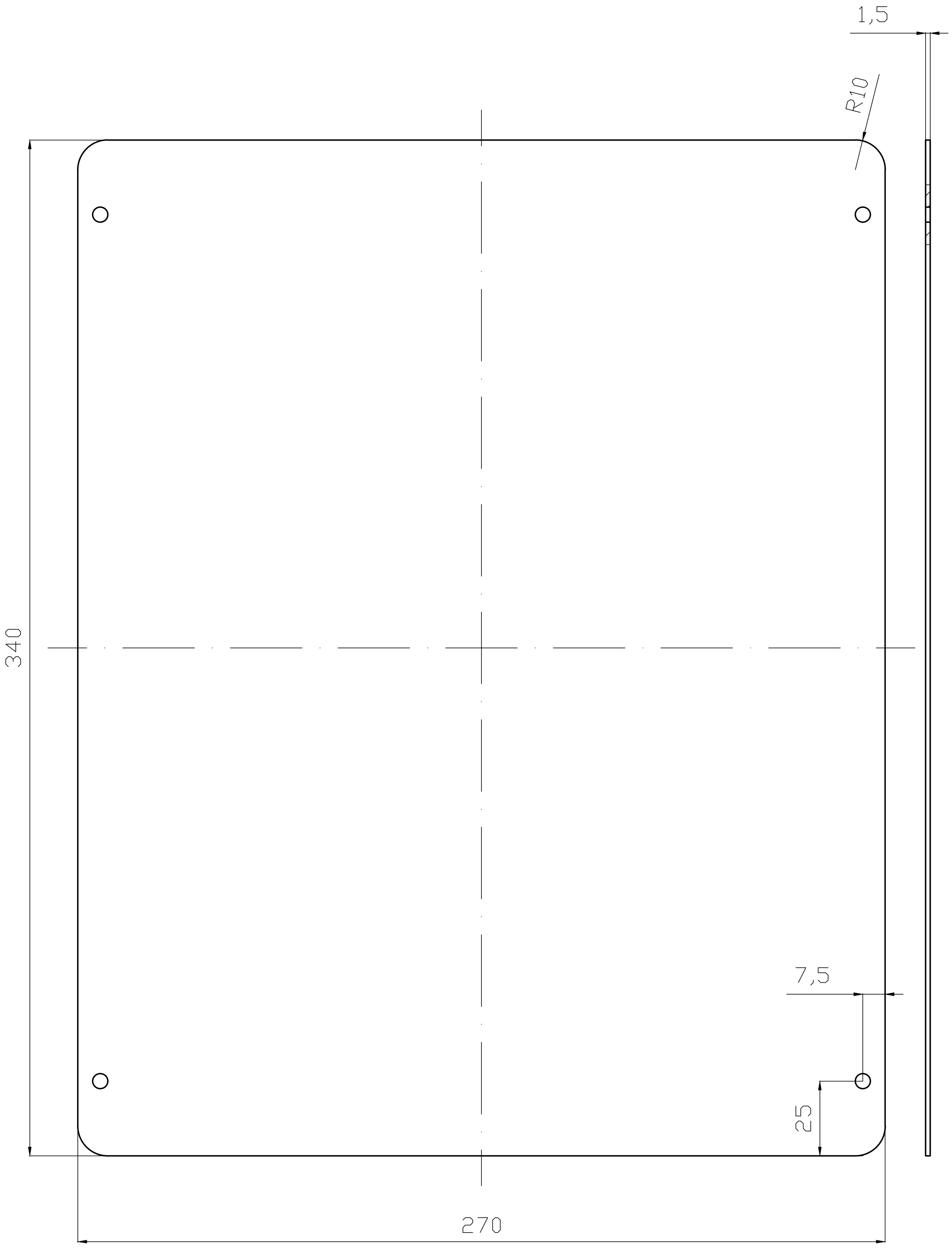
| | | | |
|---|---|---|---|
| MATERIAL | PLA | | Pieza derecha |
| TOLERANCIA | ISO 2768 m, K | | |
| | NOMBRE | FECHA | Connected Frame |
| DIBUJADO | L.B.F. | 17/07/2021 | |
| COMPROBADO | | | |
| ESCALA: 1:5 | FIRMA L.B.F. | ICAI | Nº DE LAMINA: 5 |




| | | | |
|---|---|---|---|
| MATERIAL | PLA | | Pieza superior |
| TOLERANCIA | ISO 2768 m, K | | |
| | NOMBRE | FECHA | Connected Frame |
| DIBUJADO | L.B.F. | 17/07/2021 | |
| COMPROBADO | | | |
| ESCALA: 1:5 | FIRMA L.B.F. | | ICAI |
| | | | Nº DE LAMINA: 6 |




| | | | |
|---|---|---|---|
| MATERIAL | PLA | | Piezainferior |
| TOLERANCIA | ISO 2768 m, K | | |
| | NOMBRE | FECHA | Connected Frame |
| DIBUJADO | L.B.F. | 17/07/2021 | |
| COMPROBADO | | | |
| ESCALA: 1:5 | FIRMA L.B.F. | ICAI | Nº DE LAMINA: 7 |




| | | | |
|---|---|---|---|
| MATERIAL | Aluminio | | Chapa trasera |
| TOLERANCIA | ISO 2768 m, K | | |

| | NOMBRE | FECHA | |
|---|---|---|---|
| DIBUJADO | L.B.F. | 17/07/2021 | Connected Frame |
| COMPROBADO | | | |
| ESCALA: 1:2 | FIRMA L.B.F. | | ICAI |
| | | | Nº DE LAMINA: 8 |

# ANNEX III. ARDUINO CODE OF PROTOTYPE

## MAIN FUNCTION

```
/*
CONNECTED FRAME
Date: 17/06/2021
Author: Loreto Bohigues
*/
////////// LIBRARIES //////////
#include <Wire.h>
#include <DHT.h>
#include <DHT_U.h>
#include <Arduino_LSM6DS3.h>
#include <SPI.h>
#include <WiFiNINA.h>
#include <BlynkSimpleWiFiNINA.h>
#include "secrets.h"

////////// DEFINITION OF PINS AND SENSORS //////////
#define DHTPIN 2      // Digital pin connected to the DHT sensor
#define DHTTYPE DHT22    // DHT 22  (AM2302), AM2321
#define BLYNK_PRINT Serial
#define ADDR 0b0100011

////////// INITIALIZATION OF SENSORS //////////
// Initialize DHT sensor.
DHT dht(DHTPIN, DHTTYPE);
// Initialize Blynk widgets
BlynkTimer timer;
WidgetLCD lcd(V8);
WidgetLED led_hum(V1);
WidgetLED led_temp(V2);
WidgetLED led_light(V3);

////////// DEFINE VARIABLES //////////
const int N_DATA=120; // Number of data to store per estimation
const int N_AVE=20; // Number of data to compute the moving average
const int N_MOD=100; // N_MOD = N_DATA - N_AVE
const float DELTA_V_LIMIT=0.5; // Threshold for delta_v
const float A_RMS_LIMIT=0.02; // Threshold for a_rms
const int N_PREVIOUS_STATES=3; // Number of previous states considered
when filtering the estimation
int previous_states[N_PREVIOUS_STATES];
int next_state_pos;
int previous_state, frame_state=0; // Previous and current state
variables
float previous_temp,t=0; // Previous and current temperature variables
float previous_hum,h=0; // Previous and current humidity variables
```

```
float previous_light,lx=0; // Previous and current light intensity
variables

void setup() {
  Serial.begin(9600); // Serial monitor inicialization
  Blynk.begin(auth, ssid, pass); // Connection to Blynk server through
Wi-Fi
  timer.setInterval(1000L, myTimerEvent); // Repeat myTimerEvent every 1
second
  dht.begin(); // Inicialization of DHT22
  BH1750_init(); // inizialization of BH1750 GY30 sensor
  acc_init(); // Inizialization of accelerometer
}

void loop() {
  // Wait a few seconds between measurements
  delay(1000);

  //Blynk app
  Blynk.run();
  timer.run();
}
```

**ACCELEROMETER** (Ayerra Basés, 2020)

```
////////// ACCELEROMETER FUNCTIONS //////////////
// Acc_Init: Inicialization of the accelerometer
void acc_init(){
  int i;
  if (!IMU.begin()) {
    Serial.println("Failed to initialize IMU!");
    while (1);
    }
  Serial.print("Accelerometer sample rate = ");
  Serial.print(IMU.accelerationSampleRate());
  Serial.println(" Hz");
  // Initialize array to zero
  for(i=0; i<N_PREVIOUS_STATES; i++){
    previous_states[i] = 0; // Initialize all to 0 (=Idle)
    }
  next_state_pos = 0;
}

// State: Reads acceleration of device and calculates state: IDLE or
MOVING
int state(){
  float x, y, z;
  unsigned long start_time;
  float acc_x[N_DATA], acc_y[N_DATA], acc_z[N_DATA];
  float acc_x_ave, acc_y_ave, acc_z_ave;
  float acc_x_mod[N_MOD], acc_y_mod[N_MOD], acc_z_mod[N_MOD];
  float a_rms_x, a_rms_y, a_rms_z, a_rms_max;
```

```
  float delta_v_x, delta_v_y, delta_v_z, delta_v_max;
  int i;
  int n=0;
  int state;
  int state_filtered;

  // Record the accelerations in a vector:
  while(n < N_DATA){
    if (IMU.accelerationAvailable()) {
      IMU.readAcceleration(x, y, z);
      acc_x[n] = x;
      acc_y[n] = y;
      acc_z[n] = z;
      n++;
    }
  }
  for(i=0; i<N_MOD; i++){
    acc_x_ave = average(acc_x, N_AVE, i);
    acc_x_mod[i] = acc_x[i+N_AVE] - acc_x_ave;
    acc_y_ave = average(acc_y, N_AVE, i);
    acc_y_mod[i] = acc_y[i+N_AVE] - acc_y_ave;
    acc_z_ave = average(acc_z, N_AVE, i);
    acc_z_mod[i] = acc_z[i+N_AVE] - acc_z_ave;
    }

  // Calculate delta value of acceleration in each axis and the maximum
delta
  delta_v_x = abs(summation(acc_x_mod, N_MOD, 0));
  delta_v_y = abs(summation(acc_y_mod, N_MOD, 0));
  delta_v_z = abs(summation(acc_z_mod, N_MOD, 0));
  delta_v_max = max(delta_v_x, delta_v_y);
  delta_v_max = max(delta_v_max, delta_v_z);

  // Calculate mean value of acceleration in each axis and the maximum
rms acceleration
  a_rms_x = abs(rms(acc_x_mod, N_MOD));
  a_rms_y = abs(rms(acc_y_mod, N_MOD));
  a_rms_z = abs(rms(acc_z_mod, N_MOD));
  a_rms_max = max(a_rms_x, a_rms_y);
  a_rms_max = max(a_rms_max, a_rms_z);

  // Estimate the state
  if(delta_v_max > DELTA_V_LIMIT){
    state = 2; //Moving
    }else if(a_rms_max > A_RMS_LIMIT){
      state = 1; //Working
      }else{
        state = 0; //Idle
        }
  //Filter the estimation
  previous_states[next_state_pos] = state;
  if(state == 1){
    state_filtered = 1;
    for(i=0; i<N_PREVIOUS_STATES; i++){
      if(previous_states[i] != 1){
```

```
        state_filtered = 0; //Say that the generator is idle during the
transitions
        }
      }
    }else{
      state_filtered = state; // 0 (Idle) or 2 (Moving)
      }

  next_state_pos = (next_state_pos + 1) % N_PREVIOUS_STATES;
  Serial.print("a_rms_max = ");
  Serial.print(a_rms_max);
  Serial.print(" delta_v_max = ");
  Serial.print(delta_v_max);

  Serial.print(" State: ");
  if(state == 0){
    Serial.print("IDLE");
    }else if(state == 1){
      Serial.print("WORKING");
      }else if(state == 2){
        Serial.print("MOVING");
        }
  Serial.print(" State filtered: ");
  if(state_filtered == 0){
    Serial.println("IDLE");
    }else if(state_filtered == 1){
      Serial.println("WORKING");
      }else if(state_filtered == 2){
        Serial.println("MOVING");
        }
  return state_filtered;
  }

////////// AUXILIARY FUNCTIONS //////////////
// Summation: Adds elements of array "numbers" from position "start"
(included) to "start+n" (not included)
float summation(float numbers[], int n, int start){
  int i;
  float sum=0;
  for(i=start; i<(start + n); i++){
    sum += numbers[i];
    }
  return sum;
  }

// Average: Calculates average of array "numbers" from element "start"
(included) to "start+n" (not included)
float average(float numbers[], int n, int start){
  float sum;
  float average;
  sum = summation(numbers, n, start);
  average = sum/n;
  return average;
  }
```

```
// RMS: Calculates the rms value of the first 'n' elements of array
"numbers"
float rms(float numbers[], int n){
  int i;
  float current;
  float rms;
  float sum=0;
  for(i=0; i<n; i++){
    current = numbers[i]*numbers[i];
    sum += current;
    }
  rms = sqrt(sum/n);
  return rms;
  }
```

### BH1750_GY30 (General programming of this sensor-cogido de internet)

```
// BH1750_init: Initializes BH1750 GY30 sensor
void BH1750_init(){
  Wire.begin();
  Wire.beginTransmission(ADDR);
  Wire.write(0b00000001);
  Wire.endTransmission();
  }

// Lux: reads light intensity in lux
float lux(){
  int light = 0;

  // reset
  Wire.beginTransmission(ADDR);
  Wire.write(0b00000111);
  Wire.endTransmission();
  Wire.beginTransmission(ADDR);
  Wire.write(0b00100000);
  Wire.endTransmission();

  // typical read delay 120ms
  delay(120);

  Wire.requestFrom(ADDR, 2); // 2byte every time
  for (light = 0; Wire.available() >= 1; ){
    char c = Wire.read();
    //Serial.println(c, HEX);
    light = (light << 8) + (c & 0xFF);
    }
  light=light/1.2;
  return light;
  }
```

## BLYNK_EVENT

```
////////// EVENT REPEATED IN BLYNK APP //////////////
void myTimerEvent(){
  // Actualization of previous variables
  previous_temp=t;
  previous_hum=h;
  previous_state=frame_state;
  previous_light=lx;
  // Read measurements
  t=temp();
  h=hum();
  lx=lux();
  frame_state=state();

  ////////// Send data to Blynk app //////////////
  // Send data to virtual pins in Blynk app
  Blynk.virtualWrite(V5,h);
  Blynk.virtualWrite(V6,t);
  Blynk.virtualWrite(V7,lx);
  // Send data to lcd in Blynk app
  lcd.print(0,0,"The frame is:");
  if(frame_state==0){
    lcd.print(0,1,"      Idle      ");
    }else if(frame_state==1){
      lcd.print(0,1,"   Disrrupted   ");
      }else{
        lcd.print(0,1,"   MOVING!!!   ");
        }

  ////////// Alarms //////////////
  //Alarm for state of frame (push notification)
  if((previous_state==0 || previous_state==1) & frame_state==2){
    Blynk.notify(" The painting is moving. Please check it's location ");
    }
  // Alarm for temperature
  if(t>30 || t<10){
    led_temp.on(); // Turn on warning LED
    // Push notification sent when temperature enters warning range
    if(previous_temp>10 & previous_temp<30){
      Blynk.notify("Temperature is not in the optimal range. Please check
the painting's environment ");
      }
    }else{
      led_temp.off();
      }
  // Alarm for humidity
  if(h>70 || h<40){
    led_hum.on();
    if(previous_hum>40 & previous_hum<70){
      Blynk.notify("Humidity is not in the optimal range. Please check
the painting's environment ");
      }
    }else{
```

```
      led_hum.off();
      }
  // Alarm for light intensity
  if(lx>300){
    led_light.on();
    if(previous_light<300){
      Blynk.notify("Light intensity is not in the optimal range. Please
check the painting's environment ");
      }
    }else{
      led_light.off();
      }
  }
```

## READ_DATA

```
// Temp: reads temperature in °C
float temp(){
  float temperature = dht.readTemperature();
  if (isnan(temperature)) {
    Serial.println(F("Failed to read from DHT sensor!"));
    }
  return temperature;
  }

// Hum: reads relative humidity %
float hum(){
  float humidity = dht.readHumidity();
  if (isnan(humidity)) {
    Serial.println(F("Failed to read from DHT sensor!"));
    }
  return humidity;
  }
```

## SECRETS.h

```
// You should get Auth Token in the Blynk App.
// Go to the Project Settings (nut icon).
char auth[] = "HKGSPWtZprXH7LXPSgWN-oIQ2i2GNgxv";

// Your WiFi credentials.
// Set password to "" for open networks.
char ssid[] = "Sorolla";
char pass[] = "elcantodelpajaro";
```

# ANNEX IV. PRODUCTION COSTS PER PRODUCT

| Product | Brand | Units per product | Unitary price (€) | Total price (€) | Link |
|---|---|---|---|---|---|
| Arduino nano 33 IoT board | Arduino | 1 | 18 | 18 | Arduino Store |
| USB to microUSB cable | Arduino | 1 | 2,9 | 2,9 | Arduino Store |
| Temperature and humidity sensor DHT22 | Movilideas | 1 | 7,24 | 7,24 | Amazon |
| Light intensity sensor BH1750 (GY30) | SATKIT | 1 | 1,5 | 1,5 | Amazon |
| Resistor of 4,7 kΩ | TE Connectivity | 1 | 0,044 | 0,044 | RS |
| Rechargeable Batteries 2500mAh 4pax | Duracell | 1 | 13,37 | 13,37 | Amazon |
| Battery case for 3 batteries 1,5V | Cablepelado | 1 | 4,5 | 4,5 | Amazon |
| Welding board 4x6 cm | - | 1 | 0,979 | 0,979 | Amazon |
| Long cables for welding | TUOFENG | 1,85 m | 0,370 | 0,68 | Amazon |
| M4x8 screws with countersunk head (DIN 965) | Screwerk | 6 | 0,202 | 1,212 | Screwerk |
| M4x6 screws with rounded head (DIN 7985) | Screwerk | 4 | 0,181 | 0,724 | Screwerk |
| M2,5 screws with rounded head (DIN 7985) | Screwerk | 3 | 0,175 | 0,525 | Screwerk |
| M4x8,1 threaded inserts | Ruthex | 10 | 0,22 | 2,2 | Amazon |
| M2,5x5,7 threaded inserts | Ruthex | 3 | 0,22 | 0,66 | Amazon |
| **Fixed cost of raw materals** | | | | **54,54** | |
| **Fixed cost of assembly per unit** | | | | **20,00** | |
| **TOTAL FIXED COSTS** | | | | **74,54** | |
| Cost of back Aluminium sheet | Lumetal plastic | 918 $cm^2$ | 8,96E-05 | 0,08 | Lumetalplastic |
| Cost of 3D printing | Filament2print | 1 | 260,54 | 260,54 | Filament2print |
| **Variable cost of raw materials** | | | | **260,62** | |
| **TOTAL VARIABLE COSTS** | | | | **260,62** | |
| | | | **TOTAL** | **335,16** | |

# ANNEX V. MATERIALS USED FOR PROTOTYPE

| Product | Brand | Units | Unitary price (€) | Total price (€) | Link |
|---|---|---|---|---|---|
| Arduino nano 33 IoT board | Arduino | 1 | 18 | 18 | Arduino Store |
| USB to microUSB cable | Arduino | 1 | 2,9 | 2,9 | Arduino Store |
| Temperature and humidity sensor DHT22 | Movilideas | 1 | 7,24 | 7,24 | Amazon |
| Light intensity sensor BH1750 (GY30) | SATKIT | 2 | 1,5 | 3 | Amazon |
| Resistor of 4,7 kΩ | - | 1 | 0 | 0 | ICAI |
| Jumper cables of 20 cm | AZDelivery | 1 | 5,49 | 5,49 | Amazon |
| Protoboard 400 contacts | TOOGOO | 1 | 3,73 | 3,73 | Amazon |
| Rechargeable Batteries 2500mAh 4pax | Duracell | 1 | 13,37 | 13,37 | Amazon |
| Battery case for 3 batteries 1,5V | Cablepelado | 1 | 4,5 | 4,5 | Amazon |
| Welding board 4x6 cm | - | 1 | 0 | 0 | ALTAIR |
| Long cables for welding (1,85 m) | - | 1 | 0 | 0 | ICAI |
| Spool of thread for 3D printing | Filament2print | 2 | 44 | 88 | Filament2print |
| 1 mm aluminium sheet 27x34 cm | - | | 0 | 0 | ICAI |
| M4x8 screws with countersunk head (DIN 965) | - | 6 | 0 | 0 | ICAI |
| M4x6 screws with rounded head (DIN 7985) | - | 4 | 0 | 0 | ICAI |
| M2,5 screws with rounded head (DIN 7985) | - | 3 | 0 | 0 | ICAI |
| M4x8,1 threaded inserts | Ruthex | 10 | 0 | 0 | ICAI |
| M2,5x5,7 threaded inserts | Ruthex | 3 | 0 | 0 | ICAI |
| | | | **TOTAL** | **146,23 €** | |