

Networked AI Framework for Systemic Cultural Heritage Archiving and Preservation

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Abstract

This proposal presents an innovative framework for cultural heritage documentation aiming to overcome the multifaceted threats that face cultural heritage sites. The complex interdependencies between heritage sites (e.g., archaeological, religious, and cultural) are modeled in the form of a network model. This model includes nodes (sites) and edges (shared history or geography). Then, Graph Neural Networks (GNNs) and Generative Adversarial Networks (GANs) are used to simulate degradation, prioritize conservation efforts, and generate high-fidelity 3D reconstructions from fragmented data. Preliminary results show that this networked approach identifies critical "keystone" sites whose preservation is essential for maintaining the integrity of the entire heritage ecosystem. The accuracy of GNN is 87% in predicting secondary damage patterns. The GAN successfully generates 3D reconstructions (20% of original scan data).

1. Motivation

The motivation behind this research comes from the critical need for documenting the cultural heritage at risk. In countries such as Iraq, most of tangible cultural heritage is facing threats due to many reasons (e.g., conflicts, weather conditions, and lack of knowledge). Most of the available documentation approaches are considered reactive and concentrate on individual heritage sites. Therefore, there is a need to adopt approaches that transform the documentation process from being reactive into a proactive and smart that considers the relations among different heritage sites. Also, it is needed to promote community engagement through the documentation process to include the significant heritage that represents the diverse Iraqi communities. Transparency and digital ethics are also required to verify the documentation process. This kind of approaches is critically needed not only for a particular community (e.g., in Iraq), but also for worldwide communities.

2. Problem Statement

According to the literature, there is a severe lack of a systemic framework that understands and manages the complex interdependent nature of cultural heritage. Threats do not frequently occur in isolation since a damage in a site can have cascading effects on community identity and the perceived value of related sites [1]. Furthermore, the data of many sites is incomplete, fragmented, or exists in disparate formats (e.g., 2D images, 3D scans, oral histories) [2]. Therefore, the research question in this work is how can we model these interdependencies and predict systemic vulnerabilities into actionable preservation strategies?

3. Research Method

The approach followed in this proposal is to start with generating a network model for Iraqi heritage sites, as a case study. Then, a deep

analysis on this model is performed using network and AI approaches. The general workflow of this research can be summarized as follows: 1) Data collection, 2) Network generation and modeling, 3) Network analysis and visualization, 4) GNN development and training, 5) Threat propagation simulation, 6) GAN development of 3D reconstruction, and 7) Validation and evaluation, and results analysis.

The nodes of the network model represent the significant Iraqi cultural heritage sites. The selection of the sites is based on several criteria such as UNESCO world heritage status, national heritage designation, historical significance spanning multiple eras, cultural importance to contemporary communities, and current threat status. The preliminary dataset comprises 20 sites across Iraq. These sites are categorized by historical period (e.g., Sumerian, Akkadian, Babylonian, Assyrian, etc.), site type (archaeological, architectural, religious, museum, cultural landscape), and current condition. On the other hand, the edges among nodes are created based on the relationships between sites (e.g., geographic proximity, historical link, cultural/religious significance, material vulnerability similarity, and archival co-occurrence). The total edge weight between sites i and j is given by:

$$w_{ij} = \alpha_g w_g + \alpha_h w_h + \alpha_c w_c + \alpha_m w_m + \alpha_a w_a \quad (1)$$

Where α denotes the coefficients sum to 1 and are tuned based on validation against historical relationships.

Furthermore, after generating the network model, GCN is involved for vulnerability prediction and modeling threat propagation. In this context, each site is featured by site age, current condition score, material, threat exposure score, conservation resources allocated, documentation completeness. For 3D reconstruction from fragmented data, the cGAN is used [3]. It takes partial point cloud data as input and generates complete 3D reconstructions. The architecture of the model includes the following layers:

- Input Layer that represents node feature vector.
- Hidden Layer 1, which includes 1 to 128 nodes with ReLU activation.
- Hidden Layer 2 that comprise 2 to 64 nodes with ReLU activation.
- Graph Convolution Later, which is two layers with 32-dimensional embeddings.
- Output Layer, which is the vulnerability score from 0 to 1 for each node.

It should be mentioned that the model is trained on historical damage data, in which the edges are defined by the network model. For the training, 70% was used, while 15% for validation, and 15% for testing.

4. Results

The generated Iraqi heritage sites network model exhibits complex connectivity patterns that are previously implicit but never documented in a systematic approach. Figure 1 depicts the preliminary network visualization. The nodes are colored by historical period and the edges thickness represent the strength of the relation between two sites (nodes). Network characteristics show that node degree follows a power-law distribution. This means the network has a few hubs (sites) and many peripheral sites. The top hubs observed

are; Babylon, followed by, Baghdad, Nineveh, Samarra, and Ur. Moreover, the modularity analysis shows four main communities; Community A (Southern Mesopotamia), Community B (Northern Mesopotamia), Community C (Islamic Heartland), and Community D (Kurdistan Region). This community structure reflects historical geopolitical boundaries but also shows unexpected connections. For example, there are strong ties between Hatra (Parthian) and Samarra (Abbasid) through shared architectural traditions in defensive structures.

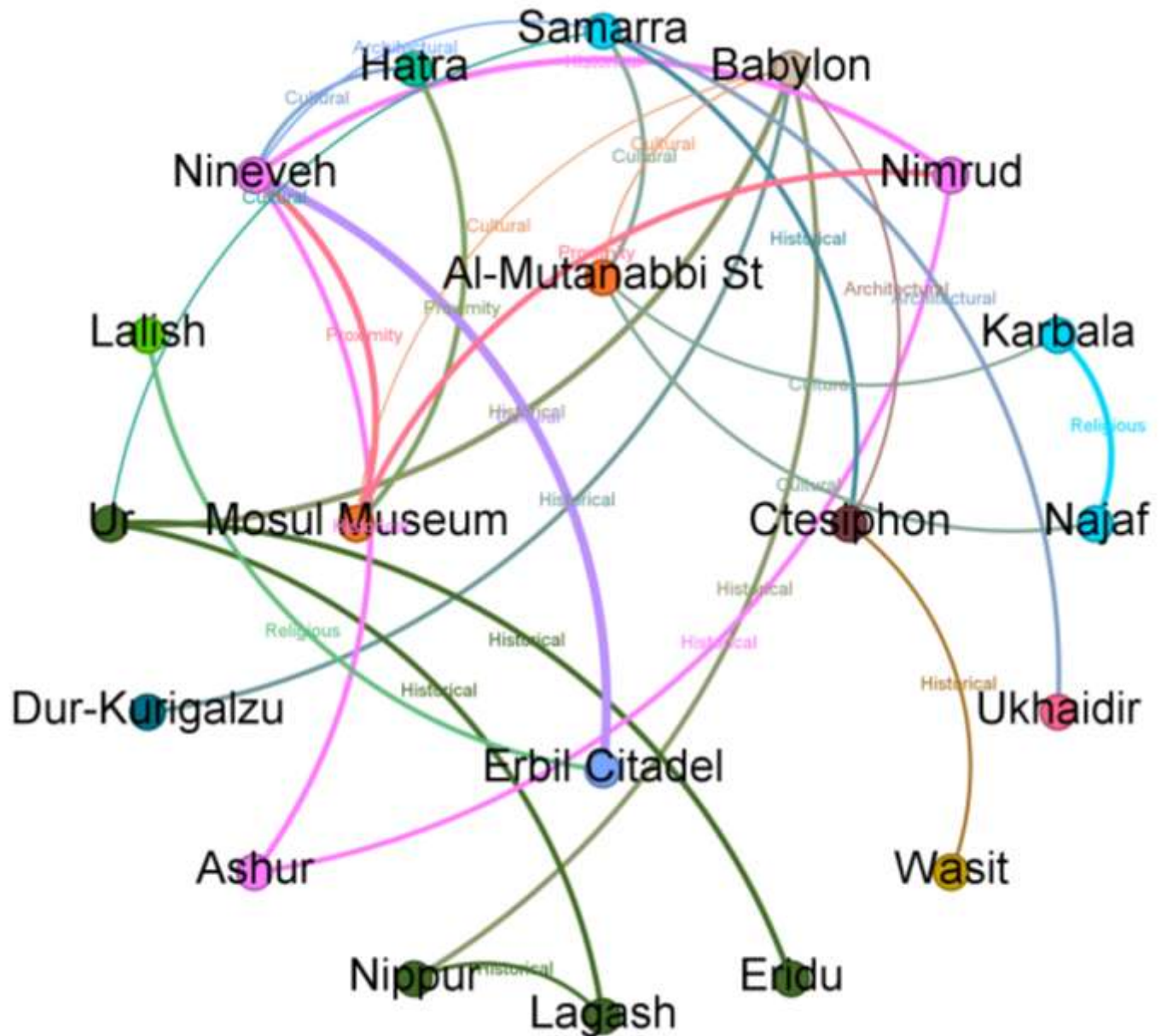


Figure 1. Visualization of Iraqi heritage sites. Nodes are colored by historical period, edge weight represents the strength of the connection

Additionally, the GNN model was trained to predict vulnerability propagation from threat sources. The predicted vulnerability distribution when a threat is simulated at Babylon is shown in Figure 2. The model achieved 87.3% accuracy in predicting secondary damage patterns on the test set. The accuracy of GNN outperformed Random Forest (71.2%), Logistic Regression (65.8%), and Proximity-only propagation (59.4%). This means that network structure is important in understanding threat propagation. Sites that are historically/culturally connected to threat sources show elevated vulnerability even when geographically distant, while geographically close but culturally unrelated sites show lower than expected vulnerability. An extended analysis on the threat propagation was also from multiple sources (Babylon, Mosul Museum, Nineveh, Samarra) on all heritage sites aiming at showing a wider view of systematic vulnerability across the network (see Figure 3). We also identified the top "keystone" sites (e.g., nodes whose removal would maximize network fragmentation). This identification process is based on the

fragmentation score as follows: Baghdad (0.82), Babylon (0.79), Nineveh (0.74), Samarra (0.68), and Mosul Museum (0.65).

The conditional GAN was tested on simulated damage scenarios where portions of scans were removed. The reconstruction quality was evaluated using Chamfer Distance, Earth Mover's Distance, and IoU (Intersection over Union). The model showed high efficiency at high damage levels. It maintains (IoU > 0.7) at 50% missing data (see Table 1). Also, the performance was better for artifacts with strong network connections. It is worth to mention that when network context embeddings were removed from the model, Chamfer distance increased by an average of 32%. This means that relational information improves generative reconstruction. Human intervention is the final step that evaluates and validates the AI-assisted decisions, as the community can contribute to their shared heritage.

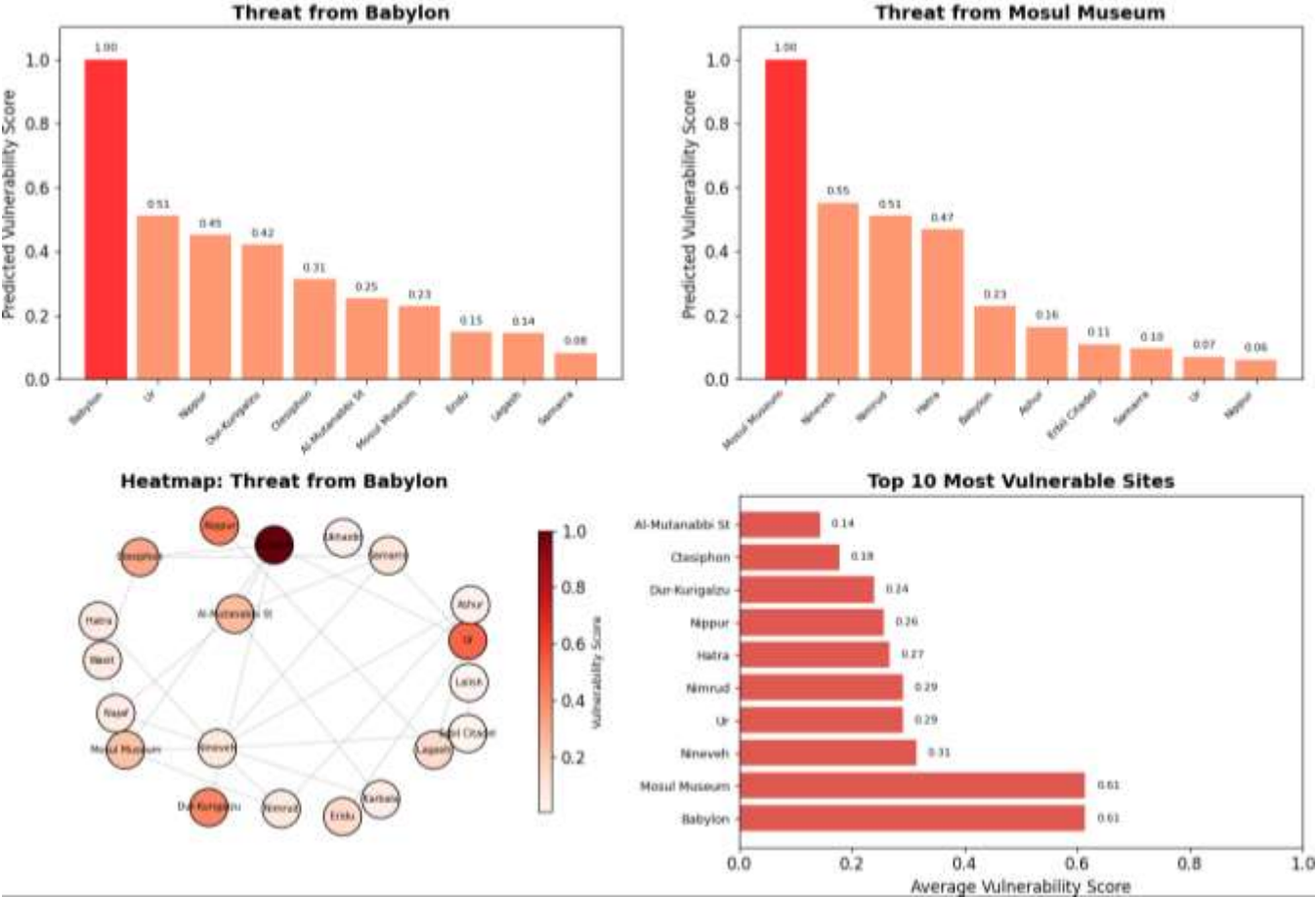


Figure 2. Threat propagation analysis (top left) represents the threat from Babylon, (top right) the threat from Mosul Museum, (bottom left) the heatmap from the impact of Babylon, and (bottom right) the top most vulnerability sites

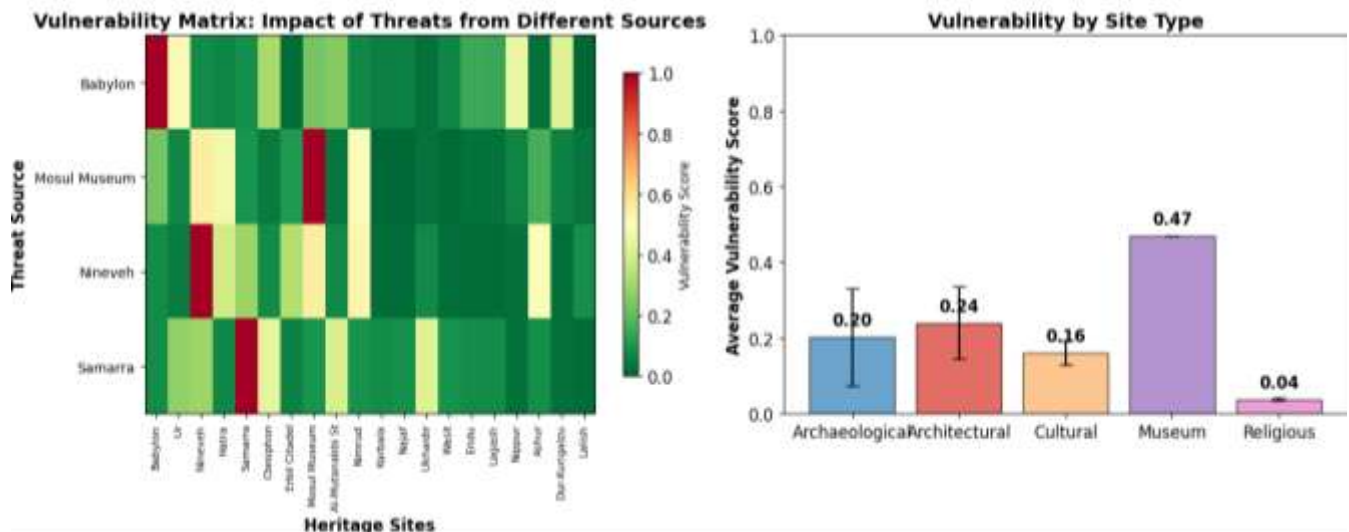


Figure 3. Comprehensive Threat Vulnerability Assessment. The subplot on the left shows the vulnerability matrix of the impact of threats from multiple sources. The subplot of the right shows the vulnerability by site type.

Table 1: Reconstruction quality over different levels of damage levels.

Damage Level	Chamfer (mm)	Distance	EMD	IoU
10% missing	0.47		0.12	0.94
20% missing	0.68		0.18	0.89
30% missing	0.92		0.24	0.85
40% missing	1.24		0.31	0.79
50% missing	1.67		0.39	0.73

5. Conclusions

This proposal suggests an innovative framework that integrates network science with AI approaches to overcome the issue of multifaceted threats of cultural heritage sites. The preliminary results showed that this integration can be considered a paradigm shift in cultural heritage documentation and preservation. Using such an approach enables stakeholders to move from protecting individual artifacts to safeguarding an interconnected cultural ecosystem. Also, this approach promotes community connections and make sure that transparency exists in AI-assisted decision-making for the preservation of the shared, diverse global heritage.

References

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Author Biography

Basim Mahmood received his Ph.D. degree in Computer Science from Florida Institute of Technology, USA, in 2015. He is currently the head of the Computer Science Department at the University of Mosul. His research interests focus on Complex Networks and Systems. He is also interested in the area of digitalizing and preserving cultural heritage.

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Julia Schnitzer is Professor of Interaction Design in the Department of Computer Science and Media at Brandenburg University. Her research focuses on user-centered design of interactive environments. As part of the UNESCO Chair on the Digitalization of Cultural Heritage in MENA Regions at Risk, she has explored efficient low-cost photogrammetry workflows. Since March 2026, she has served as Vice President for Education and Internationalization.