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COLLECTION CARE

Innovative and affordable service for PC monitoring of individual Cultural Artefacts during display, storage, handling and transport

Validation report of "basic" sensor node to cloud, including analysis of data loss ratio, RSSI and LQI behaviour in each scenario

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Abstract

Deliverable 5.1, entitled "Validation report on basic sensor node to cloud, including analysis of data loss ratio, RSSI and LQI behaviour in each scenario" falls within the framework of WP5, Task 5.1. The aim of this deliverable is to document the evaluations made on the behaviour of the basic sensor node during its validation in real-life scenarios. Specifically, the following parameters were assessed: behaviour of the wireless sensor node in transmission to the cloud database, communications behaviour, transmission loss rate and energy consumption. This validation was carried out in July 2020 in two demo sites of the project, namely the Alava Arms Museum and the Alava Fine Arts Museum of the Diputación Foral de Álava (DFA) in Spain.

The document includes four sections. The first is an introduction describing the purpose of Task 5.1, which aims to validate the "basic" sensor node, and explains the concepts and tools used to perform preliminary radio frequency (RF) tests before deployment of the sensor nodes.

Then, section 2 presents a description of the constructive features of the two museums' buildings, the results of the radio mapping tests, the description of the deployment of the sensor nodes carried out at the two museums and, finally, some graphics of the collected data of temperature (T), relative humidity (RH), visible light (L) and ultraviolet radiations (UV) during this validation phase.

Next, section 3 describes the results obtained from the evaluations carried out on wireless signal performance, data extraction rate and energy consumption. There is also a comparison between the data collected by the "basic" sensor nodes and the museums' dataloggers in order to evaluate the basic sensor nodes' performance

Finally, the conclusions summarise the work done so far and provides a brief description of the following steps.

Abbreviations and Acronyms Glossary

AB	Advisory Board
ADR	Adaptive Data Rate
AES-CBC	Advanced Encryption Standard-Cipher Block Chaining
C	Celsius
D	Deliverable
bB	Decibels
bBm	Decibel-milliwatts
DER	Data Extraction Rate
DFA	Diputación Foral de Álava
FM	Frequency Modulation
FTD	Field test devices
GHz	Gigahertz
IoT	Internet of things
ISM	Industrial, Scientific and Medical radio bands
L	Light
LoRa	Long-Range
LoRaWAN	Long-Range wide-area network
LPWAN	Low-power wide-area network
MHz	Megahertz
mW	milliwatt
NB-IoT	Narrowband-Internet of Things
RC	Radio Configuration
RDC	The Royal Danish Collection
RF	Radio frequency
RH	Relative Humidity
RSSI	Received Signal Strength Indicator
SDR	Software defined radio
SF	Spreading factor
SGF	Sigfox Wireless SA
SNR	Signal-to-noise ratio
T	Temperature (Air temperature)
UPV	Universitat Politècnica de València
URO1	Sapienza Università di Roma
UV	Ultraviolet
WiFi	Wireless Fidelity
WP	Work Package

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1. Introduction

Deliverable 5.1 is the outcome of Task 5.1 of WP5. This work package, entitled "Integration and Validation", aims to integrate all the different components of the CollectionCare system and perform continuous validations, in order to improve and evolve the product by identifying problems or deficiencies. The first task (T5.1) of this WP is designed to validate the performance of the first sensor node prototype, which is the "basic" sensor node.

In September 2019, in deliverable 4.1, a methodology was established for development of the CollectionCare sensor node. This methodology divides its design, development and refinement process into a sequence of four phases, as follows: 1) concept development; 2) system design; 3) detailed design and; 4) refinement and optimisation. With the development and completion of Task 5.1, and validation of the "basic" sensor node, the end of phase 2 (system design) has been reached (see Figure 1). The objective in this phase was to define the design of the sensor node and its infrastructure in order to obtain a final operational iteration capable of collecting data on physical environmental parameters in high-density scenarios and store them in the cloud database.

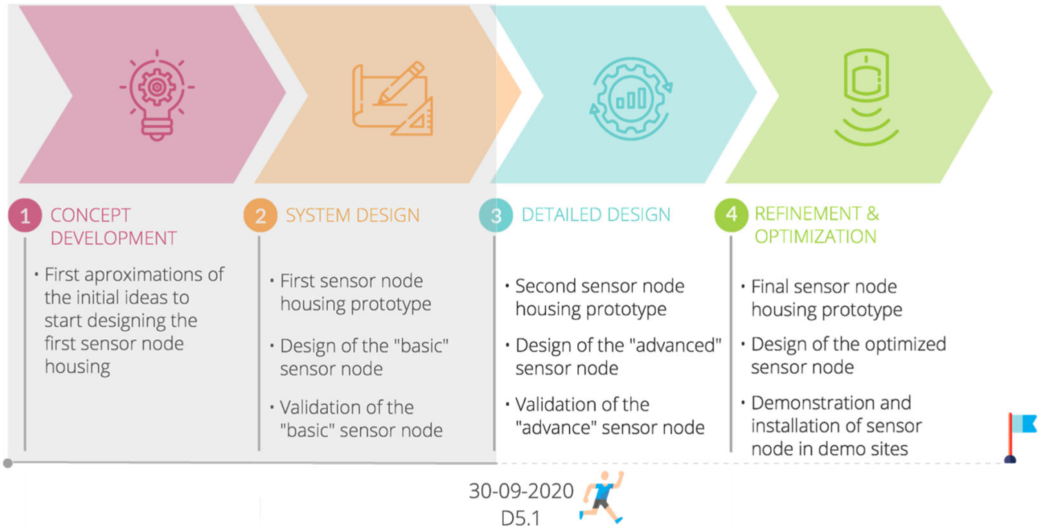


Figure 1. Methodology phases for the development of the CollectionCare sensor node.

In D4.7, it had been established that the validation of the "basic" sensor node would be carried out in the RDC and DFA museums. However, due to the COVID-19 situation, it was not possible to deploy these sensors in the RDC museum because of limitations in terms of travel and departures from the country. For this reason, it was decided to carry out this task in the two museums of the Diputación Foral de Álava (DFA), as it was not necessary to leave Spain. This is how this validation was carried out in the Alava Arms Museum and the Alava Fine Arts Museum of DFA.

For this validation task, five "basic" sensor nodes were installed in the Alava Arms Museum and ten in the Alava Fine Arts Museum at strategic points to obtain a complete evaluation of the sensor's performance, as well as wireless communication and rate of lost transmissions. However, before installing the sensor nodes in the museums' exhibition and storage rooms, RF tests were carried out in these spaces to measure the signal propagation of Sigfox and LoRaWAN technologies. Performing these tests before installing the sensors is of great interest, as the communication aspect is very important, since the sensor nodes need wide coverage to be able to upload all the data collected to the cloud.

Below is a brief explanation of the concepts and tools used to perform these preliminary RF tests before documenting all the work done for deployment of the "basic" sensor nodes at the two demo sites.

1.1 Basic concepts about radio mapping

Radio frequency (RF) is the technique used by the CollectionCare's sensor nodes to transmit the environmental information measured.

Before carrying out a deployment of the sensor nodes, it is important to assess the space where they will be placed from the point of view of their radio behaviour. Performing a technical study of the propagation of radio signals in space is a safe way to ensure the success of a wireless deployment project. This analysis would evaluate the behaviour of the technologies chosen for each specific case.

Therefore, one of the objectives of WP5, Task 5.1 is to perform a RF coverage map of the candidate technologies to be used in order to check which ones are appropriate in a given place, reducing the risk of malfunctioning. In any case, it should be noted that the nature of RF signals does not rule out a certain margin of troubles that other solutions such as wired solutions do not entail.

RF propagation is limited by physical factors that need to be taken into consideration:

- The modulation frequency used. For example, the 2.4 GHz frequency used by Wi-Fi is absorbed by water contained in plant barriers or rain.
- The modulation technique employed. That is, how the information about the RF signal is placed. For example, FM radio stations are heard more clearly than AM stations because they are less susceptible to interference.
- The distances to the receiver. Less distance provides better overall results.
- The type of material in the container space. It is easier to pass through paper than reinforced concrete or metal.
- The type of material of the object to be monitored. For example, metal sculptures are more problematic than wooden ones.
- The position of the sensor. The signal can be obstructed by objects such as metal panels.
- Other factors, such as interference from other sources.

At the same time, there is a balance between the power at which the RF signal is transmitted and the distance reached which limits the life of the batteries. Furthermore, it should be noted that radio space is regulated by the European Union and that these regulations must be followed in any deployment.

In order for this deliverable to be understood by a wider audience, some of the basic principles that are studied in the tests are introduced very basically. To maintain an RF link, it is necessary to have an adequate *link margin* (see Figure 2) which is calculated with the following formula:

Link margin (dB) = transmitted power (dBm) - receiver sensitivity (dBm) + antenna gain (dB) - path loss (dB)

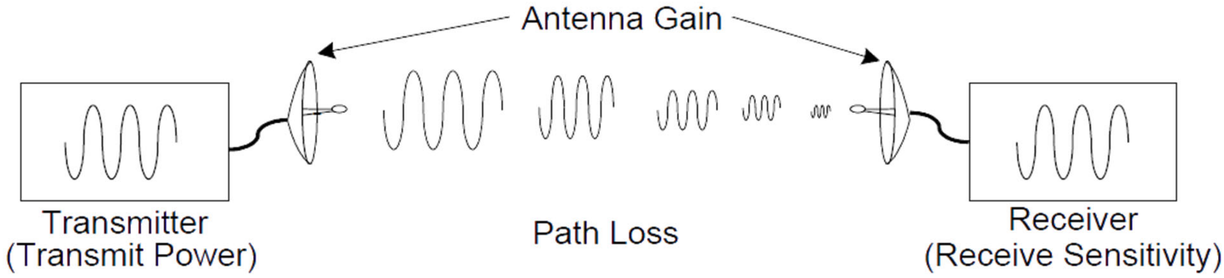


Figure 2. Link margin concept (dB)

For a transmission to work, a certain link margin must be reached. It will be favourable to have a higher transmission power, a good antenna and a sensitive receiver, and against the loss in the path. For this type of transmission, the decibel (dB) or the decibel-milliwatt (dBm) is used as a unit. These units use a logarithmic scale of base 10. The unit dBm is relative to 1 milliwatt (mW), which is a typical low power level used in wireless transmissions for the Internet of Things (IoT).

It is important to remark that path loss should not be confused with distance alone, as RF signals are affected by many factors depending on their frequency. Apart from the distance, they suffer bounces, refractions, scattering, etc., so the problem of RF transmission is very complex.

There are many RF technologies suitable for data transmission so, depending on the specific requirements, a certain technology may be appropriate. These requirements include technical aspects, such as data throughput, bandwidth, propagation patterns, quality of service and so on, and many other requirements, such as regional regulations, economic costs, etc. The choice of technology is a fundamental key to the success of the project.

Based on the specific characteristics of the CollectionCare project, it was considered that the appropriate technologies are those grouped in the term LPWAN (low-power wide-area network), which is a typical IoT category applied in smart city applications. The goal of these technologies is to employ relatively inexpensive devices that do not require much power, which is intended to achieve long battery life, and which allow long transmission distances. This ambitious goal is achieved at the cost of having very low transmission rates (bits per second) and a very small amount of information per "packet" (a few tens of bytes).

Table 1 contains the technologies that were considered appropriate in the CollectionCare project. Of these three technologies, NB-IoT was discarded and Sigfox and LoRaWAN were selected as the most suitable and therefore to be tested on site.

Table 1. RF technologies appropriate for the CollectionCare project and tested ones.

TESTED	TECHNOLOGY	COMMENTS
X	Sigfox	868 MHz, RC1 following European regulations
X	LoRa/LoRAWAN	868 MHz following European regulations
	NB-IoT	sub-GHZ

Both Sigfox and LoRaWAN work in the so-called ISM (Industrial, Scientific and Medical) bands, which use a free radio spectrum, as long as the regional regulations that are different for each country are met. As an example, Wi-Fi and Bluetooth devices use the 2.4 GHz ISM band and, in this case, due precisely to this free nature and the lack of control in its use, it has resulted in the saturation and degradation of that band.

This detail must be taken into account when using Sigfox and LoRaWAN technologies. In contrast, NB-IoT technology is provided by mobile operators who pay to license a part of the spectrum and, theoretically, are exempt from this issue, but have other problems that do not make it suitable for this project.

Sigfox and LoRaWAN have an approximate maximum sensitivity of -130 dBm, which is the limit of signal that a receiver can hear. These values are usually negative and a higher number in absolute value indicates lower signal level and, therefore, more problems to transmit (e.g. 0 dBm is much better than -15 dBm). To this sensitivity, it will be necessary to add a sufficient link margin to work, which will depend on many factors.

According to this section, before deploying the sensor nodes it will be necessary to measure the RF signal levels in the places where it is planned to deploy each sensor. If the measured level is sufficient, it is expected to provide an appropriate operation of the wireless communications. Specialised equipment is necessary to conduct this test.

1.2 Test equipment utilized for radio mapping

The approach designed to evaluate the container spaces is the use of field test devices (FTDs) that imitate the behaviour of the sensor nodes from the point of view of wireless communications and reports on RF performance.

In our case, we used FTDs from the company Adeunis (www.adeunis.com/en/). Each communication technology requires a different type of FTD, so one is necessary for Sigfox and another for LoRaWAN in our case. Figure 3 shows the FTDs used.

Figure 3. Field test devices for Sigfox (left) and for LoRaWAN (right) used in the test.

Both FTDs were configured to use a power transmission at 14 dBm. For LoRaWAN, a SF12 spreading factor was fixed to allow maximum feasible distance evaluation.

To evaluate LoRaWAN, a device is also necessary that imitates the behaviour of a gateway and a network server. Taking into consideration the restrictions that the use of a real network server can impose on the evaluation, we modified a Multitech Conduit gateway (www.multitech.com), as shown in Figure 4, to eliminate the need for a network server and application server.

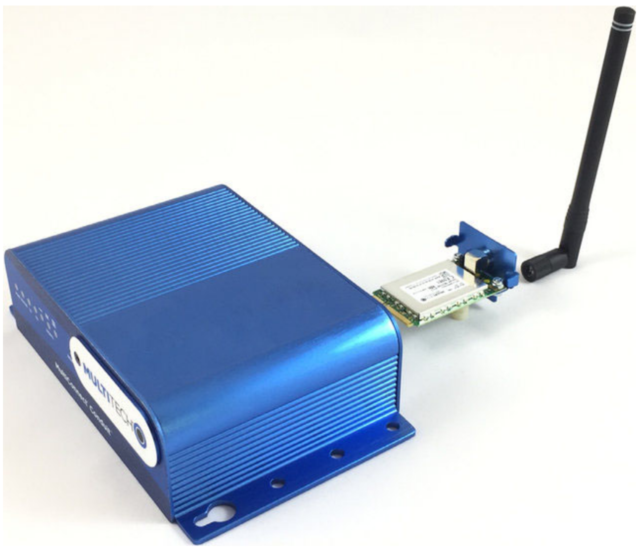


Figure 4. Multitech Conduit gateway with LoRa module and antenna.

Before starting the field campaign with the FTD devices, the RF spectrum (frequencies around 868 MHz in this case) of the frequency utilised was monitored for a while to detect whether there were interferences or devices working in that band. This was done using a software defined radio (SDR) device connected to a laptop computer and specialised software. As an example of the information obtained, Figure 5 shows the output of the set-up sampling in the FM commercial band. The bottom part of the image shows a "waterfall" where the blue colour indicates no signal and the yellow one indicates RF signal in that frequency. It is called a waterfall because it is a real-time graphic representation of the signal level appearing at the top of the screen and descending over time.

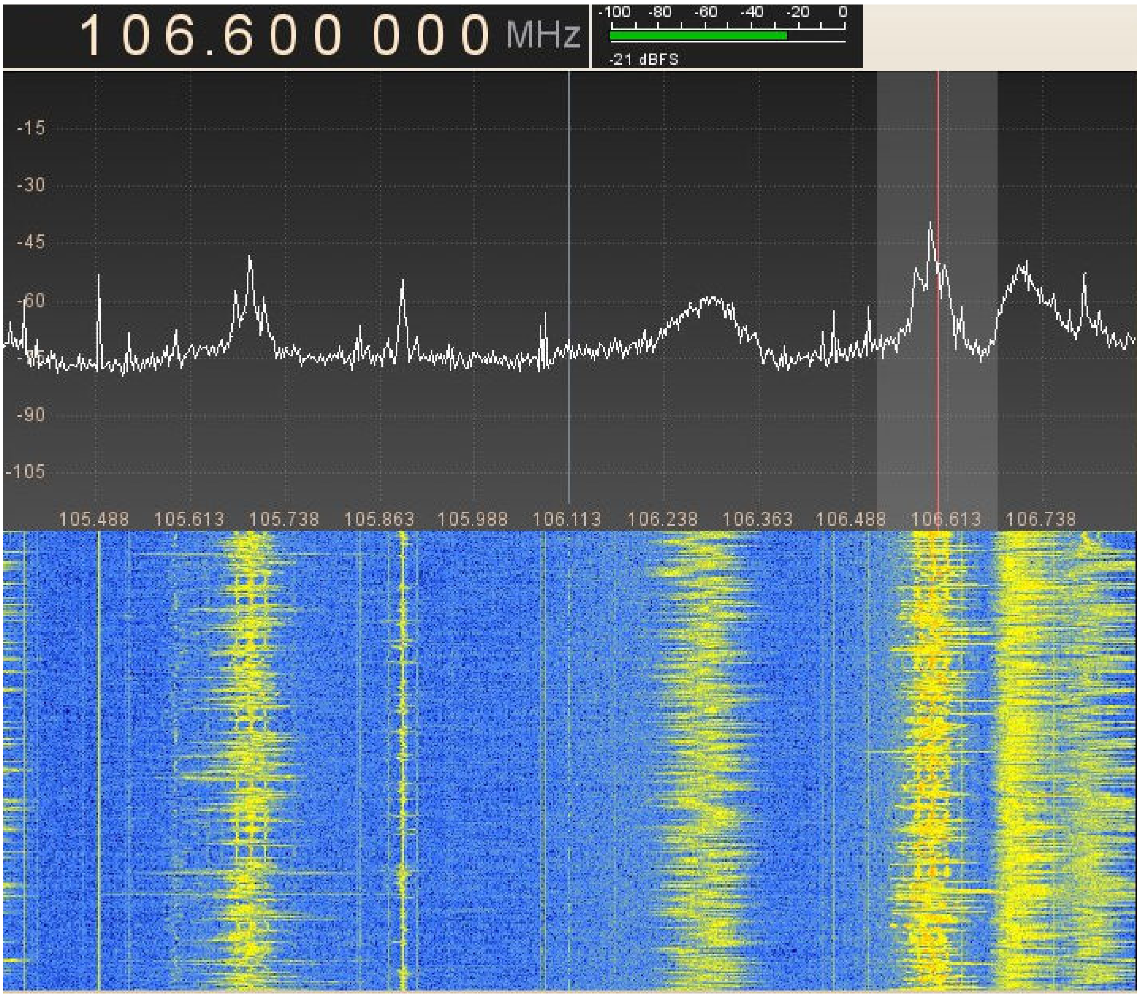


Figure 5. Output of the sept-up to scan frequencies. Example of the FM commercial band.

2. Deployment of "basic" sensor nodes in demo sites

The deployment of sensors was carried out between 21 and 24 July by the specialised team of the UPV with the active collaboration of the DFA team, with all the precautions required due to the global COVID-19 pandemic. The identification of the strategic sampling points in which to place the basic sensor node devices was done in remote collaboration with the URO1 team, following the protocol described in D4.2 and D4.9.

2.1 Alava Arms Museum of Diputación Foral de Álava. Alava, Spain (DFA)

2.1.1 Building description

The Alava Arms Museum (https://armamuseoa.eus/) is located in refurbished buildings annexed to the Palace of Ajuria Enea in Vitoria (Spain). It is a traditional building with stone and brick masonry walls and a distinctive exposed concrete waffle slab between the two main floors. The building has an exhibition room of almost 290 square metres on the ground floor and another of about 250 square metres on the first floor. Both rooms are connected by a staircase and an elevator in the centre of the rooms. Most of the objects on display are in showcases attached to the walls. There are also 2 small storage rooms on the first floor and the attic. Plans are shown in Figure 6.

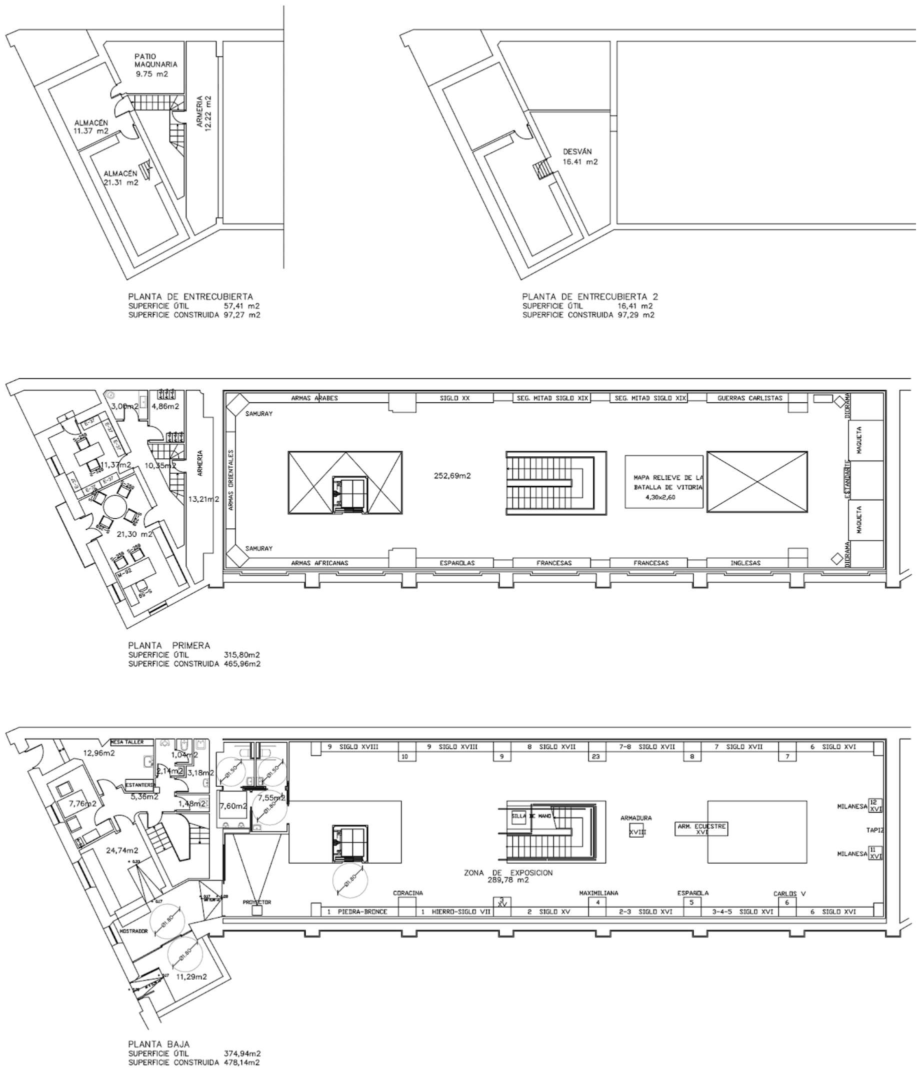


Figure 6. Plans of Alava Arms Museum.

The collection mainly consists of offensive and defensive weapons and related accoutrements dating from prehistory to the beginning of the 20th century, as well as various objects providing complementary information. It is laid out on two floors and is arranged chronologically. Although the collection has different types of artefacts, most of them are made of metal.

Figure 7. Photographs of Alava Arms Museum.

From the point of view of sensor nodes deployment, the following considerations regarding the museum and its collections should be borne in mind:

- The museum is a traditionally constructed building with stone and brick masonry walls.
- The museum has two interconnected open exhibition halls of 250 and 290 square metres, separated by a concrete waffle slab with exposed panels. Most artefacts are displayed in glass cases.
- Most of the artefacts in the museum's collection are made of metal.
- The climate in this area is not very harsh, so it is not an important condition to take into account. It is a transition zone between Oceanic and Mediterranean climates.

At first, the biggest problem in terms of connectivity will be the material of the artefacts, as metal prevents wireless data transmission. The most difficult challenge will be to study the location and installation of sensors and reception devices to overcome this problem.

For deliverable D1.4, the receiver sensitivity of Sigfox signal was estimated using the service maps of the company (see Figure 8). The estimated receiver sensitivity was around -104 dBm, so we predicted that Sigfox could provide low coverage at the museum.

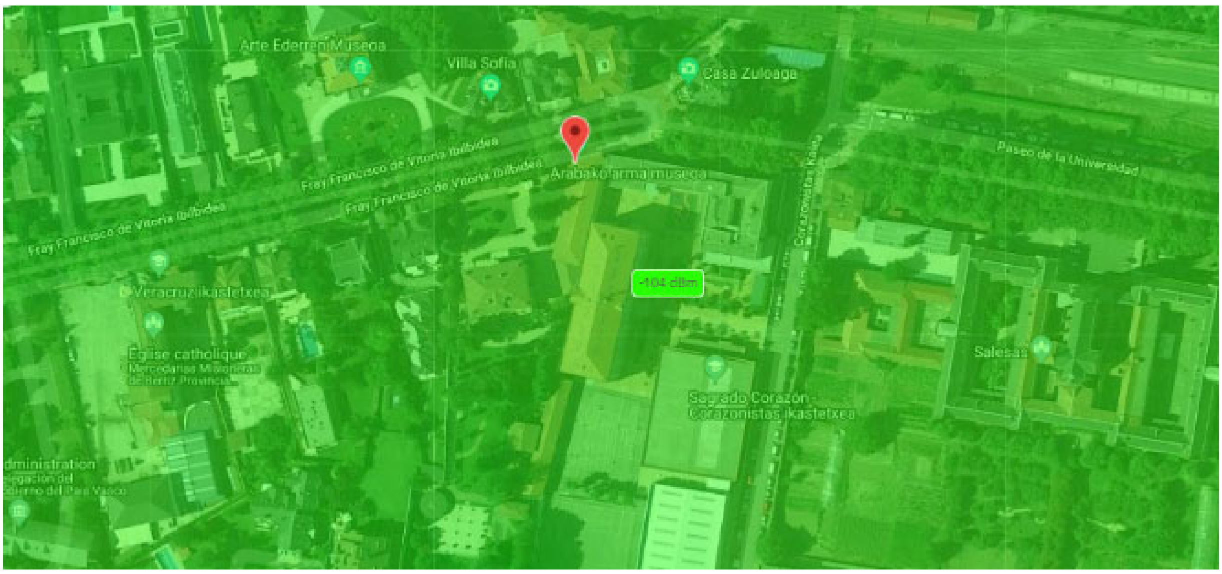


Figure 8. Sigfox coverage analysis and receiver sensitivity at Alava Arms Museum (DFA) in Alava.

All the estimations are available in Table 2 of D1.4, from which we extracted the specific information on the Alava Arms Museum, as can be seen in the following Table 2. The radio mapping will allow us to check the accuracy of this forecast and refine the estimations without carrying out field tests in-situ, helping in future deployment.

Table 2. Summary of characteristics of Alava Arms Museum as a CollectionCare demonstration site and a first approach to wireless technology requirements.

DEMONSTRATION SITE	ARTEFACTS TYPE	RESTRICTIONS			Sigfox (dBm)	LoRa	COMMENTS
		due to building conditions	due to climate	due to artefacts type			
Arms M (DFA)	metal	-	-	metal artefacts	-104	-	Open plan building simplifies complexity of a LoRa-based wireless deployment. Metallic objects can be problematic.

2.1.2 Radio mapping

Before starting the radio map per se, a central point in the building is used to perform a sweep of the RF spectrum to be used. The sweep consisted of listening for a time around 868 MHz band used by both Sigfox and LoRaWAN to make transmissions. Figure 9 shows a capture of the obtained waterfall. The image shows a clean radio electric space around the frequency of interest.

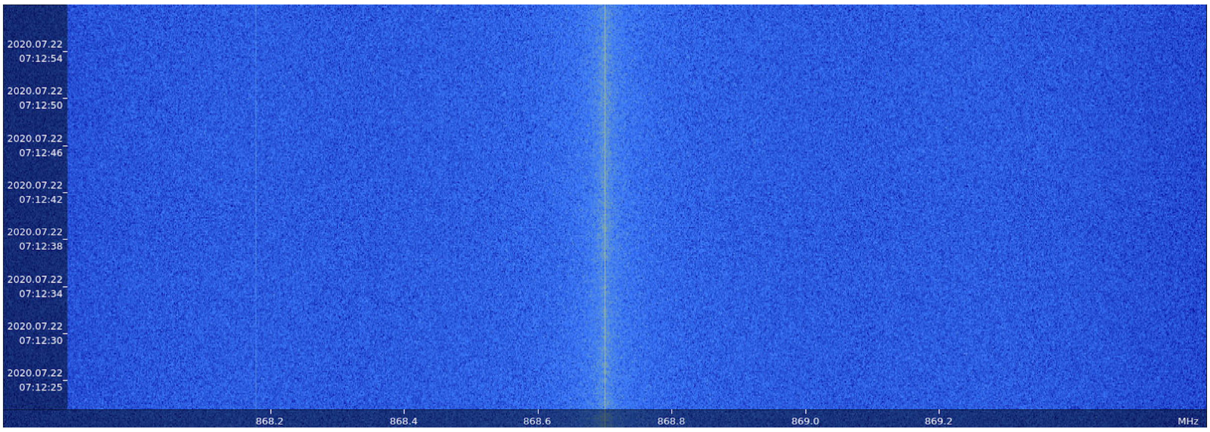


Figure 9. RF sweep waterfall obtained at the Alava Arms Museum.

The next step was the installation of the modified gateway shown in Figure 10, which imitates the behaviour of a LoRaWAN network.

An unexpected problem was the general availability of mains plugs suitable for the final installation of the gateway. Although the testing gateway is battery-powered, we decided to choose a location near available mains plugs. The location selected was the ground floor, near a corner in the main entrance of the museum (see the first plan in Annex I).

Based on our experience, this is not the best place for the gateway, but we were conditioned by the available installation resources. This should be taken into consideration in future deployments.

Figure 10. Test gateway utilized for radio mapping.

Once the gateway was set up, most available spaces of the museum were tested using the FTD to gather as much information about RF transmission in the whole building as feasible. Each point was tested both for Sigfox and LoRaWAN, as shown in Figure 11, with a difference of a few seconds.

Figure 11. FTD test in the Alava Arms Museum.

The measured values can be checked in the plans in Annex I.

For LoRaWAN, the whole building has excellent coverage, with signal levels ranging from -36 dBm to -75 dBm. The worst case was a storage room in the attic of the building, because there is a thick wall and a distance of two floors between the attic and the gateway.

For Sigfox, the measured signal levels range between -92 dBm and -112 dBm, the attic being the area best covered by this technology. Sigfox technology also seems feasible for a deployment in the museum, although near the limit, so predictions provided in D1.2 are adequate for this specific case.

2.1.3 Sensor nodes deployment

Five sensors were deployed in the Alava Arms Museum. The criteria to select where to put them was based on the requirements of the museum stakeholders, the selected artworks of interest, the positioning of sampling points defined by URO1 (protocol described in D4.9) and a representative set of points from the point of view of wireless transmission.

The nodes were placed on walls using double-sided reversible tape (3M command 17021P) or dropped near the piece or area of interest for exhibition displays and big artefacts. Figure 12 shows the aspect of the pieces comprising the sensor node, the double-sided tape and isopropyl alcohol to clean the surfaces where the nodes had to be attached.

Figure 12. Parts of the sensor node and wall attachment equipment.

Figure 13 is an example of a sensor installed in a reinforced concrete wall. This deployment is of interest to check the behaviour of the reversible adhesive stripes used to attach the device.

Figure 13. Sensor node attached to a reinforced concrete wall.

Figure 14 is an example of a sensor node dropped on a big artefact made mainly of steel, so it is especially interesting to test the behaviour of the wireless communications.

Figure 14. Artefact mainly composed of steel (left). Sensor installed in the artefact (right).

Figure 15 is an example of one sensor node installed inside a showcase side by side with objects of interest. In this particular case, the showcase is made of wood and glass, so the main interest here is to check the behaviour of the sensor inside the cabinet.

Figure 15. Sensor installed near a set of objects of interest inside a showcase.

The locations where the sensor nodes were placed are indicated in the plans in Annex II, where the locations of the selected artworks are also shown. Two sensors were installed on the ground floor, two on the first floor and one in a storage room in the attic.

2.1.4 Collected data overview

The sensor nodes were configured to collect and transmit temperature (T), relative humidity (RH), visible light (L) and ultraviolet radiation (UV) values at a sample interval of one hour.

This dataset is being gathered and stored in real time in the Amazon Dynamo databases system used in the CollectionCare cloud infrastructure. These databases also contain historical environmental information provided by the partner museums.

For illustrative purposes only, the following Figures 16-20, captured from the web interface of the system, represent the values of temperature, relative humidity, light and ultraviolet radiation collected between 24 July and 24 August by the sensor node devices S01-S05 installed in the Alava Arms Museum. As mentioned above, the locations of these sensor nodes are indicated on the plans in Annex II.

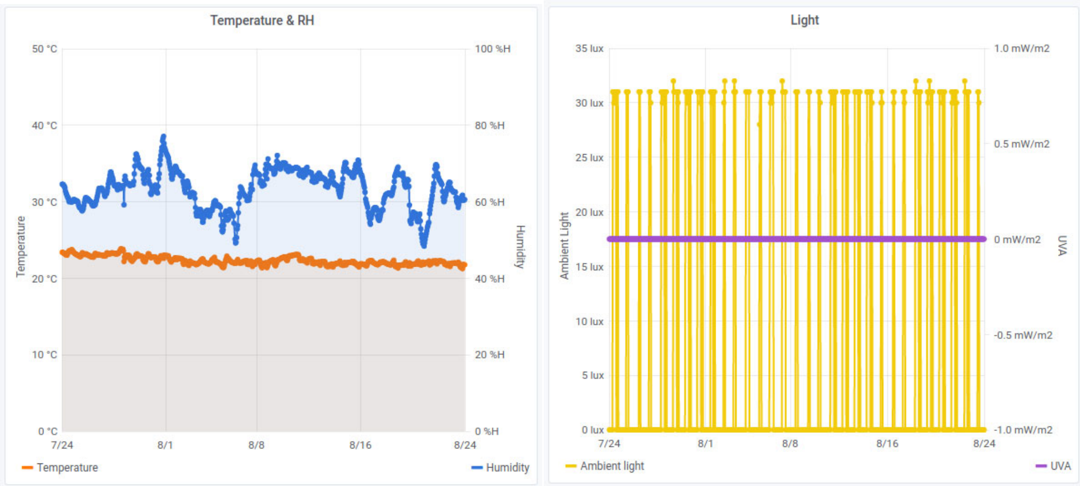


Figure 16. Alava Arms museum. Sensor node S01 (ground floor) T, RH, L, UV readings from 2020-07-24 to 2020-08-24.

Figure 17. Alava Arms Museum. Sensor node S02 (ground floor) T, RH, L, UV readings from 2020-07-24 to 2020-08-24.

Figure 18. Alava Arms Museum. Sensor node S03 (first floor) T, RH, L, UV readings from 2020-07-24 to 2020-08-24.

Figure 19. Alava Arms Museum. Sensor node S04 (first floor) T, RH, L, UV readings from 2020-07-24 to 2020-08-24.

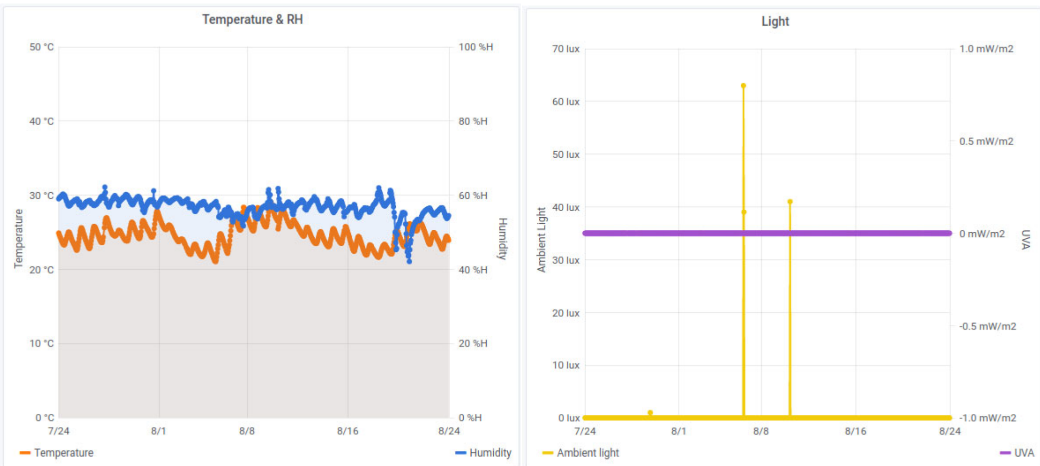


Figure 20. Alava Arms Museum. Sensor node S05 (attic) T, RH, L, UV readings form 2020-07-24 to 2020-08-24.

It is beyond the scope of this deliverable to assess the data collected from the point of view of the artworks preservation.

2.2 Alava Fine Arts Museum of Diputación Foral de Álava. Alava, Spain (DFA)

2.2.1 Building description

The Alava Fine Arts Museum is located in Vitoria (Spain). is a three-building complex: the historical Palace of Augustin Zulueta (a four-storey building constructed in 1912), an (adjoining) three-storey extension constructed in the 1960s and an annex where visitors can access the museum, which was built in 2001. In this latest renovation, the whole complex has been refurbished, architectural barriers have been eliminated and access improved with additional services for visitors.

Figure 21 shows the plan of the semi-basement floor where the connection between the three buildings can be seen. All the plans of the museum are in Annexes I and II.

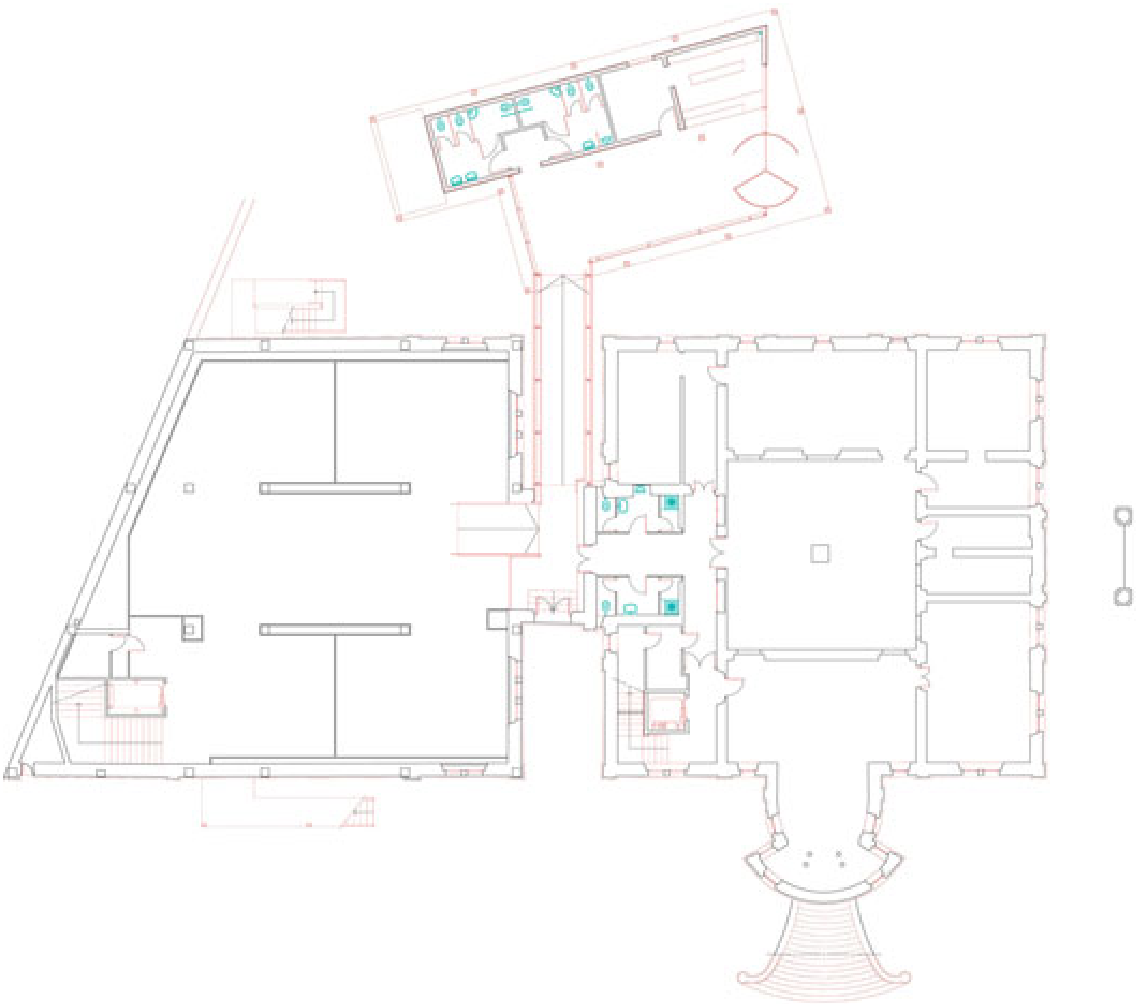


Figure 21. Plan of the Alava Fine Arts Museum semi-basement.

In terms of construction, the historical Palace consists of a masonry foundation covered with concrete, frame and beams of iron, sandstone façades, wooden floors and stairs and plaster ceilings. The three-storey extension (1960) adjoining the Palace consists of a foundation and structure made of reinforced concrete, a hipped slate roof, an enclosure based on a brick wall with outside stone cladding, marble and stone floors, a marble staircase and a false plaster ceiling.

The museum currently specialises in Basque art from dating to 1850–1950 and Spanish art from the 18th and 19th centuries. Most of the collection consists of paintings on canvas.

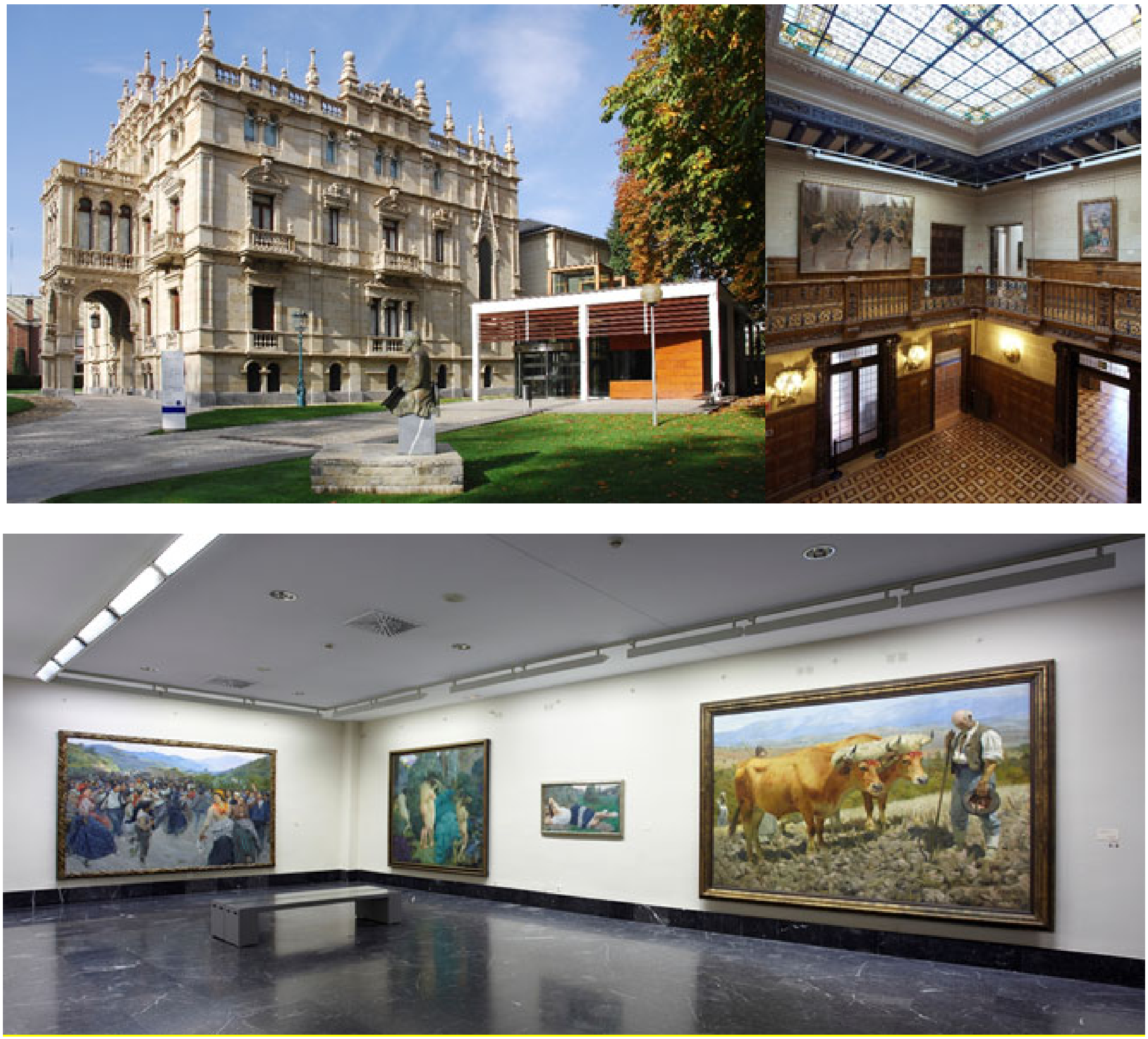


Figure 22. Photographs of the Alava Fine Arts Museum.

From the point of view of sensor nodes deployment, the following considerations regarding the museum and its collections should be borne in mind:

- The museum is made up of several connected buildings, each of which has different construction characteristics. The main building is an historical palace with thick masonry walls and the walls of the new building, which also contains exhibition halls, are made of reinforced concrete.
- The exhibition rooms have different sizes and conditions. The most complicated features that pose a challenge for wireless data transmission are the thick, compact walls of the semi-basement in the historical building and the reinforced concrete walls of the new building.
- Most of the artefacts in the museum's collection are paintings on canvas.
- The climate in this area is not very harsh, so it is not an important condition to take into account. It is a transition zone between Oceanic and Mediterranean climates.

As with the Alava Arms Museum, also in D1.4, the receiver sensitivity of Sigfox signal at the Alava Fine Arts Museum location was estimated using the company's service maps (see Figure 23). The estimated receiver sensitivity was around -108 dBm, so we predicted that Sigfox could provide low coverage at the museum.

Figure 23. Sigfox coverage analysis and receiver sensitivity at Alava Fine Arts Museum (DFA) in Alava.

All the estimations are available in Table 2 of D1.4, from which we extracted the specific information on the Alava Fine Arts Museum, as can be seen in the following Table 3.

Table 3. Summary of characteristics of Alava Fine Arts Museum as a CollectionCare demonstration sites and a first approach to wireless technology requirements.

DEMONSTRATION SITE	ARTEFACTS TYPE	RESTRICTIONS			Sigfox (dBm)	LoRa	COMMENTS
		due to building conditions	due to climate	due to artefacts type			
Fine Arts M (DFA)	paintings on canvas	historical build. (thick walls) / modern build. (reinforced concrete)	-	-	-108	+	Relatively open plan building simplifies LoRa-based deployment, but separate three-building complex could degrade the wireless performance.

2.2.2 Radio mapping

Following the same approach as for the Alava Arms Museum, a central point in the building was selected to perform a sweep of the RF spectrum to be used. As with the Alava Arms Museum, the spectrum was clean around the frequency of 868 MHz used by the wireless sensors.

The next step was installation of the LoRaWAN test gateway. In this case, the gateway was placed on the first floor in the palace. This location was selected because it is central enough and has availability of mains plugs.

Once the gateway was set up, most available spaces of the museum were tested using the FTD in order to collect as much information about RF transmission in the whole building as feasible. Each point was tested both for Sigfox and LoRaWAN, with a difference of a few seconds

The measured values can be checked in the plans in Annex I.

For LoRaWAN, the entire building has reasonable coverage with signal levels ranging from -56 dBm to -95 dBm. The worst cases were the farthest points in the new building on the ground floor and the semi-basement. These levels do not seem correlated with the distance so we speculate that the reason could be the reinforced concrete walls of this new building.

For Sigfox, the measured signal levels range from -81 dBm to -119 dBm, the North facade of the first floor being the best covered area. Sigfox technology would be problematic in most spaces of the building. In this case, predictions provided in D1.2 also seem suitable for this specific case.

2.2.3 Sensor nodes deployment

Ten sensors were deployed in the Alava Fine Arts Museum. The criteria to select where to put them was based on the requirements of the museum stakeholders, the selected artworks of interest, the positioning suggested by URO1 and a representative set of points from the point of view of wireless transmission.

All the sensor nodes were placed in walls using double-sided reversible tape. Figure 24 shows two examples of installed sensors.

Figure 24. installation of sensor nodes in the Alava Fine Arts Museum.

The locations where the sensor nodes were installed are indicated in the plans in Annex II, where the locations of the selected artworks are also shown. Four sensors were installed on the first floor, three on the ground floor and three in the semi-basement.

2.2.4 Collected data overview

As with the Alava Arms Museum, the sensors were configured to collect and transmit temperature (T), relative humidity (RH), visible light (L) and ultraviolet radiation (UV) values at a sample interval of one hour.

This data is being collected and stored in real time in the Amazon Dynamo databases system used in the CollectionCare cloud infrastructure. These databases also contain historical environmental information provided by the partner museums.

For illustrative purposes only, the following Figures 25-34 captured from the web interface of the system, represents the values of T, RH, L and UV collected between 24 July and 24 August by the sensor node devices S01-S10 installed in the Alava Fine Arts Museum. As mentioned above, the locations of these sensor nodes are indicated on the plans in Annex II.

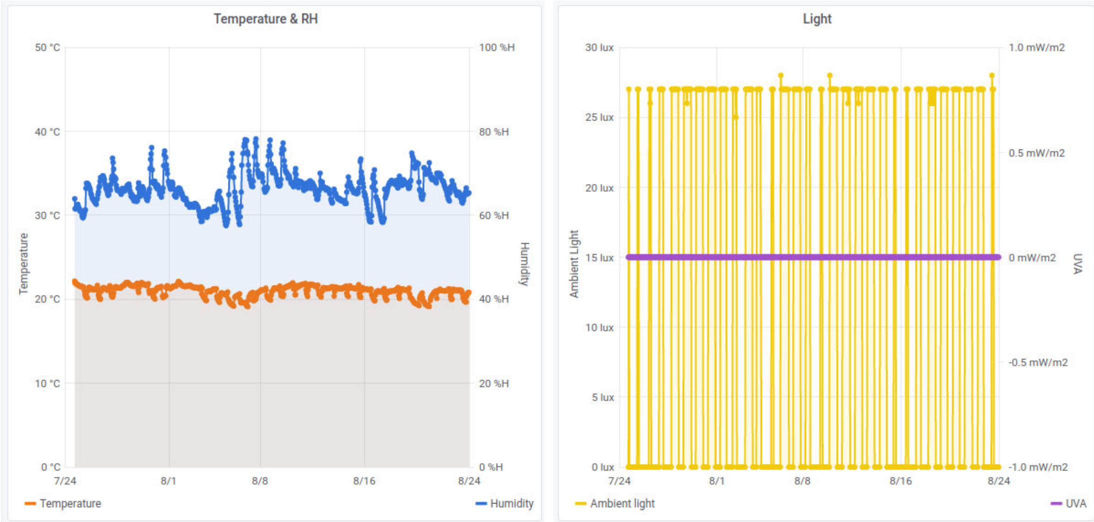


Figure 25. Alava Fine Arts Museum. Sensor node S01 (semi-basement) T, RH, L, UV readings from 2020-07-24 to 2020-08-24.

Figure 26. Alava Fine Arts Museum. Sensor node S02 (semi-basement) T, RH, L, UV readings from 2020-07-24 to 2020-08-24.

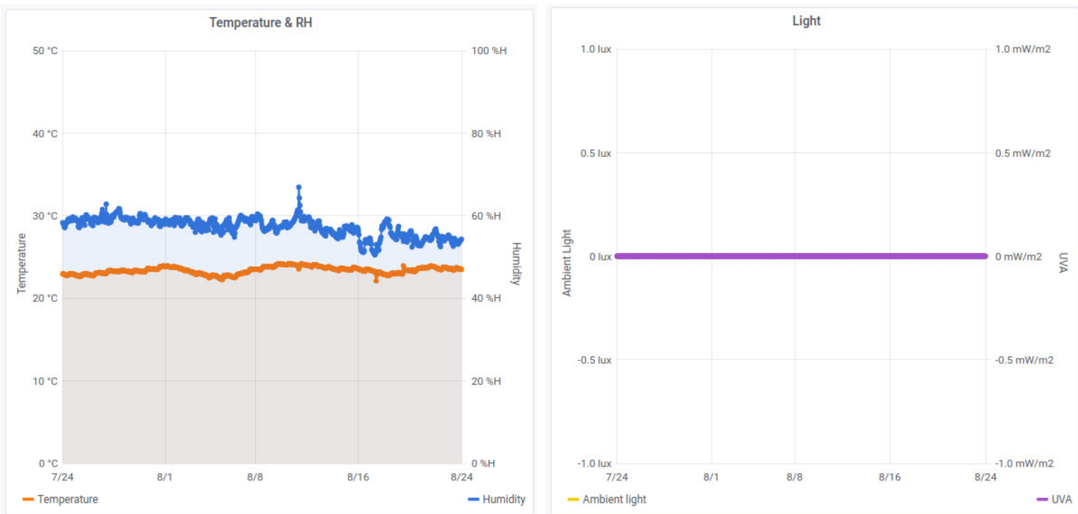


Figure 27. Alava Fine Arts Museum. Sensor node S03 (semi-basement) T, RH, L, UV readings from 2020-07-24 to 2020-08-24.

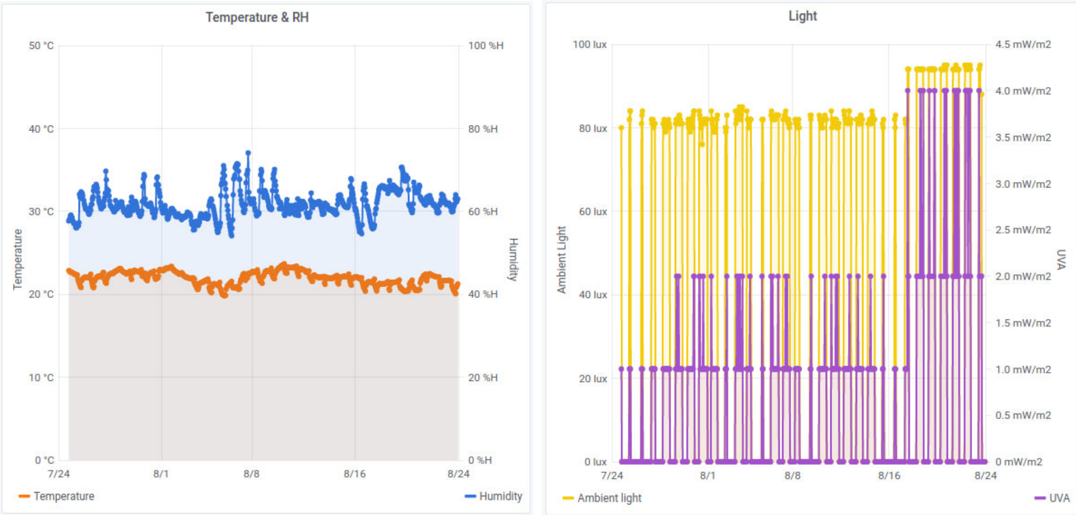


Figure 28. Alava Fine Arts Museum. Sensor node S04 (ground floor) T, RH, L, UV readings from 2020-07-24 to 2020-08-24.

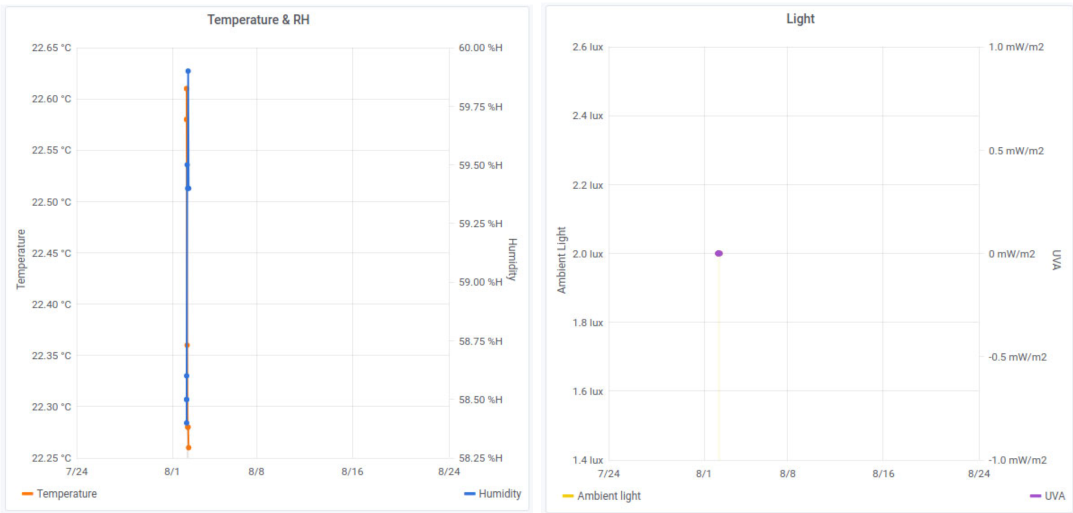


Figure 29. Alava Fine Arts Museum. Sensor node S05 (ground floor) T, RH, L, UV readings from 2020-07-24 to 2020-08-24.

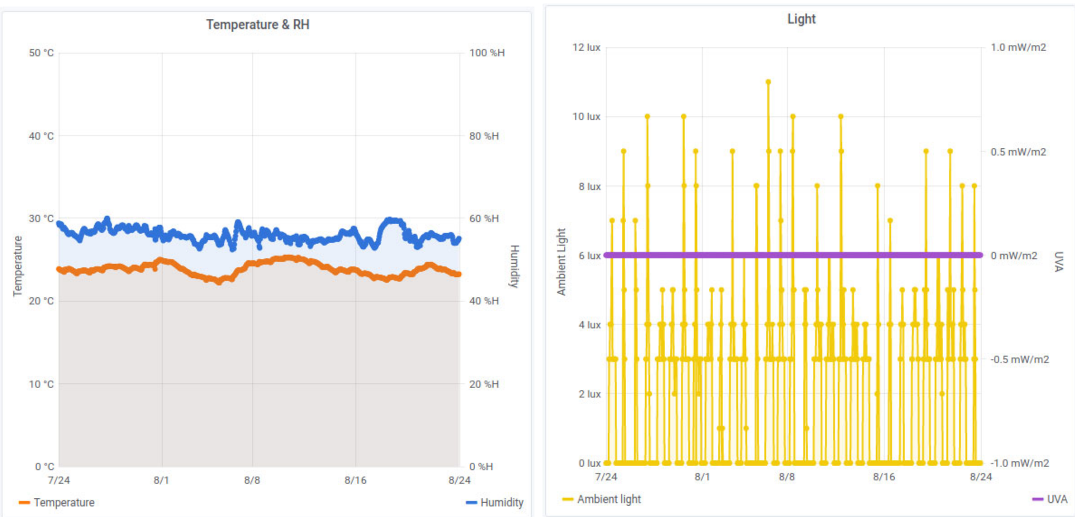


Figure 30. Alava Fine Arts Museum. Sensor node S06 (ground floor) T, RH, L, UV readings from 2020-07-24 to 2020-08-24.

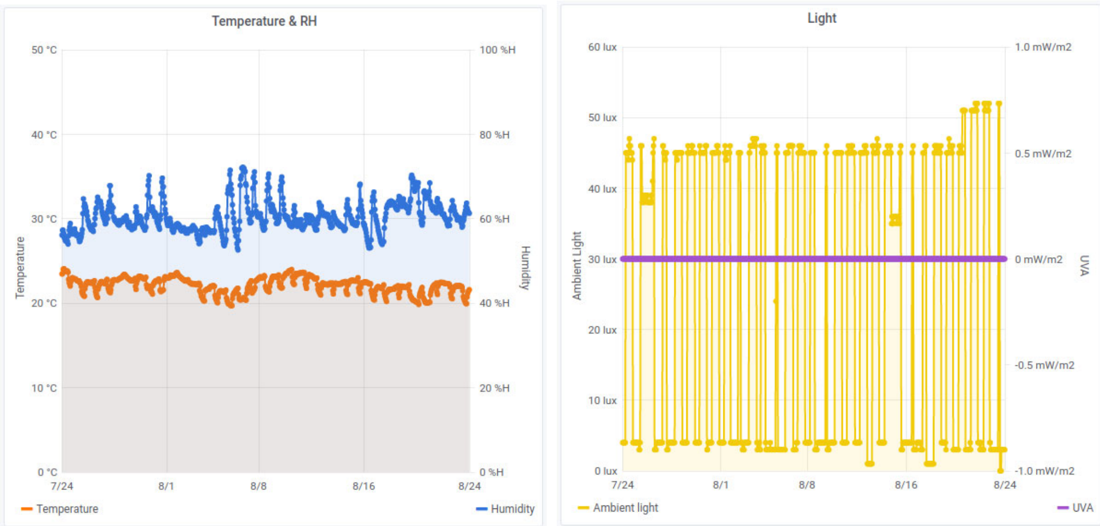


Figure 31. Alava Fine Arts Museum. Sensor node S07 (first floor) T, RH, L, UV readings from 2020-07-24 to 2020-08-24.

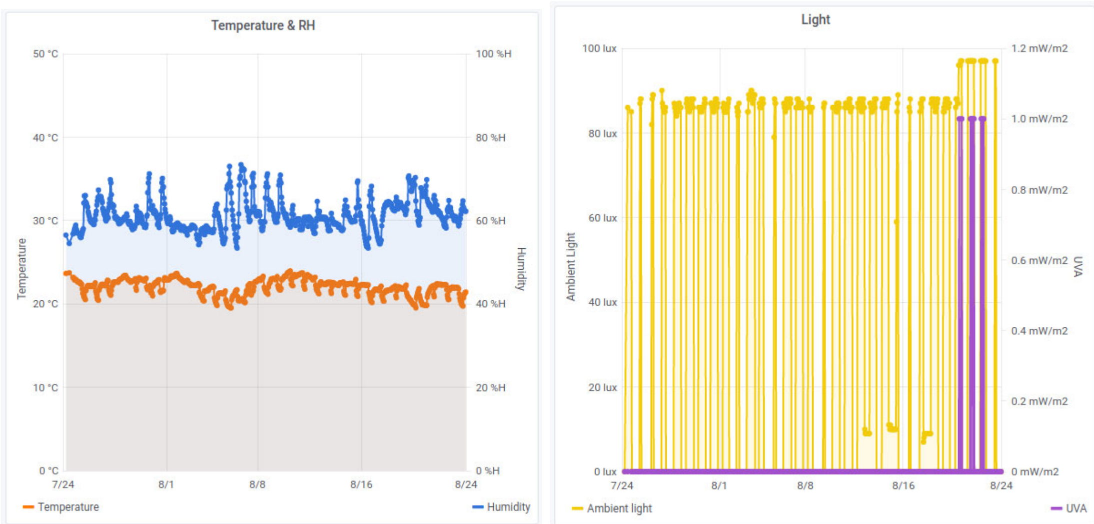
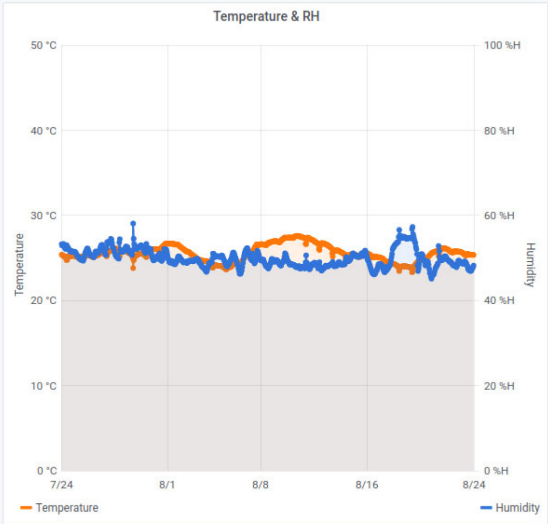


Figure 32. Alava Fine Arts Museum. Sensor node S08 (first floor) T, RH, L, UV readings from 2020-07-24 to 2020-08-24.

Figure 33. Alava Fine Arts Museum. Sensor node S09 (first floor) T, RH, L, UV readings from 2020-07-24 to 2020-08-24.



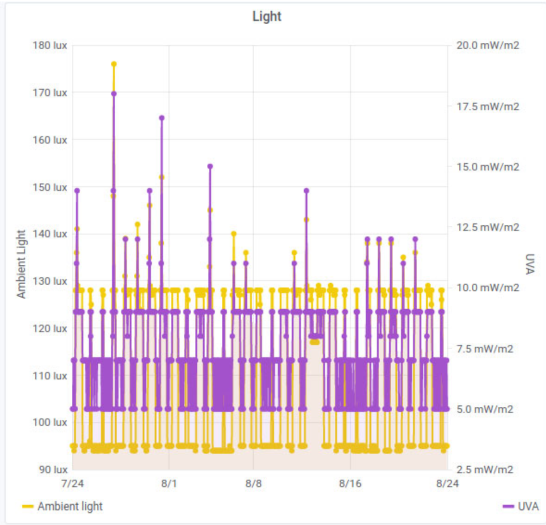


Figure 34. Alava Fine Arts Museum. Sensor node S10 (first floor) T, RH, L, UV readings from 2020-07-24 to 2020-08-24.

These figures show the data obtained from the ten sensor nodes installed in the museum, including the S05, which only transmitted data for a brief period of time.

As with the Alava Arms Museum, it is beyond the scope of this deliverable to analyse the collected data from the standpoint of the artworks preservation.

3. Evaluation of the "basic" sensor node based on the deployment in DFA museums

3.1 Wireless signal performance

In order to evaluate the wireless performance of the sensor nodes deployment, we analysed the Received Signal Strength Indicator (RSSI) and the Signal-to-noise (SNR) ratio for the Alava Arms Museum.

The Received Signal Strength Indicator (RSSI) is an estimated measure of power level that the gateway is receiving from the node. The result of the radio map is a departing reference estimation for the values obtained here, but it must be noted that the behaviour of the sensor nodes could be very different due to physical differences (placement, type of antenna, etc.) and protocol automatic configuration. In this case, LoRaWAN Adaptive Data Rate (ADR) is applied to automatically change parameters such as channel, spreading factor, etc.

The signal-to-noise ratio (SNR) compares the level of the signal of interest to the level of background noise. It is a ratio of signal power to the noise power commonly expressed in decibels, where a value greater than 0 dB indicates more signal than noise (ratio higher than 1:1). LoRa, the underlying radio of the LoRaWAN protocols, has the capability of working below the noise level, with values between -20 dB and +10 dB being the typical SNR values for LoRa-based networks.

Table 4 summarises the estimated level for RSSI for the FTD at the point where each sensor node was placed, and the RSSI and SNR values received by the gateway at a given instant of time. Also the current SF value is indicated.

Table 4. RSSI and SNR of the sensor nodes in the Alava Arms Museum.

Sensor ID	Radio map estimated (dBm)	RSSI (dBm)	SNR (dB)	Spreading factor (SF)
S01	-48	-74	10.5	7
S02	-49	-75	7.8	7
S03	-51	-83	7.3	7
S04	-51	-87	9.8	7
S05	-75	-85	8	7

The RSSI values of the sensor nodes are lower than those obtained with the FTD device. This is the expected behaviour, taking into consideration the type of antenna integrated in the "basic" sensor node and the SF utilised. Both RSSI and SNR values are excellent, the whole building being perfectly covered by the sensor nodes.

FTD measured values are well correlated with the signal levels obtained from the sensor nodes, so the radio mapping technique applied is valid in this type of deployments.

It is noteworthy that sensor S02, installed in a steel artefact, is performing correctly.

3.2 Data Extraction Rate of the deployment

Other important metrics for this solution are the Data Extraction Rate (DER), the Received Signal Strength Indicator (RSSI) and the Signal-to-Noise (SNR) ratio.

The Data Extraction Rate (DER) is the ratio between packets sent and received, expressed as a percentage. It is used in this type of test to denote the quality of the data communications.

$$DER\ (\%) = 100 \times \frac{packets\ received}{packets\ sent}$$

It is also key to clarify how data is transmitted in this particular LoRaWAN, as very different configurations are possible. We decided to use unconfirmed transmissions from the node to the gateway to keep energy requirement to a minimum. This design decision has the drawback that some transmission can be lost because there is no verification of successful delivery. To check how many transmissions have been lost, data packets include a sequence field mentioned in deliverable D4.3 that lets us know how many of them are dropped by simply following the sequence of records in the database.

Other factors will influence the DER, so Table 5 is provided to highlight the particular configuration used in the whole system. As commented in D4.3, determining where the data is lost is an open question, so it will be necessary to design a specific instrumentation system that allows us to keep record of data packages in each stage. This issue is beyond the scope at this stage of the project, but it is planned inside WP4 and in a future project.

Table 5. Stages of the data transmission.

STAGE	DESCRIPTION	UTILIZED CONFIGURATION
Sensor node to gateway	Wireless transmission of data between the sensor nodes and the gateways. Transmissions are affected by RF interferences and collisions of simultaneous transmissions.	LoRaWAN gateway with 8 channels and Adaptative Data Rate enabled. 868 MHz European band utilized and transmissions according regulations. Maximum power transmission 14 dBm. Payload of 9 bytes
Gateway packed forwarder	Wireless data received (packets) by the gateway is forwarder using Internet to a Network Server. Multiple gateways can send the same data to the network server which decides which data packet is dropped	Only one gateway (no redundancy). Semtech's standard packet forwarder was installed in the gateway and packets were submitted to Loriot's network server. Semtech's uses UDP datagram for transmissions, so there is not delivery warranty.
Internet connection	Gateways need a connection to Internet to communicate with the network server	4G mobile connection utilized using Thingsmobile worldwide SIM card service
Network server	Internet service where sensor nodes are registered. Data packets are received by the network server and redirected to and application service	Network service utilized in these tests has been Loriot
Application service	Finally, data is sent by the network server to a final consumer or "application"	The particular configuration has been a virtual machine running Influx's Timeseries data base and Grafana for visualization purposes only.

Table 6 summarises the DER of the sensor nodes deployed in the Alava Arms Museum considering the data collected from the 24th of July to the 24th of August, 2020. As shown in the table, the DER is higher than 99% for all the sensor nodes, which is an excellent outcome for this particular scenario. This result is better than that obtained in previous deployments at the Museu d'Informàtica in Valencia. As commented in D4.3, achieving 100% DER is unrealistic if a reasonable lifespan is to be achieved, and it is necessary to assume a certain data loss.

Table 6. DER (%) of the sensor nodes in the Alava Arms Museum.

SENSOR ID	TRANSMITTED PACKETS	RECEIVED PACKETS	DER (%)
S01	792	791	99.87
S02	792	790	99.74
S03	792	791	99.87
S04	792	792	100
S05	792	786	99.24

3.3 Measurement comparison

To evaluate the performance of the installed CollectionCare sensor nodes, the data collected by one of the museum's climate monitoring dataloggers (model Lascar Electronics EL-USB-2-LCD), taken as a reference, was compared with the data collected by a CollectionCare sensor. To perform this comparison, the CollectionCare S02 sensor installed in the Alava Arms Museum was chosen because it is installed in conditions very similar to those of the museum's dataloggers. Table 7 indicates the accuracy, measuring range and resolution of the datalogger and the S02 sensor according to the manufacturer's specifications.

Data of temperature (T, °C) and relative humidity (RH, %) recorded from the 24th of July to the 24th of August 2020, both days included, were used for this comparison. The museum's datalogger collects four records a day: at 5:00, 11:00, 17:00 and 23:00. The S02 sensor has a recording frequency of 1 hour, thus collecting 24 records a day. Therefore, the evaluation will be carried out by synchronising the common records and discarding the rest. In short, the number of records to be compared is 128 (four per day).

The comparison is made by subtracting the median difference between the two devices in order to have the S02 sensor node centred with respect to the reference one, the datalogger, simulating a subsequent calibration of the device. This way, it is easier to appreciate the difference in how they vary between each other.

The records differ from one sensor to another by approximately two minutes, a difference that we consider insignificant when making the comparison, assuming from now on that there is perfect synchronisation.

Table 7. Information on T and RH measurements collected with datalogger and S02 sensor from manufacturer datasheet.

	S02		Datalogger	
	T	RH	T	RH
Accuracy	±0.5°C, desirable 0.2°C	±2%	±0.55°C typical (5 to 60°C)	±2.25% typical 20 to 80 %
Measuring range	-20 to 60°C	5-95% -10°C to 50°C	-35 to 80°C	0 to 100%
Resolution	0.1°C	1 %	0.5°C	0.5 %

3.3.1 Temperature

The maximum temperature difference is 0.5 °C and the minimum is -0.4 °C. The distribution of the differences is shown in Figure 35.

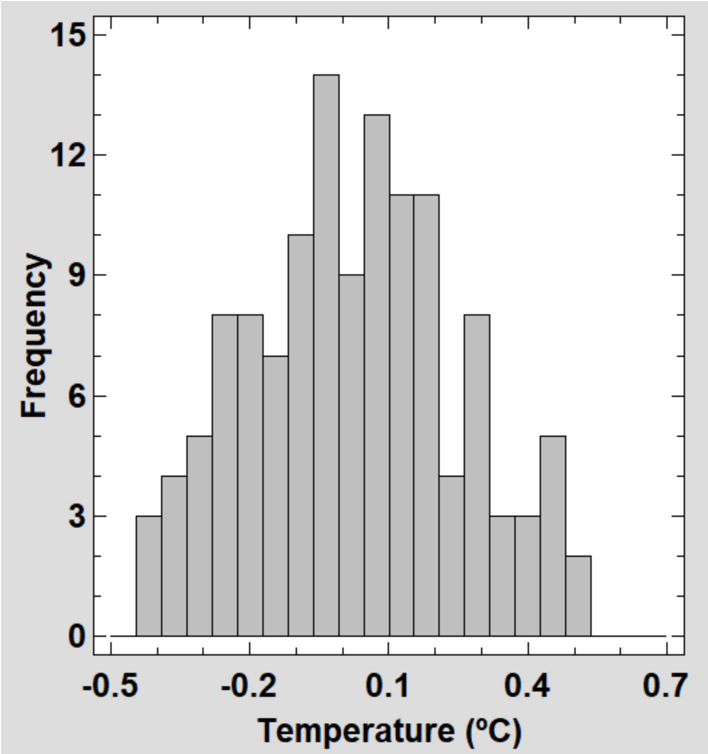


Figure 35. Histogram of the temperature differences between the datalogger and S02.

As can be seen from the histogram and the comparison in Figure 35, the variation between the two sensors is minimal. Much of the difference is due to the differences between the resolution of the two sensors, as can be seen in the evolution of the temperatures in Figure 36.

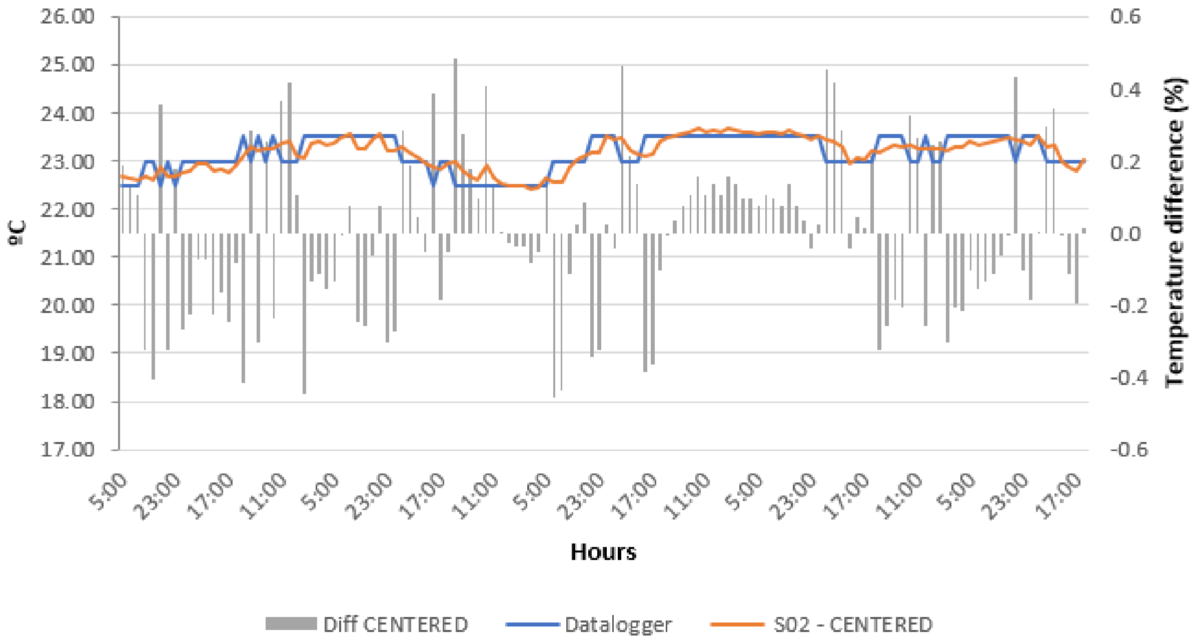


Figure 36. Temperature comparison between the datalogger and S02 after centring. The differences between both are quantified by the grey bar graph.

3.3.2 Relative humidity

The median of the relative humidity recorded by the S02 device is 0.85% lower than the [museum device]. The maximum difference in RH is 2.4% and the minimum is -3.1%. The distribution of the differences is shown in Figure 37.

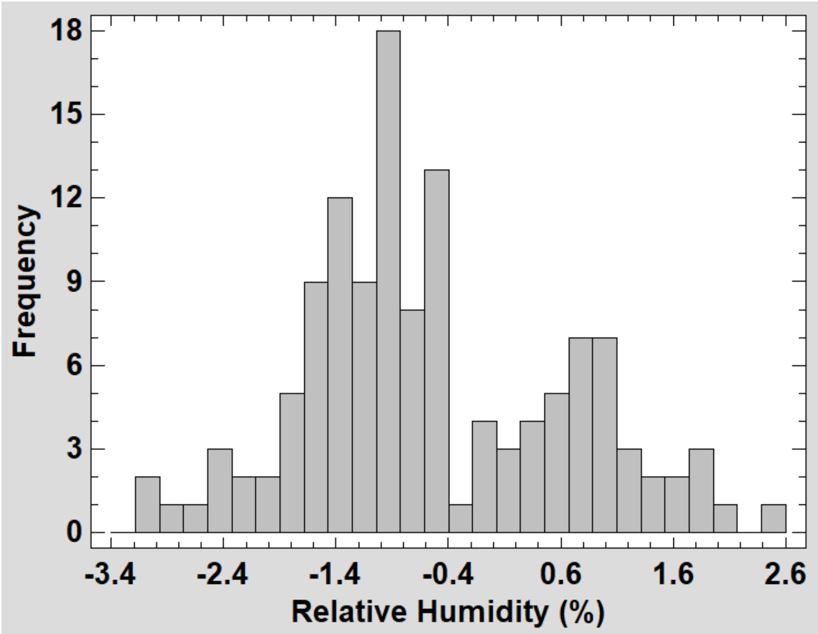


Figure 37. Histogram of the relative humidity differences between museum's datalogger and S02.

As can be seen in the histogram (Figure 37) and in the comparison between sensors once they are centred (Figure 38), the difference between the sensors is small (in most recordings there is no more than a 1% difference). The conditions of the installation and the datalogger do not allow for such a precise comparison as on previous occasions, but the great similarity between the records of the two sensors is easily appreciated.

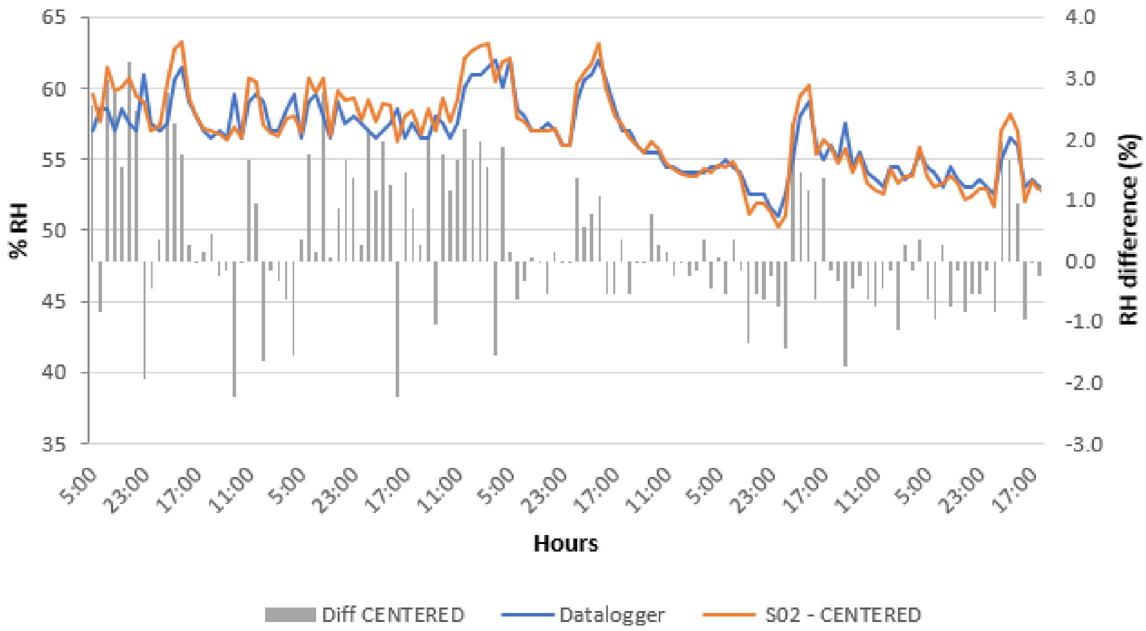


Figure 38. RH comparison between the datalogger and S02 after centring. The differences between both are quantified by the grey bar graph.

3.4 Energy requirements of the basic sensor node

One of the objectives of the CollectionCare sensor node is to achieve a lifespan of 10 years without battery replacement in order to provide a near maintenance-free experience. This is why the conception and design of the sensor are very oriented to full-fill, as shown in deliverable D4.3.

The firmware developed for deployment in the DFA's museums provides a convenient opportunity to quantise the expected life of displays based on a real deployment and measurements.

In this particular configuration, the parameters utilised are:

- LoRaWAN only mode for wireless communications.
- Spreading factor 12, bandwidth of 125 kbps and output power of -14 dBm for LoRa radio.
- One transmission of data per hour.
- One sample per hour of temperature (T) and relative humidity (RH).
- One sample per hour for light (L) and ultraviolet radiation (UV).
- Battery voltage of 3.6 volts.

Given this configuration, a detailed measurement of energy requirements of each state of the node has been carried out. Because of the limited availability of instrumentation, the states were divided into: stand-by mode, measurement of T and RH, measurement of L and UV, and data transmission.

Stand-by mode is the usual state that the node is most of the time, that is, doing nothing. It is critical to keep this to a minimum to save power, but it is difficult to achieve because some parts of the node are kept alive to allow periodic wake-ups.

The measurement of T and RH and the measurement of L and UV include the activation of the associated sensors, reading and calculations done by the embedded microcontroller. The electronic design of the sensor allows the sensors to be completely switched off, so they do not affect the stand-by mode.

Table 8 summarises the measurements obtained for the described states.

Table 8. Consumption measures obtained for the different states of the basic sensor node.

STATE	MEASURED VALUE	UNITS
Stand-by	12.7	μA
Temperature and humidity measurement	11.0	μWh
Light and UV radiation measurement	15.1	μWh
Wireless data transmission SF12BW125	50.8	μWh

Based on the values of Table 8 and the particular configuration used in the DFA's museums, the amount of daily energy can be calculated. These values are provided in Table 9 and represented graphically in the Figure 39.

Table 9. Estimated daily energy requirements of the sensor nodes installed in the DFA's museums.

STATE	ENERGY (mWh)
Stand-by	1.10
Temperature and humidity measurement	0.26
Light and UV radiation measurement	0.36
Wireless data transmission SF12BW125	1.22

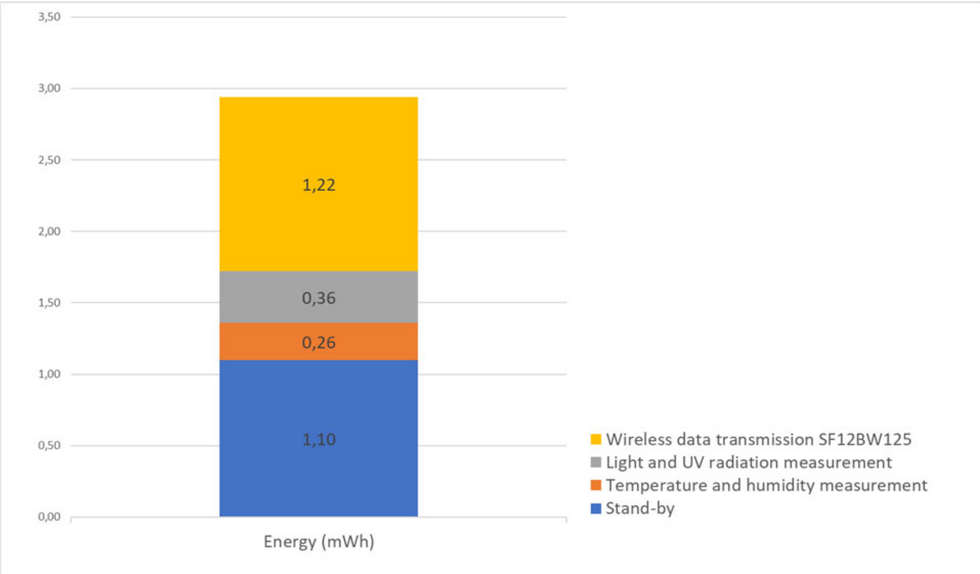


Figure 39. Estimated daily energy requirements of the sensor nodes installed in the DFA's museums.

Based on these values, the duration of a given type of battery can be calculated. For deployment in the DFA's museums, we used a Saft LS14500 primary cell. This is a Lithium thionyl-based cell with very high energy density and very low self-discharge, which is ideal for this type of application. Saft LS14500 has a nominal voltage of 3.6 V and a nominal energy of 9.36 Wh.

Given the nominal energy of the Saft LS14500 and estimating that 90% of this energy can be used, the number of days that the CollectionCare node can operate is calculated dividing the total energy by the required daily energy.

As a result, the estimated lifespan of the deployed sensor nodes is 7.8 years. The result is excellent for this first prototype and proves the validity of the design approach followed.

It is beyond the scope of this deliverable to discuss possible enhancements that are reserved for the design of the advanced sensor node.

4. Conclusions

The validation of the "basic" sensor node has made it possible to favourably evaluate four important features of the “basic” sensor node: its wireless behaviour, its communication with the cloud, its ability to collect environmental data and its energy consumption.

Regarding wireless behaviour, it was identified that before deployment of the sensor nodes, RF tests are needed to understand the coverage that the nodes will have in the different spaces. It was identified that the values measured with the FTDs tools are well correlated with the signal levels obtained from the sensor nodes, so the applied radio mapping technique is very valuable for a deployment procedure. For this reason, it was identified that it is convenient for the CollectionCare sensor nodes themselves to be able to collect the signal level, as users may not have FTD tools at their disposal. At the same time, it was noted that it is also very important to have precise plans of the museum spaces and knowledge of the construction materials in order to refine the prediction of propagation.

On the other hand, the communication between the sensor node and the cloud is stable. The packet loss rate was identified as being very low, so it is a great success for this initial prototype. However, it is due to the nature of the sensor node and its technology that this low percentage of data loss occurs.

As for the performance evaluation of the environmental data collection of the basic sensor nodes, a comparison was made between the data collected with the sensor nodes and with the museum's own dataloggers. The result was satisfactory, as only minimal variations between the data were identified. In the case of the relative humidity measurements, that's mainly due to differences between the resolution of the two sensors.

Another important parameter studied during this validation was the energy consumption of the "basic" sensor nodes. The battery lifespan calculations made have been very positive and encouraging, although there is room for improvement. It is important to refine the design of the electronics and firmware to optimise consumption in order to reach a 10-year lifetime.

Finally, it is important to note that these results obtained from the validation have enabled the identification of the next improvements to be made to the sensor node. This will allow us to begin the third methodological phase of the CollectionCare sensor node development (detail design), which aims to make all the improvements and optimise the design in order to obtain the "advanced" sensor node.

Annex I. Plans of radio mapping

Radio-mapping. Coverage in dBm

- LoRa coverage
- Sigfox coverage

Alava Arms Museum.
Diputación Foral de Álava

DFA 1.1

0 1 5 10m

COLLECTION CARE

Radio-mapping. Coverage in dBm

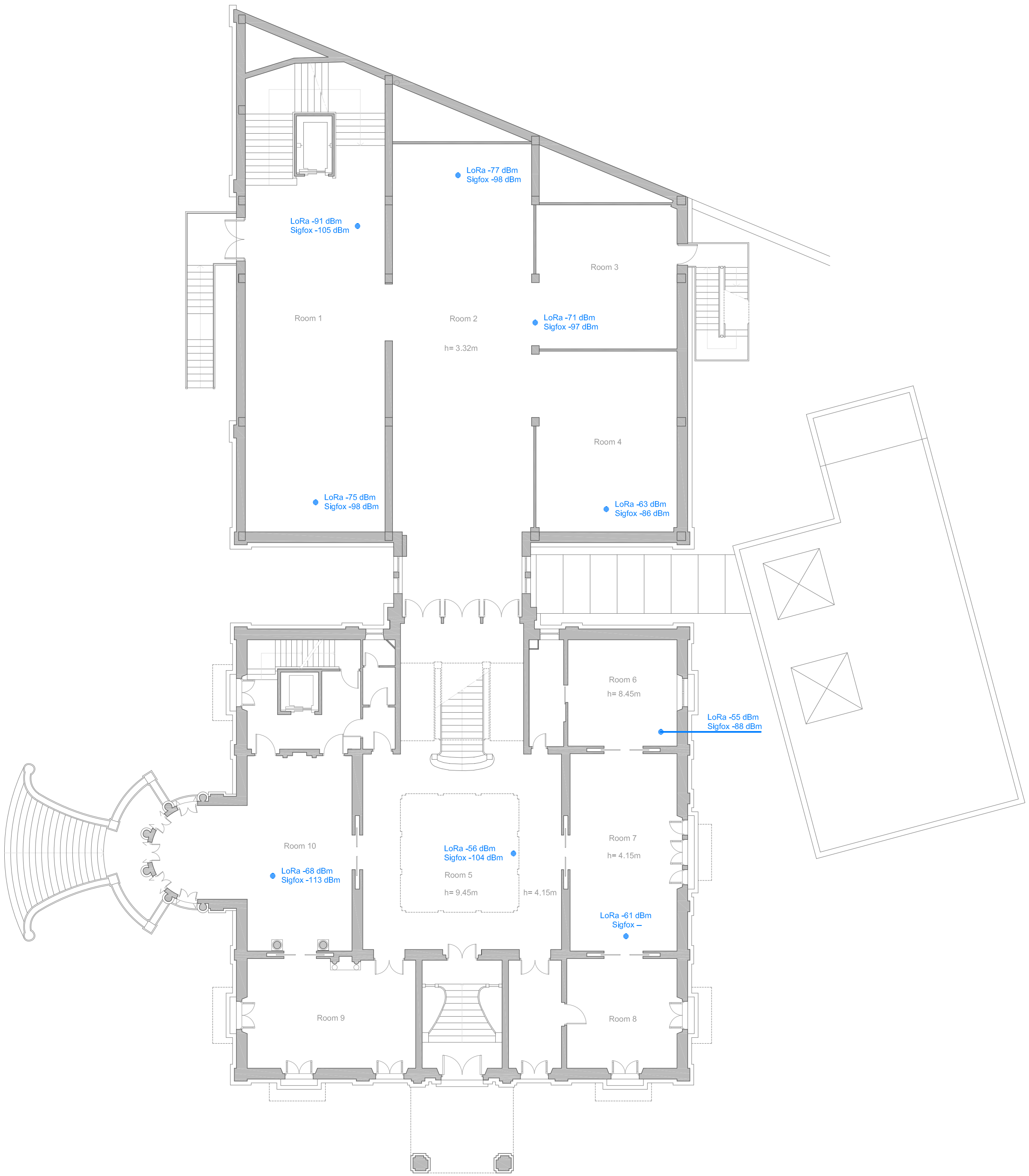
LoRa coverage

Sigfox coverage

Alava Fine Arts Museum.
Diputación Foral de Álava

Semi-basement

DFA 1.1



Radio-mapping. Coverage in dBm

- LoRa coverage
- Sigfox coverage

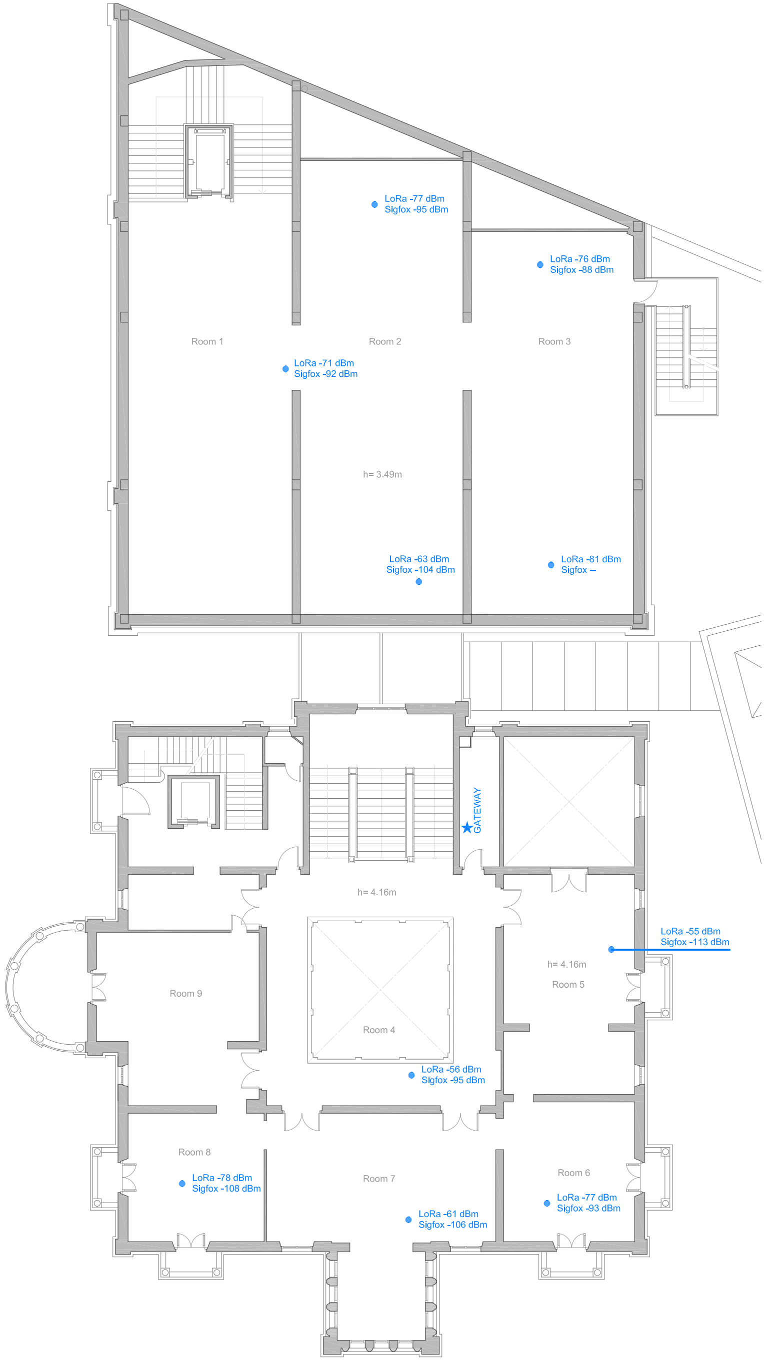
Alava Fine Arts Museum.
Diputación Foral de Álava

Ground Floor

DFA 1.2

0 1 5 10m

COLLECTION CARE



Radio-mapping. Coverage in dBm

- LoRa coverage
- Sigfox coverage

Alava Fine Arts Museum.
Diputación Foral de Álava

DFA 1.3

First Floor

COLL ECTION CARE

Annex II. Museum plans with the installed sensors' location

LEGEND

- painting on canvas (CODE X000)
- wooden object (CODE X000)
- metal object (CODE X000)
- paper object (CODE X000)
- museum datalogger (CODE d00)
- CC sensor (CODE S00)

CC Sensors S/N (height)

S01 - CC272011006 (h= 1.60m)

S02 - CC272011007 (h= 1.80m)

S03 - CC272011008 (h= 1.60m)

S04 - CC272011009 (h= 0.95m)

S05 - CC272011010 (h= 1.60m)

Alava Arms Museum.
Diputación Foral de Álava

DFA 1.1

0 1 5 10m

COLLECTION CARE

LEGEND

- painting on canvas (CODE X000)
- wooden object (CODE X000)
- metal object (CODE X000)
- paper object (CODE X000)
- museum datalogger (CODE d00)
- CC sensor (CODE S00)

CC Sensors S/N (height)

S01 - CC272011023 (h= 1.60 m)

S02 - CC272011020 (h= 1.60 m)

S03 - CC272011016 (h= 1.60 m)

Alava Fine Arts Museum.
Diputación Foral de Álava

Semi-basement

DFA 1.1

0 1 5 10m

COLL ECTION CARE

LEGEND

- painting on canvas (CODE X000)
- wooden object (CODE X000)
- metal object (CODE X000)
- paper object (CODE X000)
- museum datalogger (CODE d00)
- CC sensor (CODE S00)

CC Sensors S/N (height)

S04 - CC272011015 (h= 1.50 m)

S05 - CC272011013 (h= 1.60 m)

S06 - CC272011017 (h= 2.40 m)

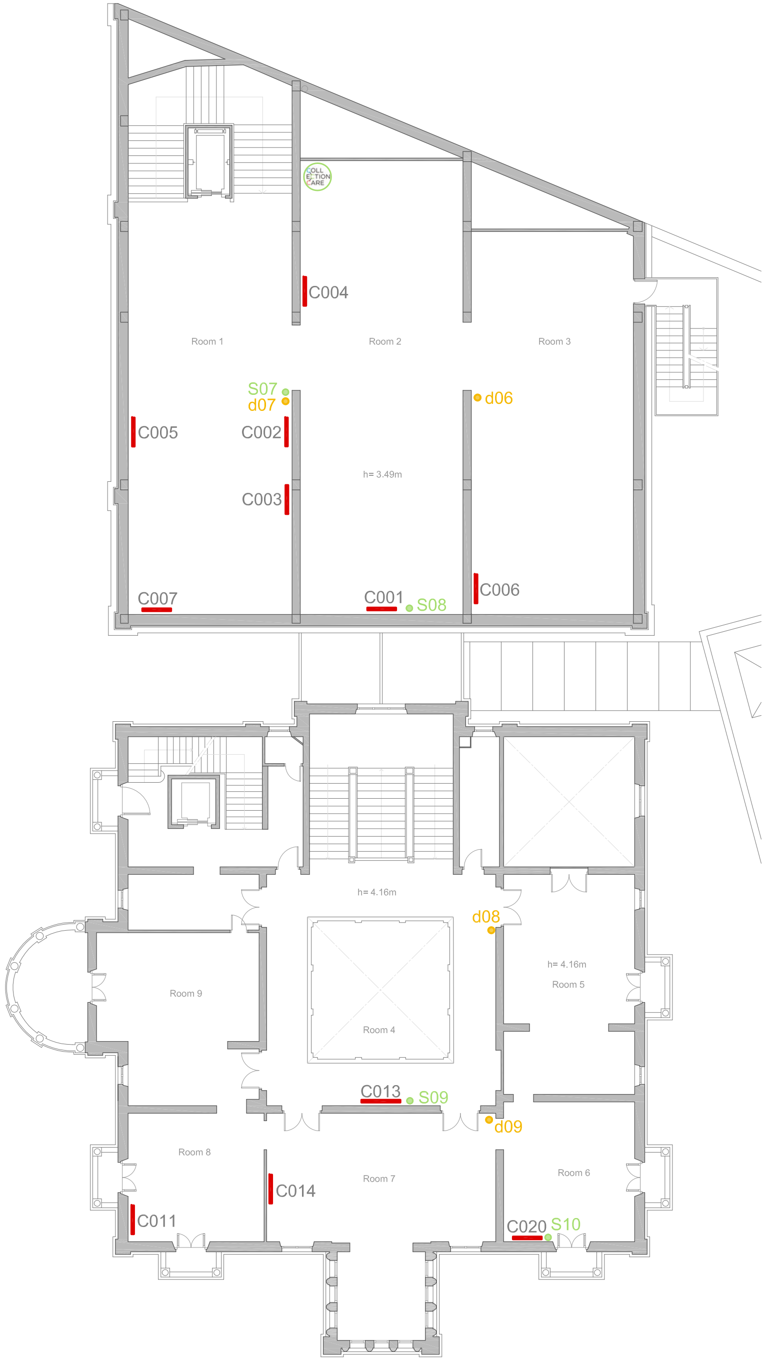
Alava Fine Arts Museum.
Diputación Foral de Álava

Ground Floor

N 0 1 5 10m

DFA 1.2

COLLECTION CARE



LEGEND

- painting on canvas (CODE X000)
- wooden object (CODE X000)
- metal object (CODE X000)
- paper object (CODE X000)
- museum datalogger (CODE d00)
- CC sensor (CODE S00)

CC Sensors S/N (height)

S07 - CC272011019 (h= 1.60 m)

S08 - CC272011021 (h= 1.40 m)

S09 - CC272011014 (h= 1.60 m)

S10 - CC272011018 (h= 1.60 m)

Alava Fine Arts Museum.
Diputación Foral de Álava

DFA 1.3

First Floor

0 1 5 10m

COLLECTION CARE