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Definition of protocols for deployment of sensor node devices II

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Abstract

Deliverable 4.9, entitled "Definition of protocols for deployment of sensor node devices II", within WP4 Task 4.2, is the second of three deliverables (D4.2, D4.9, D4.10).

D4.9 takes a step further from the previous D4.2 on the protocol for the deployment of sensor node devices. Specifically, this deliverable provides basic operational procedures to identify the number and location of sampling points in the spaces dedicated to exhibition or storage of cultural objects.

The protocol for the deployment of sensor node devices (number and position) is provided for two possible circumstances that can be experienced: i) artwork-related deployment, where there are as many sensors as the number of artefacts; ii) artwork-envelope-related deployment (Museum Scenario I and II), where a given number of sensor node devices is set.
Examples of the protocols are provided for two museums in the CollectionCare project: Alava Arms Museum (Spain) and Museo delle Origini (Italy).

The protocol for the deployment of sensor node devices in the artwork-envelope-related deployment (Museum Scenario I) was successfully applied in the real context of the Alava Arms Museum (AAM).

Abbreviations Acronyms Glossary

AC	Air Conditioning
AV	Available
CC	CollectionCare project
CR	Condition Report
AAM	Alava Arms Museum of Diputación Foral de Alava
DFA	Diputación Foral de Alava
DX.X	Deliverable number
MR	Mixing Ratio
MS	Museum Scenario
N/A	Not Available
RH	Relative Humidity
T	Air Temperature
TX.X	Task number
UPV	Universitat Politècnica de València
URO1	Sapienza Università di Roma
WP	Work Package

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1. Introduction

This document is part of the CollectionCare project, Horizon2020 Grant Agreement number 814624. The overall aim of the project is to develop an Innovative and affordable service for preventive conservation monitoring of individual cultural objects during display, storage, handling and transport.

The present document is Deliverable 4.9 (D4.9), headed "Definition of protocols for deployment of sensor node devices II" with the deadline in month 19 (September 30th, 2020) from the start date of the project. Deliverable 4.9 has been drawn up as part of Task 4.2 (T4.2) designated "Characterize/parameterize the installation of the sensing node inside the exhibition space", within Work Package 4 (WP4) named "Design of the Wireless sensing system".

The objective of T4.2 is the definition of operative procedures on the deployment of sensor node devices in spaces dedicated to exhibition or storage of artworks. The devices are designed to monitor ambient indoor climate variables (mainly temperature and relative humidity) that may have direct influence on the deterioration mechanisms of cultural objects. The task is described in Annex 1 (part A) of Grant Agreement n. 814624.

T4.2 has been structured in three phases, as reported in the Gantt Chart (Figure 1). Each of them is documented in the corresponding deliverables that describe the progress made in each phase.

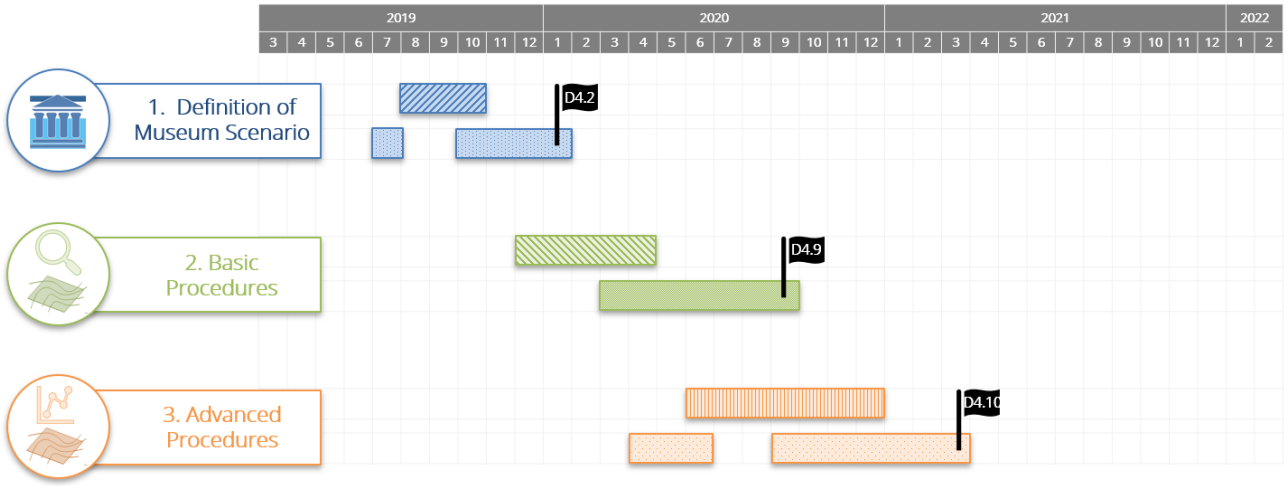

Figure 1. Gantt chart of the main activities scheduled within Task 4.2 (T4.2) as documented in Deliverables D4.2, D4.9 and D4.10

1.1 From D4.2 to D4.9

D4.2 focused on how to define the Museum Scenarios related to recurrent contexts of the indoor climate and the identification of basic and advanced procedures (Figure 2).
Figure 3 shows the activities performed in the first seven months documented in the associated Deliverable D4.2.

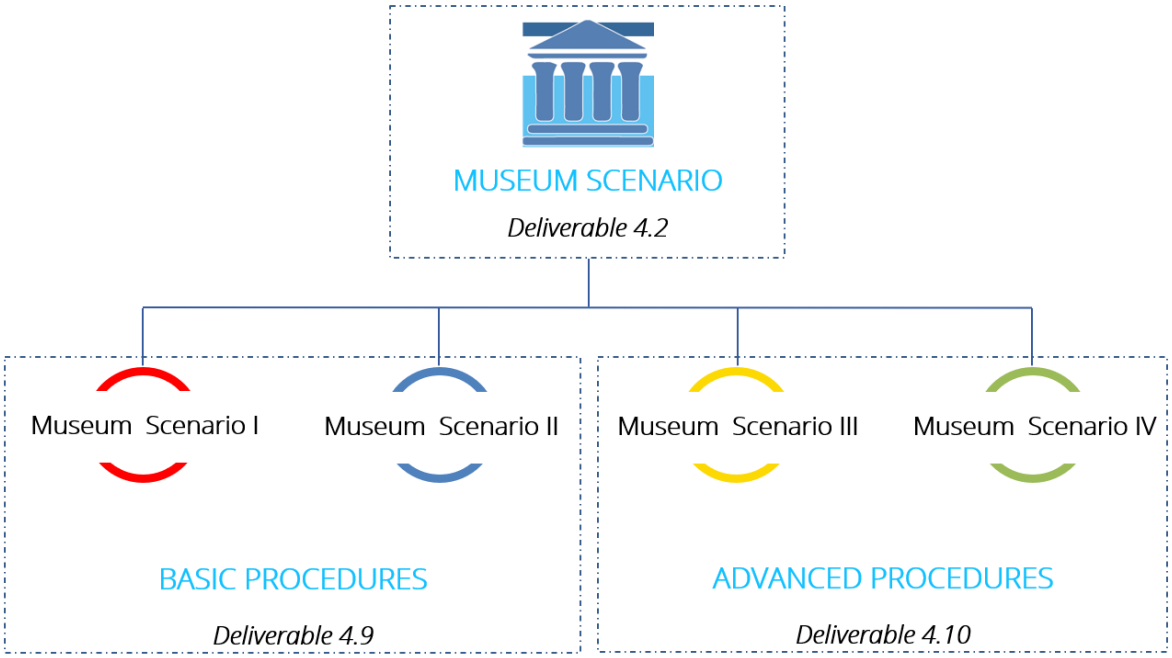

Figure 2. The main phases of task T4.2 of operative procedures on the deployment of sensor node devices

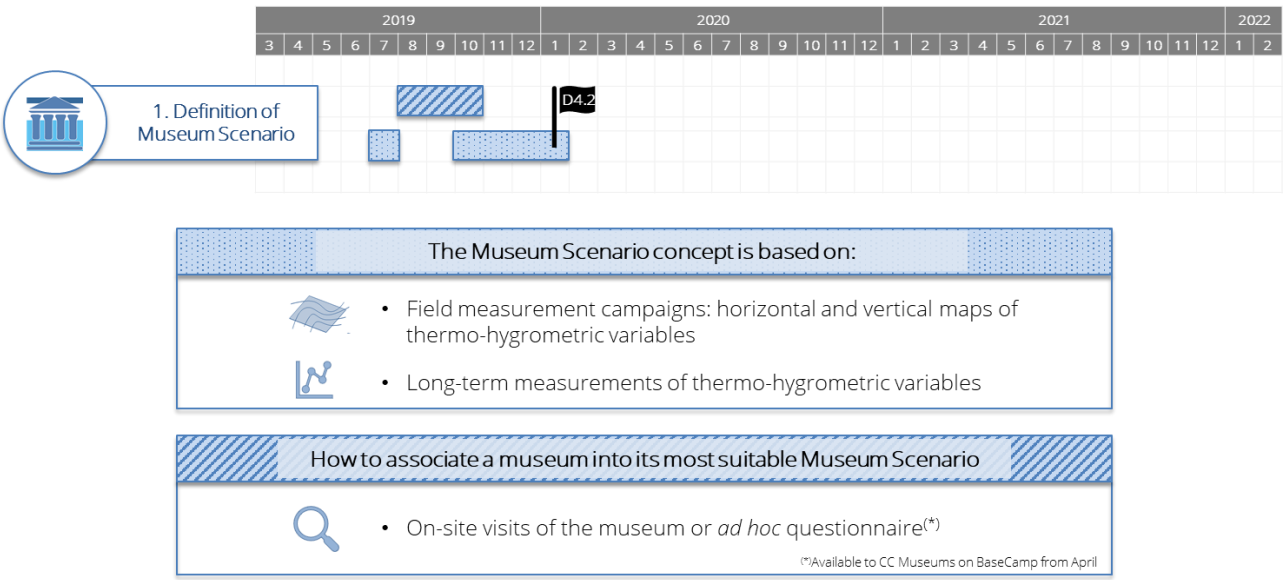

Figure 3. *Activities performed in the first phase of Task 4.2 (T4.2) and documented in D4.2*

The starting point of the proposed approach on the deployment of sensor node devices in small-to-medium sized museums was the definition of four possible Museum Scenarios, based on the feasibility of conducting field measurement campaigns and the availability of historical data, at least of temperature and relative humidity (Table 1).

Table 1 The Museum Scenario schema (N/A= Not Available, AV= available)

MUSEUM SCENARIO	THERMO-HYGROMETER FIELD CAMPAIGNS	TIME SERIES OF INDOOR CLIMATE OBSERVATIONS
I	No	N/A
II	Yes	N/A
III	No	AV
IV	Yes	AV

The second step was to classify the museum into its corresponding most suitable Museum Scenario. This classification is based on the recognition of general background information on the building and the collection (S1), and the environment (S2) where the cultural objects are preserved.

The classification can be derived by the team responsible for indoor climate monitoring through on-site visits to the museum and/or gathered through an *ad hoc* questionnaire survey developed by URO1 with UPV. The questionnaire, which is designed to be filled by the museum's curator together with the professional conservators, is structured into four main sections, as reported in Figure 4.

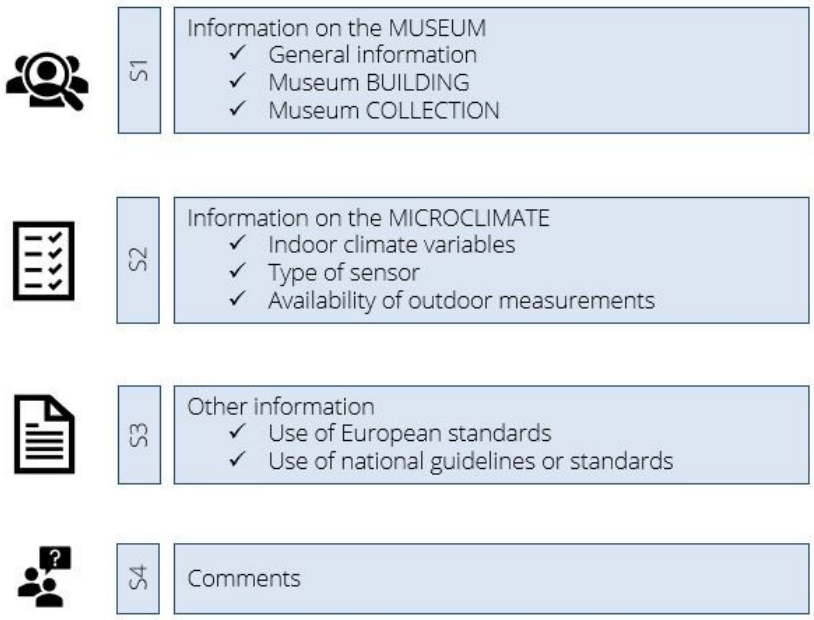

Figure 4. Structure of the questionnaire developed by URO1 with UPV and described in D4.2

A preliminary classification of CollectionCare museums associated with the corresponding Museum Scenario is depicted in Figure 5. This assessment was based on all background information gathered from the questionnaire.

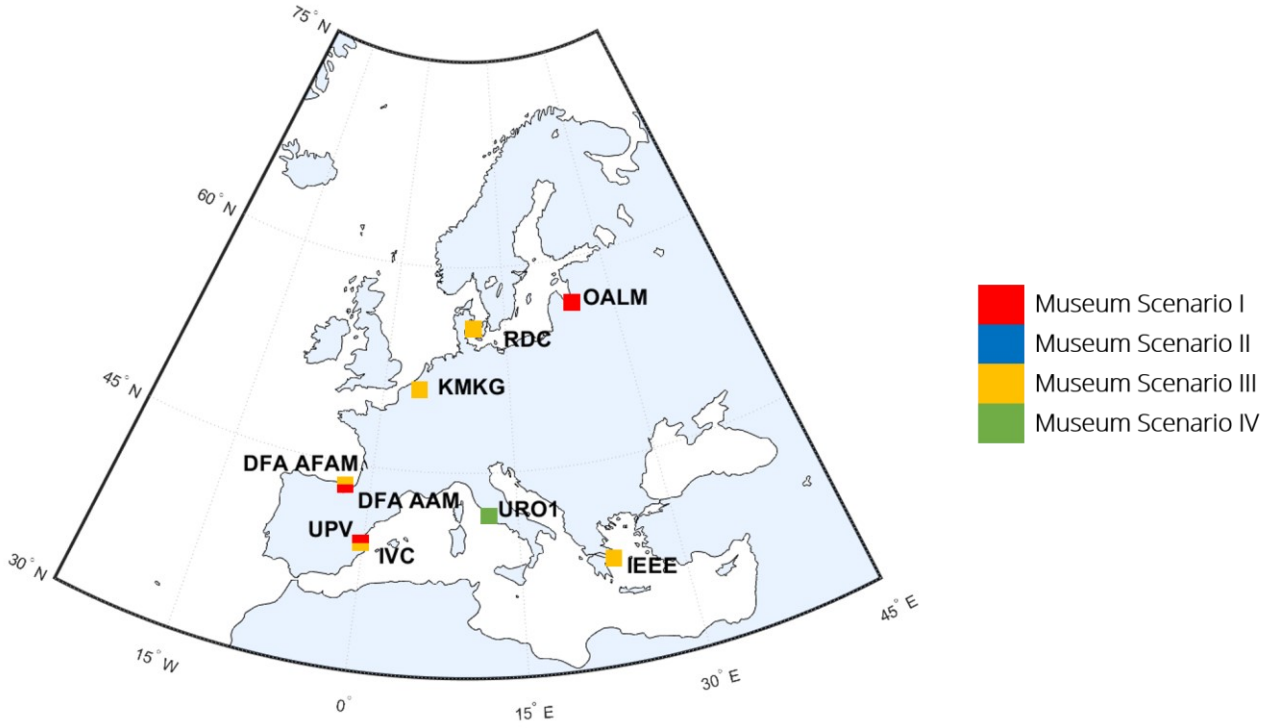

Figure 5. Geo-localisation of the different Museum Scenarios related to the CollectionCare museums

D4.9 takes a step further from the previous D4.2. Specifically, this deliverable provides:

- advisable practices to take into consideration in all museum scenarios before planning a monitoring of indoor climate;
- a specific procedure (named as Basic Procedures) for Museum Scenario I and II.

The activities of the second phase are shown in the Gantt Chart (Figure 6) and documented in D4.9.

D4.9 will be disseminated at a public level.

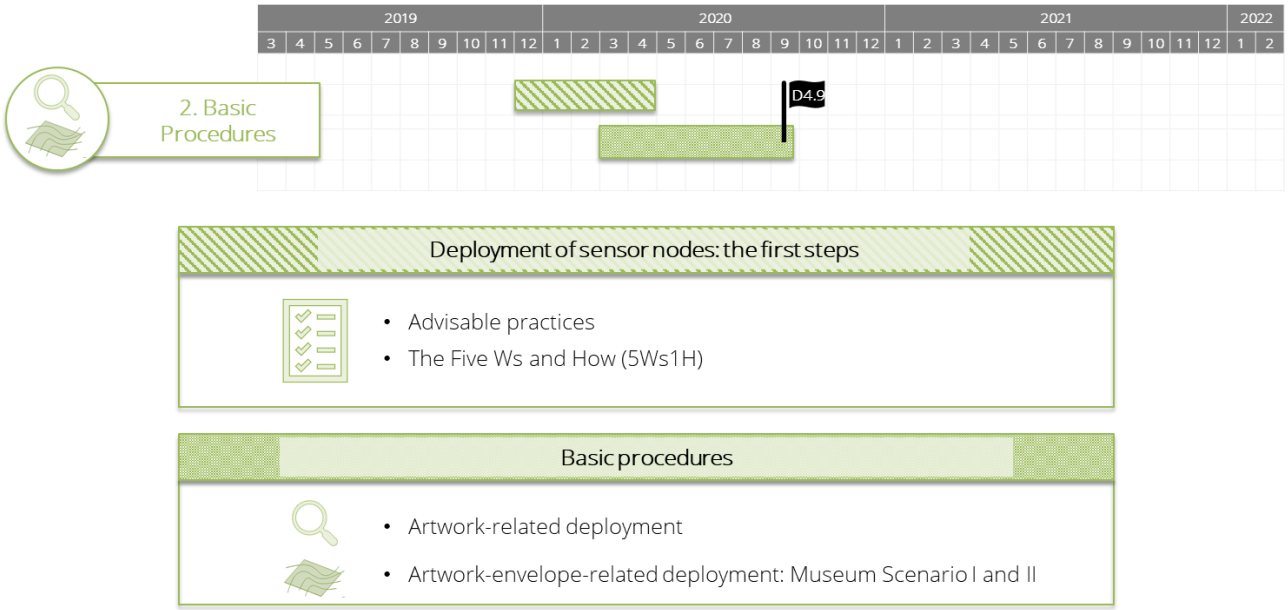

Figure 6. Activities performed in the second phase of Task 4.2 (T4.2) and documented in D4.9

2. Deployment of sensor node devices: first steps

This section is dedicated to the first steps that can be followed for an appropriate deployment of sensor node devices when indoor climate monitoring is planned.

2.1 Advisable practices

The following advisable practices should always be considered when a monitoring campaign is designed (Camuffo, 2019). In fact, whatever its objectives, all of them focus on the knowledge of the indoor climate, assessment of the climate-induced degradation phenomena and improvement of the environmental conditions in the framework of preventive conservation.

In order to define a proper number and location of sampling points to accurately record the indoor climate data, the knowledge of specific features of the building envelope helps to identify the most relevant areas where to install or not to install the sensor node devices.

Specifically, by using the plan of the museum it is possible to understand:

- orientation of the main axis of the building (north, east, south and west);
- position of the exhibition rooms with respect to outdoors (internal or external rooms);
- location of the windows to identify natural light source and ventilation;
- location of the artificial light sources, (diffuse light, spot-light, incandescent lamps, LEDs);
- location of the climate control systems (e.g. radiator, fan coils, HVAC system, de/humidification system, etc.), to study their potential impact on the variability of indoor climate.

It is also advisable to draw on the plan of the museum the location of:

- selected artworks;
- critical zones, if any (too hot, too humid, water infiltration, mould colonisation, etc.);
- indoor climate instruments, if any;
- showcases and their features (sealed, not-sealed, etc., if open for cleaning).

This approach allows to contextualise information on the museum gathered from the questionnaire (see D4.2).

In addition, as a rule of thumb, the sensor node devices must be deployed to avoid the influence of unwanted sources, such as air flows or solar radiation, heating/cooling or humidity control systems, and distance from doors and windows, as they might not be representative of the real situation (Sturaro, et al., 2003). However, if one of the objectives of the indoor climate monitoring is focused on formulating possible causes behind the degradation mechanisms due to the above disturbances, indoor climate measurements should be also taken at these sampling points. Furthermore, sensor node devices should be as least visible as possible to minimise the visual impact and reduce the risk of theft or damage along the visitors' passageways (Peralta, de Brito, Gouveia, de Sousa, & Alves, 2010).

Another aspect of the deployment of the sensor node devices to be considered is evaluation of the indoor signal propagation of wireless sensing systems due to different infrastructures of museums.

These and other possible more desired requirements should be discussed and agreed with the museum's manager together with the professional conservators.

Table 2 provides a list of advisable and not advisable practices that should be taken into account in the operational procedure of positioning sensor node devices.

Table 2 Summary of advisable and not advisable practices

Advisable	Not Advisable
Finalise the purpose of the indoor climate monitoring	Start an indoor climate monitoring without a clear purpose
Define the appropriate climate variables to record in relation with the material of the preserved artworks	Collect arbitrary climate variables without any relation with the material of preserved artworks
Choose sensors with accuracy complying with limits recommended by the European standards EN 15758 (2010) and EN 16242 (2012)	Choose sensors with poor features (e.g. high uncertainty), not calibrated and with low performance
Carry out the calibration of sensors with a reference instrument or compare all sensors among them before starting a monitoring campaign, in order to guarantee the comparability and reliability of recorded data	Use sensors with different performance and inconsistent time response in order to avoid misleading interpretation of recorded data
Exposure the sensor node devices to sampling points representative of real conditions	Deploy sensor node devices close to disturbing climate factors, or local constraints or obstacles
Evaluate indoor signal propagation of wireless sensing system	Deploy sensor node devices close to heavy masonries, underground rooms, etc. without first checking the correct data transmission in that area
Reduce the visual impact	Deploy sensor node devices along the visitors' passageways

2.2 The Five Ws and How (5Ws1H)

To collect data necessary to pinpoint and clarify the problem and how to deal with it, we apply hereinafter the methodology designated the Five Ws and How (5Ws1H), widely used in journalism, research and police investigations. 5Ws1H stands for What, Why, When, Where, and Who (the five W questions) and How many (the one H question).

The rationale behind the 5Ws1H approach is that it can help to obtain a 360° view of the issue of the deployment of sensor node devices and to sketch out the protocol for the location of the sampling points. This kind of approach can be strategic both for the monitoring of environment conditions surrounding the climate-sensitive artefacts and for the representativeness of the real environmental conditions of a specific site.

The 5Ws1H questions (Figure 7) are explained as follows:

- 1W - Why: Why is there a need for indoor climate monitoring? The answer aims to identify the triggers which lead us to require the indoor climate monitoring for the conservation risk assessment of the individual artwork and/or the whole collection.
- 2W - What: What are the indoor climate variables to be monitored? The answer should help select the most relevant indoor climate variables that better match the scopes of the indoor climate monitoring (e.g. temperature, relative humidity, light, air pollutants, etc.).
- 3W - Where: Where does the indoor climate monitoring take place? The answer should help identify the site where the indoor climate monitoring is planned (e.g. exhibition space, storage, handling, transport, etc.).

- 4W - When: When does the indoor climate monitoring start and how long for? The answer should help to plan the timing of the monitoring period in terms of duration and the sampling interval. The answer might also depend on which standards or guidelines are considered in the assessment of the climate-induced conservation risks. One calendar year or its multiples is more advisable in the case of organic and hygroscopic materials, as well as a sampling frequency of at least 1 hour.
- 5W - Who: Who is responsible for designing and conducting the indoor climate monitoring campaigns? The answer should help identify the people involved in contributing to the issue.
- 1H - How many: How many sensor node devices can be employed for indoor climate monitoring? The answer should help to find a compromise among the number of sensors needed and/or available, the environmental representativeness and the conservation requirements of the museums.

Figure 7. The 5Ws1H roadmap for the deployment of sensor node devices

3. Deployment of sensor node devices: basic procedures

The main objective in the CollectionCare project is the conservation risk assessment of individual artworks. Therefore, the configuration of the positioning of sensor node devices depends on the number of available sensor node devices. For that purpose, we have considered two possible circumstances:

1. There are as many sensors as the number of artefacts, thus the configuration will be named as artwork-related deployment.
2. A given number of sensor node devices is set, due to limited budgets for the monitoring campaigns or for other management or decision-making reasons, thus the configuration will be designated artwork-envelope-related deployment. In this case, the distribution of the sensor node devices is done in order to guarantee the representativeness in time and space of the whole environment surrounding individual artworks.

The protocol for the deployment of sensor node devices (number and position) in the first circumstance should be based on the conservation conditions of the artworks selected by conservators and reported in the Condition Reports (CRs). The protocol of the second circumstance still takes into account the conservation conditions of the artworks, along with additional general aspects of the whole exhibition space of the museum associated with its corresponding Museum Scenario.

The flow chart for the deployment of sensor node devices is schematised in Figure 8.

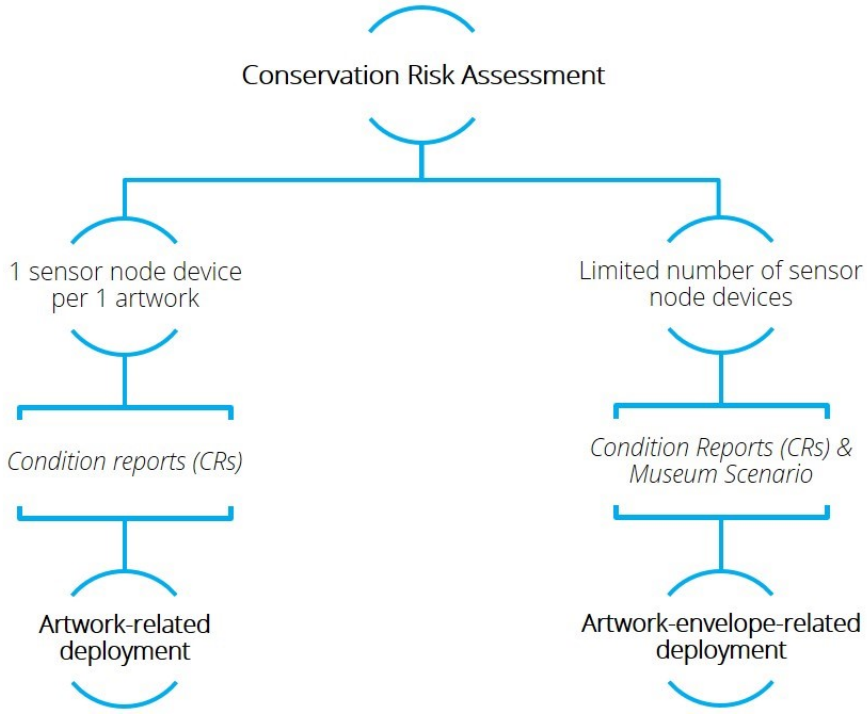

Figure 8. Flow chart of the deployment of sensor node devices

Examples of the protocol for the artwork-related and artwork-envelope-related deployments are provided for the following demonstration sites:

- Alava Arms Museum (AAM) – Diputación Foral de Alava, Spain;
- Museo delle Origini – Polo Museale of Sapienza University of Rome, Italy.

3.1 Protocol for artwork-related deployment

In the case of the artwork-related deployment, there are as many sensor node devices as the number of artworks. The number of artworks to monitor depends on: i) the evaluation made by the conservators who can select the climate-sensitive artworks, those most damaged or both; ii) the location where the artwork is exhibited; iii) the interest of the museum, collector or owner of the collection. This procedure is also highly advisable when the artwork is moved from a museum to another one, as it provides continuous control of the climate conditions it experiences, defining its own climate fingerprint.

For the conservation risk assessment of individual artworks, sensor node devices should be placed near the artwork or attached to it through compatible and reversible supports (as already discussed in the confidential Deliverable 4.1, D4.1).

Artworks displayed close to each other or in small rooms or in climatised showcases could experience the same hygrothermal conditions. This can be strategic when a sensor device associated with an artwork does not take measurements or provides anomalous data (e.g. after losing calibration, bad maintenance) or it damages or data transmission fails. Consequently, data collected by other closer sensors can be representative of the climate surrounding that artwork.

Otherwise, if the budget of the museum to purchase devices and to assure their maintenance and calibration is limited, it is advisable to follow the procedures developed for the artwork-envelope-related deployment according to the Museum Scenario associated with the museum of interest (as explained in 3.2 Protocols for artwork-envelope-related deployment).

Demonstration site 1: Diputación Foral de Álava (DFA) – Alava Arms Museum (AAM)

The Alava Arms Museum (AAM) – Diputación Foral de Alava (DFA) is one of the museums involved in the CollectionCare project. A picture of the exhibition space is shown in Figure 9.

General information about AAM can be found in D4.2. The building plan is courtesy of the Alava Arms Museum and edited in the current version by Andrea Peiró Vitoria (UPV).

Eighteen artworks were selected by conservators and reported in the Condition Reports (CRs) documented in the confidential Deliverable D1.3 of the CollectionCare project.

Figure 9. Exhibition space at the ground floor of the Alava Arms Museum (AAM) – Diputación Foral de Álava (DFA) - picture courtesy of DFA team

Figure 10 shows the list of answers to 5Ws1H that allows to sketch out the key issues necessary to deploy the sensor node devices.

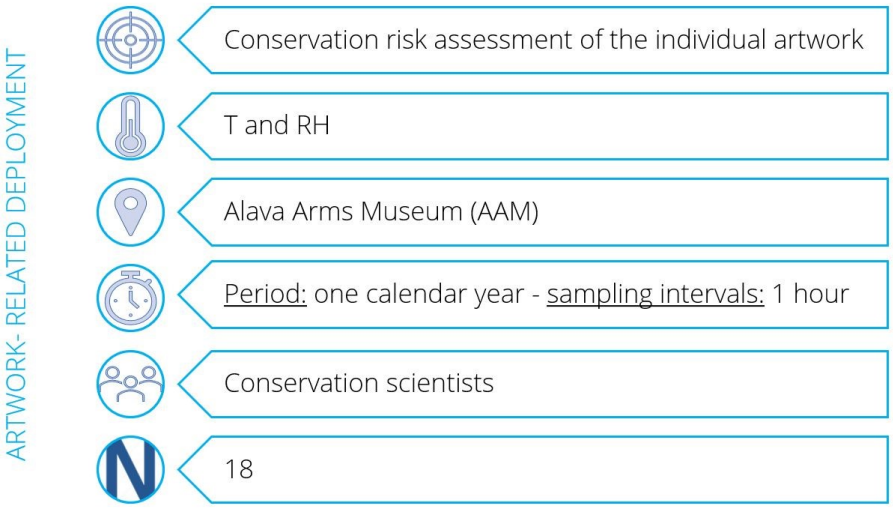

Figure 10. Answers to the 5Ws1H for artwork-related deployment in Alava Arms Museum (AAM)

In the example in Figure 11, artworks are coded by an alphanumeric code (the first letter 'D' identifies the museum as reported in D1.3) and coloured according to three of the four material typologies (wooden, metal and paper objects). Most objects are exhibited inside showcases. There are as many sensor node devices as artworks (N=18), therefore each sensor node device (green dot) is placed near each selected artwork and coded by the same alphanumeric code, by replacing the first letter with "S" (Sensor).

*Figure 11. Alava Arms Museum (AAM): Identification of the eighteen sampling points in the plan where fixed sensor node devices (CC sensor, green dots) can be deployed according to the **artwork-related deployment**. Objects are coloured in accordance with the main material typology as reported in the legend, whereas showcases are marked in yellow. The alphanumeric code of the sensor is not displayed for better readability*

Demonstration site 2: Polo Museale of Sapienza University of Rome (URO1) – Museo delle Origini

The Museo delle Origini – *Polo Museale* of Sapienza University of Rome is one of the museums involved in the CollectionCare project.

General information can be found in D4.2. Figure 12 shows the exhibition space of the museum. This museum is also chosen as another example of the application of the artwork-related deployment protocol. Eleven artworks located in the two exhibition rooms were selected by the conservator according to the protocol described in D1.3 of the CollectionCare project.

Figure 12. Exhibition spaces of the Museo delle Origini – Polo Museale of Sapienza University of Rome

Figure 13 shows the answers to 5Ws1H that allow us to sketch out the key issues necessary to deploy the sensor node devices.

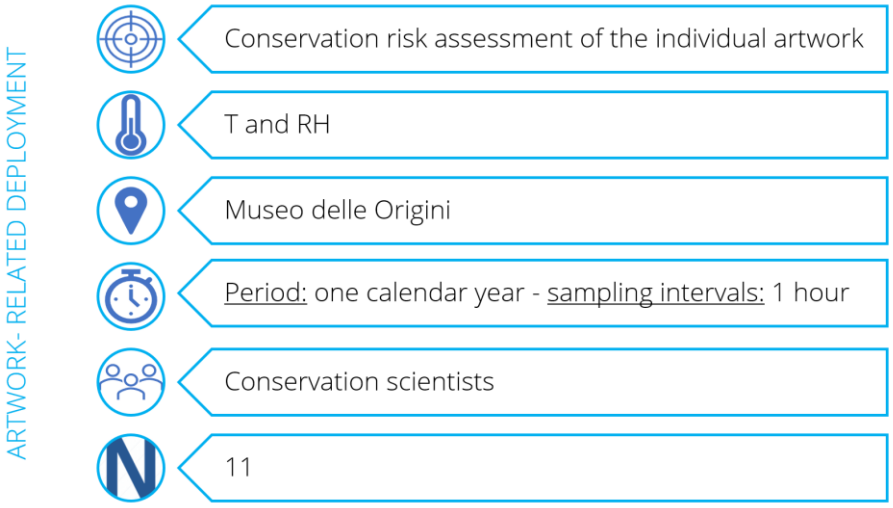

Figure 13. Exhibition spaces of the Museo delle Origini – Polo Museale of Sapienza University of Rome

Figure 14 shows the plan of the building, provided by Dr Cecilia Conati, the Director of Museo delle Origini, and edited by the URO1 team for the scope of this document.

Each artwork is sketched on the plan and coded by an alphanumeric code (the first letter 'H' identifies the museum) and coloured according to material typologies (wooden, metal and paper objects). All objects are exhibited inside showcases, except for the object H011 (a wooden artwork) located at the stairway.

In this case, assuming as many sensor node devices (N=11) as artworks are available, so each sensor node is placed close to each selected artwork, as shown in Figure 14.

*Figure 14. Museo delle Origini: Identification of the eleven sampling points in the plan where fixed sensor node devices (CC sensor, green dots) can be deployed according to the **artwork-related deployment**. Objects are coloured in accordance with the main material typology as reported in the legend, whereas showcases are marked in yellow. The plan was derived from the original document provided by Dr Cecilia Conati*

3.2 Protocols for artwork-envelope-related deployment

In the case of the artwork-envelope-related deployment, a given number of sensor node devices is set, thus the distribution of the sensor node devices is made in order to guarantee the representativeness in time and space of the whole environment surrounding individual artworks.

This section describes the procedures for the deployment of sensor node devices approached in Museum Scenario I and Museum Scenario II. These procedures are recommended for monitoring campaigns designed to establish the historic climate conditions of permanent collections in order to preserve the artworks in the same climate even when they are rarely moved from one museum to another. These procedures can also be applied to establish the environmental conditions inside rooms designated for temporary exhibitions. This aspect is expected to encourage loans among museums, as it would be possible to know in advance the environmental conditions of the hosting exhibition space.

3.2.1 Museum Scenario I

In Museum Scenario I, field campaigns cannot be both planned and performed, as portable thermo-hygrometric instruments are not available, so the spatial distribution and the gradients of microclimatic parameters remain unknown. Furthermore, indoor climate measurements have not been performed either continuously or occasionally. In this case, it is not possible to evaluate the historic climate and its variability and sensor node devices should be deployed taking into account the location where climate-vulnerable artworks are exhibited, and the features of the building envelope.

The on-site visit, if possible, or a virtual tour, if available, allows us to add more details to the background information gathered through the questionnaire on the museum.

The protocol for Museum Scenario I is schematised in Figure 15 and identifies two possible configurations:

- as many sensor node devices as the number of rooms;
- as many sensor node devices as the number of climate room-blocks.

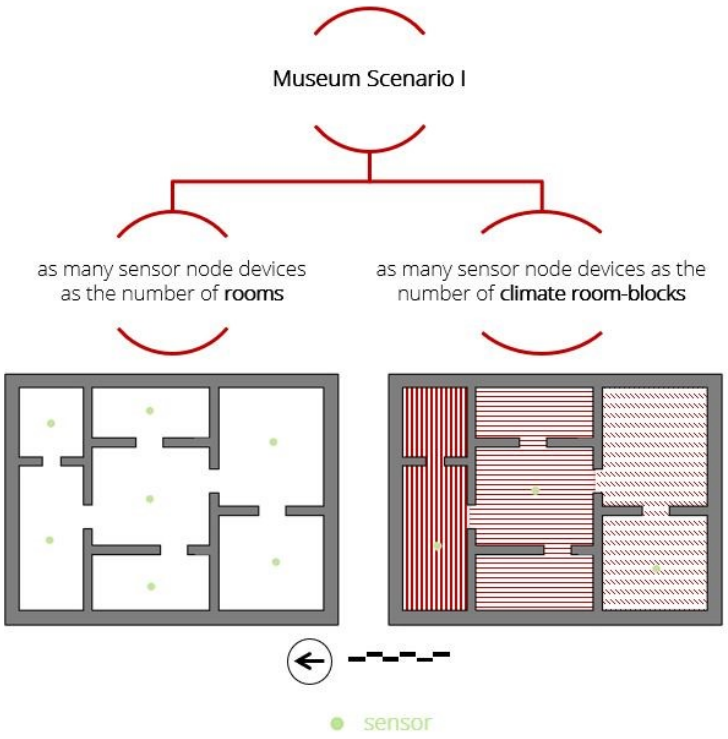

Figure 15. Schema of procedures developed for Museum Scenario I

- As many sensor node devices as the number of ***rooms***

The procedure consists of deploying sensors in the middle of each exhibition room (Bichlmair, Holl, & Kilian, 2013) all at the same height and assuming that no spatial gradients or vertical stratifications of indoor climate variables are experienced. This approach is feasible if at least as many sensors as the number of exhibition rooms are available. According to this procedure, the sensor node devices, even if small and wireless, could have a visual impact. Thus, the sensor node devices could be deployed in more hidden places. However, this would lead in some cases to a low representativeness of the climate behaviour in large-volume rooms or to a possible misinterpretation of the indoor climate, even in small-volume rooms, particularly if sensor node devices are located in corners (Siani, Frasca, Di Michele, Bonacquisti, & Fazio, 2018).

- As many sensor node devices as the number of ***climate room-blocks***

If the number of sensor node devices includes few units and/or rooms are large, another procedure for the deployment of sensor node devices can be based on ASHRAE *Standard* 90.1 (2007) which defines a method to identify the thermal zoning of residential spaces in the field of dynamic energy modelling. The handbook suggests that rooms characterised by the same orientations or internal gains or ceiling/floor loads may be reasonably grouped into one thermal block without losing information on the single room. Thus, the thermal block is representative of all rooms with the same features.

For example, the exhibition space can be broken up into a given number of climate blocks grouping rooms located on the same floor and with the same internal gains (heat and moisture sources/sinks) and placed along the same orientation of the main axis of the building, hence assuming homogeneous climate conditions. In museums, the climate room-block can be defined as the group of rooms characterised by at least one of the following features:

- to preserve artworks made with same climate-vulnerability materials having comparable state of conservation;
- to have sufficiently similar space climate conditioning systems (e.g.: heating/cooling systems and/or de/humidifiers);
- to be located at the same floor and with the orientation of the walls.

Figure 16 shows the schematisation of the climate room-block in Museum Scenario I protocol.

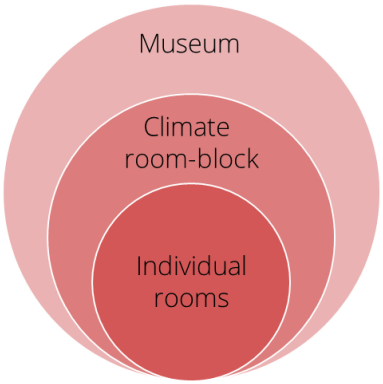

Figure 16. "Bubble in a bubble" scheme of Museum Scenario I protocol for the museum zoning adapted from the ASHRAE Standard 90.1 in the field of energy simulation

Demonstration site 3: Diputación Foral de Álava (DFA) – Alava Arms Museum (AAM)

The Alava Arms Museum (AAM) is associated with the Museum Scenario I according to the information gathered through the questionnaire (as documented in D4.2).

Starting from the answers of 5Ws1H (Figure 17) it has been possible to sketch out the necessary key issues to deploy the sensor node devices in Museum Scenario I (MS I). In this case, only five basic sensor node devices are available.

Figure 19 shows the plan of the museum with the placement of the selected artworks. Eighteen artworks were selected by conservators and reported in the Condition Reports (CRs) documented in the confidential Deliverable D1.3 of the CollectionCare project. Artworks are coded by an alphanumeric code (the first letter 'D' identifies the museum as reported in D1.3) and coloured according to three of the four material typologies (wooden, metal and paper objects). Most objects are exhibited inside showcases.

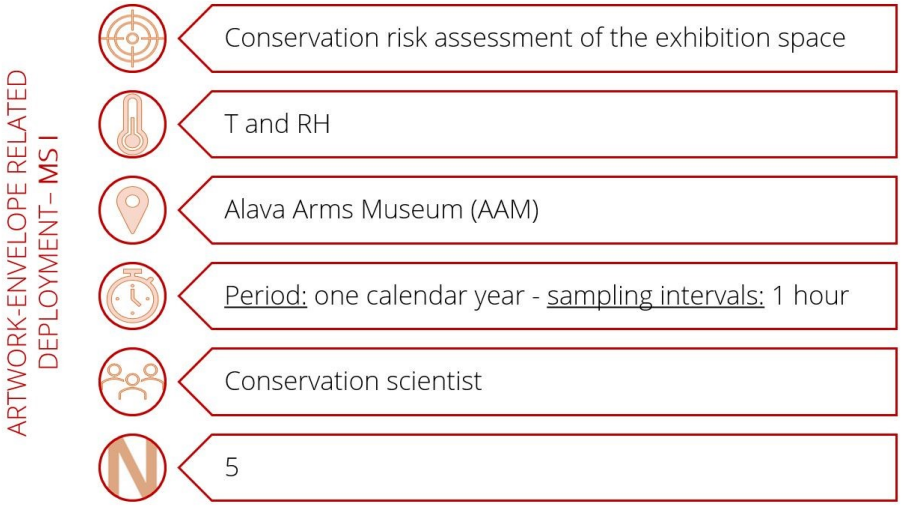

Figure 17. Answers to the 5Ws1H aimed at designing the procedure provided by Museum Scenario I

A description of the museum is provided in view of applying the ***climate room-block*** protocol adopted for MS I instead of the ***rooms*** protocol. Indeed, the former is more representative for choosing the sampling points in the site under study.

AAM is a three-floored building with the longer axis oriented along north-south direction. The ground and first floors consist of two large exhibition rooms connected by a stairwell located in the centre of the rooms; the storage rooms are on the last floors. Only a large skylight (single pane window) is in the exhibition room of the first floor. The air conditioning (AC) system is not drawn on the plan for the sake of better readability of Figure 19. However, AC vents are located above showcases both on the ground and first floors.

Before deploying the sensor node devices, it is recommended to perform connectivity tests to ensure that the data collected by the sensors is correctly transmitted to the gateways. To do this, radio frequency (RF) tests are carried out to measure the level of signal propagation of Sigfox and LoRaWAN technologies, which are the two technologies we use (for more details see Deliverable D5.1). Data transmission can be affected by construction materials of the building (e.g. reinforced concrete), object materials (e.g. metal) or long distances between the sensor and the gateway, among others. Therefore, performing these tests before deploying the sensors is encouraged, to ensure that where the sensor node devices are installed there is good wireless coverage in order to reach the gateways and hence to upload all the data collected to the cloud.

Apart from covering the needs for checking the connectivity of these sensor node devices established by the UPV team (D5.1), the configuration of the deployment of the five sensor node devices was based on the identification of the most climate representativeness of sampling points by the URO1 team.

The museum was divided into three climate room-blocks, corresponding to the two exhibition rooms (ground and first floors) and the storage rooms. Thereafter, each climate room-block was analysed to identify the climate-vulnerable artworks (brown and light blue rectangles):

1. Sensors S01 and S02 were placed in the first room close to the artworks D005 and D012, respectively. On the ground floor, most artworks are located in the showcases, except for two climate-vulnerable artworks in the centre of the room: D005 beneath the stairwell and D012 beneath the open slab between the ground and first floors. Here, the two sensor node devices deployed in correspondence with the above-mentioned artworks can reasonably collect different hygrothermal conditions due to the combined effect of the stairwells and the building orientation.

2. Sensor S03 and S04 were placed close to D001/D015 and outside the showcase, respectively. On the first floor, all artworks are exhibited inside the showcases; metal and paper artworks are often together in the same showcase. In this case, two sensor node devices deployed, one inside the showcase (S03), and one outside the showcase (S04), would allow us to understand heat and moisture exchanges between the room and the showcase (Verticchio, Frasca, Garcìa-Diego, & Siani, 2019) and the hygrothermal effect on the conservation of two different materials.

3. Sensor S05 was placed in the centre of the attic storage room. In this room is stored a selected paper artwork on a planar and is the most unfavourable room from an environmental point of view.

The positioning of the five sensor node devices took place at the end of July 2020. The UPV team installed them in the above identified sampling points for continuous data collections. The monitoring campaign is still going on.

Figure 18. Alava Arms Museum (AAM): Sensor S01 (left panel) located on the ground floor close to D005 and Sensor S03 (right panel) located on the first floor inside the showcase close to D001 and D015; pictures courtesy of UPV team (July 2020)

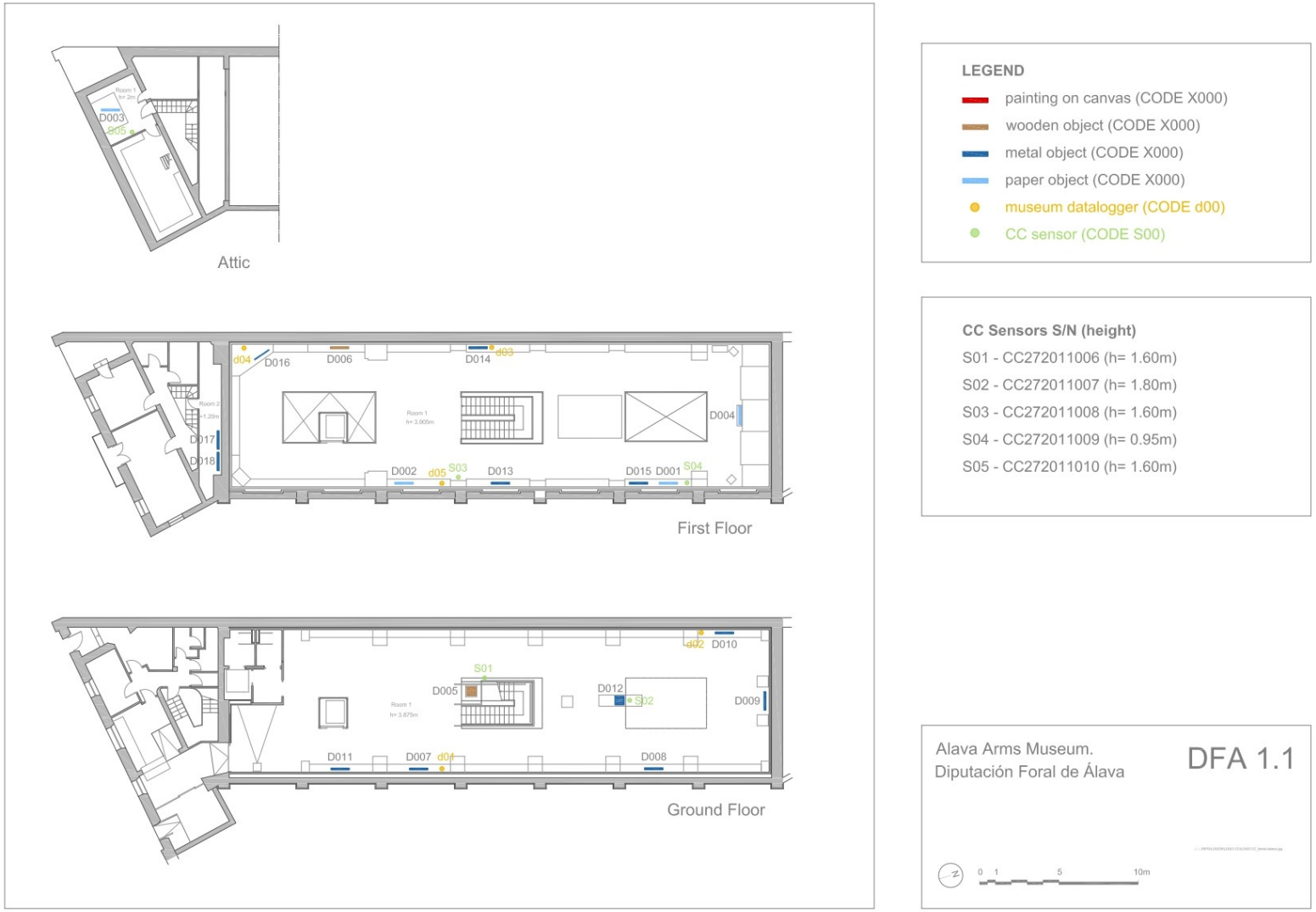

*Figure 19. Alava Arms Museum (AAM): Identification and location of the five sensor node devices (CC sensor, green dots) according to the protocol for **artwork-envelope-related deployment** developed through **Museum Scenario I**. Yellow dots are other DFA climate sensors*

3.2.2 Museum Scenario II

In Museum Scenario II, field campaigns have been conducted and/or can be planned. The observed indoor climate values can be reported in the horizontal/vertical cross-sections of each room, so that the spatial distribution of moisture and temperature is retrieved. Thus, the visual interpretation of data maps should help to design an initial configuration of the sensor node devices' deployment without jeopardising the representativeness of sampling points with respect to the real ambient conditions, either for long-term monitoring or for a short period.

It was demonstrated that knowledge of the spatial distribution of the indoor climate variables improves the awareness of the presence of heat or moisture source/sinks and horizontal transport of air mass, which is useful for the conservation risk assessment of the individual artwork and/or the exhibition spaces.

This section is subdivided into a general description of the method to conduct the field campaign, the protocol for the deployment of sensor node devices approached for Museum Scenario II and its application to the demonstration site Museo delle Origini.

General description of the method

The schematic workflow of the method is shown in Figure 20. In order to map and characterise the indoor climate (i.e. the microclimate) in a horizontal cross section of the exhibition space, discrete measurements of air temperature and relative humidity should be taken using portable instruments complying with the minimum requirements suggested by the current European standards EN 15758 (2010) and EN 16242 (2012). In addition, the instruments should have the same fast response in order to be able to obtain the measurements in a short time step, thus limiting the possibility of misleading interpretation of recorded data.

Before starting the field campaigns, all sensors should provide the same readings in order to guarantee the comparability of data provided by the instruments (Sturaro, et al., 2003). The measurements are performed for each point of a virtual regular grid representative of a horizontal cross section of the exhibition space. The grid is composed of rectangular areas with the same dimension where the sampling points are the vertices. The choice of the spacing grid, and hence of the number of sampling points, depends on the size of the exhibition room (Camuffo, 2019). However, the time interval of the field campaign should not be too long, in order to avoid changes of ambient conditions due to other causes (e.g. the effect of the daily cycle of solar radiation on the exposed walls).

All the measurements should be carried out at the same horizontal level; the generally preferred height is 1 or 1.5 m above the floor, so as to avoid a bias in the measurements. In fact, it is important to bear in mind that in a closed room a vertical temperature gradient can be experienced.

However, the field campaign should also include measurements of T and RH close to the walls (at the same height of those on the horizontal plan) in order to consider also indoor climate data at the boundary conditions and to detect air-surface interactions in terms of heat and moisture exchanges.

Measurements of the vertical distribution of indoor climate variables allow us to verify the air stability inside the room, and the thermal-moisture equilibrium between the air and the walls, as well as between the air and the surface of the object.

In museums, spot measurements at selected heights representative of the air layer where artworks or paintings are exposed can be taken by portable sensors fixed to a portable pole or a tripod. These sensors should also have the same fast response of those used at sampling points of the grid Vertical profiles of T and RH measurements can be also measured with the blackbody strip methodology, which uses a strip made of a good absorbent material with low thermal hysteresis able to quickly reach thermal equilibrium with ambient air and IR radiation.

To monitor the temperature of the walls and other surfaces in selected points, infrared cameras can be used for a more accurate evaluation of thermal behaviour.

The field campaigns should be conducted during the daytime at different time slots in order to follow the temporal evolution of the thermo-hygrometer variables in the space:

- at the start of the day, when the exhibition space usually presents a less perturbed condition;
- in the middle of day, when the museum is open;
- at the end of the day.

Moreover, the same field campaigns should be also conducted to monitor the seasonal cycle of the ambient conditions at least one per season.

After the observed indoor climate values are reported in the horizontal cross section of each room, a spatial representation of the moisture and heat is constructed in the form of contour maps of temperature and humidity, using professional contouring software.

The step for drawing isolines of a given variable includes customising the choice of the best gridding method for the interpolation of measured data, the unit step from isoline to isoline, and the values of the boundary conditions of the exhibition spaces.

Once the contour maps of the climate variables are drawn, it is possible to characterise the indoor climate behaviour by identifying patterns with significant climate variability and those characterised by climate homogeneity, those mostly affected by outdoor climate or those with other relevant phenomena. Isolines tend to be parallel to each other; they are as smooth as possible and never cross. The closer the isolines are, the steeper the variation experienced by the climate variable.

This information allows us to design an initial configuration of the sampling points to place the sensor node devices, which can be further improved if the analysis of data at different heights is included.

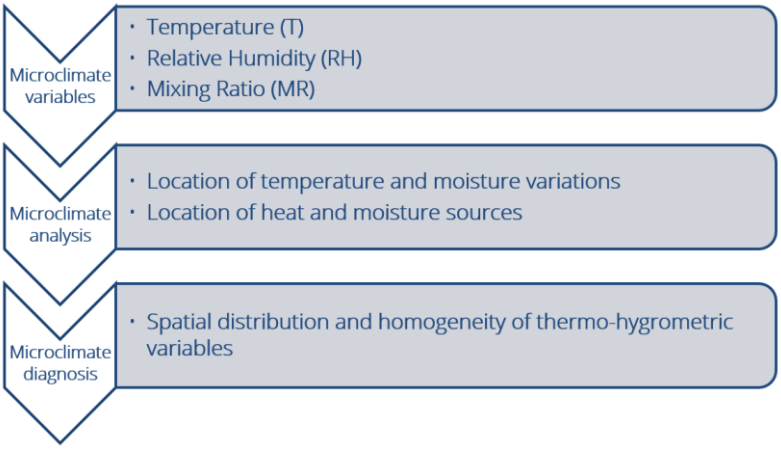

Figure 20. Schematic workflow of the field campaigns method

Demonstration site 4: Sapienza University of Rome (URO1) – Museo delle Origini

In the work-plan which was agreed during the Technical Project Meeting held in Rome (on January 23-24, 2020) and reported in the minutes, hygrothermal maps at Alava Fine Arts Museum (AFAM) belonging to the Diputación Foral de Alava (DFA), were scheduled for the end of March. Due to the Covid-19 pandemic, which led to partial or total closure of museums and travelling restrictions throughout Europe, AFAM as Museum Scenario II was replaced by the Museo delle Origini, where the hygrothermal field campaigns for mapping were performed. Consequently, the Museo delle Origini is here associated with Museum Scenario II, although it was previously associated with Museum Scenario IV in D4.2.

Starting from the answers of 5Ws1H (Figure 21), it has been possible to sketch out the key issues necessary to deploy the sensor node devices in Museum Scenario II (MS II). In this case, we assume that only four basic sensor node devices are available.

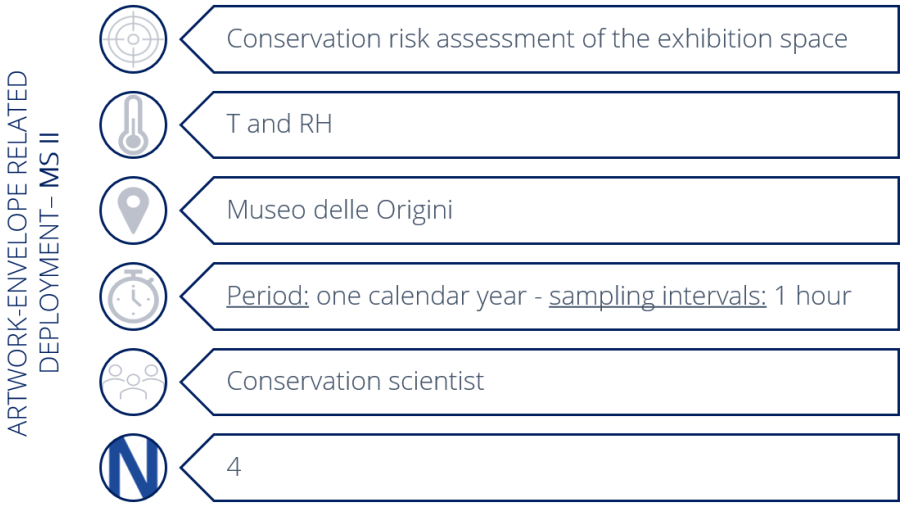

*Figure 21. Answers to the 5Ws1H for **artwork-envelope-related deployment** in Museo delle Origini*

In view of applying Museum Scenario II to the Museo delle Origini at a given time slot, the protocol is subdivided into the following four steps:

Step 1 - The virtual regular grid representative of a horizontal cross section of the exhibition space is shown in Figure 22. The vertices of the rectangles (blue dots) represent each sampling point at the same high level where climate variables can be measured with a portable instrument. In this example, the grid size is 4m x 4m. The fan coils are not drawn on the plans for the sake of better readability of Figures 22-24, as they were turned off.

Step 2 - Measurements of T and RH at the vertices of the grid were taken by the URO1 team and involved in the calculation of the mixing ratio (MR).

Step 3 - Isolines of T and MR (e.g. lines connecting points of equal value) are drawn with an interpolation method at intervals larger than the instrumental uncertainty. The maps of T and MR horizontal distributions are shown in Figure 23 and Figure 24 respectively, using the filled coloured contour plots to facilitate visual interpretation of the climate variability. A decreasing temperature tendency can be observed along the south-east north-west direction of the exhibition space, with a thermal minimum in proximity to the east side close to the large window of the museum. The temperature tends to increase in the more internal areas. Concerning the MR distribution, a more homogenous pattern can be noted.

Step 4 - N=4 sensor node devices are available; they can be placed in four distinct areas characterising the environmental variability around the selected artworks (Figure 25):

- Sensor S01, placed in the warm humid environment surrounding metal and wooden artworks;
- Sensor S02, placed in the low MR area where the wooden artwork H011 is located;
- Sensor S03, placed in the thermal minimum, where the metal artwork H017 is located:
- Sensor S04, placed in the different hygrothermal area with respect to the above conditions and where the metal artwork H013 is located.

It is advisable to repeat Steps 2 and 3 at different time slots throughout a day and/or the year in order to capture the daily and/or seasonal variability. This allows us to find a proper configuration of the sampling points where to deploy sensor node devices (Step 4).

Figure 22. The virtual grid superimposed on the plan of Museo delle Origini

Figure 23. The horizontal map of air temperature (at 0.3 °C intervals) in the two exhibition rooms of Museo delle Origini (Rome)

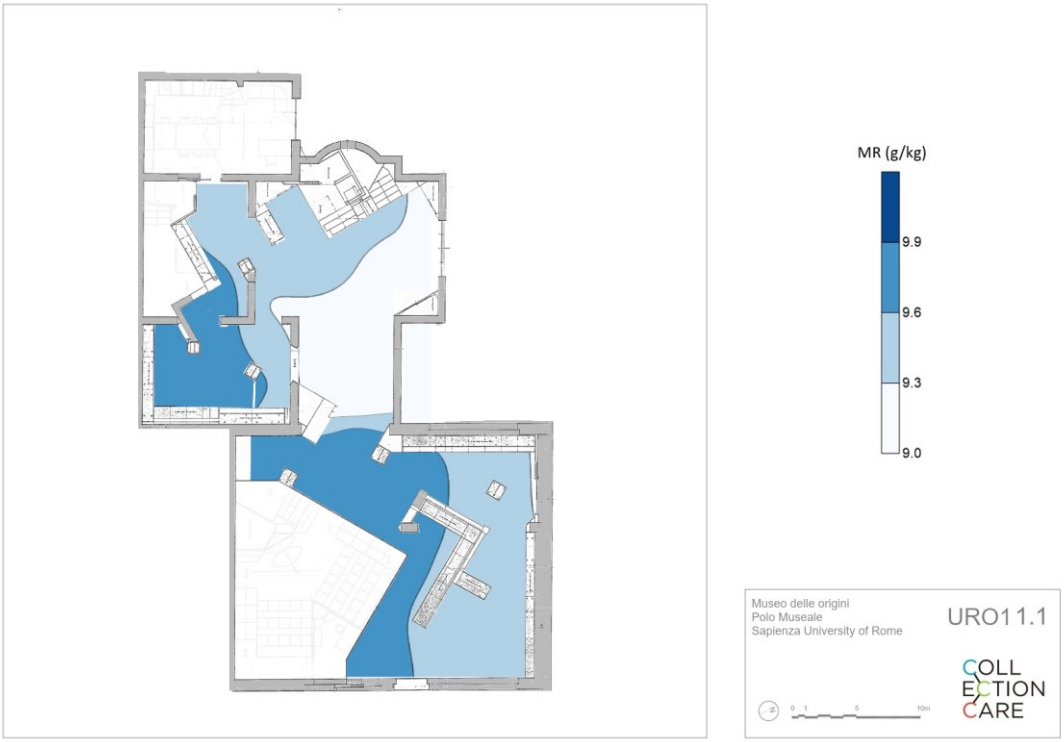

Figure 24. The horizontal map of air mixing ratio (at 0.3 g/kg intervals) in the two exhibition rooms of Museo delle Origini (Rome)

*Figure 25. Museo delle Origini: Identification of the sampling points in plan where fixed sensor node devices (green dots) can deployed according to the **artwork-envelope-related deployment** associated with **Museum Scenario II***

4. Conclusions

In a monitoring campaign, the sensor deployment should be carefully identified in order to accurately record the indoor climate space-time variability around the preserved artworks. In this context, Deliverable D4.9 is dedicated to defining the basic procedures for deployment of sensor node devices in the exhibition space of museums.

Two protocols were proposed, based on the number of available sensor node devices, which can be used in indoor climate monitoring, both for artwork-related deployment and artwork-envelope-related deployment.

Artwork-related deployment can be adopted when there are as many sensor node devices as the number of artworks. This means that the sensor node device can be placed in close proximity to the artwork, chosen in accordance with the conservator. If selected artworks are in the same hygrothermal area, this protocol can be strategic when a sensor device associated with an artwork does not take measurements or it provides anomalous data (e.g. after losing calibration, bad maintenance) or it damages or data transmission fails. Consequently, data collected by other closer sensors can be representative of the climate surrounding that artwork.

In the case of artwork-envelope-related deployment, a given number of sensor node devices is set. Thus, the setting of the sensor node devices is made to guarantee the time and space representativeness of the whole environment surrounding individual artworks. The protocol related to artwork-envelope-related deployment is outlined once a museum is associated with its corresponding Museum Scenario. In this deliverable, Museum Scenario I and Museum Scenario II were considered.

In Museum Scenario I, the identification of positioning of sensor node devices includes two configurations: 1 sensor per 1 room or 1 sensor per 1 climate room-block.

In Museum Scenario II, the identification of the sampling points is based on the characterisation of the indoor climate through the mapping of hygrothermal parameters.

The above deployment protocols were applied to four demonstration sites and critically discussed. Specifically, the climate room-block protocol for Museum Scenario I was successfully tested in the real context of Alava Arms Museum (Spain).

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