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Designing a Multidimensional Damage Information Metadata Schema for Data-Driven Cultural Heritage Lifecycle Management

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Abstract

This study presents a three-tiered metadata architecture (administrative, damage, and technical layers) to optimize long-term monitoring of outdoor cultural heritage. By integrating Dublin Core spatial identifiers (POI/ROI) with the event-centric CIDOC CRM ontology, the schema ensures semantic interoperability and data provenance. Implemented in YAML for human-readability and computational agility, the framework was validated using a decadal dataset from the UNESCO World Heritage site, Gongsanseong Fortress. This architecture establishes a standardized foundation for digital archives, offering critical implications for future AI-driven damage detection and digital twins.

1. Introduction

Outdoor cultural heritage is constantly threatened by environmental weathering and structural deformation, requiring high-precision longitudinal datasets [1]. However, contemporary management frameworks face severe interoperability gaps due to heterogeneous data acquisition hardware and non-standardized recording protocols [2]. To address these challenges, this study proposes a standardized, three-tiered metadata schema engineered for the seamless integration and cloud-based management of multidimensional damage information. The proposed architecture consists of an administrative layer that defines data identity and spatial provenance via Dublin Core, a damage layer that categorizes physical degradations into event-centric structural units, and a technical layer that integrates sensor parameters and meteorological data to secure scientific reliability. By anchoring data within international ontologies, this framework preserves the entire data lifecycle and digital lineage for high-fidelity archives.

2. Materials and Methods

Gongsanseong Fortress, a UNESCO World Heritage site with complex earthen and stone walls, served as the research locus. Following a partial wall collapse in 2013, management shifted to preventive conservation, accumulating a decadal structural monitoring dataset. Specific Points of Interest (POI) and Regions of Interest (ROI) were designated to validate the schema under a "Context → Phenomenon → Evidence" flow.

The administrative layer maps spatial identity to core Dublin Core (DC) elements: dc:identifier (RecordID), dc:title (Heritage Name), dc:spatial (Coordinates), and dc:date. Localized POI/ROI systems are structured hierarchically within the dc:spatial element to avoid non-standard extensions. For lifecycle tracking, relationships are aligned with CIDOC CRM and implemented in lightweight YAML to maximize human-

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readability and computational agility. To handle complex ontological graphs cleanly, the schema nesting defines the administrative context first, followed directly by CRM event attributes and technical sensor logs within a single integrated text-based structure.

3. Results and Discussion

The POI/ROI identifiers enabled immediate retrieval of longitudinal datasets linked via unique RecordIDs. In the damage layer, physical degradations are quantified systematically into linear (1D cracks), planar (2D spalling), and volumetric (3D bulging) metrics, allowing precise time-series analysis against historical ROI data. The technical layer filters environmental noise by coupling variables like temperature and humidity, while mapping data modifications to the CIDOC CRM E65 Creation event operationalizes a robust digital lineage.

Regarding practical challenges, a current limitation of this framework is the reliance on manual validation for technical layer attributes, which introduces potential human error during field uploads. Nevertheless, by successfully transitioning conventional status-based records into event-centric units, this metadata architecture establishes a high-integrity, interoperable information infrastructure for long-term digital heritage preservation..

4. Conclusion

The proposed architecture harmonizes complex heritage monitoring data into a standardized logical model. While not directly executed in this preliminary work, this schema provides a ground-truth benchmark supporting future AI-driven automated damage detection and National Heritage Digital Twins.

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