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Integrating Non-Destructive Testing with HBIM for the Preservation of Timber-Framed Masonry Heritage Structures in Switzerland

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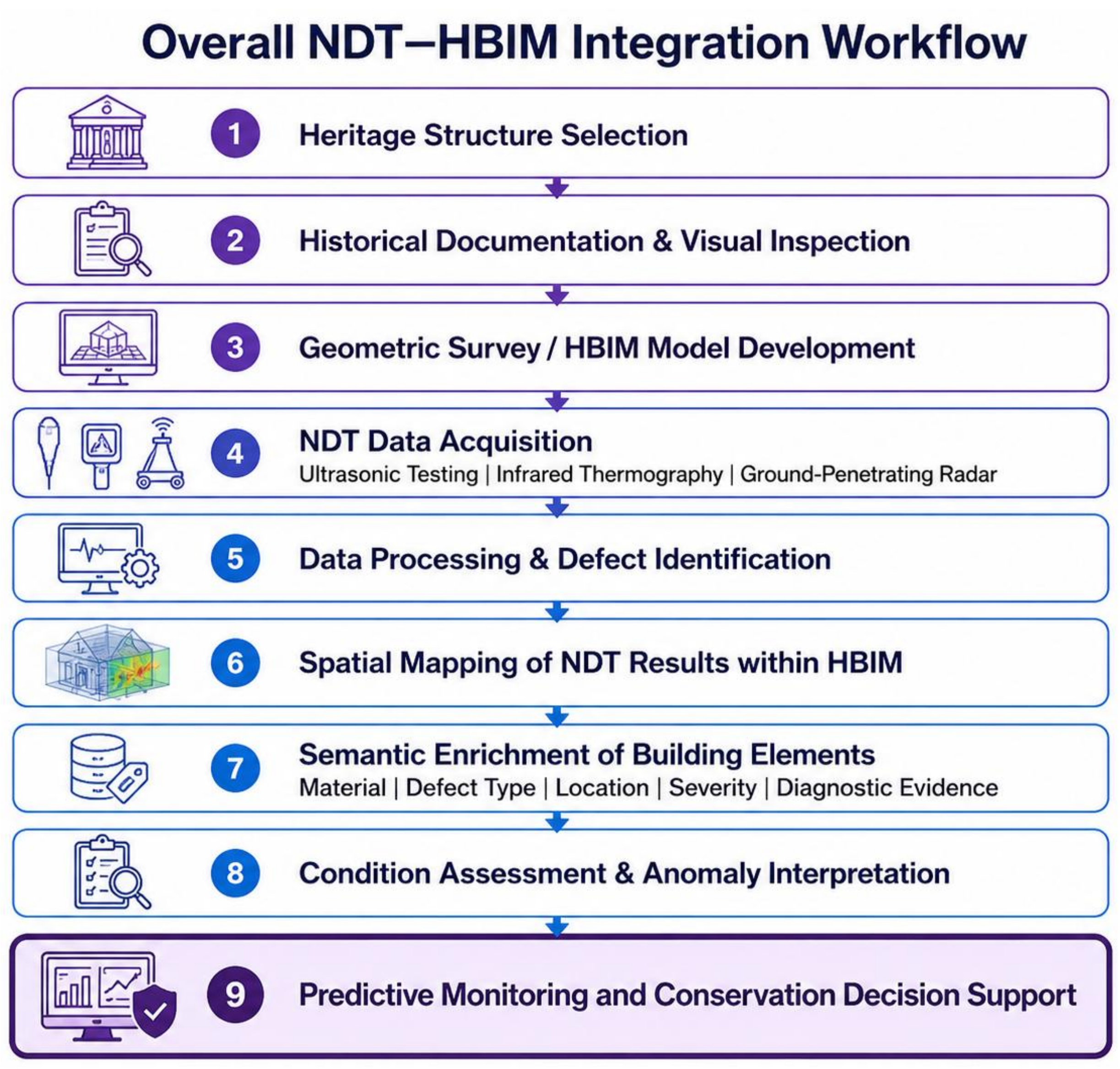
INTRODUCTION & AIM

Timber-framed masonry heritage structures are an important part of Switzerland's historic built environment, but their preservation is challenged by aging materials, hidden deterioration, moisture damage, cracking, and complex timber–masonry interactions. Although NDT methods such as ultrasonic testing, infrared thermography, and ground-penetrating radar support non-invasive diagnosis, their outputs are often fragmented and weakly integrated with digital heritage models.

This study proposes an integrated **NDT–HBIM** workflow that links documentation, geometric modeling, diagnostic data acquisition, defect mapping, semantic enrichment, and condition assessment within a unified HBIM environment. The aim is to support improved visualization, predictive monitoring, and informed conservation decision-making for timber-framed masonry heritage structures.

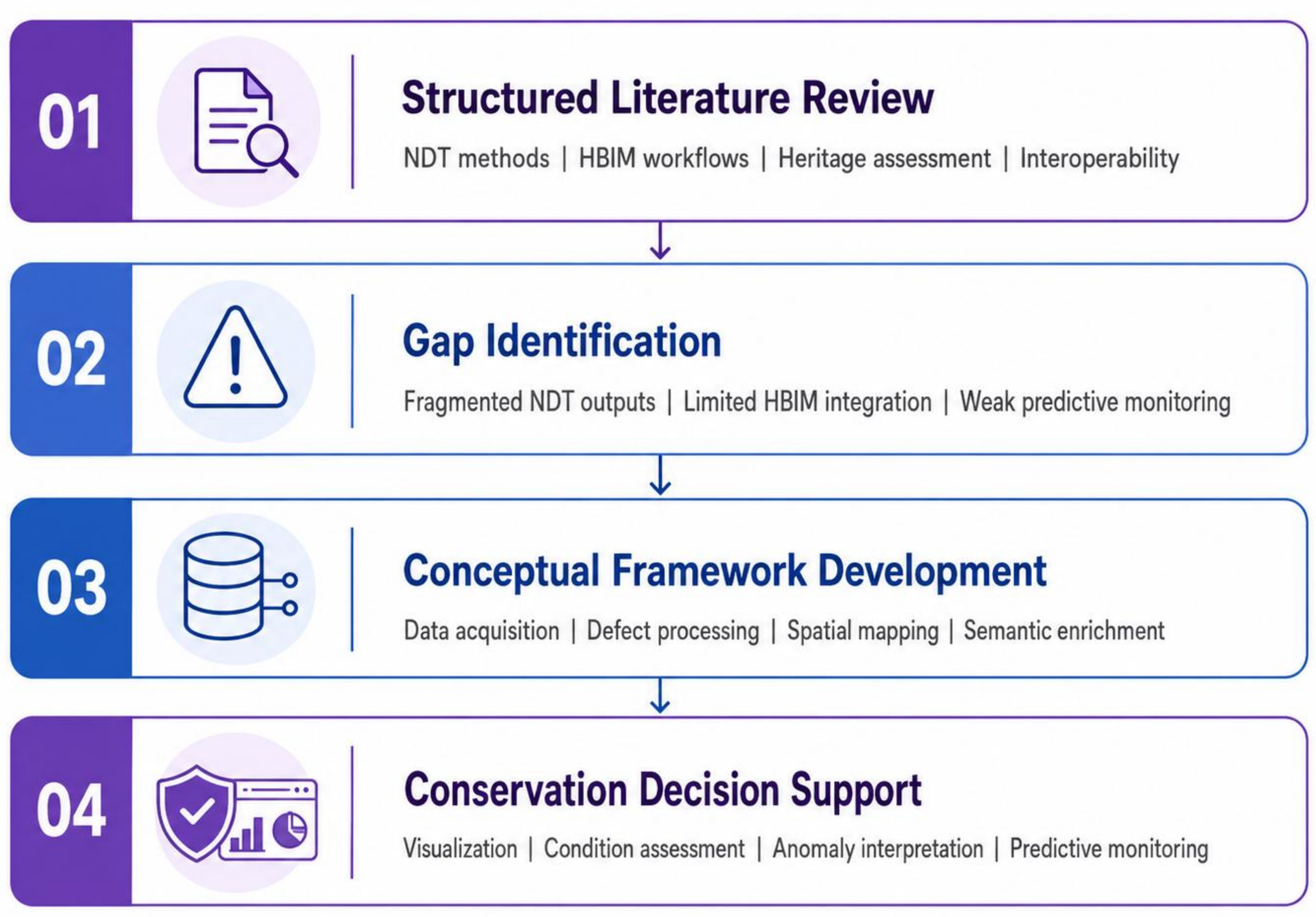


METHOD

This study adopts a structured review and framework-development methodology to examine how non-destructive testing data can be integrated with HBIM for heritage preservation. Relevant literature on NDT applications, HBIM-based heritage documentation, timber-framed masonry assessment, and digital conservation workflows was reviewed to identify current limitations in data acquisition, interoperability, visualization, and condition assessment.

Based on the identified gaps, a conceptual NDT–HBIM integration framework was developed. The framework organizes the process into four main stages: diagnostic data acquisition, data processing and defect identification, HBIM-based spatial and semantic integration, and condition assessment for conservation decision support. NDT outputs from ultrasonic testing, infrared thermography, and ground-penetrating radar are considered as heterogeneous diagnostic inputs that can be linked to HBIM elements through location, material, defect type, severity level, and diagnostic evidence.

The proposed methodology enables fragmented inspection data to be transformed into a structured digital information environment for visualization, anomaly interpretation, predictive monitoring, and proactive heritage management.



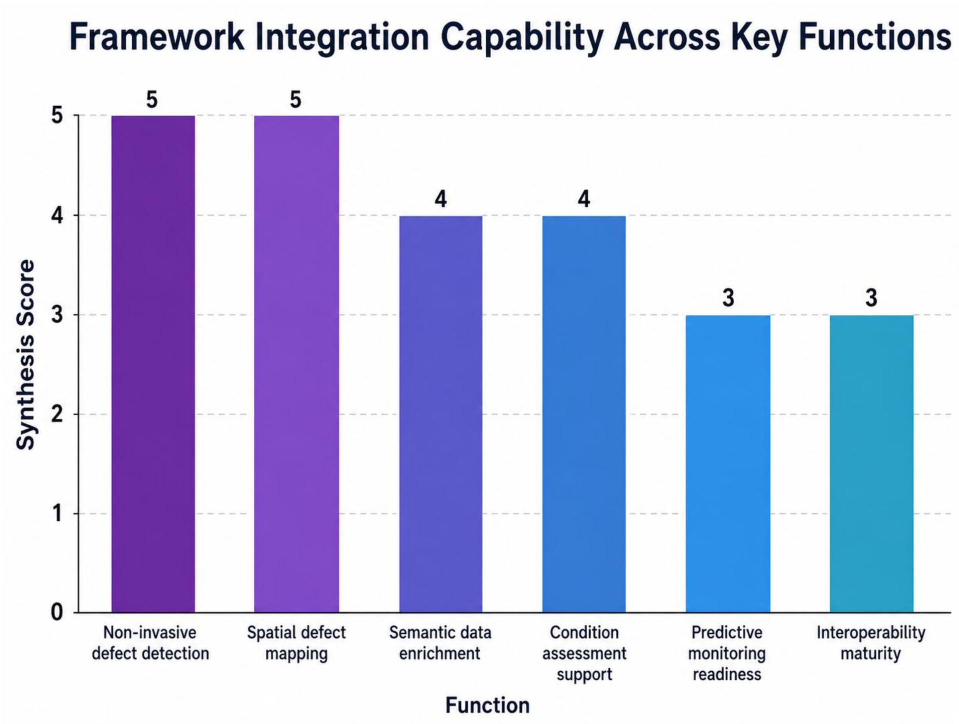
RESULTS & DISCUSSION

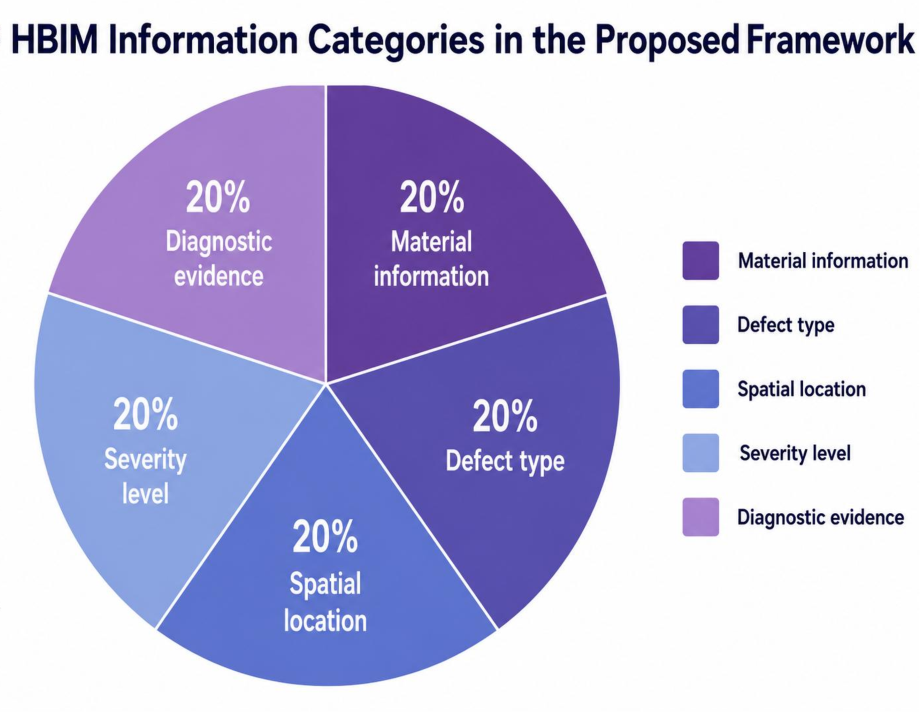
The review indicates that current heritage diagnostic workflows remain fragmented, with NDT outputs often interpreted separately from geometric and semantic building information. Ultrasonic testing, infrared thermography, and ground-penetrating radar provide valuable evidence for detecting hidden defects, moisture-related anomalies, material discontinuities, and subsurface irregularities; however, their results are commonly stored as isolated reports, images, or measurement files rather than being linked directly to HBIM elements.

The proposed NDT–HBIM framework addresses this limitation by transforming heterogeneous diagnostic outputs into structured, spatially mapped, and semantically enriched heritage information. By linking NDT evidence with element-level attributes such as material, defect type, location, severity, and diagnostic source, the framework improves visualization, anomaly interpretation, condition assessment, and conservation decision-making.

The synthesis shows that the strongest contribution of the framework is not only the use of NDT, but the formal integration of diagnostic data within HBIM to support predictive monitoring and proactive heritage management.

Diagnostic Component	Main Detectable Information	HBIM Integration Output	Conservation Value
Ultrasonic Testing	Internal discontinuities, voids, material degradation	Element-level defect attribute and severity tag	Supports structural condition interpretation
Infrared Thermography	Moisture anomalies, thermal irregularities, detachment, surface/subsurface defects	Thermal anomaly map linked to walls, panels, and interfaces	Supports moisture and deterioration diagnosis
Ground-Penetrating Radar	Hidden layers, voids, inclusions, internal irregularities	Subsurface evidence layer within HBIM	Supports non-invasive investigation of concealed features
Visual Inspection	Cracking, surface decay, deformation, biological deterioration	Defect location and visual evidence record	Supports baseline condition documentation
HBIM Semantic Enrichment	Material, defect type, location, severity, diagnostic evidence	Structured conservation database	Supports monitoring, comparison, and decision-making





CONCLUSION

The proposed NDT–HBIM framework provides a structured pathway for transforming fragmented diagnostic outputs into a unified digital heritage information environment. By linking NDT-based evidence with material properties, defect type, spatial location, severity, and diagnostic source, the framework improves visualization, condition assessment, and interpretation of hidden deterioration in timber-framed masonry heritage structures. Overall, the study supports a more data-driven and proactive approach to heritage conservation and predictive monitoring.

FUTURE WORK

Future work should focus on applying the proposed framework to real Swiss timber-framed masonry heritage case studies and validating the integration of NDT outputs within HBIM under field conditions. Further development should include automated NDT-to-HBIM data linking, AI-assisted anomaly detection, long-term monitoring, and digital twin-based conservation planning to support predictive and evidence-based heritage management.