Protection of cultural heritage through an integrated Digital Twin and IoT system

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I. Introduction

Cultural Heritage Buildings need to be preserved through interventions and actions that ensure accessibility and availability to present and future generations. Cultural Heritage conservation is the set of interventions and actions to protect artworks, ensuring their values accessibility to present and future generations. The advent of new technologies introduced many possibilities and strategies to monitor environments, including those with Cultural Value. The diffusion of new technologies, including low-cost sensors and devices, has introduced many possibilities and strategies to monitor environments, including Historical and Cultural value buildings. Based on the Internet of Things (IoT) paradigm, modern devices and sensors can collect and manage helpful information to build a Digital Twin of the surrounding environment. In this scenario, reproducing a Digital Twin of Cultural Heritage Buildings could be crucial to monitoring, managing, and performing action aiming to protect them. One of the challenges in recent years is the automatic analysis of collected information. This abstract introduces a novel approach to protecting Buildings using Heritage Building Information Modeling (HBIM) [1], which leverages a sensor network and Deep Learning techniques to analyze sensor data. Then, collected data are analyzed through a Deep Learning technique to prevent future issues related to Cultural Heritage Buildings, particularly humidity inside structures, which is crucial for ancient building preservation. One of the main issues related to cultural heritage concerns its preservation and maintenance. The conservation of tangible and intangible assets is a priority so that the property remains accessible to future generations by ensuring physical integrity and value. One of the disciplines belonging to the field of restoration is the Preventive Conservation (PC), which is all those interventions made to avoid or decrease the loss of materials or prevent any damage that may occur over time not only to tangible cultural heritage but also to the context in which it is located. In the field of Preventive Conservation, monitoring environmental and climatic factors is an extremely delicate operation, especially when it comes to historic buildings often open to continuous visits by tourists. The probability that the conditions of a building and its context will change over time is therefore very high, for this reason, it is necessary to have a system of accurate and non-invasive analysis of these structures to identify the best and required maintenance operations[2]. Thus, developments in information technology (IT) and the paradigm of Internet of Things (IoT) are significant in achieving the aforementioned objectives. Indeed, the possibility of storing and developing, even remotely, data on the climatic conditions of architectural spaces is a very effective tool for the conservation of the built heritage. The continuous development of new sensors and new technologies for data transmission allow a greater availability of environmental data. Furthermore, thanks to the Internet of Things approach, the introduction of warning and restriction signals can be implemented more easily and smoothly by installing small IoT sensors near the monitored elements connected to environmental gateways to transfer data to a cloud platform. In this way, the continuous advancement of IoT-based technologies have made it possible to implement an architectural space, a model, equipped with real-time environmental data with a small economic investment [3]. With this approach, the crux remains the workflow to support appropriate decisions for preventive conservation and the possibility to make appropriate changes to environmental conditions through manual or automatic actuators. So the complexity of the process must be pointed out and requires integrating multidisciplinary knowledge between scientists, architects, and conservators. In fact, the study of potential environmental changes must be supported by an accurate knowledge of the state of conservation of architectural elements and optimal conditions and an IT knowledge focused on IoT[4].

II. The Proposal Workflow

To this purpose, once a digital model of the tank was developed in a BIM environment, the work focused on the climatic characterisation of the internal environments and the simultaneous monitoring of external environmental data.

The first phase focused on experimental investigations and climatic monitoring to identify historical input data. The second phase concerned the definition and validation of the appropriate temperature and humidity levels for the preservation of the state of affairs, through the installation of a real-time control and monitoring system via IoT nodes. The entire monitoring and control phase is managed through a Digital Twin based on an HBIM model and integrated with a cloud-based data management platform named "ThingsBoard". The system was implemented using ThingsBoard – an open-source cloud platform dedicated to the management of IoT devices – capable of communicating with the devices in real time via different protocols, used to connect the sensors for environmental monitoring to the platform[5].

The proposed workflow includes the collection of sensor data, their integration, a parametric control mechanism, visualization modules for easy management and monitoring, and the possibility of activating autonomous choice mechanisms to improve dew-point temperature control. Indeed, the workflow presented can be divided into three phases: Data Ingestion, Data Processing and Data Visualization, which interact with each other. Data Ingestion is the first level of the process and is responsible for the raw data collection from the installed sensors, then in the data processing stage the raw data is retrieved from the cloud to generate knowledge useful for the predictive analysis of the monitored object. In particular, sensors data are combined and integrated with data from BIM. Finally, the data visualisation, refers to a structured display of the data both through dashboards that allow to visualise the data coming from the sensors in the form of graphs, and within the BIM model, importing the data through a dedicated Dynamo script, thus obtaining a three-dimensional visualisation of the relevant information.

To simulate the reactions of the Digital Twin (DT) on the model, an extension has been developed that can communicate in real-time with the ThingsBoard platform. As a matter of fact, Dynamo BIM does not provide the possibility to interact with external software and data. Taking advantage of the API (Application Programming Interface) provided by the cloud platform, it was possible to build customised Dynamo nodes, in order to enable the reading of real-time information for each sensor in the field. Specifically, to make Thingsboard communicate with Dynamo, nodes were implemented through the C# language; these nodes were then imported into Dynamo in the form of packages using the login credentials of the Thinsboard account. Dedicated external APIs automatically connect to the ThingsBoard platform for real data acquisition and then, through a Dynamo visual script, directly to its DT in BIM. The actual interconnection between the sensor and the BIM is done through the generation of dedicated families and the setting up of shared parameters to be populated with the values derived from the effective conditions of the physical model in real-time. The use of real-time data can support conservators and restorers in their studies to simulate possible corrective actions on the DT, based on the immediate feedback (fig. 1).

Fig. 1

III. Conclusion

The aim is to safeguard the integrity of the structural asset and prevent possible alterations caused by excessive surface humidity and wet-dry cycles that can alter its physical characteristics.

The purpose of this proposal was to design a methodology to support conservators and restorers to monitor and visualize temperature and humidity data of a space of historical interest. The data from the sensors can be easily represented within a BIM environment to support decisions requiring interdisciplinary skills. The proposed methodology integrates the use of an IoT-based platform – Thingsboard – which enables communication between sensors and Dynamo software to access sensor data, automatically updating the information contained in the BIM model.

A future implementation of the system could include the application of Machine Learning techniques using the collected data and, possibly, several additional sensors that can be integrated with those already in place to enrich the different applicable approaches, such as the use of thermal cameras [6].

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