HBIM, IoT and Digital Twin for Cultural Heritage: An Educational Application

Liliana Cecere
DIIn
University of Salerno
Fisciano (SA), Italy
lcecere@unisa.it

Francesco Colace
DIIn
University of Salerno
Fisciano (SA), Italy
fcolace@unisa.it

Angelo Lorusso
DIIn
University of Salerno
Fisciano (SA), Italy
alorusso@unisa.it

Michele Pellegrino
DIIn
University of Salerno
Fisciano (SA), Italy
mipellegrino@unisa.it

Domenico Santaniello
DISPAC
University of Salerno
Fisciano (SA), Italy
dsantaniello@unisa.it

Carmine Valentino
DIIn
University of Salerno
Fisciano (SA), Italy
cvalentino@unisa.it

***Abstract*— This article outlines an interdisciplinary teaching experience developed within a university course in Construction Architecture, which incorporated sophisticated digital tools and approaches to address a real-world example of cultural heritage conservation. Students engaged in a five-step process that encompassed the complete information flow, from 3D surveying to HBIM semantic modeling, followed by the installation of environmental sensors and the conceptualization of a Digital Twin system. The Villa Regina case study at the Pompeii archaeological site facilitated the development of technical and analytical skills within a genuine context, underscoring the educational potential of an integrated approach and the operational constraints presently faced in platform interoperability. The findings validate the efficacy of experiential and interdisciplinary pedagogy, suggesting a replicable paradigm that can be applied in both academic and cultural settings.**

Keywords—Digital Twin, IoT, Predictive Maintenance

I. Introduction

In recent years, the increasing incorporation of digital technology into the documentation and preservation of cultural heritage has created new prospects for training in design and engineering. Nonetheless, these technologies, although firmly entrenched in professional settings, are infrequently included in university curricula, particularly in courses designed for students outside the realms of computer science or automation[1]. This paper outlines a pedagogical experience undertaken in the "Computer Graphics" course of the Construction Engineering-Architecture degree program at the University of Salerno, which employed an interdisciplinary approach to introduce advanced concepts such as Heritage Building Information Modelling (HBIM), the Internet of Things (IoT), and Digital Twin (DT) through a practical project. The primary aim of the program was to foster systemic learning via direct interaction with a genuine cultural asset, employing professional tools and procedures within a legitimate educational framework[2], [3]. The initiative emphasizes practical training techniques that integrate technical skill acquisition with a critical comprehension of digital transformation processes in architectural heritage. The effort aimed to create an educational experience that empowers students to serve as protagonists in an integrated process where architectural representation interacts with environmental sensors and simulates decision-making situations. The use of an actual case study, such as Villa Regina, provided a tangible opportunity to examine the intricacies of historic building systems and address the issues of preventive conservation through digital methods[4], [5]. The activity aimed to enhance students' proficiency in managing the complete information cycle, encompassing the collection of three-dimensional data and the development of dynamic interpretative models while progressively introducing intricate concepts such as parametric modeling, sensor integration, and the principles of DT[6]. Interdisciplinarity was a crucial component of the training curriculum, requiring collaboration across competencies in historical analysis, architectural modeling, programming, and data visualization. The initiative functioned as an advanced educational platform, fostering a critical understanding of technology's role in cultural preservation.

II. Methodology

The training course was organized according to a project-based learning paradigm, enabling students to participate in a series of interconnected and progressive activities centered on a genuine case study. The approach was segmented into five principal phases, each offering an opportunity to examine specific technologies and concepts relevant to the digitalization of heritage (Fig.1). During the initial phase, students performed a historical and functional investigation of Villa Regina, utilizing archival materials, excavation records, and existing surveys. This first research elucidated the morphological stratification and spatial arrangement of the archaeological complex, establishing a basis for future information modeling. The second step encompassed the collection of three-dimensional data using terrestrial laser scanning with a Leica BLK360 and aerial photogrammetry with a DJI Mavic Pro 3 drone. The acquired data was processed, sanitized, and incorporated into an HBIM system using Autodesk Revit. The model encompassed the geometry of the rooms and architectural features, as well as semantic information about materials, building methods, and deterioration phenomena. The students subsequently devised and executed an environmental monitoring system with IoT devices. Sensors were added to platforms such as Raspberry Pi and Arduino to measure various characteristics, including temperature, humidity, vibrations, air quality, and UV radiation. The gathered data was relayed and displayed in real-time via interactive dashboards created on the ThingsBoard platform, enabling direct monitoring of the simulated conservation conditions. The last phase involved the conceptualization of a DT, designed not only as a digital clone but also as a logical model capable of reproducing dynamic behaviors based on the collected data. Despite the inability to attain complete automation of integration between sensors and the HBIM model, the students formulated conceptual frameworks and theoretical predictive maintenance scenarios, delineating critical thresholds, risk circumstances, and simulated reactions to environmental occurrences.

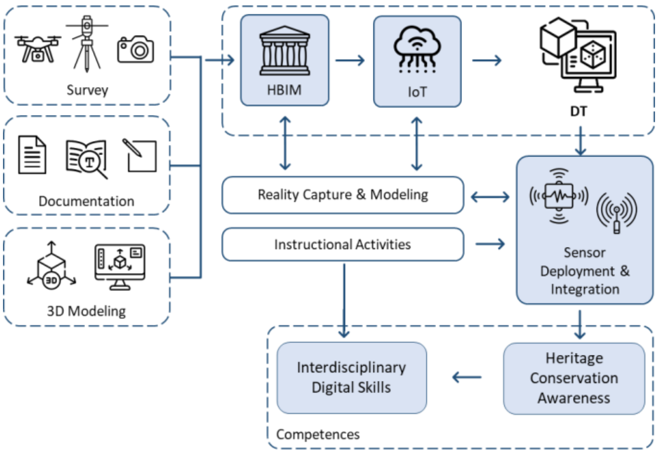

Fig. 1 Workflow of Educational Settings

III. Case study

The experience yielded substantial outcomes both technically and educationally, validating the efficacy of an interdisciplinary approach grounded in the actual application of knowledge. Despite the majority of students lacking prior expertise with sensors, microcontrollers, or programming platforms, a significant improvement in digital competencies was observed, particularly in environmental data management, embedded system configuration, and the development of parametric models within the HBIM domain. The final projects demonstrated a sophisticated comprehension of the information architecture of an HBIM model, including the semantic structuring of data, the annotation of degradation events, and the stratigraphic modeling of materials. The introduction of the IoT, initially regarded as challenging by certain students, fostered an adventurous mindset and enhanced motivation to learn, partly due to the ability to visualize in real time the impact of ambient circumstances on the subject of study. The utilization of intuitive interfaces for data visualization enhanced the development of abilities in temporal analysis and pattern recognition, offering an initial exposure to predictive analysis within conservation contexts. An especially pertinent issue that arose during the final evaluation pertains to the student's capacity to comprehend, albeit in a preliminary form, the rationale underlying the operation of a DT. Utilizing conceptual models and simulations, they envisioned environmental risk scenarios and developed response hypotheses predicated on crucial thresholds, deadlines, and mitigation measures. This shift from a descriptive to a decision-making approach signifies a significant progression in how students comprehend the interplay between data, models, and design actions within the realm of historic conservation. The exercise promoted collaborative learning and communication among various disciplinary profiles. Students possessing advanced technical abilities frequently assumed facilitator positions within the groups, whilst others offered their expertise in history and architecture, fostering a collaborative learning atmosphere that appreciated diverse backgrounds.

IV. Conclusions and Future Outcomes

This teaching experience effectively introduces sophisticated concepts, such as HBIM, IoT and DT, in training courses for non-specialist computer science students. The absence of a native connection between the HBIM model created in Autodesk Revit and real-time monitoring systems has constrained the complete operational execution of the DT, confining the simulation to a conceptual stage. This constraint has sparked significant considerations regarding the future advancement of middleware and standardized interfaces that can facilitate communication between BIM environments and IoT devices, as well as the development of interoperable formats and open BIM methodologies. The enthusiasm exhibited by students in autonomously investigating the subjects addressed, especially the DT paradigm, indicates the potential to incorporate specialized teaching modules or theme workshops into the curriculum. From a strategic perspective, the proposed model is amenable to replication and adaptation in various academic and cultural contexts, owing to its flexibility and the use of low-cost, open-source technology. The utilization of cost-effective sensors and accompanying cloud platforms facilitate experimentation in resource-constrained locations, enabling the adaptation of the format to international or museum settings. In conclusion, the project presented a substantial opportunity to implement an educational model that integrates digital technologies and cultural heritage, fostering technical competencies and critical awareness in a domain often perceived as distinct from the technological realm. The experience underscored that interdisciplinarity, data centrality, and predictive modeling serve not only as instruments for heritage preservation but also as educational methods for cultivating informed professionals who can operate responsibly in the digital transformation of historic structures.

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