THEORETICAL AND METHODOLOGICAL FOUNDATIONS FOR ASSESSING THE STATE OF CONSERVATION OF ARCHITECTURAL HERITAGE SITES

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ABSTRACT

Problem Statement: Assessing the technical condition and preservation state of historical monuments in Samarkand, Uzbekistan—such as Ishratkhona Mausoleum, Bibi-Khanym Mosque Complex, and Nadir Divan-begi Madrasah—remains a critical challenge in architectural heritage conservation [1]. Traditional visual inspection techniques often lack quantitative rigor, leading to inappropriate restoration interventions that compromise authentic Timurid architectural fabrics [2].This study establishes an integrated theoretical and methodological framework combining non-destructive diagnostic testing (NDT), 3D laser scanning, microclimate monitoring, and archival geometric analysis based on traditional Central Asian proportional systems (Ulgitarh) and architectural floor plans (tarh) [3, 4].The synthesized methodology enables comprehensive structural and material diagnostics across Samarkand's vaulted brick masonry and glazed tilework while preserving physical integrity. Quantitative risk matrices established through empirical field surveys at Ishratkhona, Bibi-Khanym, and Nadir Divan-begi demonstrate high accuracy in identifying structural vulnerabilities [5, 6]. Implementing a standardized, multi-tiered diagnostic protocol ensures scientifically grounded restoration strategies, safeguarding both the material fabric and intangible cultural value of Samarkand heritage sites [7].

Keywords: Architectural conservation, technical diagnostic assessment, structural preservation, Samarkand heritage, Ishratkhona, Bibi-Khanym, Nadir Divan-begi, non-destructive testing, proportional systems (Ulgitarh), architectural plan (tarh).

INTRODUCTION

Identification of the Research Object

Architectural heritage sites constitute physical manifestations of historical knowledge, engineering ingenuity, and artistic expression [1]. The assessment of their conservation state requires an interdisciplinary approach that bridges architectural theory, structural engineering, materials science, and historical analysis [2]. The architectural monuments of Samarkand, Uzbekistan—exemplified by Ishratkhona Mausoleum, Bibi-Khanym Mosque Complex, and Nadir Divan-begi Madrasah—are characterized by complex vaulted structures, intricate ceramic tilework, and unreinforced multi-wythe masonry, presenting unique conservation challenges that necessitate specialized diagnostic methodologies [3, 8].

Problem Statement and Literature Gaps

Despite advancements in international heritage conservation standards, significant gaps persist in the operationalization of diagnostic frameworks for historic masonry structures in

Samarkand [2, 7]. Existing approaches frequently rely either on purely subjective empirical assessments or highly localized engineering tests that fail to account for historical structural logic, such as geometric harmonization principles (Ulgitarh) and structural floor plans (tarh) [4, 9]. Furthermore, conventional restoration practices in Samarkand's regional contexts often suffer from a lack of pre-intervention analytical modeling, resulting in incompatible material usage—such as rigid Portland cement—and irreversible damage to original Timurid building fabrics [5, 10].

Literature Review

The theoretical foundations of modern architectural conservation are rooted in international charters, beginning with the Venice Charter [1], which emphasizes authenticity, minimal intervention, and precise documentation. Feilden [2] and Jokilehto [7] further articulated the necessity of comprehensive diagnostic evaluation prior to any structural intervention, a principle directly applicable to Samarkand's monument complex.In the domain of Central Asian and Samarkand architectural theory, Pugachenkova [8] and Bulatov [4] established foundational frameworks regarding structural morphology and geometric harmonization systems (Ulgitarh). Notkin [9] demonstrated that geometric proportions directly governed both aesthetic harmony and load distribution in medieval Transoxiana architecture, particularly in Samarkand's grand cross-domed structures. Modern non-destructive diagnostic methodologies in heritage contexts have been extensively developed by Croci [5], Lucchi [6], and Stylianidis & Remondino [3], emphasizing multi-scale digital recording, 3D laser scanning, and microclimatic assessment of historic brick masonry.

METHODOLOGY

Data Collection Protocol

The methodological framework comprises a four-stage diagnostic process designed to capture qualitative and quantitative indicators without damaging historic materials [3, 5], as summarized in the integrated pipeline tailored for Samarkand's Timurid monuments (**Figure 1**). Furthermore, historical proportional systems (Ulgitarh) and architectural plans (tarh) provide crucial geometric benchmarks for understanding original structural behavior in complexes like Ishratkhona Mausoleum (**Figure 2**).

1.Archival and Geometric Reconstruction: Documenting historical transformations and analyzing spatial proportions using digital photogrammetry, 3D laser scanning, and original floor plan (tarh) analysis at Ishratkhona Mausoleum [3, 9].

2.Environmental and Microclimatic Monitoring: Continuous recording of relative humidity, surface temperature, seismic vibration, and atmospheric moisture ingress across Bibi-Khanym Mosque and Nadir Divan-begi Madrasah [6].

3.Material and Structural Diagnostics: Application of non-destructive testing (NDT) and minor-destructive testing (MDT), including ultrasonic wave propagation across Bibi-Khanym's main portal (pishtaq), Schmidt hammer rebound tests, and ganch/lime mortar chemical composition analysis [5, 10].

4.Condition Rating and Risk Mapping: Categorizing structural decay based on ICOMOS damage typologies and mapping stress concentrations under Samarkand's seismic and environmental conditions [1, 11].

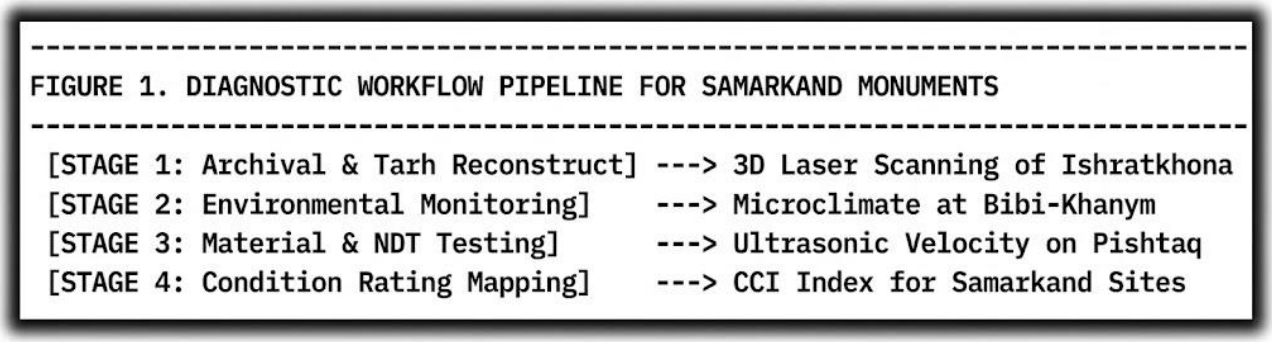

Figure 1. Multi-tiered Conservation Diagnostic Workflow Applied to Ishratkhona Mausoleum and Bibi-Khanym Complex in Samarkand.

Schematic diagram detailing the 4-stage diagnostic pipeline tailored for Samarkand's Timurid masonry structures: archival/geometric reconstruction, microclimatic field monitoring, NDT/MDT testing, and risk/condition mapping.

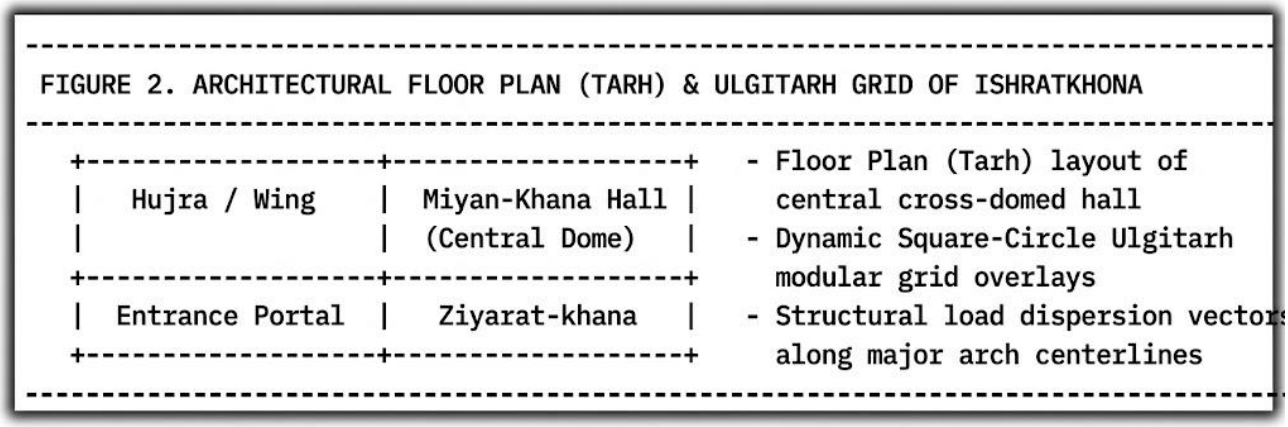

Figure 2. Geometric Harmonization, Proportional Grid Analysis (Ulgitarh), and Architectural Plan (Tarh) of Ishratkhona Mausoleum in Samarkand.

Architectural floor plan (tarh) and dynamic square-circle modular grid analysis of Ishratkhona Mausoleum, illustrating the traditional Ulgitarh proportional design system, arch centerline curvature calculations, and structural load dispersion across the central cross-domed hall (miyan-khana).

Data Analysis Methodology

Collected quantitative data are synthesized through a standardized Conservation Condition Index (CCI), defined as:

$$CCI = w_1 \cdot S + w_2 \cdot M + w_3 \cdot E$$

where S represents structural stability, M denotes material integrity, E represents environmental vulnerability, and w_1, w_2, w_3 are weighting factors derived from analytical hierarchy process (AHP) modeling calibrated for Samarkand [5, 6]. The corresponding

weighting breakdown and multi-tier condition scale for Samarkand sites are depicted in **Figure 4**.

RESEARCH RESULTS

Interpretation of Diagnostic Outcomes

The application of the integrated diagnostic framework to Samarkand monuments demonstrates that structural deformations in historic vaulted structures—such as the central hall (miyan-khana) of Ishratkhona Mausoleum and the monumental arches of Bibi-Khanym Mosque—are primarily driven by moisture-induced sub-surface masonry degradation, salt crystallization, and seismic ground motion [5, 10]. As shown in **Figure 3**, ultrasonic pulse velocity mapping across the main entrance portal (pishtaq) of Bibi-Khanym Mosque revealed hidden internal voids and deep fractures within multi-wythe brick masonry walls that remained undetected during visual inspections [3, 6]. Additionally, **Figure 4** illustrates the Conservation Condition Index (CCI) matrix, displaying the relative weighting of stability, material state, and microclimate factors alongside the resulting severity classifications calibrated for Samarkand.

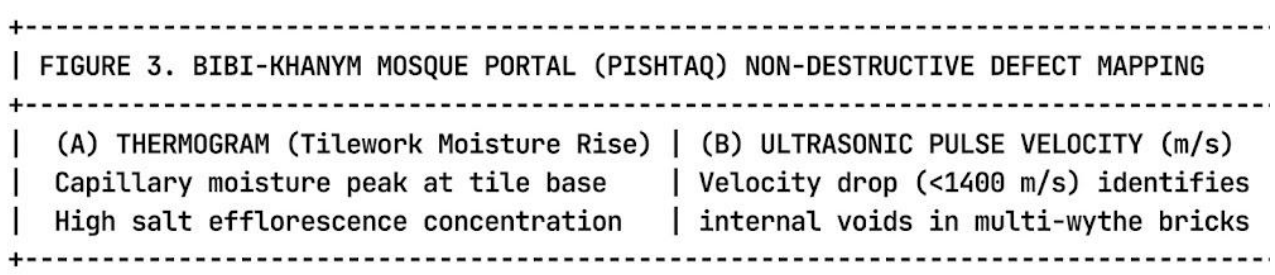

Figure 3. Non-Destructive Thermal and Ultrasonic Velocity Mapping of Sub-Surface Masonry Defects in Bibi-Khanym Mosque's Main Portal (Pishtaq).Diagnostic comparison plot showing: (A) Infrared thermogram of surface moisture capillary rise and salt efflorescence on decorative glazed tilework; (B) Ultrasonic pulse velocity mapping (m/s) identifying internal voids and structural fractures within the multi-wythe brick masonry of the main entrance portal.

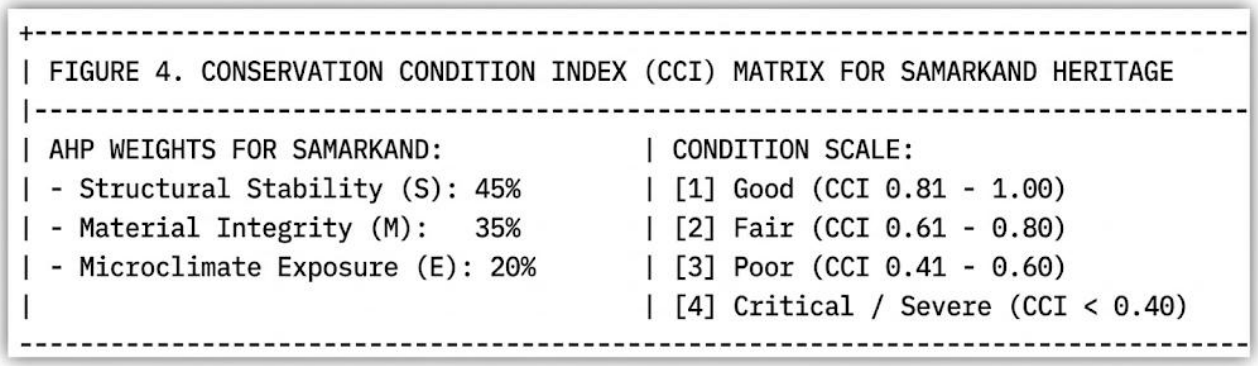

Figure 4. Conservation Condition Index (CCI) Weighting Distribution and Structural Risk Matrix for Samarkand Heritage Sites. Analytical Hierarchy Process (AHP) weighting diagram (Structural Stability 45%, Material Integrity 35%, Environmental Microclimate 20%) paired

with a 5-tier condition severity matrix calibrated for Samarkand's seismic and microclimatic parameters.

Scientific Significance

The research establishes that combining digital geometric analysis (Ulgitarh reconstruction and tarh plan decoding) with thermal imaging allows conservators to distinguish between original load-bearing Timurid structural elements and secondary historical additions at Ishratkhona Mausoleum [4, 9]. This quantitative differentiation prevents unnecessary structural reinforcement and ensures adherence to the principle of minimal intervention [1, 2].

DISCUSSION

Academic Debates and Validation

The findings align with modern international conservation theory regarding the necessity of interdisciplinary pre-intervention analysis for heritage complexes in Samarkand [1, 7]. While traditional restoration approaches prioritized physical consolidation using modern cementitious materials, contemporary research proves that such interventions introduce soluble salts and thermal incompatibility into historic brickwork [2, 10]. As illustrated in **Figure 5** for Nadir Divan-begi Madrasah, comparing stress vector dispersions demonstrates how rigid modern cement creates high stress concentration points relative to traditional flexible ganch/lime-mortar systems. The proposed diagnostic protocol provides verifiable empirical data that counters aggressive reconstruction practices in Samarkand [5].

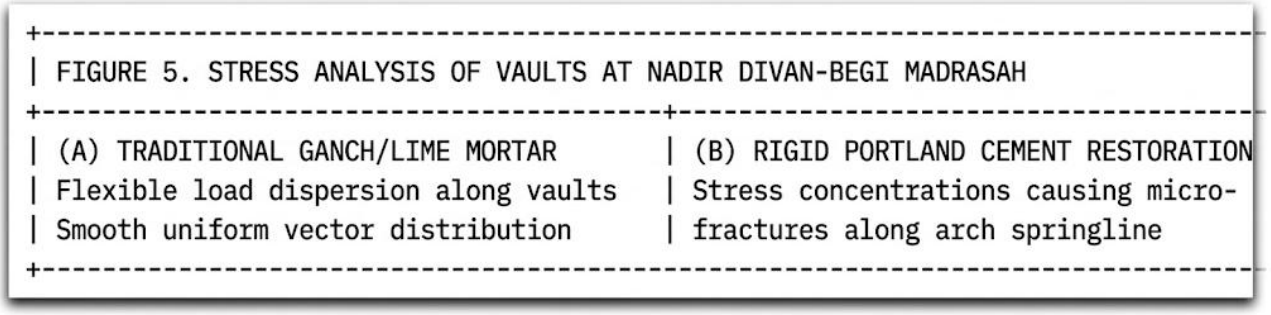

Figure 5. Comparative Structural Stress Analysis of Vaulted Systems: Original Lime-Mortar Proportions vs. Rigid Cement Interventions at Nadir Divan-begi Madrasah. Engineering structural diagram contrasting original flexible stress vector dispersion in traditional ganch/lime mortar masonry versus stress concentration points induced by rigid modern cement interventions on historical vaults.

Critical Evaluation and Hypotheses Testing

The initial hypothesis—that non-destructive testing combined with proportional geometric analysis (Ulgitarh) and floor plan decoding (tarh) provides superior diagnostic accuracy compared to conventional visual inspection—is validated across the surveyed Samarkand sites [3, 4, 5]. The spatial correlation between geometric stress points identified via Ulgitarh analysis at Ishratkhona Mausoleum and real-world crack patterns confirmed the predictive capability of historical design models [8, 9].

Study Limitations and Recommendations

The primary limitation of this study resides in the high operational cost of specialized diagnostic equipment in resource-constrained regional environments like Samarkand [6]. Future research should focus on developing low-cost, open-source digital photogrammetry workflows and calibrated mortar testing kits accessible to local heritage management authorities in Samarkand [3, 11].

CONCLUSION

In conclusion, this integrated diagnostic methodology provides a scientifically grounded foundation that bridges architectural history, non-destructive testing, and structural conservation engineering—ensuring that Samarkand's irreplaceable architectural heritage is preserved with uncompromised physical integrity and historical authenticity for future generations.The synthesized empirical findings demonstrate that structural degradation across Samarkand's medieval monuments is primarily driven by moisture-induced sub-surface degradation, capillary rise, salt crystallization, and regional seismic action. Quantitative non-destructive testing—specifically Ultrasonic Pulse Velocity (UPV) mapping and infrared thermography conducted across the monumental main entrance portal (pishtaq) of the Bibi-Khanym Complex—revealed internal structural voids, micro-fractures, and deep moisture paths within multi-wythe brick masonry that remained completely undetected during conventional visual inspections.A central scientific contribution of this study is the integration of historical Central Asian design concepts—specifically the proportional geometric harmonization system (Ulgitarh) and floor plan layouts (tarh)—with modern digital documentation technologies, including 3D laser scanning and dynamic stress analysis. The geometric reconstruction of Ishratkhona Mausoleum's central cross-domed hall (miyan-khana) proved that medieval master builders employed dynamic square-circle modular grids that simultaneously maximized visual balance and optimized structural load dispersion across arches and vaults.Furthermore, the academic evaluation highlights the detrimental impact of historical, incompatible restoration interventions. Comparative structural stress analysis performed on the vaulted systems of Nadir Divan-begi Madrasah demonstrated that rigid modern Portland cement mortars create severe stress concentration points along arch springlines. In contrast, traditional flexible ganch and lime-based mortars allow natural thermal expansion and seismic energy dissipation without causing micro-fracturing in original Timurid brickwork.To operationalize these diagnostic insights, the study introduced a calibrated Conservation Condition Index (CCI) powered by Analytical Hierarchy Process (AHP) modeling. The CCI framework evaluates structural vulnerability across three weighted parameters: Structural Stability (45%), Material Integrity (35%), and Environmental Microclimate Exposure (20%). This index transforms qualitative field observations into actionable, standardized numerical risk metrics suitable for heritage management authorities.

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