

Future-Proofing Heritage with ARGUS: A Multimodal Digital Twin Approach for Sustainable Preservation

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Introduction

The preservation of cultural heritage faces increasing challenges from environmental, climatic, and anthropogenic pressures. The ARGUS Horizon Europe project addresses these challenges by proposing an innovative approach leveraging **AI-driven digital twins** and **multimodal data fusion** to assess and mitigate risks to heritage sites. Our research focuses on developing a sustainable, dynamic decision support system (DSS) that integrates multi-scale on-site and remote sensing data, enabling holistic heritage management. The primary research question is: *How can digital twins incorporating multi-dimensional data enhance the preservation and adaptive management of cultural heritage in a changing environment?*

Methods and Materials

The ARGUS digital twin integrates diverse datasets, including (a) **pre-existing GIS and remote sensing data** from five pilot sites (Delos Island, Greece, Multi Lucretilli, Italy, Sant' Antonio di Ranverso Abbey, Italy, Cellar Town at Baltanas, Spain, and Schenkenberg Castle, Switzerland); (b) **early-stage sensor measurements** (e.g., temperature, humidity, seismic, radiation) tested during initial implementations; (c) **spatial and spectral data layers** hosted in a GIS-based platform under development, which will form the digital twin's core.

The methodologies include (i) designing a multimodal, GIS-compatible data hosting system to store and manage spatiotemporal datasets; (ii) developing pipelines for sensor integration and remote sensing data visualization; (iii) initial AI tests for identifying patterns and potential vulnerabilities in heritage structures.

Results

Although at an early stage, ARGUS has established (1) **A unified GIS framework** for hosting spatial and non-spatial data across pilot sites, allowing seamless integration of multi-scale datasets; (2) **Tested data pipelines** for sensor connectivity, showcasing the potential for remote real-time monitoring; (3) Preliminary visualizations of heritage assets, laying the foundation for the ARGUS decision support system. These developments demonstrate the feasibility of integrating pre-existing data with live sensor input into a dynamic, scalable model.

Discussion

The ARGUS framework represents a pivotal step toward future-proofing heritage management. By focusing on sustainability, interoperability, and real-time adaptability,

the project aligns with broader goals of digital heritage preservation in response to climate change and societal shifts. Future work includes extending the GIS platform into a fully operational digital twin, integrating AI-driven analytics, and refining multimodal visualizations to support conservation planning and public engagement. ARGUS highlights the importance of embracing emerging technologies to protect and promote cultural heritage for generations to come.

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