Giving a Voice to the Past: Predictive AI for Climate-Resilient Heritage and Community Well-being

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Introduction

Cultural heritage sites often remain “silent” until damage becomes visible. Climate change, pollution, flooding, heat and urban pressure accelerate deterioration, while traditional monitoring methods are mostly reactive.

This work explores how AI and satellite data can unmute early warnings and support proactive, community-centered conservation. By protecting these historical anchors, we preserve the social identity, cultural continuity and well-being of the surrounding urban communities *[1, 2]*.

Methodology

To address the complexity of urban decay, we implement a multimodal data fusion approach using **Google Earth Engine** for acquisition and **PyTorch** for model training on an NVIDIA Tesla T4 GPU.

The framework 'listens' to data by detecting **millimetric structural shifts** (Sentinel-1), **vegetation/moisture stress** (Sentinel-2) and **atmospheric pollutant concentrations** (Sentinel-5P) simultaneously *[3]*. Monthly observations were stored in separate satellite streams before synchronization.

Data were preprocessed using logarithmic normalization, floating-point conversion and rescaling to ensure numerical stability across sensors.

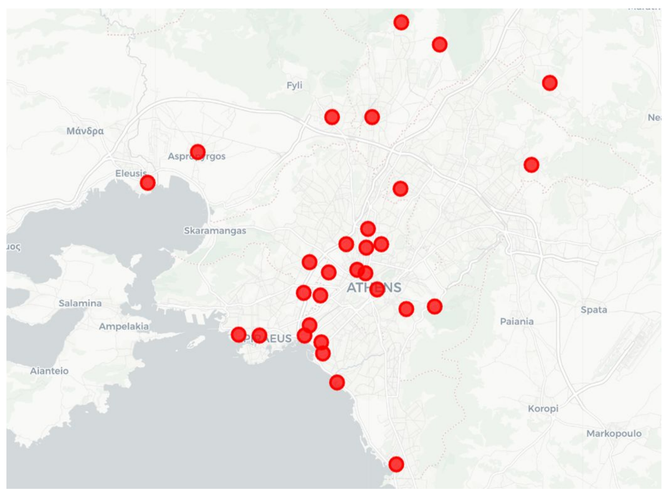

Figure 1. Spatial distribution of the 30 Athens study sites

What does “unmuting” mean?

- Heritage structures cannot communicate early distress.
- Satellite observations reveal subtle changes in movement, moisture, surface and pollution.
- AI combines these signals and converts them into an interpretable risk trajectory.

Results

The resulting hybrid **CNN-LSTM** architecture extracts spatial 'fingerprints' from satellite image chips while modeling **temporal dependencies of risk**.

By formulating decay as a probabilistic regression problem, the model achieved *rapid stabilization* (MSE loss) within 10 epochs. This enables a **ranked risk scoring system** to identify 'unmuted' hotspots requiring priority inspection.

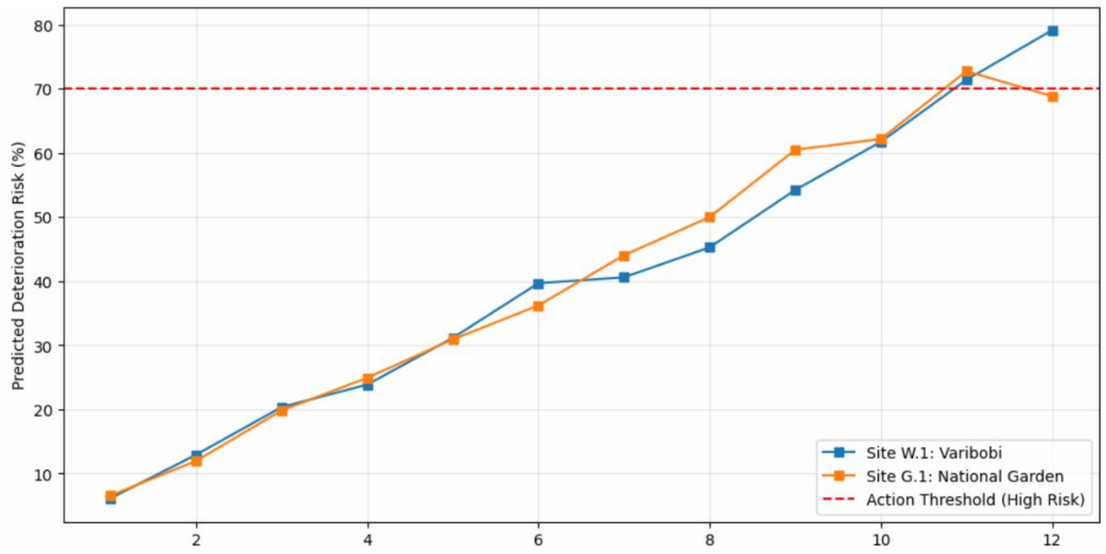

Figure 2. 12-Month deterioration-risk trajectories for selected sites

The model generates 12-month risk trajectories to help heritage managers prioritize inspections. By 'listening' to data trends, we estimate when a site may cross the Action Threshold, signalling the need for expert inspection.

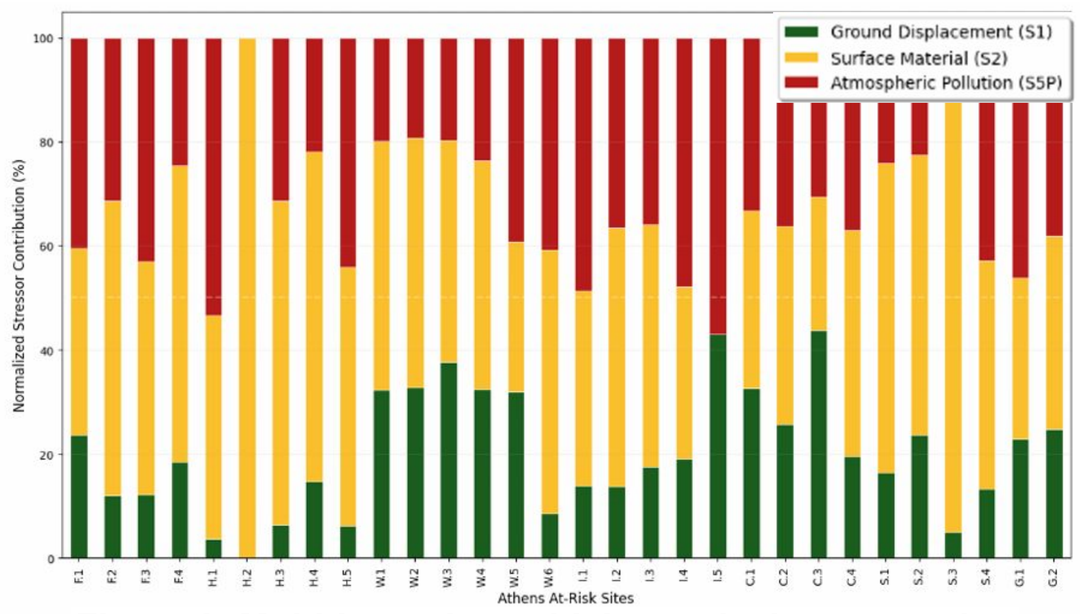

Figure 3. Multi-hazard sensitivity analysis across sites

The sensitivity analysis indicates that different satellite signals contribute differently across urban contexts. Sentinel-1 was more influential in infrastructure and flood-sensitive areas, Sentinel-5P in polluted urban/transport zones and Sentinel-2 where moisture and surface changes were crucial *[2,3]*.

Implications: *Governments can shift from 'Emergency Repair' to 'Preventive Maintenance,' providing city planners with evidence-based tools to prioritize local climate strategies, community safety and heritage education, making local environmental risks clearer to students and the wider public.*

Conclusion

By transforming monitoring into predictions and "unmuting" data signals, we shift from reactive monitoring to proactive care. This inclusive approach **helps us 'Grow Stronger Together'** to safeguard our *shared history*, supporting the long-term *well-being* and *social cohesion* of residents in resilient cities *[1]*. AI directs **attention**; heritage professionals, authorities and communities decide the **intervention**.

References

Live Demo

1. Chalkidou, S. et al. (2021). Spatially enabled web application for urban cultural heritage monitoring and management. Sustainability, 13(21), 12289.
2. Thomas, H. et al. (2025). Multi-determinant climate change risk assessment for heritage: A review of current approaches and future needs. Climate Services.
3. Cuca, B. (2023). Monitoring damage to cultural heritage across Europe using Earth Observation techniques. Remote Sensing, 15(15), 3748.

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