

# Digital Heritage Conservation: The SENNSE IoT Platform as a Structured Approach for Cultural Heritage Monitoring Projects

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**Abstract** – The care of tangible heritage is a relevant aspect in the field of cultural heritage (CH). New systems have been developed to monitor and protect cultural assets such as buildings, monuments, archaeological sites and artifacts preserved in museums. IoT technologies play a key role in the design and implementation of CH monitoring services. This paper proposes the design of the workflow for the planning of a Monitoring Project (MP) in the context of the implementation of a software platform called SENNSE (Spatial hEritage scieNce oNline Sensor Environment) based on IoT technologies, which aims to create an online system for sharing, managing and processing data coming from acquisitions in the CH field. The workflow is planned to assist the user in adopting a scientific approach, from the design to the installation of a sensor network in indoor and outdoor locations.

**Keywords**— IoT platform, sensor network, cultural heritage, monitoring, conservation

## I. INTRODUCTION

The protection and monitoring of CH are currently subjects debate, with efforts being made to address the impact of climate change on physical assets [1], [2] and to optimise and plan maintenance and restoration operations.

Due to their intrinsic historical and architectural complexity, cultural heritage buildings, often composed of heterogeneous structural elements, pose significant challenges in terms of conservation, diagnostic assessment, structural analysis, monitoring, and consolidation.

As stated in the ICOMOS charter [3], the study of a MP requires a multidisciplinary approach and precise methodologies. ICOMOS has defined a set of precise steps that should be adopted for the realization of an MP. These

steps include gathering data and information about the asset to be monitored, the identification of the causes of degradation, and the planning of maintenance operations.

In this context, IoT technologies [4], [5] have been extensively adopted, enabling the real-time transmission, acquisition, storage and analysis of a substantial volume of data, facilitating the monitoring of cultural assets over time and leading to a deeper understanding. Data collection is achieved by deploying devices throughout the designated site or building, providing a real-time view of critical parameters related to the health status of the monitored asset.

Although there are several research projects dealing with the protection and enhancement of CH [6], [7] and general purpose IoT platforms are available online, there is no global platform dedicated to CH that employs a scientific approach based on the specific MP requirements, providing versatile tools and functionalities to design the sensor network and manage devices. The SENNSE platform aims to facilitate the planning and managing of MPs from the design to the installation of the IoT sensor networks (SNs), gathering and visualising data acquired by IoT devices distributed over archaeological sites or in historical buildings. This will enable the collection, processing, display and dissemination of data to the scientific community.

The SENNSE platform is composed of three main sections: the first one, which is discussed in this manuscript, is the “Monitoring Project” section, which provides a procedure for setting up a SN based on the requirements of a MP. This set of tools facilitates the design of IoT networks using a graphical interface. The SN can be built as a node graph directly on a map or a planimetry of the monitored site or building. Furthermore, the procedure permits to define the technical parameters that will be used to configure the physical devices. Designed SN can be saved as template for reuse in future projects.

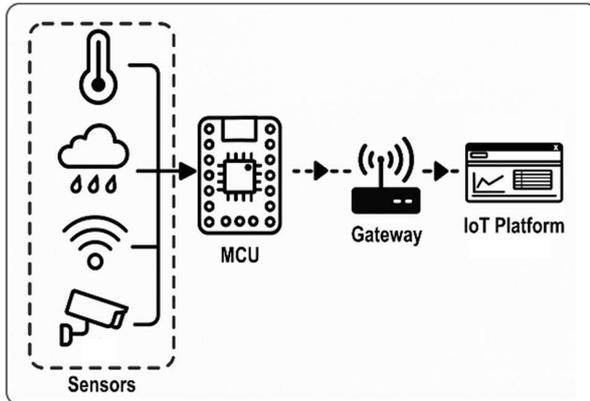


Fig. 1. Basic structure of an IoT SN: the architecture is composed of a set of sensors that acquire data relating to physical parameters of interest. The data is processed by a Microcontroller Unit and sent to the IoT platform via a gateway that is connected to the internet network.

The second section deals with the visualization and elaboration of data collected by the SNs. The data visualization takes place using dashboards composed by a selection of graphic widgets that are selectable and configurable by the user. This allows to have a personalised experience, highlighting the most relevant data based on the user research context. Where it is available, the collected data can be showed in virtual reality on a 3D reconstruction of the asset. Here the user can explore the 3D model, see where the sensors are placed and visualize acquired data through pop up widget. If available, the data can be read directly on place in augmented reality mode.

The last section is represented by the annotation editor. This tool allows to create dataset gathering data belonging to sensors of a single or multiple SNs in a specific temporal range. The data can be annotated using a key-value system and exported as JSON files.

As mentioned above, this paper presents the design of the workflow that has been implemented in the platform for the planning of a MP.

The structure of the paper is as follows: the next two sections will provide a concise overview of the aspects to be considered in a MP. In particular, in the second section, a brief overview of the environmental physical quantities employed in the domain of CH monitoring is provided. The subsequent section discusses the aspects that need to be considered during the design and installation of a SN for CH applications. Finally, in the last section, the SENNSE guided procedure for the planning of a MP will be illustrated.

## II. DATA OF INTEREST FOR CULTURAL HERITAGE MONITORING PROJECT

The first step in the planning of a MP is the identification of the physical quantities associated with the assessment

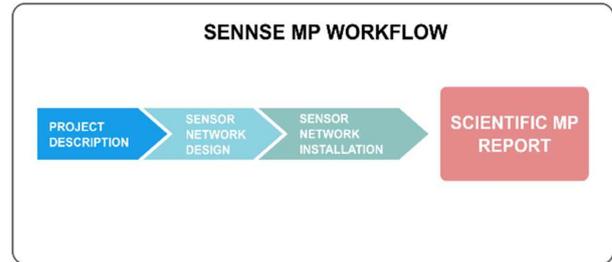


Fig. 2. MP design workflow. The process is composed of a sequence of three steps that guide the user designing a monitoring infrastructure starting from the analysis of the requirements up to the production of a detailed scientific report containing the information necessary for the installation of the SN.

of the state of conservation of a cultural asset and the corresponding acquisition methods.

There are several articles in literature describing methods and devices for monitoring archaeological sites and monuments [8], [9]. In some cases, the concepts of HBIM and digital twin [10] are associated to this topic, underlining the importance of following the evolution of an asset from different points of view.

In the present study, particular attention has been paid to micro-environmental monitoring, for example in subterranean sites and historical buildings, where the most common parameters acquired in such contexts have been identified, such as temperature, humidity, air quality, air speed and UV radiation. The combinations of these values have the potential to reveal several possible underway scenarios [11]. In certain instances, monitoring can also be employed to assist in the administration of historical buildings or museums. This may encompass initiatives aimed at reducing energy consumption or enhancing visitor experience and fruition [12].

## III. REQUIREMENT AND STRUCTURE OF AN IOT SENSOR NETWORK FOR CULTURAL HERITAGE APPLICATIONS

The second step in the implementation of a MP is represented by the network of sensor nodes used for data acquisition. In CH monitoring field, these sensors often must operate in critical conditions, such as in underground sites. Moreover, aspects such as power sources must be considered. In fact, connection to the electricity grid is not always possible and alternative types of power supply are required, such as via battery pack or, where possible, via solar panels.

Another aspect concerns the connection to a network for data exchange. In some environments it is not possible to install wired network systems and in others wireless network propagation problems could be present. For these reasons, in each project it is necessary to design a specific IoT SN able to overcome any issue due to environmental conditions and satisfy monitoring needs.

Fig. 3. The image shows a mock-up of the interface that has been implemented in the platform. After defining the name of the network, the user can add gateways and nodes.

Figure 1 shows the basic communication structure used in SENNSE platform. Basically, one or more sensors are connected to a MicroController Unit (MCU) board, which represents a node of the SN. Each node transmits data using different technology, such as WiFi, LoRaWAN or LAN, depending on the specific MP. Data is sent to a gateway and after which it is relayed to the IoT platform.

#### IV. THE MONITORING PROJECT WORKFLOW

As previously mentioned, the key aspects to consider in the implementation of a MP are the following: firstly, the uniqueness of each MP, which is derived from the state of the places to be monitored; secondly, the aims to be achieved by carrying out the monitoring. For these reasons, a workflow has been devised in SENNSE to address the specific requests that arise from these two aspects, supporting a scientific approach and guiding the user in all phases of project planning.

Currently, the platform does not support users in the decision-making process when creating an MP. However, previously created SNs can be saved as templates and subsequently reused and modified. This feature can help to speed up and refine the SN setup procedure.

The process has been divided into three phases as can be seen in figure 2: the description of the MP, the design of the IoT SN and the installation of the devices.

In the initial phase, the user is required to input general information regarding the MP, such as the project title and its geographical location. A complete description of the project requirements and the strategy to be employed to

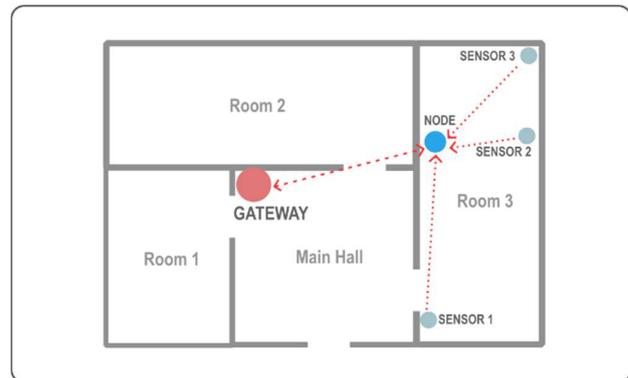


Fig. 4. Example of the SN IoT node graph. The graph helps the user to organise the position of nodes on the plan, providing an overview of the entire project.

achieve the desired outcomes must also be provided. This description should encompass the physical quantities that need to be acquired, the number of sensors that may be necessary and the requirement for an internet connection, among other specifications. This is the preliminary delineation of the project, the purpose of which is to provide a comprehensive overview of the project objectives.

The subsequent stage involves the conceptualisation of the IoT SN. The execution of this step is facilitated by a network designing tool that uses a node tree graph.

The network designer tool enables the creation of networks in a modular way. As previously outlined, the basic unit of the SN incorporates a gateway to which a node is connected, equipped with a specific number of sensors. The interface (Figure 3) allows the addition and deletion of gateways, as well as the adding and removal of nodes and sensors for each of them. The selection of devices to add will be possible from a list already preloaded in the platform. Upon implementation of the platform, the user will be granted the option to create custom devices.

Whenever a new element is selected and inserted, the node graph is updated. If available, a map of the location to be monitored can be uploaded as background of the graph, where the nodes can be arranged according to their actual installation place (Figure 4).

Each device will have a series of parameters that the user can set (e.g. SSID and password for gateways or sampling rate for sensors) that will be used to set up the network devices in the installation phase.

Upon completion of the SN design process, a report is generated that includes all the information about the MP, such as the description, the list of the devices needed for the network installation and their positioning on the map. Moreover, the report will include all the information required for the setup of the network.

At this stage, all the information required for the SN installation is available, and the MP can be realised.

## V. CONCLUSIONS AND FUTURE WORK

In this paper the SENNSE platform is presented with the purpose of collecting and visualising data from sensors for diagnostic investigations in the field of CH.

In particular, the workflow for creating an MP using a scientific approach has been illustrated. This process involves defining the project requirements, designing the SN and providing all the necessary installation information, thereby emphasising the multidisciplinary nature of the conservation and monitoring of cultural heritage.

Once the MP has been set up a detailed report is produced. The report includes all the information inserted by the user during the process: in addition to the project description, the report contains the information needed to physically implement the network, such as a floor plan of the locations with the points where the devices are to be installed, a list of the necessary devices and their configuration parameters.

The acquired data can be shared with other users and visualised using customisable dashboards. Analysis can then be performed by annotating dataset created by the user in the annotation editor section.

Moreover, where available, it is possible to carry out a virtual inspection of a 3D model of the asset on the platform web viewer or in immersive mode through virtual or augmented reality. This enables users to move through the virtual model and view acquired data in real-time.

Further developments will involve the incorporating of AI and machine learning-based mechanisms. These include features to support the user during the creation of a new MP and in data visualization, as well as predictive analysis and real-time optimization of the monitored environments.

Currently, the platform is not directly interoperable with other standards such as HBIM. Data exchange is possible through the annotation editor, which can be used to export datasets containing information such as values acquired over a time range, monitored physical quantity, sensor positioning, and dataset annotations with information regarding the state of conservation of the monitored asset in relation to the acquired values.

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