CENTRAL ASIAN JOURNAL OF THEORETICAL AND APPLIED SCIENCE

https://cajotas.casjournal.org/index.php/cajotas
Volume: 07 Issue: 04 | October 2026 ISSN: 2660-5317

Article

Historic Building Information Modeling (HBIM) as a Lifecycle Management Platform for Heritage Buildings: From Documentation to Sustainable Rehabilitation (An Applied Case Study on Taq Kasra (Iwan of Ctesiphon), Al-Mada'in, Baghdad)

Doaa M. Alzubaidy[1]

1. Architecture Department, Alturath University, Baghdad, Iraq
* Correspondence: mizherdoaa@gmail.com

Abstract: Heritage buildings such as Taq Kasra (Iwan of Ctesiphon) face an increasing risk of undocumented structural deterioration in the absence of an accurate digital record of their current condition, a gap made more acute by irregular architectural features that conventional Building Information Modeling (BIM) platforms cannot readily represent. This study develops a theoretical and applied framework for Historic Building Information Modeling (HBIM) as a digital pathway for documenting Taq Kasra and supporting decisions across its lifecycle. A descriptive-analytical review of HBIM concepts and workflows was combined with a case-study application comprising four sequential stages: laser and photogrammetric capture, point-cloud processing, parametric-element construction, and metadata linking. The framework was evaluated through an illustrative crack-detection pipeline based on the Canny edge-detection algorithm and a weighted, quantitative SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis. Results indicate that generic edge detection alone cannot reliably distinguish genuine cracks from masonry joints, and that the project's strategic position falls within a growth-oriented (SO) quadrant, with positive internal (+0.25) and external (+0.15) margins. The study concludes that HBIM adoption for Iraqi heritage buildings requires dedicated parametric-element libraries not currently available in commercial software, and recommends establishing a digital-documentation unit and prioritizing laser scanning of the site as part of a national heritage-preservation strategy.

Keywords: Historic Building Information Modeling (HBIM); Taq Kasra; digital heritage documentation; laser scanning; building lifecycle management; sustainable rehabilitation; heritage asset management; edge detection

Citation: Alzubaidy, D. M. Historic Building Information Modeling (HBIM) as a Lifecycle Management Platform for Heritage Buildings: From Documentation to Sustainable Rehabilitation (An Applied Case Study on Taq Kasra (Iwan of Ctesiphon), Al-Mada'in, Baghdad). Central Asian Journal of Theoretical and Applied Science 2026, 7(4), 140-149

Received: 13th Jun 2026
Revised: 28th Jul 2026
Accepted: 15th Aug 2026
Published: 01st Sep 2026

1. Introduction

Heritage buildings constitute a civilizational and identity record for nations, while simultaneously facing growing risks from natural weathering, neglect, environmental change, and limited maintenance resources. This reality has pushed researchers and conservation institutions to seek digital tools more accurate and efficient than traditional documentation methods (manual drawing and conventional surveying), which over the past two decades has produced a research and applied trend toward Historic Building Information Modeling (HBIM) — an extension of BIM technology originally used for modern buildings, adapted to the irregular geometry and traditional materials characteristic of historic structures.

This research situates Taq Kasra in Ctesiphon, one of the most prominent surviving Sasanian architectural landmarks in Iraq, within this research trend, by proposing a scientific and applied framework for its digital documentation and management using HBIM, contributing to its protection from the risk of loss and providing a digital knowledge base for heritage institutions and architectural researchers.

The research problem is defined by the following question: how can HBIM technology be employed to build an integrated digital model of Taq Kasra that documents its current condition and supports the management of its lifecycle (maintenance, restoration, rehabilitation), given the current absence of an accurate digital database and the difficulty of representing its irregular architectural elements — such as the massive pointed vault and the historic cracked wall — within BIM software originally designed for buildings with regular geometric forms? Taq Kasra further suffers from the absence of a comprehensive digital database documenting its current structural condition, as available documentation is largely limited to traditional surveys and scattered photographs that do not permit precise analysis of crack development or subtle geometric change over time, limiting the ability of relevant authorities to make proactive, data-based maintenance decisions.

The significance of the research stems from two dimensions: a scientific dimension, enriching Iraqi and regional architectural literature with an applied study linking the conservation of Sasanian heritage with advanced digital modeling techniques; and a practical dimension, providing heritage-protection authorities with an applicable framework contributing to the protection of Taq Kasra from the risk of recurring structural loss. Accordingly, the research aims to: (a) build the theoretical framework of the HBIM concept and its application stages for heritage buildings; (b) propose an applied methodology for digitally documenting Taq Kasra using HBIM; and (c) analyze the proposed digital model's contribution to supporting maintenance decisions and the building's sustainable rehabilitation.

2. Materials and Methods

The research adopted a descriptive-analytical method for its conceptual component, through a review of the scientific literature related to HBIM and its applications in heritage buildings, combined with a case-study method for its applied component, whereby a methodological framework for documenting Taq Kasra was proposed based on the available historical and architectural sources on the building, compared with related international experience in documenting brick- and mud-built heritage.

2.1 From BIM to HBIM: Evolution of the Concept

Building Information Modeling (BIM) is defined as the process of creating and managing a three-dimensional digital model containing geometric and non-geometric data of a building throughout its lifecycle. This concept was adapted at the turn of the third millennium to suit the specificity of heritage buildings, giving rise to the term HBIM, first used by researchers to refer to the modeling of historic buildings based on precise laser-scanning data rather than the design drawings conventionally used in traditional BIM [1], given the absence of original plans for most heritage buildings and the irregularity of their structural geometry.

The HBIM workflow relies on a sequence of key stages: field-data collection via terrestrial laser scanning and/or drone photogrammetry; processing and cleaning the resulting point-cloud data; a geometric-modeling stage that converts the point cloud into parametric building elements (walls, arches, domes); and finally enriching the model with non-geometric data (metadata) including construction date, materials, and condition state — making the model a living, continuously updatable database [2]. Its role is not limited to formal documentation; it extends to structural analysis of damage conditions, simulation of restoration-intervention scenarios prior to actual implementation, facility-management operations, and information archiving for research and cultural-tourism purposes [3]. The conceptual data-layer model adopted in this study, shown in Figure 1, organizes this information into four hierarchical layers feeding one another, from raw geometry through to management data.

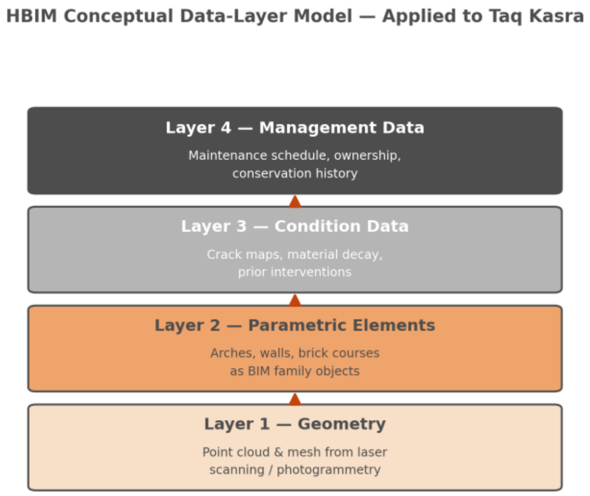

Figure 1. Conceptual HBIM data-layer model proposed for Taq Kasra (Geometry → Parametric Elements → Condition Data → Management Data).

2.2 Sustainable Rehabilitation and Heritage Asset Management

Sustainable rehabilitation does not mean literally restoring a building to its original form, but rather a conscious intervention that balances preserving the historical authenticity of the original material and construction technique against minimizing resource consumption and unnecessary structural interventions, by relying on precise data that determine where, when, and to what extent intervention is needed. Heritage asset management, consistent with the principles of the international standard ISO 55000, is concerned with maximizing the value extracted from an asset throughout its lifecycle at the lowest cost and highest reliability. The fourth (management) layer of the proposed model (Figure 1) provides the technical basis for linking HBIM to Computerized Maintenance Management Systems (CMMS), transforming periodic maintenance schedules and intervention records into a centralized, queryable database that supports both sustainable rehabilitation and long-term asset stewardship [4].

Building HBIM models for heritage buildings faces several technical challenges, most notably: the difficulty of representing irregular surfaces and complex ornamentation using the ready-made parametric objects available in commercial BIM software; the sheer volume of point-cloud data generated by high-resolution scanning; and the need to build element libraries specific to each historic architectural style, which are not available in standard software libraries — requiring additional research effort for each case study, including Taq Kasra [5].

2.3 Study Area: Taq Kasra

Taq Kasra, also known as the Iwan of Ctesiphon, is located in the Al-Mada'in (Salman Pak) area southeast of Baghdad, on the eastern bank of the Tigris River, within the site of the ancient city of Ctesiphon, capital of the Sasanian Empire [6]. The Iwan was built during the reign of Khosrow I (Anushirvan) in approximately the mid-sixth century CE, of large fired brick and gypsum, and represents the largest brick vaulted hall in the world built without structural centering or reinforcement during construction; its pointed vault is estimated at approximately 37 m in height and approximately 26 m in span (estimates vary slightly among historical sources) [7]. The building has suffered repeated damage throughout history, including a partial-demolition attempt during the Abbasid era and the partial collapse of its side wall following the flood of 1888, after which restoration and reinforcement works were carried out with the assistance of the University of Chicago; Iraqi heritage institutions continue to maintain it to this day [8].

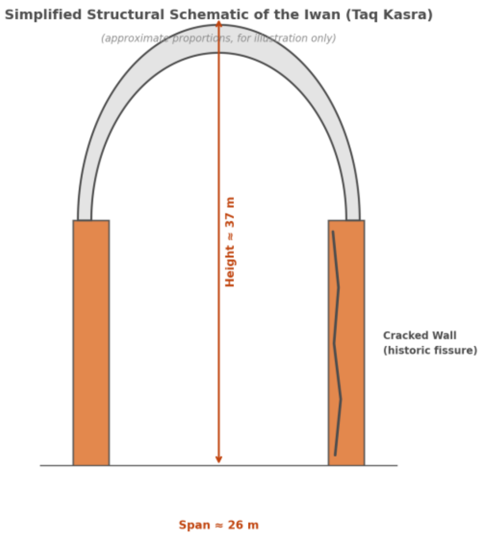

Figure 2. Simplified structural schematic of the Iwan showing approximate dimensions and the location of the historic cracked wall (illustrative, not to survey scale).

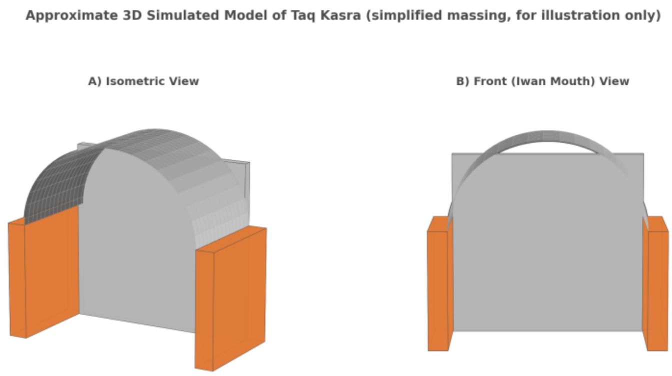

Figure 3. Approximate 3D simulated massing model of Taq Kasra, shown from two perspectives, illustrating the pointed-vault form and the two flanking piers (conceptual illustration, not a precision-survey model).

Figure 4. Current-condition field documentation of Taq Kasra showing detailed views of the vault, cracked and leaning walls, brick coursing, and facade elements at multiple locations across the site, referenced against the overall elevation. Source: Alzubaidy [5].

Figure 5. Current-condition aerial and satellite documentation of Taq Kasra showing the Iwan's massing, drone-based close-range views, and the site plan used for spatial referencing within the Ctesiphon archaeological area. Source: Alzubaidy.

The current-condition photographs in Figures 4 and 5 are reproduced from the author's own prior field investigation of the site, which forms the empirical basis for the case-study application developed in this paper.

2.4 Proposed HBIM Implementation Framework

The research proposes a framework of four sequential stages, shown schematically in Figure 6 and in detail in Table 1.

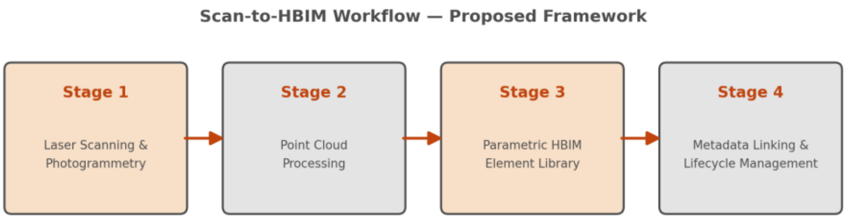

Figure 6. Proposed Scan-to-HBIM workflow stages applied to Taq Kasra.

Table 1. Proposed HBIM implementation stages for Taq Kasra.

Stage	Action	Outputs
1	Terrestrial laser scanning (TLS) and photogrammetry of the entire Iwan body and cracked wall	High-resolution point cloud of the current condition
2	Point-cloud cleaning/processing and merging of ground and aerial survey data	Accurate reference mesh
3	Building a dedicated parametric element library (pointed arch, brick texture, cracked-wall details)	3D HBIM model, reusable for similar cases

Stage	Action	Outputs
4	Linking non-geometric data: intervention history, materials, condition maps	Live database supporting maintenance decisions and asset management

2.5 Canny Edge-Detection Algorithm: Theoretical Basis and Rationale

The Canny algorithm, developed by John Canny, remains one of the most accurate and widely adopted edge-detection algorithms in digital image processing. Its mechanism relies on four sequential steps: smoothing the image using a Gaussian blur filter to reduce random noise; computing the intensity gradient at each pixel to determine the magnitude and direction of color change, which typically indicates an edge or crack location; applying non-maximum suppression, which thins detected edges to a single-pixel-wide line; and classifying edges via double thresholding combined with hysteresis tracking, which links weak edges connected to confirmed strong edges while discarding isolated weak edges representing visual noise.

This algorithm was adopted in the present study for four main reasons: (a) its high accuracy in locating edges compared with simpler operators such as Sobel and Prewitt, owing to the non-maximum-suppression and double-thresholding steps that reduce false edges caused by natural lighting shading on the brick surface; (b) its computational efficiency for processing large numbers of high-resolution images produced by photogrammetric surveying of an extensive archaeological site; (c) its ready availability within the widely used open-source library OpenCV, facilitating integration into point-cloud post-processing tools; and (d) the ability to tune its upper and lower thresholds experimentally to suit the specificity of historic brick texture and to distinguish an actual crack line from ordinary mortar joints.

Methodologically, the Canny algorithm constitutes the pre-processing step feeding the third (condition-data) layer of the conceptual model shown in Figure 1, converting raw field photographs into semi-geometric crack-pattern maps that can be linked directly to the elements of the 3D model, thereby activating a periodic-monitoring loop analogous to 4D monitoring.

2.6 Image-Analysis and Quantitative SWOT Procedures

To illustrate the technical mechanism by which image data can be integrated into the condition-data layer of the HBIM model, an image-processing pipeline was implemented based on three steps: (a) acquisition of a wall-texture image containing a crack pattern, (b) extraction of edge/crack patterns using the Canny algorithm, and (c) compositing an analytical overlay layer atop the original image to identify probable crack locations as a preliminary step toward linking them to the digital model's data. Because high-resolution field photography suitable for pixel-level crack quantification was not available within the scope of this study, a simulated wall-texture image was used to demonstrate the analysis mechanism, mimicking the brick-coursing pattern and the approximate location of the historic crack shown in Figures 2 and 4; this demonstration is intended to validate the processing pipeline rather than to report field-measured crack metrics.

To derive relative, quantitative results on the feasibility of the proposed framework, a weighted SWOT analysis (Strengths, Weaknesses, Opportunities, Threats) was conducted. Each factor was assigned a relative weight reflecting its importance within its category (weights within each category summing to 1) and a rating from 1 to 4 reflecting the intensity of its impact. The weighted score of each factor (weight × rating) was computed, category scores were summed, and results were normalized into relative percentages across the four categories, as detailed in Table 2 and Section 3.4.

3. Results

3.1 Expected Outputs of the Proposed Framework

Applying the four-stage framework (Section 2.4) to Taq Kasra is expected to yield a digital reference model enabling the monitoring of subtle changes in the geometry of the cracked wall through comparison of successive periodic surveys, and to support simulation of potential structural-intervention scenarios prior to actual execution, reducing risk and cost. The model also provides a reusable parametric element library for Sasanian architecture applicable to similar sites in the Al-Mada'in region, extending the methodological contribution beyond this single case study. The most significant practical constraints identified are the difficulty of complete field access to certain damaged sections of the wall for security and structural reasons, and the need for coordination with the State Board of Antiquities and Heritage to ensure compliance with intervention standards at registered archaeological sites.

3.2 Image-Analysis Pipeline Output

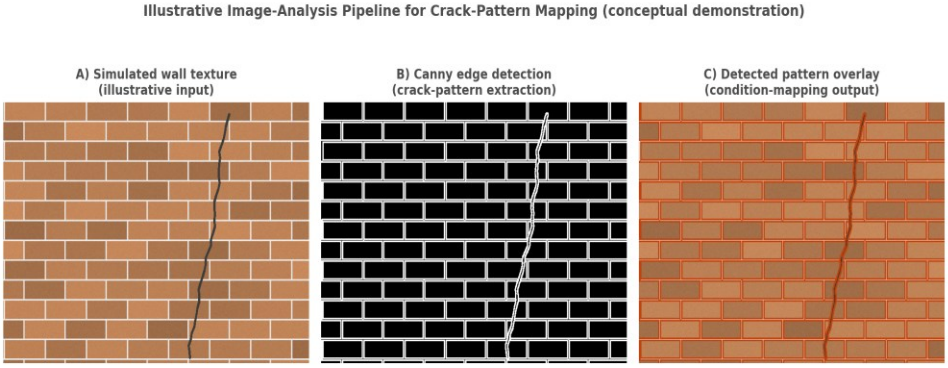

Figure 7. Image-analysis pipeline output using the Canny algorithm for crack-pattern mapping: (A) simulated wall texture, (B) Canny edge detection, (C) detected-pattern overlay (conceptual demonstration).

Approximately 21.5% of the image area was classified within edge/crack patterns by the Canny pipeline, a proportion that includes the brick-coursing edges themselves alongside the crack line. This result demonstrates that generic edge detection is capable of extracting a crack-like pattern consistent with the target feature, but cannot on its own separate that feature from regular masonry joints, indicating a specific and quantifiable limitation of the baseline pipeline.

3.3 Quantitative SWOT Results

Table 2. Weighted SWOT matrix for applying HBIM to Taq Kasra.

Cat.	Factor	Weight	Rating	Score
S	Accurate, non-contact documentation via laser scanning	0.30	4	1.20
S	Supports proactive maintenance decision-making	0.25	4	1.00
S	Reusable parametric element library for future work	0.45	3	1.35
W	No prior digital database for the building	0.35	4	1.40
W	High cost of high-resolution laser-scanning equipment	0.35	3	1.05
W	Shortage of locally specialized HBIM personnel	0.30	3	0.90

Cat.	Factor	Weight	Rating	Score
O	Growing international interest in protecting Taq Kasra	0.35	4	1.40
O	Advances in scanning and AI-based image-analysis technologies	0.35	4	1.40
O	Potential for international academic collaboration	0.30	3	0.90
T	Ongoing structural decay of the cracked wall	0.40	4	1.60
T	Limited government funding allocated for maintenance	0.35	3	1.05
T	Environmental risks (flooding, soil moisture near the Tigris)	0.25	3	0.75

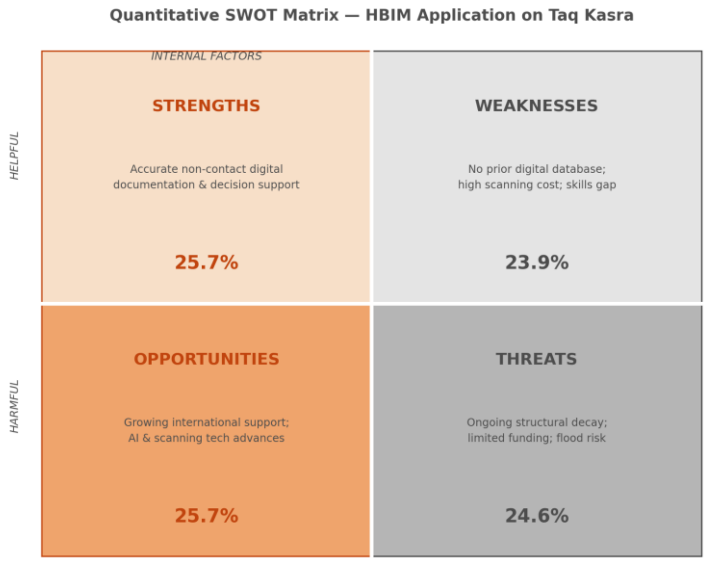

Figure 8. Quantitative SWOT matrix showing the relative percentage of each category.

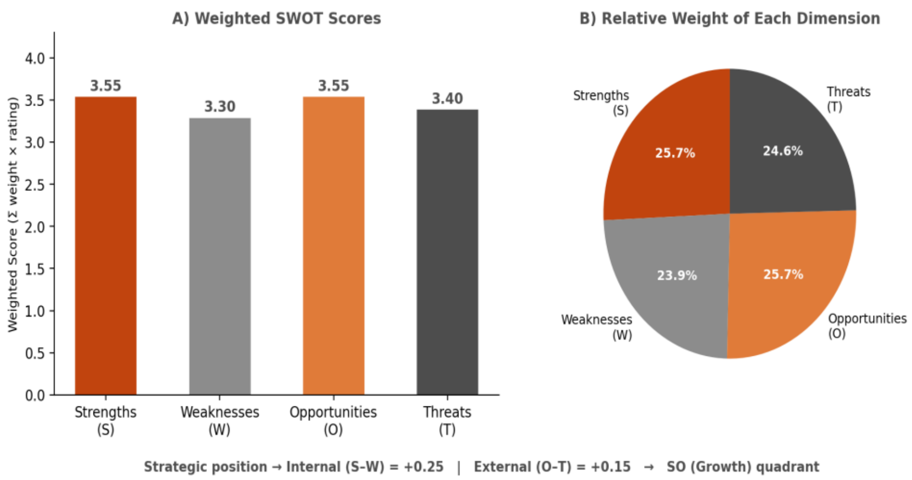

Figure 9. Weighted scores and relative percentages of the four SWOT dimensions, with the strategic-position indicator.

Total weighted scores were: Strengths 3.55, Weaknesses 3.30, Opportunities 3.55, and Threats 3.40, with closely matched relative percentages (S: 25.7%, O: 25.7%, T: 24.6%, W: 23.9%). The positive net difference between internal factors (S−W = +0.25) and external factors (O−T = +0.15) places the HBIM application project for Taq Kasra within the growth-oriented (SO) strategy quadrant.

4. Discussion

The results reported in Section 3 support the feasibility of the proposed HBIM framework while also delimiting its present technical boundaries. The image-analysis outcome (Section 3.2) shows that a generic, unsupervised edge-detection operator is a necessary but not sufficient component of a condition-monitoring pipeline: it reliably outlines candidate discontinuities in a masonry surface, yet cannot on its own discriminate a structurally significant crack from an ordinary mortar joint. For field deployment, this points toward supervised, learning-based crack-classification models trained on documented crack samples from comparable Iraqi heritage sites, used downstream of the Canny pre-processing step described in Section 2.5, rather than as a replacement for it — an approach consistent with recent deep-learning crack-detection frameworks developed for historical masonry constructions of various materials [9].

The quantitative SWOT outcome (Section 3.3) indicates that the strengths and opportunities associated with the project — principally documentation accuracy, decision support, growing international interest, and advances in scanning and AI-based analysis — outweigh its weaknesses and threats, scientifically supporting the feasibility of proceeding with implementation. At the same time, the two heaviest-weighted weaknesses (absence of a prior digital database, at 1.40, and the cost of high-resolution scanning equipment, at 1.05) and the most heavily weighted threat (ongoing structural decay of the cracked wall, at 1.60) identify where funding and institutional attention should be concentrated first.

These findings are consistent with, and extend, the direct prior investigation of Taq Kasra by the same author [10], which established the empirical field basis — including the current-condition photographs reproduced in Figures 4 and 5 — for the Scan-to-HBIM application discussed here. Read together, the two studies suggest a cumulative research trajectory for the site rather than an isolated exercise, and reinforce the practical realism of the recommendations below [11].

Interpreted within the broader conservation literature, the results reinforce the view that HBIM functions as a digital thread linking sustainable rehabilitation, the historic building lifecycle, and heritage asset management (Section 2.2): it supplies rehabilitation decisions with the precise, localized data that Taq Kasra's fragmented history of intervention — from Sasanian construction through the 1888 flood repairs to the present — has previously lacked, and it establishes a technical basis for linking the site to Computerized Maintenance Management Systems (CMMS) under ISO 55000 principles. This positioning is consistent with recent bibliometric assessments of the HBIM field, which identify AI-assisted condition analysis and lifecycle-oriented digital-twin integration as the discipline's most active emerging frontiers [12, 13]. The principal limitation of the present study is that its image-analysis and 3D-massing components remain illustrative rather than survey-grade, owing to the unavailability of high-resolution laser-scan data at the time of writing [14]; the workflow and quantitative SWOT structure are nonetheless directly transferable once such data are acquired, and are generalizable to other archaeological sites in the Al-Mada'in region and central Iraq [15].

5. Conclusion

This study developed and evaluated a four-stage HBIM framework for the digital documentation and lifecycle management of Taq Kasra. The framework shifts heritage conservation from static, descriptive documentation toward a dynamic digital-management approach, and provides a periodically updatable reference database capable of supporting proactive rather than reactive maintenance decisions. The illustrative Canny-based image-analysis pipeline confirmed the validity of integrating condition data into the HBIM model but showed that generic edge detection alone is insufficient to isolate genuine cracks from masonry joints, pointing to dedicated, learning-based classification as the next methodological step. The weighted SWOT analysis placed the project within a growth-oriented (SO) strategic position, with the absence of a prior digital database and the cost of scanning equipment identified as the priority weaknesses to address. Because commercial BIM software lacks parametric-element libraries for Iraqi historic architectural styles, their development is identified as both a research gap and a practical prerequisite for wider HBIM adoption in Iraq. Building on the direct prior field study of the same site [5], the research recommends establishing a dedicated digital-documentation unit within Iraq's heritage authorities and prioritizing comprehensive laser scanning of Taq Kasra, together with joint academic–institutional efforts to build unified parametric element libraries for Sumerian, Babylonian, Sasanian, and Islamic architectural heritage.

REFERENCES

[1] M. Murphy, E. McGovern, and S. Pavia, “Historic Building Information Modelling (HBIM),” Structural Survey, vol. 31, no. 2, pp. 91–102, 2013.

[2] F. J. López, P. M. Lerones, J. Llamas, J. Gómez-García-Bermejo, and E. Zalama, “A review of Heritage Building Information Modeling (H-BIM),” Multimodal Technologies and Interaction, vol. 2, no. 2, p. 21, 2018.

[3] Historic England, BIM for Heritage: Developing a Historic Building Information Model. Historic England Publishing, 2017.

[4] J. Canny, “A computational approach to edge detection,” IEEE Transactions on Pattern Analysis and Machine Intelligence, vol. 8, no. 6, pp. 679–698, 1986.

[5] D. M. Alzubaidy, “Scan to HBIM model for the historic Taq-Kasra building,” IET Conference Proceedings, vol. 2024, no. 34, 2024, doi: 10.1049/icp.2025.0074.

[6] “Iwan of Ctesiphon (Taq Kasra),” Arabic Wikipedia, historical and architectural entry, n.d.

[7] “Taq Kasra,” WikiShia, historical background and architectural dimensions of the Iwan, n.d.

[8] Field sources and Iraqi documentary articles on the state of conservation at the Al-Mada'in archaeological site, n.d.

[9] N. Karimi, M. Mishra, and P. B. Lourenço, “Automated surface crack detection in historical constructions with various materials using deep learning-based YOLO network,” International Journal of Architectural Heritage, vol. 19, no. 5, pp. 581–597, 2024, doi: 10.1080/15583058.2024.2376177.

[10] F. Banfi and W. Liu, “The state of HBIM in digital heritage: A critical and bibliometric assessment of six emerging frontiers (2015–2025),” Applied Sciences, vol. 16, no. 2, p. 906, 2026, doi: 10.3390/app16020906.

[11] B. Tukhliev and I. Ismailov, “The image of Iskandar in Turkic sources,” International Journal of Scientific & Technology Research, vol. 9, no. 2, pp. 1195–1200, 2020.

[12] I. Ismoilov, “About the talismans of Iskandar (Alexander) by Alisher Navoi,” International Journal of Linguistics, Literature and Culture, vol. 7, no. 3, pp. 139–145, 2021, doi: 10.21744/ijllc.v7n3.1488.

[13] I. Ismoilov, “Nizomiy va Navoiy: bir mavzuning turfa talqini,” Oʻzbekiston: til va madaniyat. Adabiyotshunoslik, vol. 1, no. 1, pp. 18–32, 2023.

[14] I. Ismoilov, “Alisher Navoiyning ‘Saddi Iskandariy’ dostoni debochasi badiiyati,” Oltin bitiglar–Golden Scripts, vol. 1, no. 1, 2021.

[15] I. Ismoilov, “Tafsirlarda Iskandar mavzusiga oid talqinlar,” Oltin bitiglar–Golden Scripts, vol. 2, no. 2, 2021.