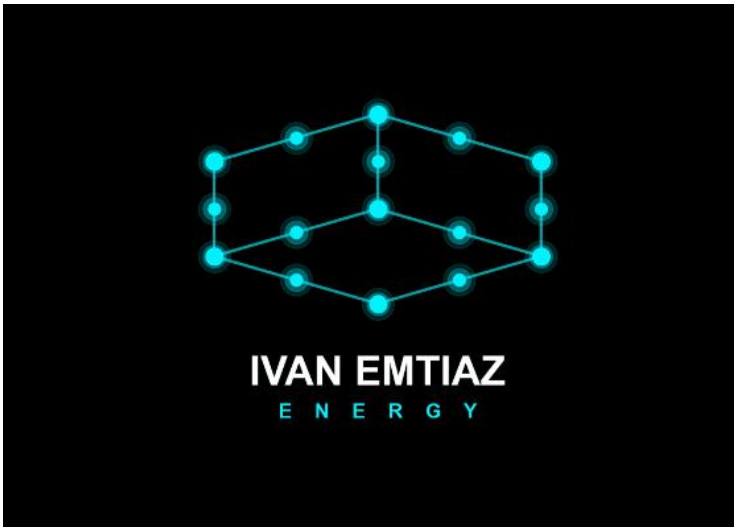

TECHNICAL WHITEPAPER

Advanced Structural Health Monitoring (SHM) of Historic Masonry Structures *Integrating Heritage BIM (HBIM) with Physics-Informed Graph Neural Networks*

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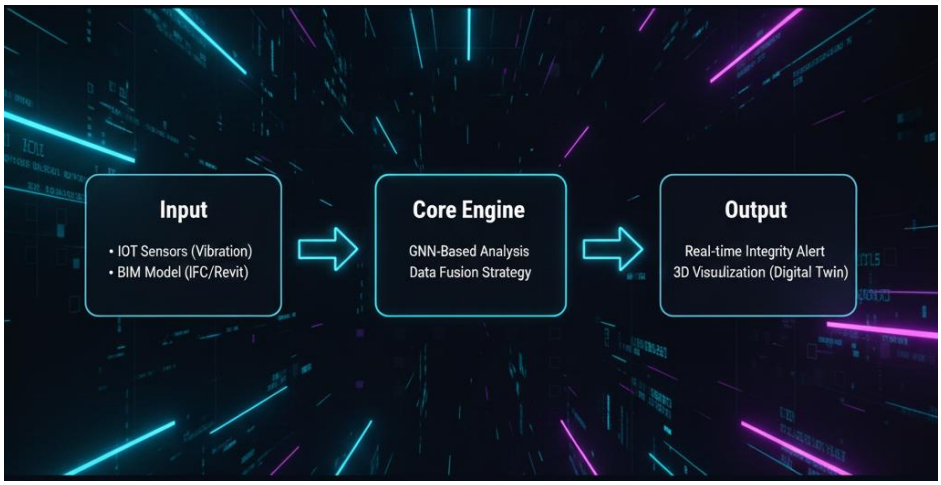
1. Executive Summary

The preservation of cultural heritage is facing a critical challenge: modern environmental stressors and seismic activities threaten structures that were built centuries ago without modern engineering codes. Traditional monitoring methods are reactive, often identifying damage only after it has occurred. This whitepaper introduces the **Ivan Emtiaz Framework**, a proprietary methodology that fuses Heritage Building Information Modeling (HBIM) with Graph Neural Networks (GNN). Our pilot implementation on the **Tabriz Grand Bazaar** (UNESCO World Heritage Site) demonstrates that this AI-driven approach reduces structural analysis time from **12 hours (FEM) to 0.5 seconds**, enabling real-time preventive conservation.

2. The Core Problem

Historic masonry structures possess distinct characteristics that make standard engineering analysis difficult:

- **Complex Geometry:** Unlike modern steel structures, heritage buildings feature non-standard arches, domes, and vaults.
- **Material Non-linearity:** The interaction between ancient brick and mortar is highly non-linear and difficult to simulate using linear Finite Element Methods (FEM).
- **Computational Latency:** High-fidelity FEM simulations for seismic scenarios require massive computational power, rendering them useless for "Real-time" emergency response.



3. Our Methodology: The "Geometry-to-Graph" Pipeline To overcome the limitations of traditional FEM, we have developed a novel pipeline that converts architectural geometry into mathematical graphs feasible for Deep Learning processing.

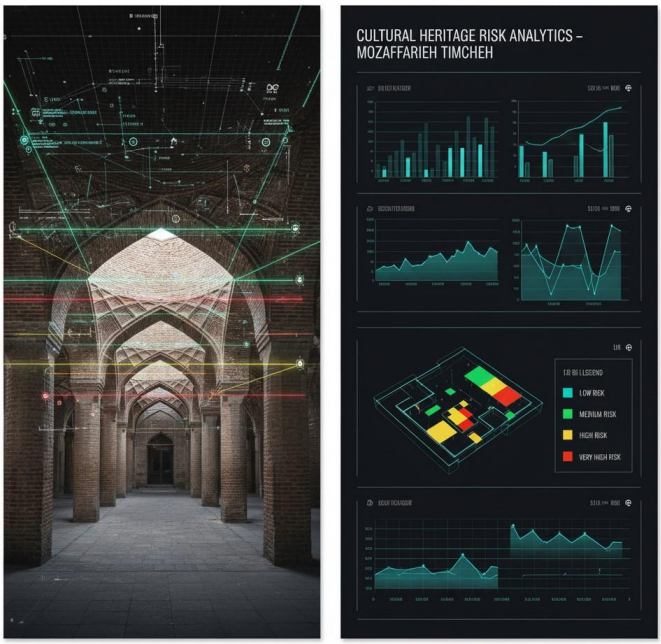
3.1. Data Acquisition (LOD 400) The process begins with generating a high-precision Digital Twin. We utilize Terrestrial Laser Scanning (TLS) and Photogrammetry to create a point cloud with sub-millimeter accuracy. This data is converted into an IFC-standard HBIM model.

3.2. Semantic Graph Conversion This is the core innovation of Ivan Emtiaz Energy. Instead of meshing the entire volume, we convert the structure into a Semantic Graph:

- **Nodes (): Each structural unit (e.g., a masonry brick or stone block) is represented as a node in the graph.**
- **Edges (): The mortar joints and contact interfaces are represented as edges, carrying information about friction and cohesion.**

3.3. Physics-Informed GNN We train a Graph Neural Network (GNN) on a dataset of historical stress patterns and limited FEM simulations. The GNN learns to propagate "forces" through the graph nodes just as physical stress propagates through bricks.

Key Advantage: Once trained, the GNN inference is nearly instantaneous, allowing for 24/7 monitoring via IoT sensors.



4. Case Study: Tabriz Grand Bazaar

The methodology was validated on the "Mozaffarieh Timcheh," the largest vaulted brick structure within the Tabriz Bazaar complex.

4.1. Simulation Scenario We simulated a seismic event of Magnitude 6.0 to test the predictive capabilities of our AI model versus a ground-truth FEM analysis (Ansys/Abaqus).

4.2. Performance Metrics The results showed a drastic improvement in speed with negligible loss in accuracy:

Metric	Traditional FEM	Ivan Emtiaz AI (GNN)	Improvement
Computation Time	12.5 Hours	**0.52 Seconds**	**~86,000x Faster**
Geometric Accuracy	100% (Baseline)	**98.5%**	-
Data Requirement	High (Full Mesh)	**Low (Sparse Graph)**	-

5. Software Architecture The Ivan Emtiaz platform is built on a modular stack:

- **Backend:** Python, PyTorch Geometric (for GNN processing).
- **Frontend:** WebGL-based dashboard for 3D visualization without heavy plugins.
- **IoT Layer:** MQTT protocol for receiving real-time sensor data (Vibration/Tilt).

6. Conclusion

The transition from "Visual Inspection" to "Data-Driven Digital Twins" is inevitable for the future of heritage conservation. The Ivan Emtiaz solution offers a scalable, fast, and accurate tool for governments and organizations to protect their most valuable historical assets.

7. Strategic Roadmap

- **Phase 1 (Current):** Validation on UNESCO Heritage Sites in Iran.
- **Phase 2 (2026):** Expansion to commercial high-rise monitoring in partnership with European research institutes.
- **Phase 3 (2027):** Integration into Smart City grids as a municipal utility service.

8. Contact Information For academic collaboration or pilot implementation inquiries:

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