République Algérienne Démocratique Et Populaire

Ministère de l'Enseignement Supérieur et de la Recherche Scientifique

Université d'Adrar

جامعة أحمد دراية–ادرار

Année/2023

Faculté de technologie
Département Génie électrice

Mémoire de fin d'étude en vue d'obtention
Du diplôme de Master Académique
En : Génie électrique

Option: Commande électrique

Adaptation and Implementation of a Building Management System for a Literature Museum

Présentée par :

Mlle. Bensoudan Hayat

Devant le jury composé de :

Mr. Dahbi Hassan	Président	MCB	Université Ahmed Draia-Adrar
Mr. OuledAli Omar	Examinateur	MCB	Université Ahmed Draia-Adrar
Mr. Harrouz Abdelkader	Promoteur	Pr	Université Ahmed Draia-Adrar

Année Universitaire 2022/2023

الجمهورية الجزائرية الديمقراطية الشعبية

People'sDemocraticRepublic of Algeria

وزارة التعليم العالي و البحث العلمي

جامعة أحمد دراية- أدرار

المكتبة المركزية

مصلحةالبحثالبيليوغرافي

Ministry of Higher Education and Scientific Research

University Ahmed Draia of Adrar

The central library

جامعة احمد دراية - أدرار

شهادة الترخيص بالإيداع

انا الأستاذ(ة): حروز عبد القادر

المشرف مذكرة الماستر الموسومة بـــ :

من إنجاز الطالب(ة): بن سودان حياة

و الطالب(ة):

كلية : العلوم والتكنولوجيا

القسم : الهندسة الكهربائية

التخصص: تحكم كهربائي

تاريخ تقييم / مناقشة: 2023/07/03

أشهد ان الطلبة قد قاموا بالتعديلات والتصحيحات المطلوبة من طرف لجنة التقييم / المناقشة، وان المطابقة بين النسخة الورقية والإلكترونية استوفت جميع شروطها.

وبإمكانهم إيداع النسخة الورقية (01) والاليكترونية (PDF).

- امضاء المشرف:

Pr. HARROUZ Abdelkader

ادرار في : 2023/07/09

مساعد رئيس القسم:

رئيس قسم الهندسة الكهربائية

د. [illegible]

ملاحظة :لاتقبل أي شهادة بدون التوقيع والمصادقة.

ADAPTATION AND IMPLEMENTATION OF A BUILDING MANAGEMENT SYSTEM FOR A LITERATURE MUSEUM

H. BENSOUDAN ; M.GENDREU ; P.ESPIN ; B.TAICHE ; B.DANUT

Supervisor university: Mr. Harrouz Abdelkader
Scientific Coordinator's NAME: Elena Badea, The girl from the museum
UPB Coordinators' NAME: Delia Prisecaru

EUROPEAN PROJECT SEMESTER
UNIVERSITY POLITEHNICA OF BUCHAREST
2023

Contents

Acknowledgements

The Bermudes Pentagon team would like to thank the European Project Semester (EPS) and University POLITEHNICA of Bucharest for allowing us to take part in this semester. This is a unique opportunity for each of us to grow and develop personally and professionally. We would also like to thank our tutor Delia Prisecaru and the whole team of teachers who have supported us and given us invaluable advice over the last few months.

And finally, we'd like to thank the museum and our contributors who have enabled us to develop a technical and ecological project.

Abstract: Building management system, it's a computer-based control system that manage and monitors the various mechanical and electrical systems in a building, such as heating, ventilation, air conditioning, lighting and security. Its primary function is to maintain a comfortable and safe environment while also optimizing energy consumption and reducing operating coast. The aim of this project is to know what is the relationship between presence of people in (occupancy and utilization), and energy consumption and space quality? And which variables can best be used to predict the utilization of spaces, and in what way can they be applied to predict utilization? For this, our mission is to create the BMS System which will collect the necessary data. So, for this project we study many requirements in order to find a feasible solution that meets maximum expectations.

Key words : Building management, BMS, environment, energy consumption, space quality

Résumé : Système de gestion de bâtiment est un système de contrôle informatisé qui gère et surveille les différents systèmes mécaniques et électriques dans un bâtiment, tels que le chauffage, la ventilation, la climatisation, l'éclairage et la sécurité. Sa fonction principale est de maintenir un environnement confortable et sûr tout en optimisant la consommation d'énergie et en réduisant les coûts d'exploitation. Le but de ce projet est de savoir quelle est la relation entre la présence de personnes dans un espace (occupation et utilisation) et la consommation d'énergie et la qualité de l'espace. Et quelles variables peuvent être utilisées pour prédire au mieux l'utilisation des espaces, et de quelle manière peuvent-elles être appliquées pour prédire cette utilisation ? Pour cela, notre mission est de créer le système BMS qui collectera les données nécessaires. Donc pour ce projet, nous avons étudié de nombreuses exigences afin de trouver une solution faisable qui répond aux attentes maximales.

Mots clés : gestion de bâtiment, BMS, consommation d'énergie, qualité de l'espace

التلخيص: نظام إدارة المباني هو نظام تحكم يعتمد على الحاسوب يدير ويراقب مختلف الأنظمة الميكانيكية والكهربائية في المبنى، مثل التدفئة والتهوية وتكييف الهواء والإضاءة والأمان. وظيفته الرئيسية هي الحفاظ على بيئة مريحة وآمنة في الوقت نفسه تحسين استهلاك هدف هذا المشروع هو معرفة العلاقة بين وجود الأشخاص في المساحات (الاحتلال والاستخدام) .الطاقة وتقليل تكاليف التشغيل. واستهلاك الطاقة وجودة المساحة. وما هي المتغيرات التي يمكن استخدامها بشكل أفضل لتوقع استخدام المساحات، وكيف يمكن تطبيقها الذي سيجمع البيانات اللازمة لهذا، قمنا بدراسة BMS للتنبؤ باستخدام هذه المساحات؟ لتحقيق هذا الهدف، فإن مهمتنا هي إنشاء نظام العديد من المتطلبات لإيجاد حل ممكن يلبي أقصى توقعات.

الكلمات المفتاحية: إدارة المباني، استهلاك الطاقة ، جودة المساحة

Glossary

Abbreviation	Description
API	*Application Programming Interface*
UPB	*University Politehnica of Bucharest*
AQI	*Air quality index*
CO_2	*Carbon dioxide*
EPA	*Environmental Protection agency*
EPS	*European Project Semester*
EU	*European Union*
GPIO	*General purpose input/output*
HVCC	*Heating, ventilation and air conditioning*
I2C	*Inter-Integrated circuit*
ICT	*Information and communication technology*
IDE	*Arduino software*
IoT	*Internet of things*
LCD	*Liquid Crystal Display*
LED	*Light-emitting diode*
TVOC	*Total volatile organic compounds*
BMS	*Building Management System*

Table of figures

1. Introduction

1.1. Presentation

Figure 1.1.1: Team presentation

Bermudas Pentagon team took part in the Erasmus Project Semester at UPB last February, finishing in June 2023 in Bucharest, Romania. This name comes to us from the international legend of the Bermuda Triangle, known throughout the world thanks to the legendary disappearance of people of different origins, this name brings us together. Together, we make our differences a strength, our team is made up of 5 members from different countries, with different cultures, speaking different languages and studying different specialties (see members below). These differences, which may at first seem like difficulties, have been a strength for us, as each member has brought to the group his or her knowledge and experience in different fields, which has helped to bind the team together and move forward together.

1.2. Motivation

Creating a BMS System in a museum is very interesting from a technical point of view for all of us. Improving the energy performance of the building by saving energy brings an ecological dimension to the project. This experience also brings us transversal skills such as teamwork or project management.

1.3. Objectives

The aim of this project is to know what is the relationship between presence of people in (occupancy and utilization), and energy consumption and space quality? And which variables can best be used to predict the utilization of spaces, and in what way can they be applied to predict utilization? For this, our mission is to create the BMS System which will collect the necessary data.

1.4. Requirements

For this project we have different requirements:

- To be placed in the museum without aesthetic problem
- Record the presence of people
- Reading the temperature
- Raise the humidity
- Read the CO2 concentration
- Reading the CO concentration
- Record the total volatile organic compounds
- Read the NO2 concentration
- Raise the Particulate matter
- Measure the Sound pressure

We will study these requirements in order to find a feasible solution that meets maximum expectations.

2. State of the art

2.1. BMS State of the art

A BMS is a computer-based control system that manages and monitors the various mechanical and electrical systems in a building, such as heating, ventilation, air conditioning, lighting and security.

Its primary function is to maintain a comfortable and safe environment while also optimizing energy consumption and reducing operating coast.

2.1.1. BMS Systems nowadays

Let's try to understand simply how this system works :

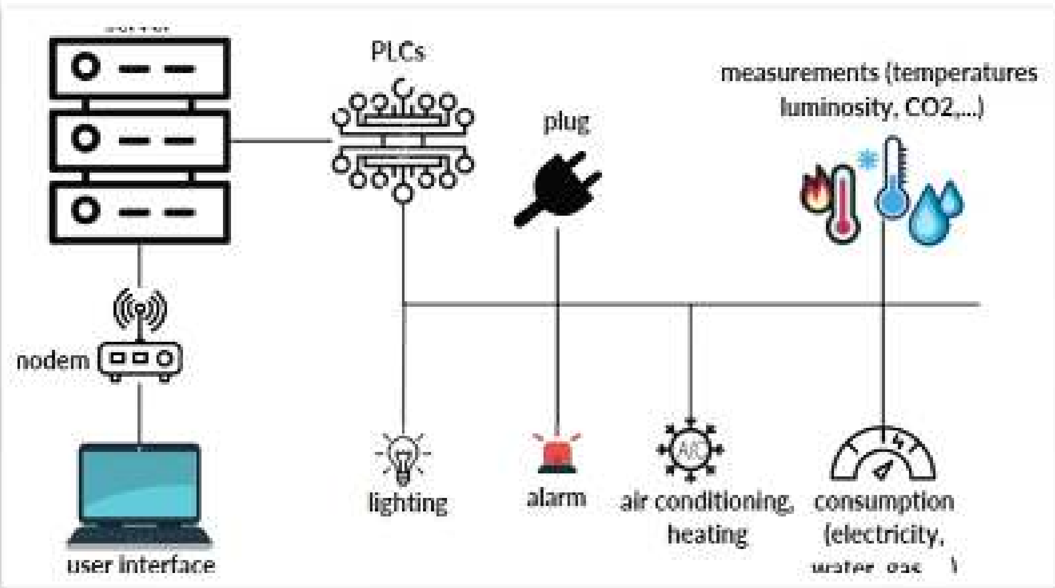


Figure 2.1.1 : *Schema of the operation of BMS System*

Basically, a BMS System is composed of:

- Sensors: for the acquisition of information intended for an information processing system
- Actuators: to translate a command order into action
- PLCs and a central interface which are part of the local unit

The benefits of BMS system:

- Better control of the building's energy performance
- Make equipment more reliable with seamless operation, and enable better 24/7 monitoring of equipment with sensors: you can anticipate and remedy problems quickly
- Better comfort for operators and occupants while improving the indoor environment
- Reduce travel and intervene quickly at a distance. This also reduces operating costs

Various Systems:
There are many different systems, let's see in a first part the possible fields of application:

- Heating: The BMS system controls the boilers: management, operation and monitoring; circuit control; optimization of operating times; control of the various heating zones
- Air conditioning: The BMS system regulates air conditioning with the installation of indoor and outdoor temperature sensors; management of cold production; regulation of air handling unit circuits; regulation of fan coil circuits; individual regulation of building premises
- Security: Can act on the monitoring of equipment and alert the supervisor in the event of a malfunction. Can send alerts by email or SMS. Can act on the interconnection of equipment and fire devices.
- Meters: Recovery of various measurements or remote readings (water, electricity, gas, etc.). Analysis of overconsumption, leakage, and establishment of history, statistics or consumption graph.
- Electricity: Control of lighting or other electrical equipment, load shedding of certain electrical equipment, and the switching on or off lighting at certain defined times.

The BMS system can also be used in building access systems, or in the connection with a hypervisor for the management of several sites.

All these application areas can be managed at different levels:

The monitoring function (level 1) for centralized maintenance management: Systems that only include the monitoring function are rarely installed in are rarely installed today in new buildings because the new buildings, as supervision and energy monitoring functions are functions are becoming more common. However, BMSs installed ten or twenty years ago are sometimes used only for monitoring technical installations, whereas they could at least be used for supervision. The monitoring function allows the building manager to centralise on a computer station the functions of:

→ Equipment regulation (calendar, set point, etc.)

→ Identification of deviations through the implementation of simple indicators (understandable by all)

→ reporting of all malfunctions through alarms.

The supervision function (level 2) to optimize the operation of energy-intensive equipment: In the level 2 system, supervision is added to the monitoring function described above. This BMS system is therefore much more complete than those that only provide monitoring, as it allows the programming of equipment to be influenced. The supervision function allows several parameters to be monitored in real time, the supervision function allows the monitoring of several parameters in real time, which makes it possible to adapt the operation of the equipment to the needs of the occupants. It also allows the identification of operating deviations, such as lighting on or heating temperatures that are too high during periods of unoccupied periods. Given the requirements for occupant comfort and the thermal regulations that require the need to control heating and air-conditioning temperatures, it is therefore at least systems integrating supervision that are installed in new buildings.

The monitoring function (level 3) towards intelligent operation? In level 3, in addition to the monitoring and supervision functions and supervision functions, monitoring (at least of energy but sometimes also water consumption) is carried out. This monitoring mainly consists of identifying. This monitoring consists mainly of identifying fluid consumption by use and making a critical analysis of it. Depending on the monitoring plan validated by the manager, the frequency may be monthly or annual, or even shorter if the shorter if the use of the building requires it. According to the initial feedback available, the return-on-investment time for a of a BMS with monitoring function is variable, but generallybetween 2 and 10 years.

BMS is a valuable aid for any building manager wishing to improve both the control and monitoring of its technical installations and the comfort of its occupants. However, its implementation must be integrated into an overall approach to optimising the operation/maintenance of the building(s), including a review of the organisation and skills. The gains can then become quite significant, particularly in terms of reducing energy consumption.

2.1.2. Realistic Preservation Environment in a literature museum

The importance of temperature and humidity control in museums

Literary artifacts like books, manuscripts, and letters can be significantly impacted by changes in temperature and humidity. For instance, contact to high humidity and temperatures can turn paper brown and brittle, while exposure to cold temperatures might make the paper more fragile and prone to breaking, so maintaining a stable environment is critical for preserving the integrity of literary artifacts, and literature museums take great care to ensure that their collections are protected for future generations to enjoy and by controlling temperature and humidity levels, museums can help to minimize damage to these important artifacts, and ensure that they remain in excellent condition for years to come.

Ideal temperature and humidity ranges for museums:

According to the most recent interim regulations, cultural institutions should aim for a relative humidity set point of 45 to 55 percent with a total annual range of 40 to 60 percent. Moreover, a temperature ranges of "18 °to 26 ° "Celsius is advised. These levels take into account the typical ranges found in museum settings.

While these are general guidelines, different materials may necessitate different conditions for preservation, and loan requirements between institutions should be determined in consultation with conservation professionals.

Techniques for maintaining temperature and humidity control:

The preservation of cultural items in museums depends on maintaining temperature and humidity management. To accomplish this, several strategies are used to provide a stable and appropriate environment in exhibit and storage facilities for example:

HVAC systems: HVAC systems can be configured to suit the precise temperature and humidity needs of museum collections in addition to maintaining a comfortable and stable environment for human comfort. These systems can regulate temperature and humidity using a variety of techniques, including as air filtration, heating and cooling systems, humidifiers, and dehumidifiers. Museums can give their collections a stable atmosphere and ensure their long-term preservation by installing an HVAC system suited for preservation.

Figure 2.1.2.1: HVAC systems

The importance of VOCs, co2 and Noise Pollution control in museums

Controlling VOCs is important to prevent chemical reactions that can damage artworks. Managing CO2 levels, ideally within the range of 5-20 µg/m3, helps preserve sensitive materials and prevents their deterioration. Noise pollution control is crucial, aiming to maintain ambient noise levels below 45-50 decibels (dB) and maximum noise levels around 65-70 dB ,these measures protect the longevity and value of museum collections while enhancing the visitor experience.

Different devices that can be used to measure temperature and humidity

Relative humidity may be measured by using any of the following devices

- sling psychrometer
- thermohygrograph
- hair hygrometers
- calibrated electronic devices which provide a digital readout of temperature and RH
- data loggers linked to relative humidity sensors

Temperature may be measured by using various devices, such as:

- Mercury thermometers
- Digital thermometers
- Infrared thermometers
- Thermocouples
- Data loggers linked to temperature sensors - devices that collect and record temperature data over time, allowing for analysis and monitoring of temperature fluctuations.

Different devices that can be used to measure VOCs, co2 and Noise Pollution

1-VOCs:

- Photoionization Detectors

- Gas Chromatography-Mass Spectrometry

2-CO2 :

- Indoor Air Quality Monitors
- Non-Dispersive Infrared (NDIR) CO2 Sensors

3-Noise Pollution:

- Sound Level Meters
- Acoustic Calibrators

Conclusion:

Finally, maintaining optimum temperature and humidity levels, as well as limiting VOCs, CO2, and noise pollution, is critical for protecting the integrity and longevity of museum artworks and artifacts. Controlling temperature and humidity helps to avoid physical damage and deterioration, while controlling VOC, CO2, and noise pollution protects against chemical reactions and physical disruptions. Temperature and humidity sensors, VOC detectors, CO2 monitors, and sound level meters, among other equipment, allow for reliable measurement and monitoring of these parameters. Museums can conserve their artifacts and improve the visitor experience by installing efficient management mechanisms and frequently monitoring the museum environment.

2.1.3. Software at Building Management Systems

Current BMS systems use different software tools for various purposes.

In this segment of the report, we will analyze a complete Building Management System software that is sold to businesses and one of the most used open-source communications protocols in BMS.

Optergy-BMS

Summary

Optergy is an Australian based company that provides different services, among them we can find the following:

- Energy Management Systems
- Tenant Billing
- Building Management Systems

We will focus our research on the last one mentioned.

Optergy’s BMS system allows you to monitor and control different equipment in a building.

The system can be accessed from an application in your smartphone or within a web dashboard in a web browser.

It lets users monitor and interact with a wide range of equipment that can be integrated into the BMS system, some of them are listed below:

- Elevators
- Heat Pumps
- Lighting
- Gas detection systems
- Computer Room Air-conditioning

<u>Web Dashboard</u>

To control all of them, Optergy provides its users with a web application that can beaccessed from anywhere, not locking the access to just one computer or one worker.
Their web application is user-friendly meaning that the learning curve for a worker who hasnever interacted with this kind of system will be flat.

Figure 2.1.3.1: *Optergy’s Web dashboard*

The dashboard integrates different features to accomplish the user-friendliness.

One of them is a toolbox on the left side of the screen where there are icons with a small text beneath them which are draggable to the other side of the dashboard in order to include them in a “dashboard view” or “display”.

A different feature but one of the most important ones is Security levels, you can define different access levels, later you can choose what displays have a level access to.

This way a worker who only is in charge of monitoring and regulating the Computer Room Air Conditioning will only have access to that equipment and others included in the BMS system will be restricted.

Programming Tool

Automation is key in all the Building Management Systems, Optergy’s one brings its users a programming tool to automate all the mechanisms controlled by the BMS.

The design of it is also easy for users although some knowledge on logic and logic gates is required to create new automations.

Designs are very easy to create, as shown in the last image about Optergy’s Web dashboard, for the Programming Tool a menu with all the logic gates and components is provided in the left side of the screen. These are as well draggable to the “display” where you can later connect the components between each other and create specific rules.

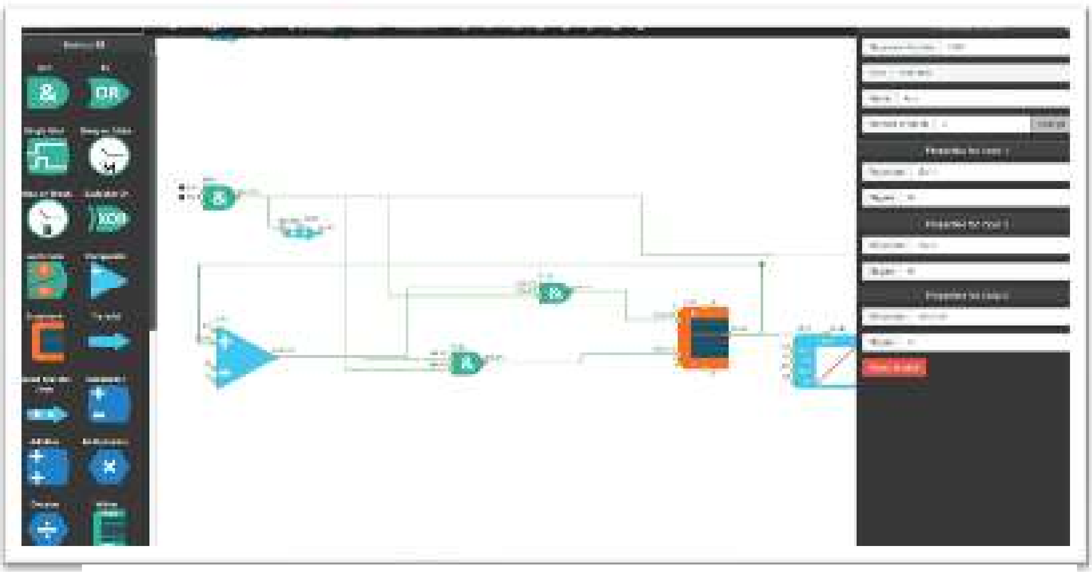


***Figure 2.1.3.1:** Dashboard integrated programming tool*

Integration with BACNet and Modbus

Optergy-BMS supports both communication protocols BACNet and Modbus for connecting end devices with the BMS.

These communications protocols are still widely used although they were created a long time ago, Modbus was created in 1979 for communicating Programmable Logic Computers (PLC), this protocol had to be adapted over time and it is managed by the Modbus Organization.

For BACNet, we will dig deeper in the next section of this State of the art report.

BACNet Protocol

BACNet is an open-source protocol created by the ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers), it is currently extensively used in BMS.

BACNet protocol is composed of three main parts:

- Objects
- Properties
- Services

BACNet Objects

The protocol takes an object-oriented approach, this is that a device taking part into a BACNet network will be showing one or many objects of itself to other devices in the same net.

An object is just a control function that the device can expose to the rest of the devices.

BACNet defines 60 objects, these are some of them:

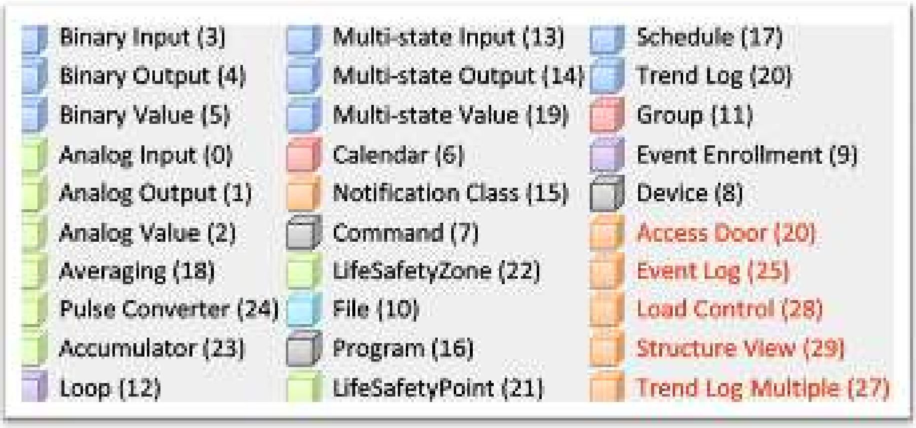


Figure 2.1.3.3: A sample of 30 BACNet objects

Let's say we want to change the desired temperature of our room, we want it to go from 10°C to 15°C, we would use the Analog Value object that the device, in this case the heating system, is exposing to the BACNet network. This would change the setpoint of our heating system to 15°C.

In case that the setpoint concept doesn't sound familiar, it can be described as the desired value of an essential variable in a control system. Once we have given our heating system the order to change the room temperature to 15°C, that is, we have changed the setpoint to 15°C, the system will start checking and correcting with the feedback that the heat sensors are providing it until it achieves the desired temperature.

<u>BACNet Properties</u>

All BACNet objects must also have different properties, some of them are mandatory to the objects and defined by the BACNet protocol, there are objects that may require only a set of properties and others that require more.

BACNet also allows the possibility for vendors to define their own properties for their own functionality, however, these properties must follow the BACNet standard. This implies that even if a vendor did create its own properties, called proprietary, this one would be accessed the same way that the other not proprietary properties are accessed, this is key to the protocol as it can be deployed with devices from different vendors and still be used all together.

In the next image we see some of the properties, also called attributes, of the Analog Value object that we talked about when describing a BACNet object. This Analog Value object is described by Johnson Controls, a multinational company from the United States of America dedicated to, among other things, producing equipment for building automation.

Attributes

Specific Attributes

The attributes specific to the Analog Value object are listed in Table 1. The Analog Value object also has the attributes of the Metasys® Common object. Refer to Table 1 in the *Metasys Common Object* chapter *(LIT-694020)* for details.

Table 1: Attribute Properties

Attribute Name	Data Type	N30 Flags*	M-Series Flags*	N30 Default Value	Options/Range
Metasys Common Attributes	See Table 1 in the *Metasys Common Object* chapter *(LIT-694020)*.				
		BACnet Required Attributes			
Event State	Enumeration			Normal	Normal, Fault, Offnormal, High-Limit, Low-Limit
Object Identifier	BACnet Object ID	C			
Out of Service	Boolean			False	Always False
Present Value	Float	DNRW	DNRW		
Status Flags	Bit String			False, False, False, False	In Alarm, Fault, Overridden, Out of Service See *BAC Status Flags Enumeration Set* in *Appendix A: Object Enumeration Sets (LIT-694980)*.
Units	Enumeration	CW	W	Deg F	See *Units Enumeration Set* in *Appendix A: Object Enumeration Sets (LIT-694980)*

Figure 2.1.3.4: BACNet required properties for Analog Value Object

If we take the Object Identifier property as an example, we see that it is required by the protocol and that it is a BACNet Object ID type, this is that this property will be composed of 32 bits that uniquely identify the BACNet object.

Johnson Controls also defines its own proprietary properties for the same object, here we can see some of them.

Attribute Name (Cont.)	Data Type	N30 Flags*	M-Series Flags*	N30 Default Value	Options/Range
		Johnson Controls Proprietary Attributes			
Display Precision	Enumeration	CW	W	10ths	See *Display Precision Enumeration Set* in *Appendix A: Object Enumeration Sets (LIT-694980).*
Intrinsic Alarming	Boolean	C		False	True, False
Max Value	Float	CW	W	1.7E38	
Min Value	Float	CW	W	-1.7E38	

* C - Configurable, W - Writable

Figure 2.1.3.5: Johnson Controls proprietary properties

<u>BACNet Services</u>

Services in BACNet is an abstraction of how different devices get information or send commands to perform a specific action to other devices through it objects and properties.

BACNet requires one service to be supported by all devices, this is the Read-property service.

All other services are optional, 32 of which are standard by the protocol, these are also divided into different categories, i.e., for the Alarm and Event category there are the following services:

ALARM AND EVENT	
	Change of Value Reporting ....
	Intrinsic Reporting ....
	Algorithmic Change Reporting................
	Alarm and Event Occurrence and Notification.
	AcknowledgeAlarm Service

Figure 2.1.3.5: Alarm and event category of services, services listed on the right column

Attribute Name (Cont.)	Data Type	N30 Flags*	M-Series Flags*	N30 Default Value	Options/Range
Johnson Controls Proprietary Attributes					
Display Precision	Enumeration	CW	W	10ths	See *Display Precision Enumeration Set* in *Appendix A: Object Enumeration Sets (LIT-694980).*
Intrinsic Alarming	Boolean	C		False	True, False
Max Value	Float	CW	W	1.7E38	
Min Value	Float	CW	W	-1.7E38	

* C - Configurable, W - Writable

Figure 2.1.3.5: Johnson Controls proprietary properties

<u>BACNet Services</u>

Services in BACNet is an abstraction of how different devices get information or send commands to perform a specific action to other devices through it objects and properties.

BACNet requires one service to be supported by all devices, this is the Read-property service.

All other services are optional, 32 of which are standard by the protocol, these are also divided into different categories, i.e., for the Alarm and Event category there are the following services:

ALARM AND EVENT	
	Change of Value Reporting ....
	Intrinsic Reporting ....
	Algorithmic Change Reporting................
	Alarm and Event Occurrence and Notification.
	AcknowledgeAlarm Service ....

Figure 2.1.3.5: Alarm and event category of services, services listed on the right column

Now, coming back to the example we used while explaining BACNet Objects. A new approach can be taken to describe how BACNet works with its three main parts.

After this explanation, let's put that the current temperature of the room is handled by a different device also connected to the BACNet network, when the heating system gets our instruction of the new setpoint for the temperature it will communicate first to the device measuring the temperature by one of its objects and reading one of the properties of that object, the act of reading this property is called the Read-property service that must always be available in all of the BACNet devices.

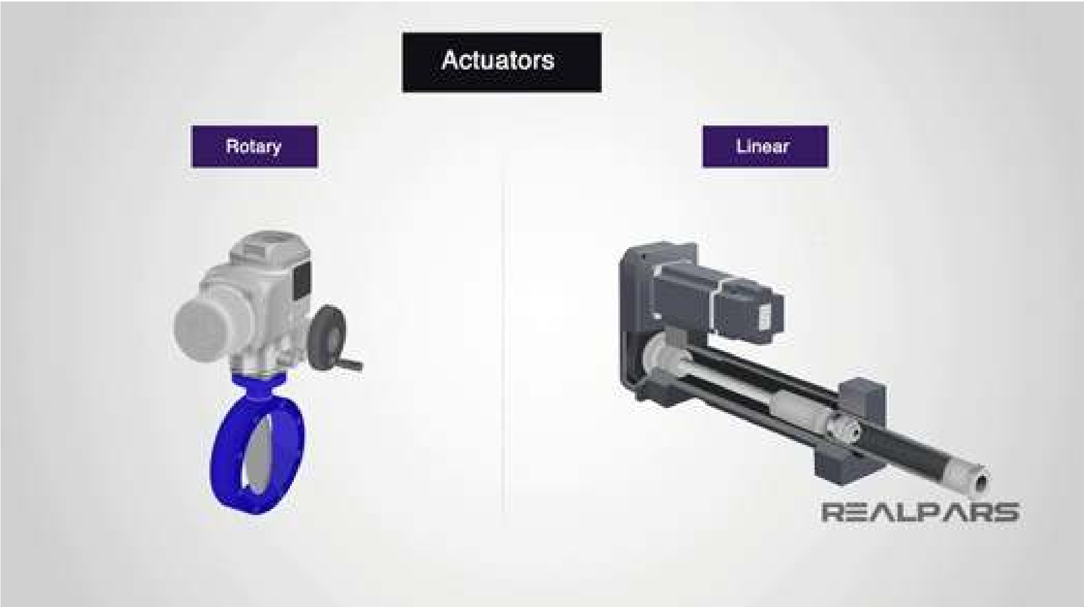
With this info gathered from the thermometer device, the heating system can start heating the room, the act of asking for the current temperature to the thermometer will keep happening for the heating system to approach the desired temperature. This is a constant BACNet communication between two different devices that may be from different vendors but are working perfectly together.

2.1.4. BMS Hardware Architecture

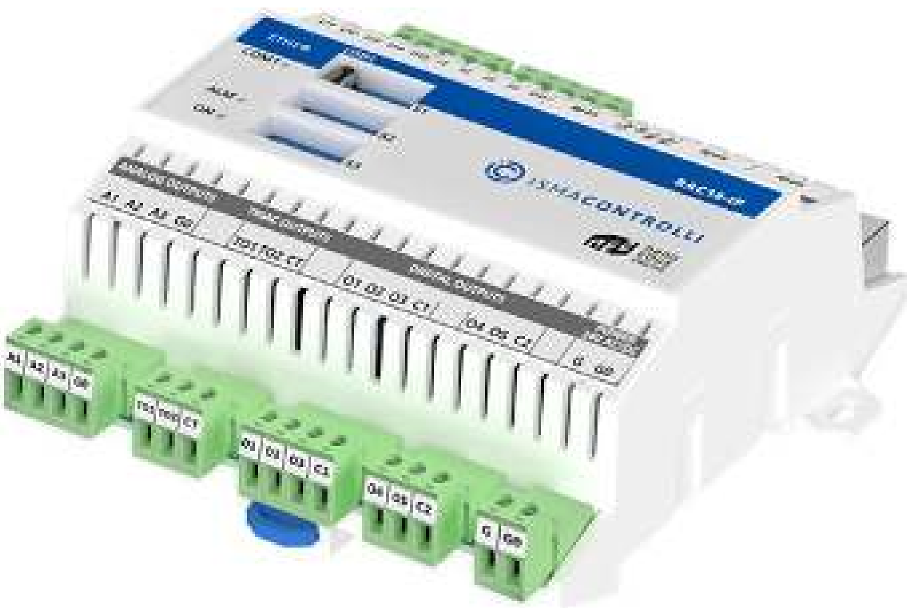
Currently building management systems are comprised of different devices that can ensure the best possible stability and security usually comprised of:

- Sensors (temperature, humidity, CO2, particulate matter, motion sensors, occupancy sensors, smoke detectors, pressure, carbon monoxide) only used to output data.

- Actuators are devices that can physically interact with other mechanical systems/devices, these include switches, valves and dampers.



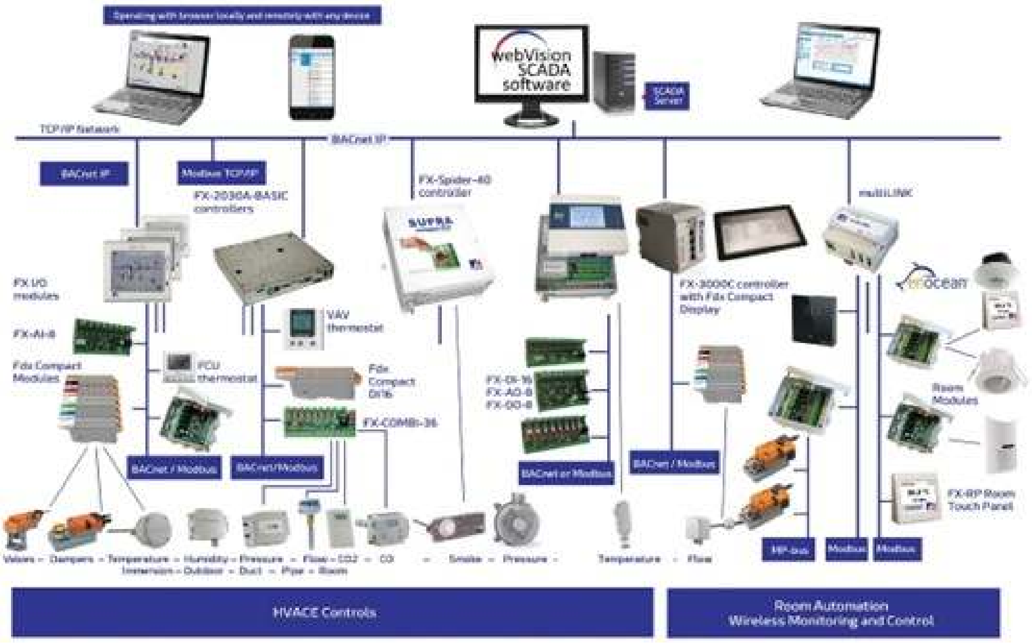
- Controllers are essentially small, purpose-built computers with input and output capabilities. These controllers come in a range of sizes and capabilities to control devices commonly found in buildings, and to control sub-networks of controllers.



- Communication between the devices is established by various protocols such as TCP, BACnet, Modbus. These are tried and tested protocols that ensure a good communication between the devices.

- Servers are used to store and log all the sensors and controllers data to monitor the systems stability.

- Clients are devices (computers, phones) that can visualize the data that is logged on the servers.



However, these systems are not bulletproof, building automation systems were repeatedly reported to be vulnerable, allowing bad actors to attack their devices. Buildings can be exploited by hackers to measure or change their environment: sensors allow surveillance while actuators allow to perform actions in buildings. Several vendors and committees started to improve the security features in their products and standards, including KNX, Zigbee and BACnet. However, researchers report several open problems in building automation security.

These systems are highly efficient, and can quickly cut down on overall building power consumption.

2.2. Conclusion

All this research on the museum, and the functioning of a BMS system allowed us to better define our project, to establish the different stages to be carried out. We can now use project management tools to guide the project and establish priorities and risks to be taken into account.

3. Project management

3.1. SWOT Analysis

Swot analysis is a strategic planning tool used to evaluate the and analyse the internal and external factors that can impact the success of a business or project .It focuses on identifying project’s strengths, weaknesses, opportunities, and threats.

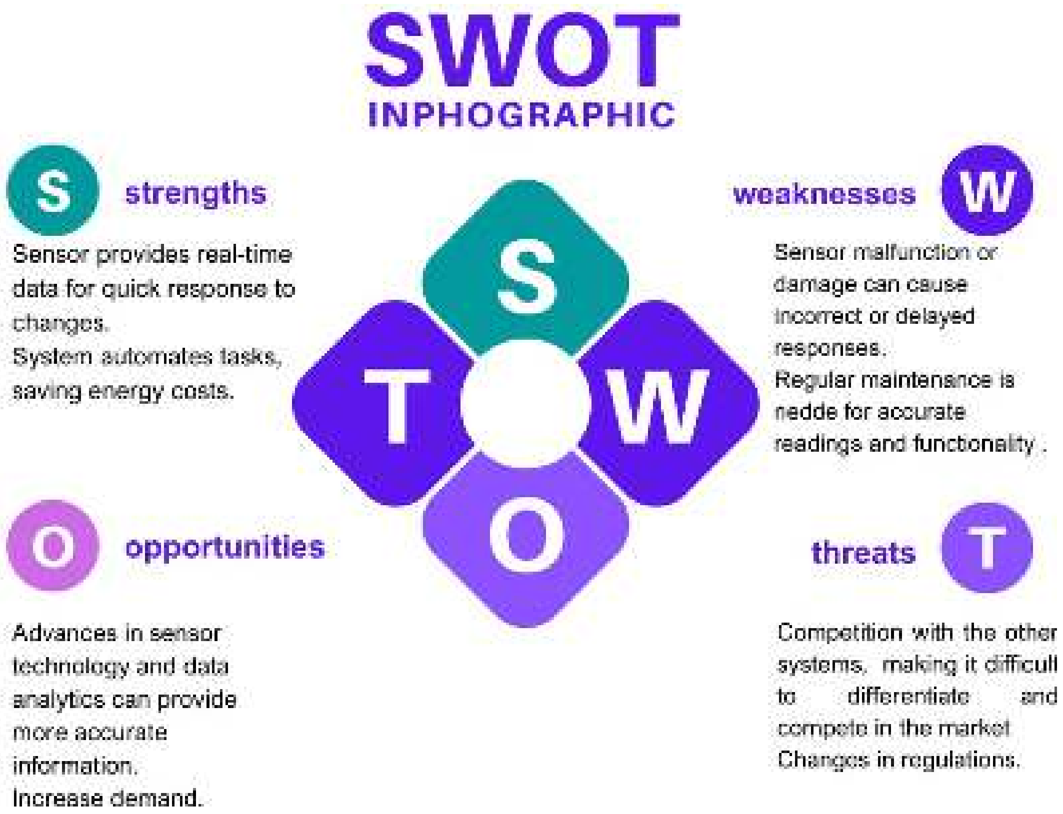


Figure 3.1.1: SWOT Diagram

Strengths:

- Real time monitoring: this BMS can provide real time data on energy usage and indoor air quality, allowing building managers to make informed decisions and optimize system performance.
- The building management system can help automate and streamline processes, saving time and effort, and costs.

Weaknesses:

- Sensor malfunction or damage can cause incorrect or delayed responses, s o it mustbe placed in the correct location within the building, and calibrated to ensure accurate readings.

Opportunities:

- Advances in sensor technology and data analytics can provide more accurate information, and using technological advancement may reduce the complexity of BMS making them more accessible to a wide range of building owners.

- Increase demand: by increasing awareness of the importance of energy efficiency and environmental sustainability.

Threats:
- Competition with the other systems, making it difficult to differentiate and compete in the market.
- Energy codes are regulations that set minimum standards for energy efficiency in buildings. Changes in energy codes can impact the installation and operation, for example: energy codes require the use of an energy management system, which could limit the effectiveness of a BMS that does not meet the required standards.

3.2. PESTEL Analysis

Pestle analysis is a tool used to analyze the external macro-environmental factors that can impact a business or project. It focuses on identifying political, economic, social, technological, environment and law factors.

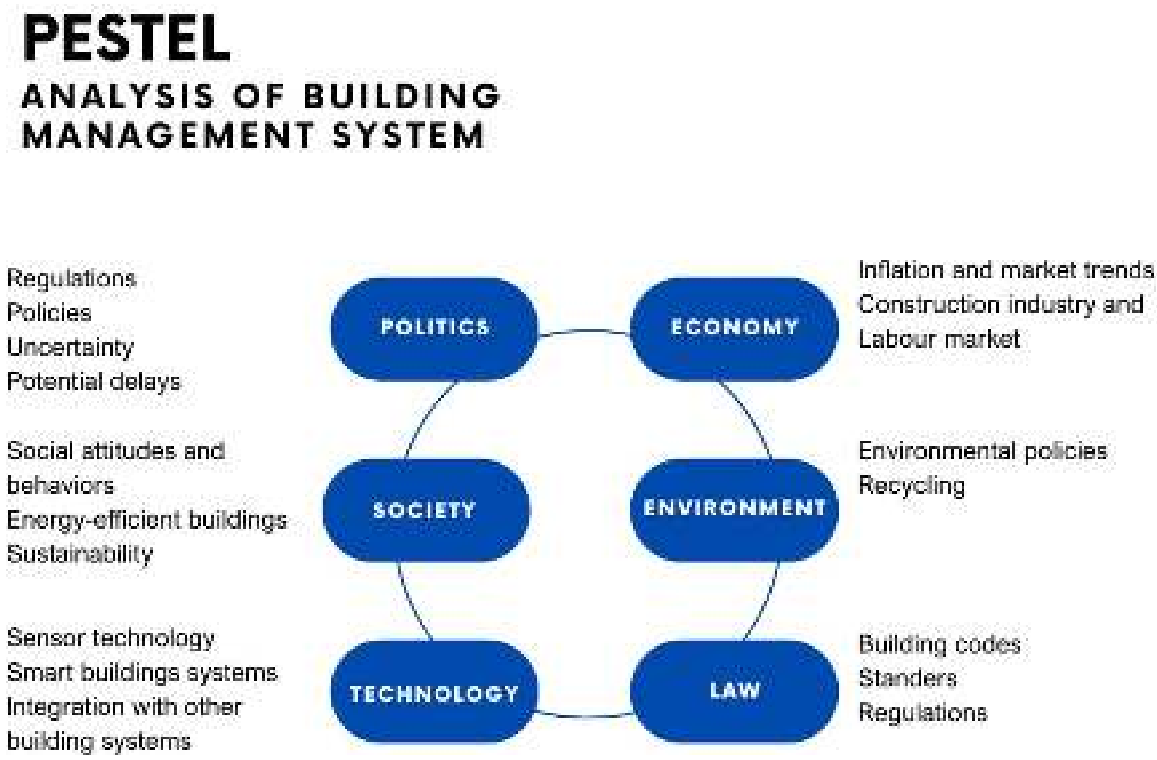


Figure 3.2.1: PESTEL Diagram

Political:

- Government regulations and policies can impact the project's design and implementation.
- Changes in government leadership can lead to uncertainty and potential delays.

Economic:

- Economic factors such as inflation and market trends can impact the project's budget and financing options.
- Changes in the construction industry and labour market can affect the project's timeline and labour costs.

Social:

- The demand for sustainable and energy-efficient buildings is increasing, creating a market opportunity.
- Changes in societal attitudes and behaviours may impact the project's acceptance and adoption.

Technological:

- Advances in sensor technology and smart building systems provide opportunities for innovation and optimization.
- Integration with other building systems can create more comprehensive and efficient approach to building management.

Environmental:

- Environmental factors such as climate change and resource availability can impact the project's sustainability and resilience.
- We use the “PLA” plastic acide which we can recycle.

Legal:

- Building codes, regulations, and standards must follow in the project's design and construction to ensure compliance and safety.
- Intellectual property laws and regulations must be considered to protect the project's technology and data.

3.3. GANTT

The Gantt chart is a tool used in scheduling and project management to visualise the various tasks in a project over time. It allows the progress of the project to be represented graphically. This tool meets two objectives: to plan optimally and to communicate on the established schedule and the choices it imposes. The diagram makes it possible to:

- Determine the dates of completion of a project;
- Identify the margins existing on certain tasks;
- Visualise at a glance the delay or progress of work.

Here is the GANTT for our project to allow us to see who is in charge of each task, the progress of the project and what we need:

Design system

Nom	Personnes	Statut	What we need ?
research about available tools	Pablo, Danut	done	
implementation research	Pablo, Danut	done	
setup of the VPS and its software	Pablo, Danut	done	
database setup	Pablo, Danut	done	
database design and tests	Pablo, Danut	done	
database and sensors linking	Pablo, Danut	not started yet	
dashboard setup and tests	Pablo, Danut	not started yet	
database and dashboard linking	Pablo, Danut	not started yet	
alerts and notifications set up	Pablo, Danut	not started yet	
dashboard and mobile app linking	Pablo, Danut	not started yet	
testing of built prototype	Pablo, Danut	not started yet	
after test fixes	Pablo, Danut	not started yet	
sensors documentatio check	Pablo, Danut	done	
connection of sensor to network ar	Pablo, Danut	done	

Figure 3.3.1: GANTT Table

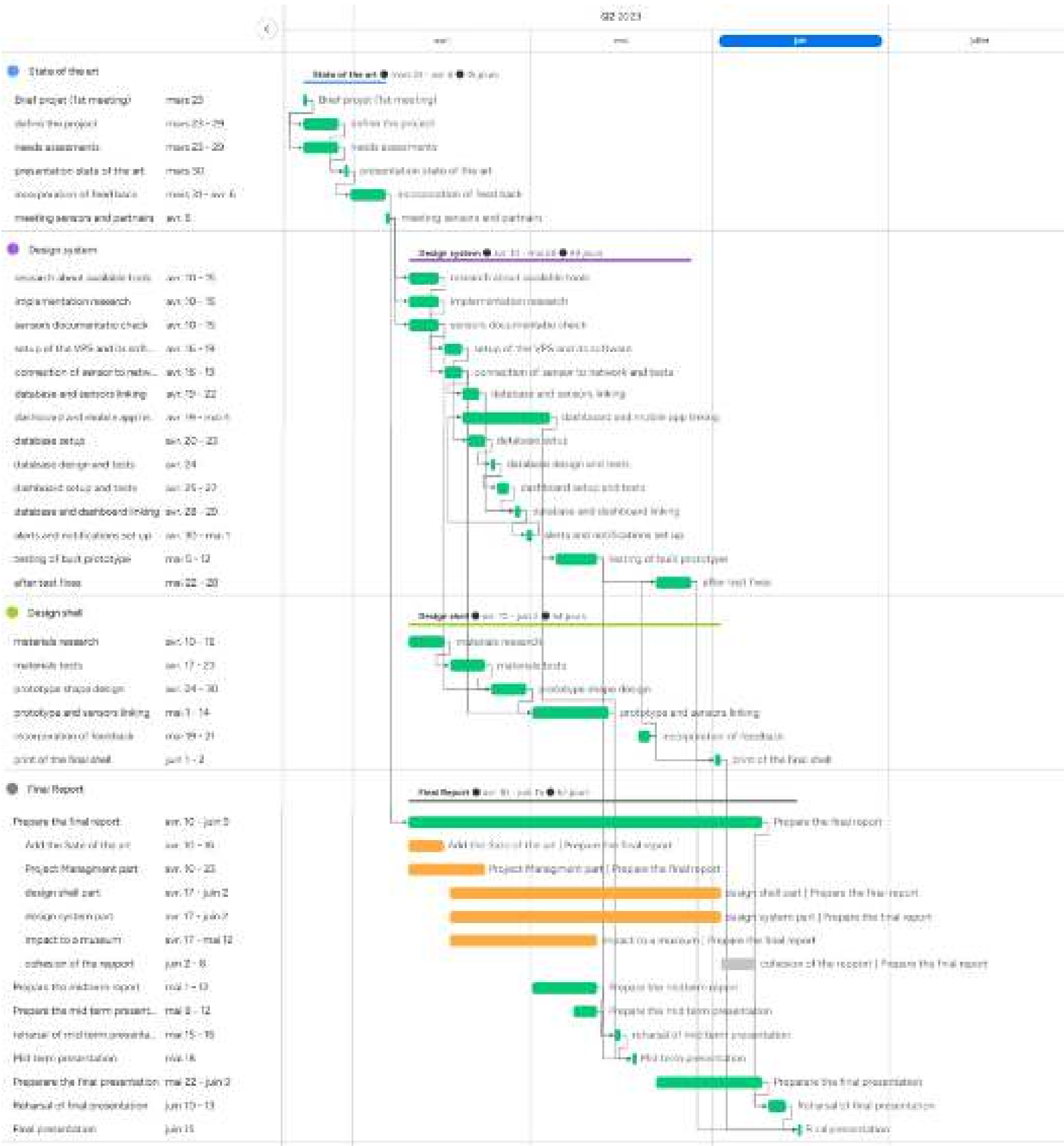


Figure 3.3.1: GANTT Diagram

3.4. Risk analysis

The risk analysis is detecting, evaluating, and prioritizing risks using a risk matrix that assesses the chance and impact of each risk. This aids in the comprehension of prospective dangers and possibilities, allowing for effective risk reduction and decision-making.

Risks

- Technical risks: lack of mastery of sensor software, lack of mastery of the 3D printer;
- Human risks: a team member leaves the project, a member does not have sufficient knowledge to carry out an assigned task;
- Legal risks: bankruptcy of the software/sensor supplier;
- Risks to deadlines: risk of slippage in the schedule due to a poor initial estimate of the time needed to complete the tasks; (rewrite)
- Risks intrinsic to project management: misallocation of responsibilities on tasks, several people assigned to the same tasks without a clear distribution of roles;

Meditative and preventive actions

- Technical risks: assess the possible training needs of your project team before starting the tasks requiring the mastery of these weak points;
- Human risks: provide back-up people who have the same skills as the person in charge and who can replace them in the event of prolonged absence;
- Legal risks: Provide a solution if the supplier cannot keep up;
- Risks intrinsic to managing your project: use project management tools and talk to the people who are going to work on these tasks and revalidate with them the time needed according to their experience.

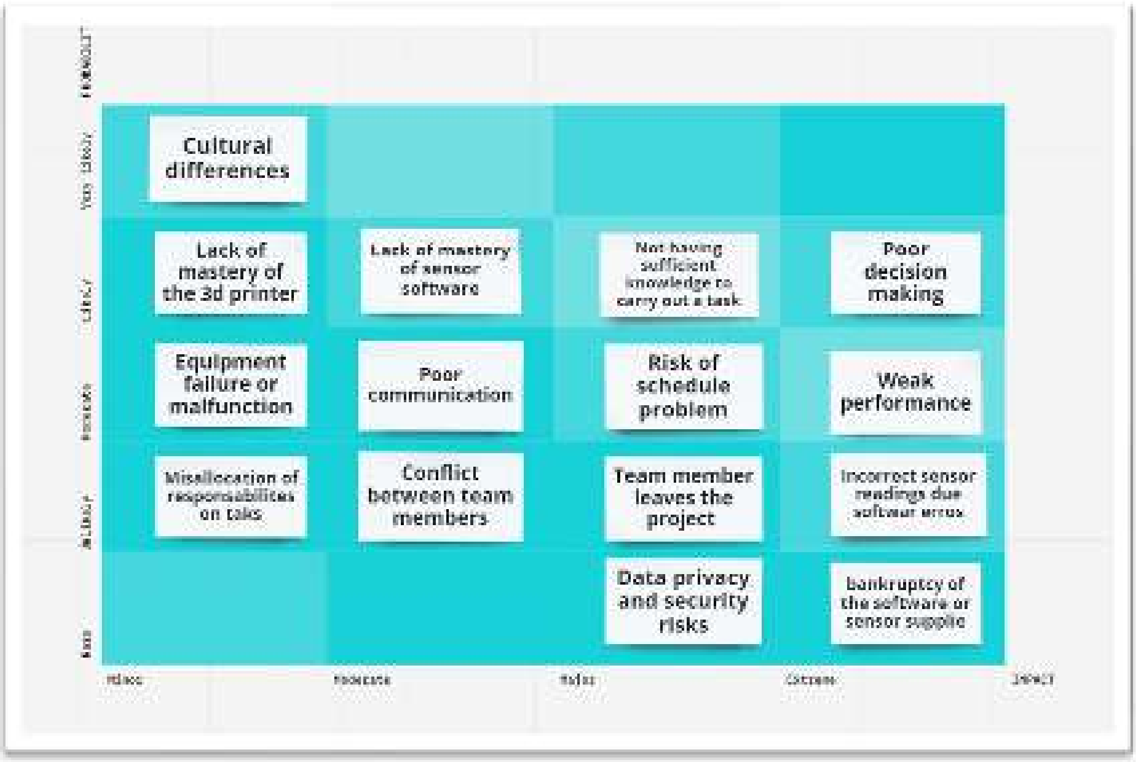


Figure 3.4.1: Risk matrix

3.5. Conclusion

These project management tools helped us to meet the real needs of the project, as well as to have an overall view. They help to visualise all the elements to be taken into account and to organise teamwork.

4. Environmental Conditions Research

4.1. The Effects of VOCs on Museums and Their Collections

Definition of VOCs

Volatile organic compounds are a group of chemicals that are commonly found in indoor environments, including museums. VOCs can come from a variety of sources, such as building materials, furniture, cleaning products, and even human activities.
In museums, common sources of VOCs include adhesives, sealants, paints, coatings, and varnishes used in the preservation and restoration of collections. VOCs can evaporate at room temperature and mix with the air, leading to increased levels of indoor air pollution.

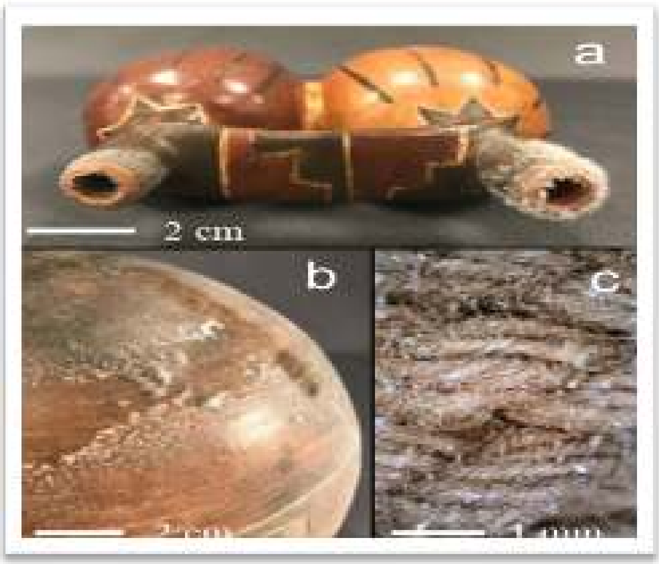


Figure 4.1.1: Microscopic visualization of particles in an object

The impact of VOCs on museum materials

VOCs can have a significant impact on various museum materials, including paintings, textiles, and metals. Paintings, for example, can be particularly vulnerable to the effects of VOCs. Some VOCs can react with the pigments and other components of paint, causing discoloration, fading, and even degradation of the painting over time. This can result in the loss of important cultural and historical artifacts.
VOCs can also cause the fibers of textiles to weaken, leading to tears and deterioration and they can also cause discoloration and fading of the fabrics.

Strategies for controlling and reducing VOC levels in museums

1- Ventilation systems are one of the most effective ways to reduce VOCs in museums because good ventilation systems can help to exchange indoor air with outdoor air, diluting the concentration of VOCs in the museum's indoor air. Additionally, opening windows and doors can also help to increase the flow of outdoor air into the museum and reduce VOC levels.

2-Air purification can help to remove VOCs from the air by filtering them out or by breaking them down with UV light. These systems can be particularly useful in areas where it is difficult to achieve proper ventilation.

3- Museums can use low-VOC paints and sealants and can choose cleaning products that are less toxic, and avoid bringing in objects that are known to emit high levels of VOCs. Additionally, they can implement policies that limit the use of VOC-emitting products, such as adhesives and solvents, in certain areas of the museum.

4.2. The Impact of Noise Pollution on Art and Antiques in Museums

Definition of Noise Pollution

Noise pollution, especially sustained or high levels of noise, can cause physical damage to delicate museum materials. Vibrations from loud noises can cause fine art and antique objects to shift, leading to damage or even breakage. This is particularly true for objects that are mounted or displayed on pedestals or other structures that are not firmly anchored to the floor or walls. Constant exposure to low-level background noise can cause fabrics and textiles to fade or deteriorate more quickly than they would under normal conditions. This can lead to a loss of color and detail in historic tapestries, clothing, and other objects.

b- Controlling the impact of noise pollution

1-Implementing sound barriers

2-Controlling visitor behaviors

3-Monitoring noise levels

4.3. PM1, PM2.5, and PM10 in Museum Environments

PM stands for particulate matter, which refers to tiny particles suspended in the air.
PM1, PM2.5, and PM10 refer to the size of the particles, with PM1 being the smallest and PM10 being the largest. These particles can come from a variety of sources, both indoors and outdoors, and can have a significant impact on indoor air quality.
Particulate matter, especially PM2.5 and PM10, can have a damaging effect on museum collections. These particles can settle on surfaces and cause discoloration, staining, and degradation of materials over time. They can also attract other pollutants and create a film on surfaces that is difficult to remove without damaging the object.
Exposure to high levels of PM can have negative health effects, particularly on individuals with pre-existing respiratory or cardiovascular conditions. In addition, museum visitors and staff may experience discomfort or irritation due to exposure to particulate matter, which can impact their overall experience at the museum.

4.4. CH2O in Museums

Definition of CH2O

CH2O, or formaldehyde, is a colorless gas that is commonly found in indoor environments, including museums. It is often used as a preservative or disinfectant for museum collections, but can also be released from various materials, such as adhesives, paints, and coatings.
Exposure to CH2O can pose risks to both museum collections and visitors, making it important to properly assess and control levels of this substance in museum environments.

Strategies for controlling and reducing CH2O levels

1- Using air purifiers is effective in removing CH2O from the air. HEPA filters and activated carbon filters are two types of filters that can help to reduce CH2O levels in museum environments.

Figure 4.4.1 Filter used in air purifiers

2- Monitoring CH_2O levels in museum environments can help to identify potential issues and inform strategies for controlling and reducing levels. Monitoring can be done using specialized equipment or testing kits.

4.5. Conclusion

The presence of VOCs in museums poses a substantial risk to collection preservation. These chemicals have the potential to deteriorate and discolor artworks and artifacts. Similarly, noise pollution can harm sensitive art and antiques by generating vibrations and physical damage. Furthermore, the presence of particulate matter (PM1, PM2.5, and PM10) and CH_2O in museum surroundings can compromise the collection's preservation.

Museums must implement proper ventilation systems, assess pollution levels on a regular basis, and take appropriate mitigation steps to ensure the long-term preservation of cultural material.

5. Product Development

5.1. Introduction

After researching we started working on building the BMS, there were two things to build, a shell to protect the monitor that contains all the sensors from light, dust and humidity, and the software that would communicate and save all the information collected by the sensor to the staff of the museum.

5.2. System's Software Design

Design morphology

The design of the system consists of a data source, sensors measuring the different environmental values, a database to store the values along the time, a data visualization application to display in a graphical way all the values from the sensors, an alert system for notifying when a certain value exceeds a threshold that is directly connected to a mobile app for notifying the staff and logging all the alerts.

The sensors are all put together into the monitor that we were provided, uRAD Model A3[1]. This sensor connects to the internet via WIFI and sends all the captured data to the uRAD dashboard where later this can be pulled thanks to their API Rest.

Here is a diagram of how the system is designed and its components:

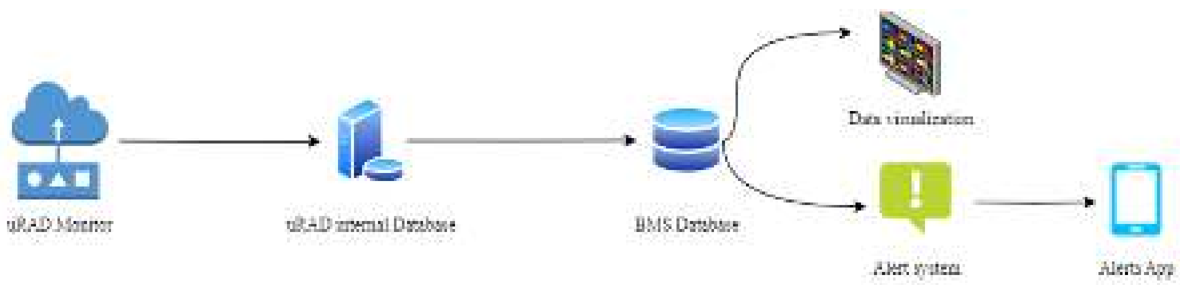


Figure 5.2.1: System's Design

The monitor

As noted earlier, for our BMS we will be using a monitor from the uRAD company. uRAD is a Romanian company known for designing monitors that include many sensors inside to control different variables of the environment.

These variables are helpful for us, many are to be considered when preserving artefacts and pieces from a museum as explained in the "Environmental Conditions Research" part of this project. Hence we needed a powerful monitor to be able capture as many variables from our list as possible.

The company designs and sells their own monitors, currently they offer more than ten different models ranging from basic ones that only measure certain variables to very complex ones that are able to gather lots of information from the environment.

From their catalogue of available monitors we are using the Model A3.
This monitor is able to capture the following information from the surroundings: Temperature, Relative Humidity, Volatile organic compounds (VOC), Formaldehyde, Ozone, Particulate matter PM1, PM2.5, PM10, Carbon Dioxide and Noise level.

Internally the uRAD Model A3 monitor has different parts, in the next image, all these parts are detailed.

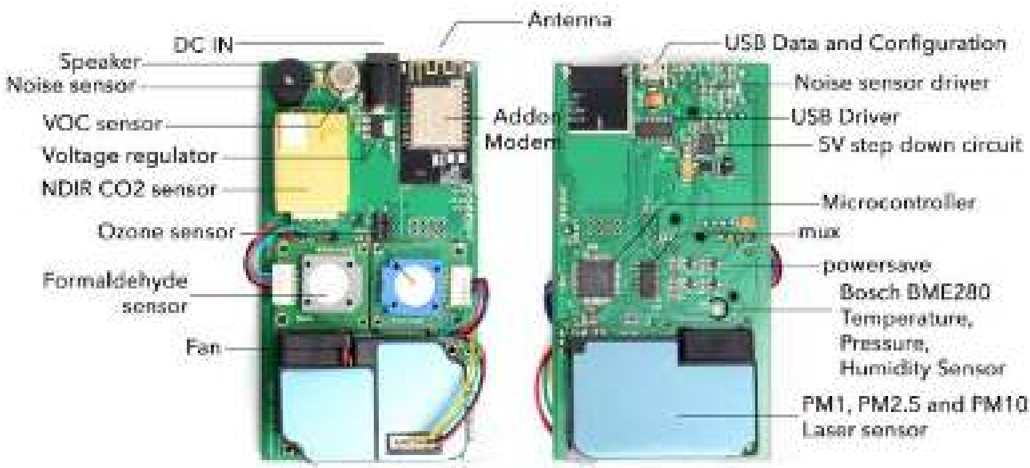


Figure 5.2.2: uRAD A3 Monitor

We will talk about the database, data visualization app, alarm system and mobile app in the following subsection.

Iteration of proposals and final choice

When building a system, it is important to choose the right tools. During the initial phase ofthis project, we talked about all the options we had available, there were plenty of them foreach part of the system on its software side but only a few fit.

All the data that is received from the uRAD API Rest should be stored, this was one of the requirements from the MNLR, they wanted to have a log of values along the time. For this we had some options, we could have gone with a SQL approach but this did not make much sense as we were just receiving a bunch of data from the sensors and all from different measurements being really hard to categorize and unnecessary to relationate.

So instead, we took a NoSQL strategy. There are plenty of NoSQL databases, from document-oriented databases such as MongoDB to time series databases like InfluxDB. Time series databases[2] store data that happened in one date and time, as we have to store all the datathat happened in one exact second of a day we will go for the time series one and use InfluxDB as it provides an easy way to populate and later retrieve the data.

For the data visualization our objective was making it really easy to use for the final users. Some of the tools were very obscure or not so visual for people who should not have a software background for their job development.

We wanted to have something that was clear and concise where all the data that we dumped from the sensors was distinctly recognized; this left us two main choices: building the visualization part ourselves from scratch or using one of the available tools on the internet.

Building it from scratch was something that we considered, there are some great libraries for displaying data in almost all programming languages, and the drawback of this choice was connecting it to our data source, Influx DB.

InfluxDB already displays the data that it stores in charts and allows us to organize these charts in different panels in a dashboard but the main purpose of Influx DB is storing data sowe used a tool whose main purpose was displaying data.

As we also needed an alarm system besides the data visualization app, we used Grafana.

Grafana3 is an open-source monitoring and data visualization app that connects to almost all existing data sources. Most specifically, Grafana connects greatly to InfluxDB, it can display all the data based on the time that it was captured and in many different chart types, for our final users this solution works the best. Grafana also supports alerting4 so we can create all the alert rules for when a certain value exceeds a threshold and notify the workers at the MNLR.

Inside Grafana we can create different dashboards just as InfluxDB works, when a new dashboard is created, we can then place different charts contained in panels inside the samedashboard we created earlier. This is useful because when the staff from the museum want to do a quick check on how things are going and need to visualize a dashboard from their computers, they will have all the data displayed together in a grid layout without the need ofmoving to other dashboards.

This is why we created a main dashboard with all the necessary information contained in it.

Here is how the Grafana dashboard we designed for the BMS looks like:

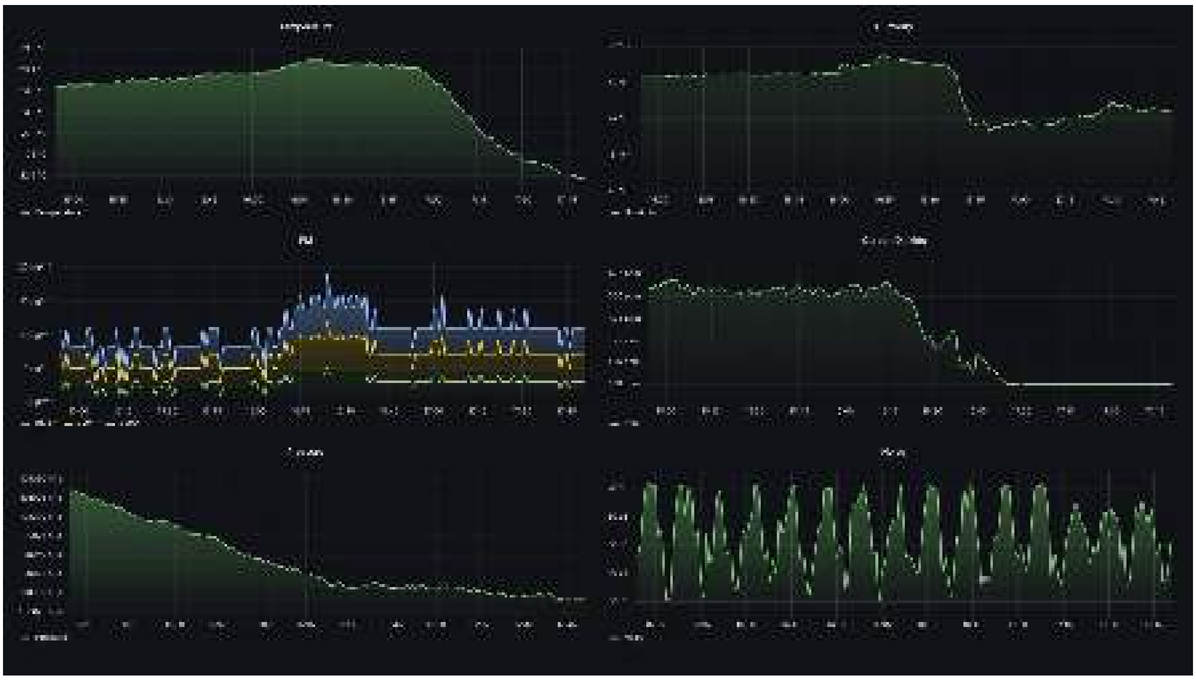


Figure 5.2.3: Grafana’s BMS main dashboard

For the final part of our BMS we developed a mobile app to lighten the workload of the staff of the museum. The museum staff can be in a place other than their statical workstations and still know what is going on in the building by simply having with them their mobile phone.

The mobile app serves notifications to the staff's phones and also keeps a history of past notifications, all notifications sent to the app are stored in a MySQL database for later lookup.

There are three types of notifications in the app depending on the severity of the problem. Alert levels are: High, Medium and Low.

Each notification is classified in one of these three groups depending on different factors, such are if a specific change of a variable might be more damaging to artefacts than other variables and if the difference between the normal condition intervals is really high or not too far from the bounds.

Next is a screenshot of the developed mobile app on how the notifications are displayed:

Red color is used for high alert notifications, yellow is used for medium ones and green is for low. All the notifications include a footer indicating if the event has been resolved or if it hasn't been yet, thus it's unhandled.

This is useful for looking at the history of notifications and filtering which must be handled more quickly.

Figure 5.2.4: Notifications shown in the app

When an alert rises and the staff click on its notification the app displays the alert filling all the screen and with two buttons for dismissing the alert or viewing more details.

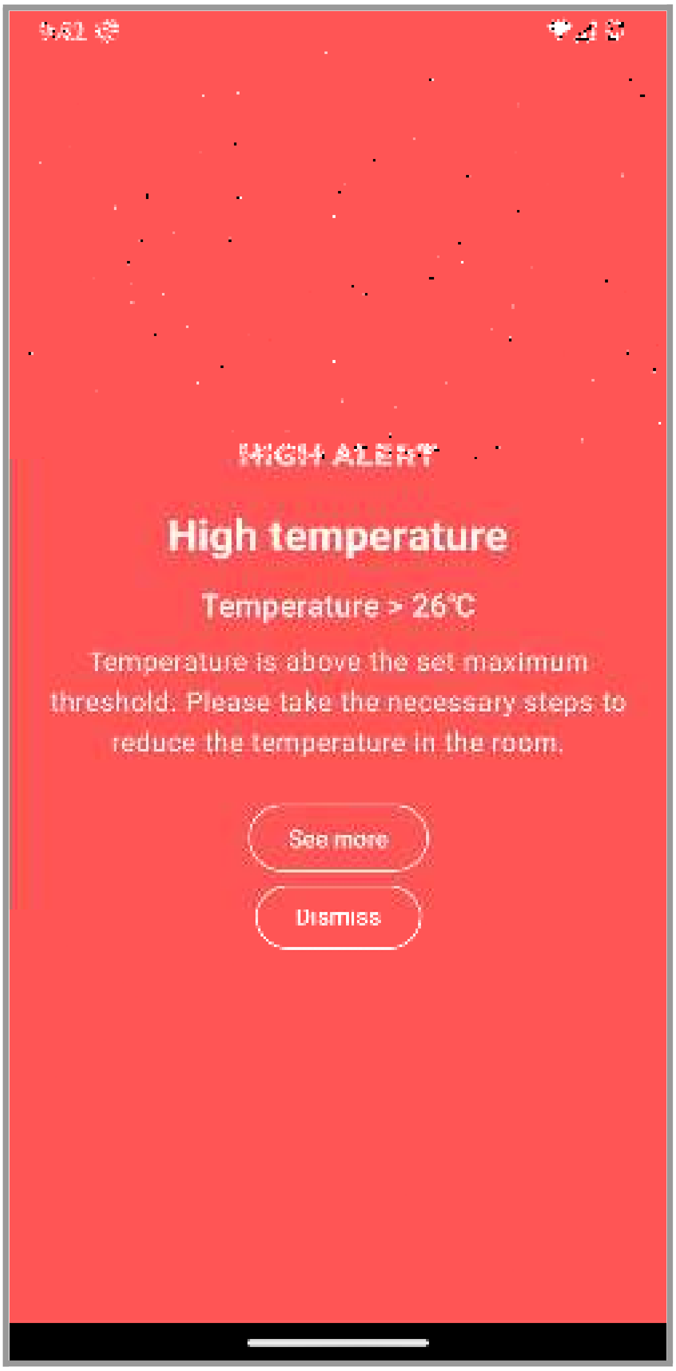


Figure 5.2.4: Display of an alert

5.3. Shell design

To start with the design of the shell, let's look at what is available on the market. What materials are used? What attachment system is used? What are the advantages and disadvantages of each?
After a lot of research into BMS systems, it is noticeable that the shells are :

- Either metal, which protects the elements from water, dust, moisture or heat. Metal cabinets are expensive to produce and are always used when the system is placed outdoors or on a building site.
- Or Plastic, which are occasionally used indoors, are low in production costs, and their protective properties depend on the polymer used.

Figure 5.4.1: *BMS System metal cabinet*

Figure 5.4.2: *BMS System plastic shell*

Within the means of our project, it is preferable to elaborate a polymer shell, which will be less expensive to produce, and simpler to shape in order to best adapt the shell to the inner system.

Which polymer is used?
In the ecological interest of the project, to reduce energy production and minimize it, it is essential to choose a polymer that will have a minimum impact on the environment. But also, that will respect all the characteristics of the device: High mechanical strength for a small thickness, impermeable to gases, $H2O$, electrical insulation and unaltered mechanical characteristics between -10 and 50°C.

There are 4 families of Bioplastics, as shown in the diagram below, but we will not be interested in agropolymers, which are still too weak for our project. We are not interested in petrochemical polymers because we want to limit the impact on the planet from the moment of production, even if they are biodegradable, we will favor a non-biodegradable product that can be recycled and produced in a clear way for the environment.

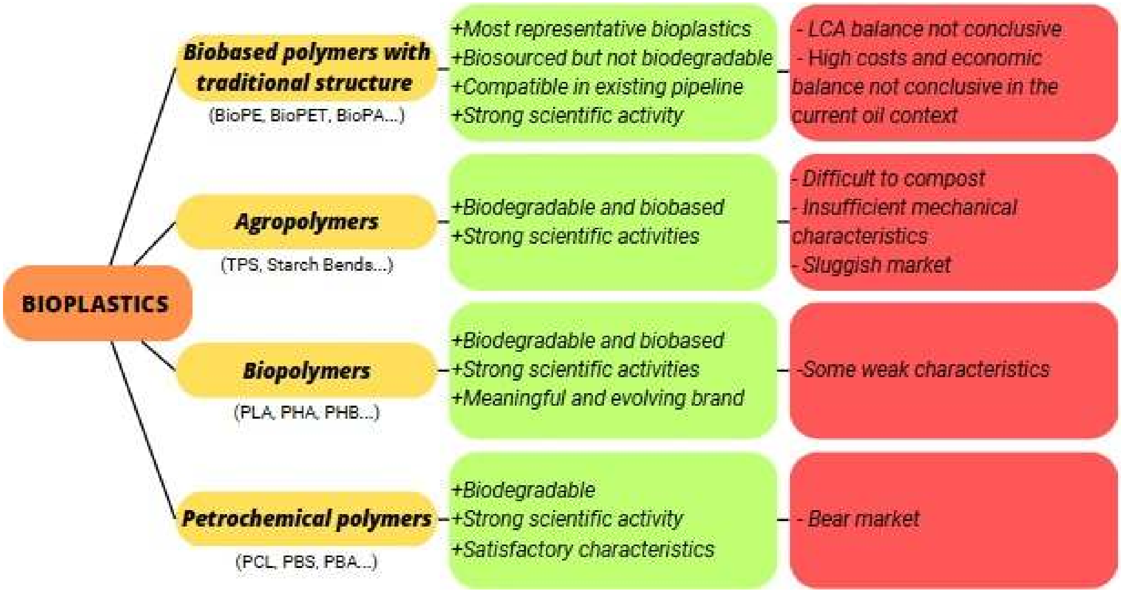


Figure 5.4.3: *Different bioplastics*

Biobased polymers with traditional structure and biopolymers are the ones we are most interested in for their environmental characteristics. Among these we have looked for the 3 most suitable polymers for injection molding for parts similar to our project. We will therefore compare the characteristics of each in a comparative table:

- ***BioPolypropylene [PP]:*** A recyclable thermoplastic, known to be hard and tough. It has an ultimate tensile strength of 27 MPa, a Young's modulus of 1.3 GPa, and is highly heat resistant, has a melting point of 337°C, is brittle at room temperature as its glass transition temperature is close to -4°C.

- ***BioPolyethylene [HDPE]:*** A recyclable thermoplastic, its characteristics depend on the number of its branches, we are interested here in high density PE. Ultimate tensile strength 30 MPa, Young's modulus 1 GPa, melting point 317°C, glass transition temperature -50°C.

- ***Polylactic Acid [PLA]:*** A bioplastic made from corn starch, biodegradable by industrial composting (at a temperature above 60°C), Young's modulus between 3 and 3.5 GPa, tensile strength between 50 and 70 MPa, melting temperature of 185°C, glass transition temperature of 60°C

	bioPP	**bioPEHD**	**PLA**
Environment	🟧	🟧	🟩
H2O permeability	🟩	🟩	🟩
Gas permeability	🟩	🟩	🟧
T° resistance	🟧	🟩	🟩
rigidity/solidity	🟩	🟧	🟩
electrical insulation	🟩	🟩	🟩
bonding characteristics	🟧	🟩	🟩

🟧 insufficient property

🟩 sufficient property

Figure 5.4.4: *Polymer comparison table*

After this analysis, the choice of PLA is made, as its characteristics are sufficient for our project and correspond to its environmental ethics.

What about the choice of thicknesses?

Now that we have chosen our material, before we move on to the design of the prototype, we will carry out tests to determine the thickness needed for our shell. We will print 6 PLA samples and subject them to a tensile test.

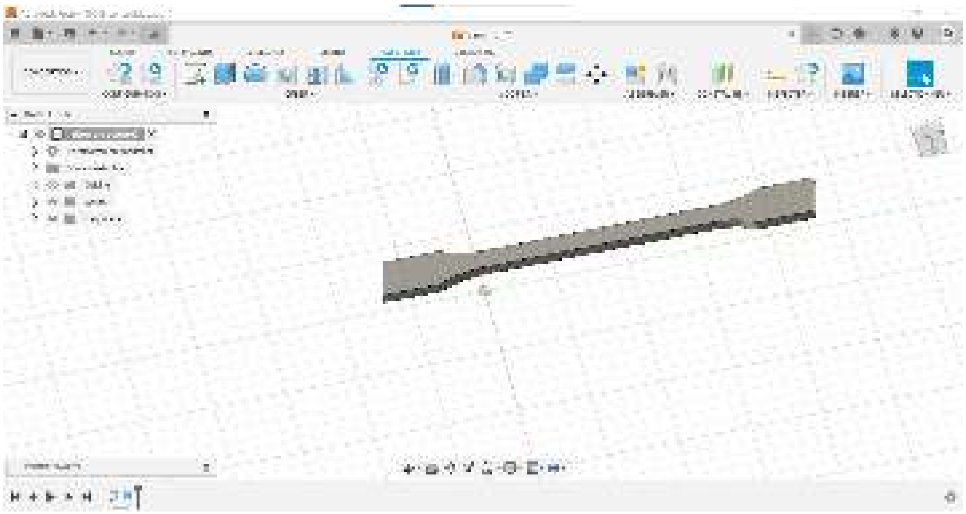


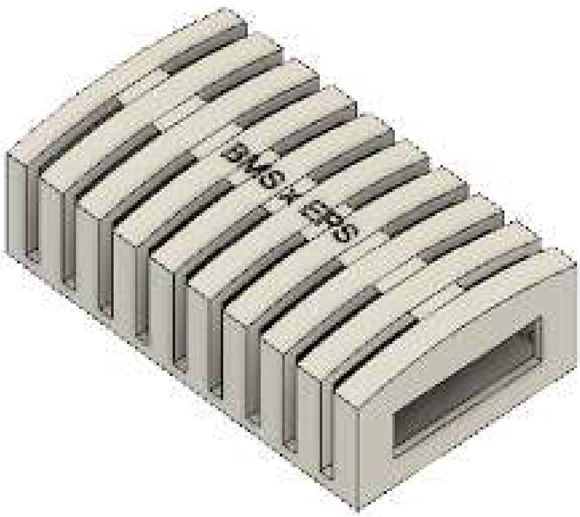
Figure 5.4.5: *Test tube with Fusion360*

In the process of designing and fabricating a shell using Fusion 360, we worked on bringing the concept to life through 3D printing. Fusion 360 provided us with the essential tools and capabilities to create a precise shell design, ensuring that every detail was meticulously incorporated. Through the software's intuitive interface, we were able to optimize the structure for 3D printing. With the design completed, we transferred the file to a 3D printer using an SD card, we utilized the Flashforge Creator Pro 3D Printer that include a 120℃-heating build plate and a full enclosed body with a build volume of 230*150*140（mm）so it provided ample space to accommodate the size of the shell and with the direct extruder mechanism ensured precise and accurate material deposition, resulting in a high-quality print and It took approximately 12 hours to complete the printing of the shell.


Figure 5.4.6: *3D printer* ***Figure 5.4.7:*** *Shell printed*

The selection of materials is an essential phase in the creation of the hull, we await the impression of the testers, in order to create the shape of the hull in correct measures.

Finally, for the final hull we chose ... thickness for its resistance. In addition, we have chosen to leave ventilation so as to impact the sensor as little as possible.



Figures 5.4.6: *Final shell*

With fusion 360 we made the model and then printed it. This shell allows the user several options, either to be placed on a table or to be stuck against a wall. These two options allow a simple connection of the wires and to remove and remove the sensor from the interior when desired, for example for maintenance.

5.4. Conclusion

We learned new skills and improved our teamwork doing this development process, by understanding each other we were able to develop a working software system for our BMS that can be easily expanded and a custom shell for protecting the monitor from external conditions.

6. Conclusion

6.1. Discussion

We have set up a BMS System connected to an application in order to measure the temperature, the humidity and the concentration of some gases in an atmosphere. This system makes it possible to compile the data in order to improve the follow-up of the conditions of conservation of the works. The user is alerted if the threshold predefined by the user is exceeded. The system is limited to storage and alert functions, the user will have to intervene on the heating, ventilation and air conditioning equipment. The system is not autonomous.

6.2. Experiences

In anticipation of feedback, it is more comfortable for museum management to have automated real-time monitoring and data archiving. However, the system still requires human action to regulate the parameters.

6.3. Future Development

What follows is expanding our BMS to also being able to control the devices that regulate the indoor conditions based on the information gathered by the sensors.

This BMS can be easily extended to other literature museums and moreover, to museums that preserve a different kind of art. The system we designed and developed is easy to install in all kinds of facilities. The next steps for this product to be successful in all museums would be working on different use cases other than literature museums and implementing little tweaks based on these use cases.

7. References

[1] Optergy (2023) - Building Management System Application Datasheet:
https://optergy.com/wp-content/uploads/2023/02/Optergy-BMS-Application-Sheet-Rev1-US-LS.pdf

[2] David C. Wyld, Michal Wozniak, Nabendu Chaki, Natarajan Meghanathan, Dhinaharan Nagamalai (Eds.) (2011) - Advances in Computing and Information Technology, A BMS Clientand Gateway Using BACnet Protocol: https://link.springer.com/chapter/10.1007/978-3-642-22555-0_45

[3] Johnson Controls - Analog Value/ BACnet Analog Value:
https://docs.johnsoncontrols.com/bas/api/khub/documents/YxkShPQmAbN_Zs7bXatviw/content

[4] The "NEW" Environmental Standards for Museums:
https://ahtahthiki.wordpress.com/2011/03/16/the-new-environmental-standards-for-museums/

[5] HVAC system Image:
https://buildingandinteriors.com/why-are-hvac-systems-the-backbone-of-buildings/

[6] 3D printing infos:
https://www.flashforge.com/product-detail/flashforge-creator-pro-3d-printer

[7] La Gestion Technique duBâtiment (GTB) (2017):
https://fidelixme.com

[8] Octavo systems – Images - https://octavosystems.com

[9] https://www.uradmonitor.com/products/

[10] https://hazelcast.com/glossary/time-series-database/

[11] https://www.redhat.com/en/topics/data-services/what-is-grafana

[12] https://grafana.com/docs/grafana/late