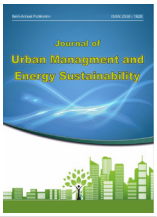
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CASE STUDY RESEARCH PAPER

Historic-Bridge Landscape Restoration in Iran: A Weighted Indicator Assessment of Three Sassanid Bridges

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ABSTRACT

Historic bridges sit at the intersection of hydraulic engineering, architectural heritage and cultural landscape, yet restoration practice still treats them largely as isolated structural objects, detaching the crossing from the watercourse, terrain and settlement pattern that give it meaning.This study develops an eight-indicator assessment framework and applies it to three case-study bridges spanning a deliberate gradient of setting and statutory status: the riverine, World-Heritage-listed Band-e Kaisar at Shushtar; the valley-bound, nationally registered Pol-e Mehr Narseh at Tangab; and the gorge-bound, unlisted Pol-e Dokhtar at Mianeh. The framework was derived through a five-phase mixed-methods sequence: qualitative content analysis of expert interviews and technical documents yielded eighteen candidate factors; three rounds of fuzzy Delphi reduced these to eight validated indicators across five dimensions; fuzzy analytic hierarchy process produced global weights; and partial least squares structural equation modelling confirmed the dimensional structure, explaining 54 per cent of variance in restoration sustainability. Applying the weighted indicators produced composite condition indices of 80.5, 67.7 and 63.2, placing the three cases in three distinct intervention pathways. Critically, the spread was concentrated not in fabric-related indicators but in restoration standards, process design and architectural-element conservation, while the remote gorge case outperformed the listed monument on ecological protection. Inscription status and managerial infrastructure, rather than intrinsic material condition, therefore drive measured performance, and landscape-restoration policy for historic bridges should be tiered by measured condition rather than applied uniformly.

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INTRODUCTION

Bridges are among the most persistent artefacts of pre-modern infrastructure, and among the least well served by conventional heritage doctrine. A bridge is simultaneously a structural system answering to hydraulic force, an architectural object carrying stylistic and symbolic meaning, and a landscape element that organises how a valley, a river or a town is perceived and traversed. Charters that shaped twentieth-century conservation practice were framed principally around the monument as a bounded object (ICOMOS, 1964), and although successive instruments progressively widened the frame to the cultural context of authenticity (ICOMOS, 1994), to landscape as a public-interest category in its own right (Council of Europe, 2000), and to the historic urban landscape as a management approach (UNESCO, 2011) operational assessment tools for bridges have lagged behind this doctrinal shift. The consequence is visible in practice. Restoration of historic bridges is still frequently scoped as fabric repair: consolidating piers, repointing arches, replacing deck surfaces. Such interventions may be technically competent yet leave the bridge estranged from the riverbed, embankments, sightlines and settlement fabric that constitute its landscape value. Recent scholarship has begun to push against this narrowing. Value-based approaches to bridge conservation have been articulated for World-Heritage-class structures (Chen et al., 2026); hydrological reasoning has been folded into the conservation of riverine bridges (Ccanccapa Puma et al., 2024); cultural-memory frameworks have been proposed for vernacular bridge types (Yang et al., 2025); and digital documentation workflows have matured to the point where geometric and material records can underpin, rather than merely follow, conservation decisions (León-Robles et al., 2019; Sacco et al., 2026; Willkens et al., 2024). What remains scarce is a compact, weighted, empirically validated indicator set capable of comparing bridges that differ radically in setting, status and resourcing. Iran offers an unusually demanding test bed. The Sassanid period (224–651 CE) produced a bridge culture whose signature type, the pol-band or bridge-dam, fused passage, water diversion and energy generation in a single structure (Huff & Kleiss, 1989). These works were not crossings placed upon a landscape but instruments that produced one: canal networks, mills, irrigated terraces and settlement patterns organised themselves around the hydraulic regime the bridge-dam established. At the same time, the surviving stock is extraordinarily heterogeneous. A handful of assets enjoy World Heritage inscription and active management; the great majority are remote, undocumented and effectively unattended. Comparative frameworks developed for well-resourced European or East Asian contexts do not transfer cleanly to this condition, and Iranian heritage scholarship has repeatedly identified documentation infrastructure and institutional coordination rather than technical knowledge as the binding constraint (Ashrafi et al., 2024; Hassani & Rafiee, 2013; Vafadari Komarolya & Sajedi, 2026).

This study therefore asks a deliberately narrow question with broad implications: when Sassanid-associated bridges distributed along the setting-and-status spectrum are assessed against the same weighted indicator set, where does the performance difference actually fall? The answer matters for policy. If the gap lies in material condition, the appropriate response is technical and site-specific. If instead it lies in managerial and procedural indicators, the appropriate response is systemic, and resources are better spent on documentation, standards and process than on fabric intervention at any single site. Three case studies were selected to populate that spectrum rather than merely to bracket it. Band-e Kaisar at Shushtar is riverine, located in the alluvial Khuzestan plain on the Karun, inscribed on the World Heritage List as part of the Shushtar Historical Hydraulic System (UNESCO World Heritage Centre, 2009), and supported by comparatively rich technical documentation. Pol-e Mehr Narseh at Tangab lies in a confined valley near Firuzabad, within

the cultural region of the Sassanid Archaeological Landscape of Fars (UNESCO World Heritage Centre, 2018), and occupies an intermediate position: nationally registered and partially documented, but without a continuous management regime. Pol-e Dokhtar at Mianeh is gorge-bound, located on the Qezel Ozan in the cold mountainous north-west, carries no inscription, and is remote enough that neither systematic documentation nor local custodianship is in place. Together the three trace a gradient in which setting, statutory status and managerial capacity vary jointly, allowing the intermediate case to test whether performance changes gradually along that gradient or steps discontinuously with inscription. The paper proceeds as follows. Section 2 sets out the mixed-methods derivation of the eight-indicator framework and the scoring protocol applied to the three cases. Section 3 reports the comparative results: physical and morphological characteristics, indicator profiles, composite condition indices and the importance–performance map. Section 4 interprets these findings against the international bridge-conservation literature and draws out the policy implication. Section 5 concludes.

MATERIALS AND METHODS

Research design

The study follows an interpretive paradigm with a descriptive–analytical design and an applied–developmental purpose. The framework was not imposed deductively; it was constructed through a five-phase sequence in which each phase constrains the next, and only then applied to the cases. Figure 1 summarises this architecture. (Fig. 1)

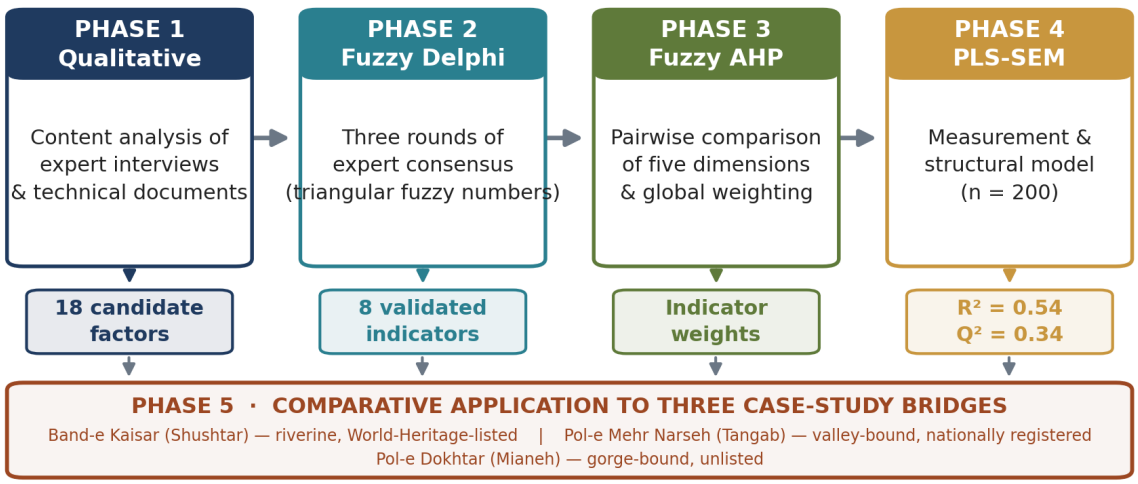


Figure 1: Five-phase mixed-methods research design, from qualitative factor extraction to comparative case application.

Phase 1 established the candidate factor pool through qualitative content analysis of semi-structured expert interviews and specialist technical documents, coded in three stages (open, axial, selective) using MAXQDA. Coding produced a three-level thematic network global themes (dimensions), organising themes (sub-categories) and basic themes (factors) from which eighteen candidate factors emerged. Inter-coder reliability was assessed to confirm coding stability before the factor list was carried forward. Phase 2 subjected the eighteen candidates to three rounds of fuzzy Delphi. Expert judgements were expressed as triangular fuzzy numbers and defuzzified by the centre-of-area method, an approach well established for handling the linguistic imprecision inherent in expert elicitation (Hsu et al., 2010; Ishikawa et al., 1993). Convergence across rounds was monitored, and factors falling below the acceptance threshold were eliminated, leaving

eight validated indicators distributed across five dimensions. Phase 3 weighted the five dimensions through fuzzy analytic hierarchy process. Pairwise comparison matrices were constructed using triangular fuzzy numbers and resolved following established extent-analysis and fuzzy-hierarchy procedures (Buckley, 1985; Chang, 1996); the consistency ratio was checked and remained within the conventional tolerance. Dimension weights were then combined with within-dimension shares to produce a global weight for each of the eight indicators. Phase 4 tested the dimensional structure empirically through partial least squares structural equation modelling on a survey of 200 valid responses, using reflective measurement for all constructs and reporting in line with current guidance for the method (Hair et al., 2019). Convergent validity was established through factor loadings, composite reliability and average variance extracted; discriminant validity through both the Fornell–Larcker criterion (Fornell & Larcker, 1981) and the heterotrait–monotrait ratio (Henseler et al., 2015). The structural model was evaluated for collinearity, path significance via bootstrapping, explanatory power and predictive relevance. Phase 5 applied the weighted indicator set comparatively to the three case-study bridges.

Case Studies

Cases were chosen to span a gradient in setting (alluvial plain, confined valley, mountain gorge), statutory status (World Heritage inscription, national registration, none) and managerial capacity (active heritage administration, intermittent oversight, effectively absent custodianship), while holding constant the broad cultural horizon of Sassanid-associated bridge building. The two end-members make any systematic difference in indicator performance maximally visible; the intermediate case establishes whether that difference accumulates continuously along the gradient or appears only at its extremes. Band-e Kaisar, the core of the Shushtar Historical Hydraulic System inscribed in 2009 (UNESCO World Heritage Centre, 2009), is traditionally associated with the reign of Shapur I in the third century CE and with the employment of Roman engineering expertise following the capture of Valerian. It combines three functions in one work: a road crossing, a diversion weir, and a platform supporting watermills. Its masonry piers are bonded with sarooj, the traditional Iranian hydraulic lime mortar, and protected upstream by triangular cutwaters that break flow pressure and deflect floating debris. Lateral canals distribute water to mills and agricultural land, so that the structure functions as a node within an integrated hydraulic-cultural landscape rather than as a discrete object. Pol-e Mehr Narseh at Tangab, near the Sassanid city of Gur (Ardashir-Khurreh) at Firuzabad, is attributed to the powerful minister Mehr Narseh in the first half of the fifth century CE. It crosses the Tangab in a confined valley on the historic route linking the Sassanid capital to the Persian Gulf littoral, and its nine semi-circular spans carry a comparatively narrow deck of five to six metres. The bridge lies within the cultural region of the Sassanid Archaeological Landscape of Fars, inscribed in 2018 (UNESCO World Heritage Centre, 2018), but is itself protected only by national registration; documentation exists yet is partial and discontinuous, and no permanent custodial regime is in place. This combination a legible historic setting and moderate fabric condition alongside weak procedural infrastructure makes it the informative middle term of the study rather than a mere reference point. Pol-e Dokhtar at Mianeh spans the Qezel Ozan on one of the historic communication routes of the north-western plateau. It represents the mountain and inter-urban bridge type, built in a regime of powerful seasonal flows and freeze–thaw cycling. Unlike the plain-situated bridge-dams, such structures contend above all with structural stability under severe hydraulic loading. Relative remoteness, incomplete technical documentation and the absence of local custodianship make it the most vulnerable of the cases examined; the same remoteness, however, has left its natural

setting comparatively undisturbed. Table 1 summarises the comparative physical and structural characteristics of the three bridges, and Figure 2 presents their aerial setting, reconstructed plan and reconstructed longitudinal section. (Tab. 1 and Fig. 2)

Table 1: Comparative physical, structural and historical characteristics of the three bridges.

Attribute	Band-e Kaisar (Shushtar)	Pol-e Mehr Narseh (Tangab)	Pol-e Dokhtar (Mianeh)
Province	Khuzestan	Fars	East Azerbaijan
Watercourse	Karun River	Tangab River	Qezel Ozan River
Setting type	Alluvial plain, riverine	Confined valley	Mountain gorge
Primary function	Dam and bridge	Road bridge	Road bridge
Approximate length	≈ 500 m	≈ 110 m	≈ 133 m
Top width	8–10 m	5–6 m	6–7 m
Number of spans	40–44	9	11
Arch type	Semi-circular	Semi-circular	Pointed
Maximum height	6–7 m	9–10 m	10–11 m
Pier thickness	4.0 m	3.5 m	3.5 m
Water-level difference	1.5–2.0 m	1.2–1.5 m	1.2–1.5 m
Attributed period	Sassanian era	Sassanian (attributed)	Ilkhanid–Safavid (Sassanian piers debated)
Statutory status	UNESCO World Heritage (2009)	Nationally registered	Not inscribed

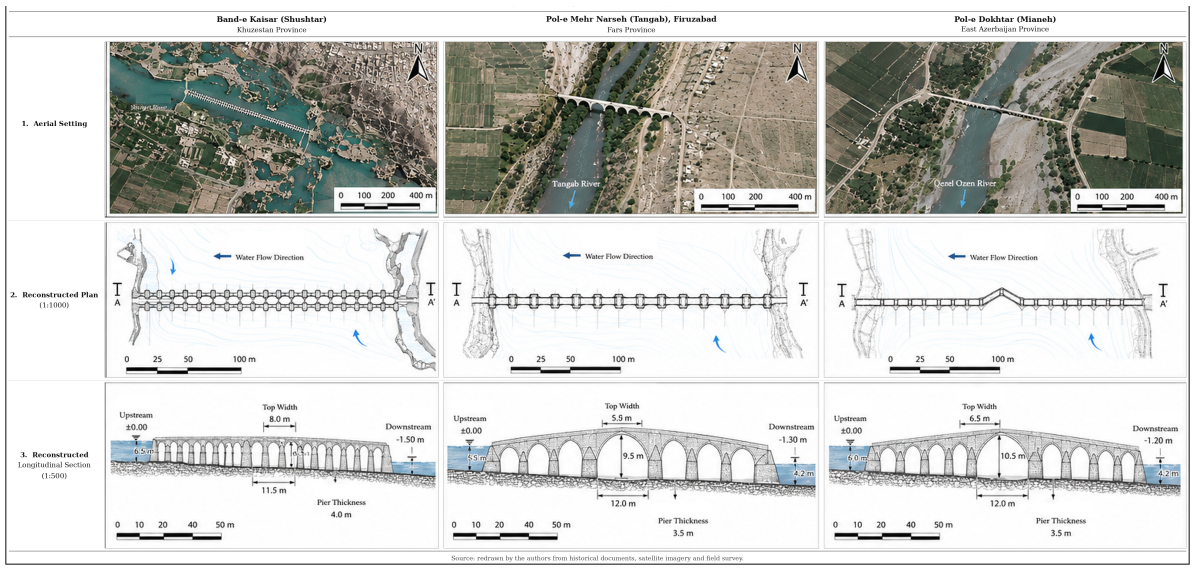


Figure 2: Comparative documentation of the three case-study bridges: aerial setting, reconstructed plan (1:1000) and reconstructed longitudinal section (1:500). Redrawn by the authors from historical documents, satellite imagery and field survey.

Indicator set and scoring protocol

The eight validated indicators and their global weights are given in Table 2. Two features of the weight distribution deserve comment. First, the weights are closely clustered, ranging only from 11.82 to 12.95 per cent; the framework therefore does not privilege any single indicator but treats restoration performance as a balanced

composite. Second, the ordering is nonetheless meaningful: architectural-element conservation ranks first, followed immediately by restoration standards and durable materials, so that heritage-authenticity and managerial-standard concerns bracket the purely material at the top of the hierarchy.

Table 2: The eight validated indicators, their dimensions and global weights derived by fuzzy AHP.

Rank	Indicator	Dimension	Dimension weight (%)	Global weight (%)
1	Architectural-element conservation	Heritage–identity	29.3	12.95
2	Restoration standards	Managerial–social	19.5	12.83
3	Durable materials	Physical–structural	23.4	12.74
4	Ecological and environmental protection	Environmental–hydraulic	12.0	12.61
5	Natural-landscape design principles	Natural–cultural landscape	15.8	12.46
6	Restoration-process design	Managerial–social	19.5	12.43
7	Aesthetic standards	Natural–cultural landscape	15.8	12.16
8	Vernacular and traditional architecture	Heritage–identity	29.3	11.82

Each bridge was scored on every indicator using a 0–5 ordinal scale anchored by descriptive criteria, drawing on field observation, available technical documentation, and assessment of the surrounding landscape. Scores were then combined with global weights to yield a composite condition index (denoted SHI) rescaled to 0–100:

$$\mathrm{SHI} = \left(\Sigma\, w_i \cdot s_i / 5 \right) \times 100 , \quad i = 1 \ldots 8$$

where wi is the normalised global weight of indicator i and si its 0–5 score. Three intervention pathways were defined on this index light (SHI ≥ 75), standard (60 ≤ SHI < 75) and full (SHI < 60) so that the depth of intervention is proportioned to measured condition rather than applied uniformly. Finally, indicator importance was plotted against mean performance across the three cases in an importance–performance map, following the established IPMA logic in which the quadrant combining above-average importance with below-average performance identifies first-priority action (Ringle & Sarstedt, 2016).

FINDINGS AND DISCUSSION

Validation of the assessment framework

The measurement model met all conventional thresholds. Standardised factor loadings for all reflective items exceeded 0.70; composite reliability and Cronbach's alpha values were above 0.70 for every construct; and average variance extracted exceeded 0.50 throughout, establishing convergent validity. Discriminant validity was supported on both criteria applied: in the Fornell–Larcker matrix the square root of AVE exceeded all inter-construct correlations, and all heterotrait–monotrait ratios fell below the 0.85 benchmark. The structural model likewise performed well. Maximum variance inflation factor was 1.22, far below the collinearity threshold. All five dimensional paths to restoration sustainability were positive and statistically significant, as summarised in Table 3. The model explained 54 per cent of variance in the endogenous construct ($R^2 = 0.54$, adjusted $R^2 = 0.52$) with predictive relevance confirmed ($Q^2 = 0.34$), and approximate fit indices were acceptable (SRMR = 0.063; NFI = 0.92).

The ordering of path coefficients is informative for what follows. The physical–structural dimension carries the strongest direct effect (β = 0.320), followed by natural–cultural landscape (β = 0.274) and managerial–social (β = 0.255). The heritage–identity dimension, which carries the

highest AHP weight, exerts the weakest direct structural effect (β = 0.180). This divergence between prescriptive weight and empirical effect is taken up in Section 4.

Table 3: Structural model results: path coefficients, significance and effect sizes (PLS-SEM, n = 200).

Path to restoration sustainability	β	t	p	95% CI	f^2	VIF	Result
Physical–structural	0.320	5.25	0.000	[0.20, 0.44]	0.199	1.12	Supported
Natural–cultural landscape	0.274	3.89	0.000	[0.14, 0.42]	0.140	1.17	Supported
Managerial–social	0.255	4.78	0.000	[0.15, 0.36]	0.128	1.10	Supported
Heritage–identity	0.180	2.63	0.010	[0.05, 0.31]	0.058	1.22	Supported
Environmental–hydraulic	0.157	2.31	0.023	[0.01, 0.28]	0.048	1.11	Supported

Comparative indicator profiles

Table 4 reports indicator-level scores for the three case-study bridges, and Figure 3 displays their profiles and the indicator-by-indicator gap between the end-members.

Table 4: Indicator scores for the three case-study bridges (0–5 scale), with the end-member gap.

Indicator	Global weight (%)	Band-e Kaisar (Shushtar)	Pol-e Mehr Narseh (Tangab)	Pol-e Dokhtar (Mianeh)	Gap (Shushtar − Mianeh)
Architectural-element conservation	12.95	4.4	3.6	3.2	+1.2
Restoration standards	12.83	4.2	3.0	2.8	+1.4
Durable materials	12.74	4.1	3.3	3.0	+1.1
Ecological and environmental protection	12.61	3.5	3.2	3.6	−0.1
Natural-landscape design principles	12.46	3.8	3.7	3.4	+0.4
Restoration-process design	12.43	4.0	3.1	2.7	+1.3
Aesthetic standards	12.16	3.9	3.4	3.1	+0.8
Vernacular and traditional architecture	11.82	4.3	3.8	3.5	+0.8
Composite condition index (SHI, 0–100)	—	80.5	67.7	63.2	+17.3

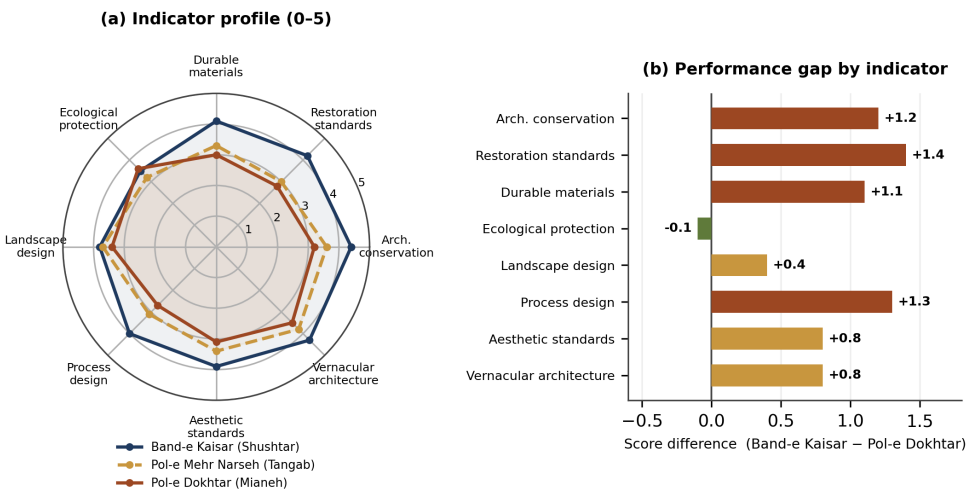


Figure 3: Comparative indicator assessment: (a) profile of the three case-study bridges across the eight validated indicators (0–5); (b) score difference by indicator between the two end-members.

Band-e Kaisar outperforms Pol-e Dokhtar on seven of the eight indicators, but the margin is markedly uneven. The three largest gaps are restoration standards (+1.4), restoration-process design (+1.3) and architectural-element conservation (+1.2). Durable materials follow at +1.1. By contrast, aesthetic standards and vernacular architecture differ by only +0.8, and natural-landscape design principles by +0.4.

Pol-e Mehr Narseh sits between the two on every indicator but one, and its position is not uniformly central. It approaches Band-e Kaisar closely on natural-landscape design principles (3.7 against 3.8) and on vernacular and traditional architecture (3.8 against 4.3), where the valley setting and the surviving masonry tradition remain legible. It falls much closer to Pol-e Dokhtar on restoration standards (3.0 against 2.8) and restoration-process design (3.1 against 2.7). The intermediate case therefore does not descend evenly from the listed bridge to the unlisted one: it retains most of the landscape and craft qualities of the former while sharing the procedural deficit of the latter.

One indicator reverses the pattern entirely. On ecological and environmental protection, Pol-e Dokhtar scores higher than the World-Heritage-listed bridge-dam (3.6 against 3.5), with Pol-e Mehr Narseh lowest of the three (3.2). The remoteness that undermines Pol-e Dokhtar's documentation and maintenance has simultaneously insulated its natural setting from development pressure, whereas Band-e Kaisar contends with urban encroachment on its visual buffer, sedimentation in its canal network and concentrated visitor loading in peak season, and the Tangab valley absorbs agricultural and road development without the protection that either inscription or remoteness confers. On this indicator, accessibility rather than status governs the outcome. Grouping these results by dimension clarifies the structure of the difference. Between the end-members the gap is widest in the managerial–standard cluster (restoration standards and process design, mean gap +1.35), substantial in the heritage and material cluster (+1.15), narrower in the landscape–aesthetic cluster (+0.60), and negative in the environmental cluster (−0.10). The intermediate case reproduces the same asymmetry in miniature: measured against Band-e Kaisar it loses 1.05 points on average in the managerial–standard cluster but only 0.30 in the landscape–aesthetic one. The difference between these bridges is therefore not primarily a difference in fabric; it is a difference in the managerial and procedural apparatus surrounding the fabric.

Composite condition and intervention pathway

Weighting the indicator scores produced composite condition indices of 80.5 for Band-e Kaisar, 67.7 for Pol-e Mehr Narseh and 63.2 for Pol-e Dokhtar (Fig. 4b). Under the thresholds defined in Section 2.3, the three cases fall into three different pathways: Band-e Kaisar exceeds 75 and qualifies for the light pathway of preventive maintenance and periodic monitoring; Pol-e Mehr Narseh falls in the standard band requiring light restoration, documentation and buffer definition; Pol-e Dokhtar, at 63.2, sits close to the lower threshold and requires the full pathway, including systematic documentation, compatible reconstruction and participatory assessment. The 17.3-point spread between the end-members is substantial, but its composition is more instructive than its magnitude. Because indicator weights are closely clustered, the spread is not produced by a single catastrophic deficiency; it accumulates across the managerial and procedural indicators identified in Section 3.2. The distribution of the three indices is also informative: the intermediate case sits 12.8 points below the inscribed bridge but only 4.5 above the unlisted one, so the index is not evenly spaced along the status gradient. Most of the measured distance opens between inscription and national registration rather than between national registration and no designation at all.

Importance–performance analysis

Plotting global weight against mean performance across the three cases (Fig. 4a) locates three indicators in the priority quadrant of above-average importance and below-average performance: restoration standards, durable materials and ecological protection. Restoration standards is the most consequential of these, combining the second-highest weight in the framework with the lowest mean performance of any indicator inside the quadrant. Restoration-process design falls just outside it on the importance axis its global weight of 12.43 per cent sits marginally below the indicator mean of 12.50 yet records the lowest mean performance of any indicator in the set, and Section 3.2 showed it to be the second-largest source of divergence between the cases. It is therefore treated here as a fourth priority notwithstanding its position on the map.

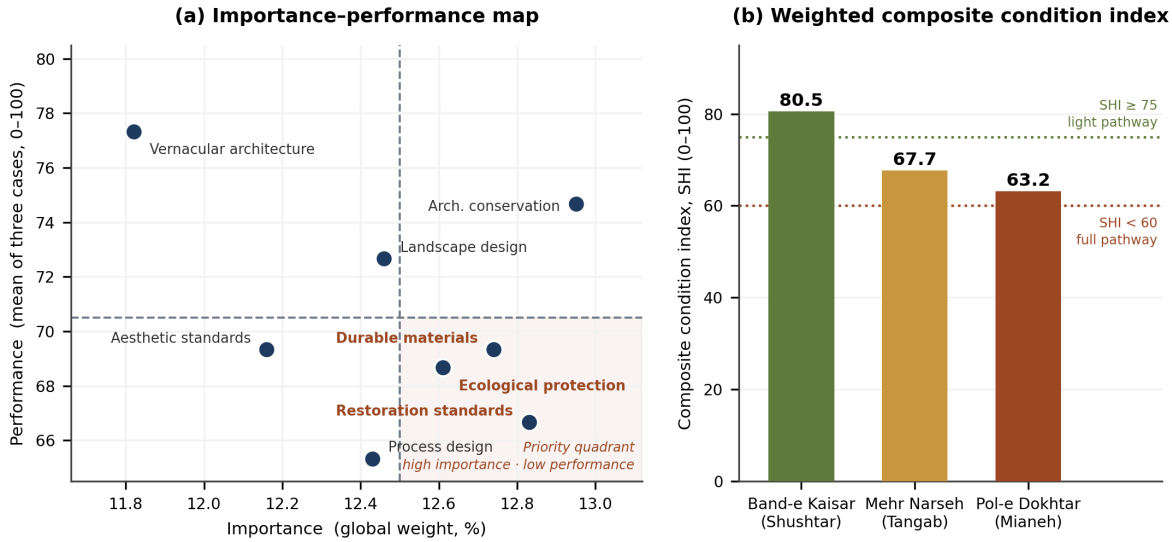


Figure 4: (a) Importance–performance map of the eight indicators, with the priority quadrant shaded; (b) weighted composite condition index for the three case-study bridges against the intervention-pathway thresholds.

Architectural-element conservation, although carrying the highest weight, performs above average and therefore does not appear in the priority quadrant; vernacular architecture combines the lowest weight with the highest mean performance. The diagnostic conclusion is consistent across all three cases: the binding constraint is procedural and standard-related, not a deficit of traditional building knowledge.

Strategic profile of the three cases

Table 5 sets out the comparative SWOT profile. The two end-members are close to mirror images. Band-e Kaisar's strengths are institutional inscription, documentation, an active management system and its threats are largely external and pressure-driven: seasonal flooding and pier scour, climate-driven reduction in base flow, tourism density, and jurisdictional tension between water and heritage authorities. Pol-e Dokhtar's strengths are intrinsic an undisturbed natural setting, material and formal authenticity, structural interest as a mountain type and its weaknesses are institutional: minimal documentation and maintenance, absent restoration standards and process, difficult access, and weak institutional and community engagement. Pol-e Mehr Narseh does not fall between these two profiles so much as combine one side of each. It shares the intrinsic strengths of the unlisted bridge a legible valley setting, an intact relationship between crossing, river and historic

route, and the strongest vernacular-architecture score of the three while sharing its procedural weaknesses almost in full. Its threats, however, resemble those of the inscribed site rather than the remote one: development pressure in the immediate setting, not neglect, is what erodes it. This is the configuration that makes it strategically distinctive. Because its fabric indicators are already moderate, the cost of moving it from the standard to the light pathway is lower than the cost of the equivalent move for Pol-e Dokhtar, while the setting it stands to lose is more exposed.

Table 5: Comparative SWOT profile of the three case-study bridges.

Factor	Band-e Kaisar (Shushtar)	Pol-e Mehr Narseh (Tangab)	Pol-e Dokhtar (Mianeh)
Strengths	World Heritage inscription and comparatively rich documentation; integrated hydraulic–architectural landscape; high material and semantic authenticity of architectural elements; active heritage management system	National registration and association with the Sassanid capital landscape of Ardashir-Khurreh; coherent valley setting in which bridge, river and historic route remain legible; strongest vernacular-architecture score of the three cases	Relatively undisturbed natural setting; structural interest as a mountain bridge type; authenticity of material and historic form; symbolic role in local identity
Weaknesses	Urban development pressure on the visual buffer; fluctuating water quality and canal sedimentation; visitor density in peak season; absence of continuous digital structural monitoring	Restoration standards the weakest of its own indicators, with process design little better; documentation partial and discontinuous; contested attribution complicating intervention decisions	Lowest level of documentation and maintenance; no restoration standard or defined process; difficult access and remoteness; weak institutional and community engagement
Opportunities	Benchmark model for national restoration practice; community-based sustainable tourism; international cooperation through UNESCO; pilot site for a national heritage data bank	Integration into the heritage itinerary of the Sassanid Archaeological Landscape of Fars; pilot site for the standard intervention pathway, where moderate fabric condition makes upgrading comparatively inexpensive	National prioritisation for rescue intervention; three-dimensional survey and creation of a technical dossier; linkage to regional nature-based tourism; template for mountain-bridge rehabilitation
Threats	Severe seasonal flooding and pier scour; climate change and reduced base flow; potentially incompatible restoration interventions; jurisdictional conflict between water and heritage authorities	Seasonal flow and pier scour in a confined valley; agricultural and road development encroaching on the immediate setting; gradual loss of the visual relationship with the river	Severe scour from seasonal flow; risk of partial structural collapse; freeze–thaw cycling; progressive neglect and gradual loss

The asymmetry is precisely the one revealed by the indicator analysis. What the listed bridge possesses and the other two lack is an apparatus of documentation, standards and process; what the unlisted bridge retains and the listed bridge is losing is an intact landscape setting; and what the intermediate case shows is that the two can come apart independently of statutory category.

RESULTS AND CONCLUSION

Status and managerial infrastructure as performance drivers

The central empirical finding is that the performance difference between a World-Heri-

tage-listed bridge-dam and a remote unlisted mountain bridge is concentrated in managerial and procedural indicators rather than in material or aesthetic ones. This has a direct interpretive consequence: measured restoration performance in this sample is driven substantially by inscription status and the institutional apparatus that accompanies it, rather than by intrinsic differences in the heritage value or the material integrity of the assets. The finding is consistent with comparative evidence from other contexts. Studies of management effectiveness at world cultural landscape properties have shown that inscription reorganises institutional attention and resource flows as much as it changes physical treatment (Zhou et al., 2022), and analyses of heritage governance in Iran have identified stakeholder fragmentation and contested authority as decisive for conservation outcomes (Vafadari Komarolya & Sajedi, 2026). The pattern also mirrors the structural contrast the wider literature draws between settings where documentation infrastructure, restoration standards and financing mechanisms are taken-for-granted preconditions of practice, and settings where these same preconditions are themselves the critical bottleneck. The intermediate case makes the mechanism visible rather than merely bracketing it. Pol-e Mehr Narseh carries a statutory designation and a partial documentary record, yet its restoration-standards and process-design scores sit within 0.3 of the wholly unprotected bridge. What separates it from Band-e Kaisar is therefore not designation in the abstract but the continuous institutional apparatus that inscription happens to bring with it a permanent custodian, a maintenance cycle, an accountable technical authority. Where designation exists without that apparatus, as at Tangab, measured performance behaves much as it does where no designation exists at all. The operative variable is administrative capacity, and legal status matters largely to the extent that it delivers it. The reversal on ecological protection sharpens the point. That the unmanaged bridge outperforms the managed one on environmental setting indicates that active management is not uniformly protective: it concentrates on fabric and visitor infrastructure while the surrounding landscape absorbs development and tourism pressure. This is the failure mode that landscape-scale instruments were designed to address the European Landscape Convention's insistence that landscape is a public-interest category across ordinary as well as outstanding territory (Council of Europe, 2000), and the historic urban landscape approach's treatment of setting as an object of management rather than a backdrop (UNESCO, 2011). The present results suggest that for historic bridges these instruments remain imperfectly operationalised even at inscribed sites.

Prescriptive weight versus empirical effect

A second finding concerns the divergence between the AHP weighting and the structural model. Experts assigned the heritage–identity dimension the highest weight, yet it exerted the weakest direct effect on restoration sustainability in the PLS-SEM ($\beta = 0.180$), while the physical–structural dimension showed the strongest ($\beta = 0.320$). This is not a contradiction but a distinction between two different questions. The AHP elicits what practitioners believe ought to govern restoration a normative ordering in which authenticity is primary, consistent with the doctrinal tradition running from critical restoration theory through the Venice and Nara instruments (ICOMOS, 1964, 1994) and articulated in values-based conservation frameworks (Avrami et al., 2019; Historic England, 2008). The structural model estimates what actually predicts sustainable outcomes in current practice, where physical durability and hydraulic resilience dominate. Read together, the two results define the reform agenda rather than undermining each other. Authenticity is held to be primary but is not yet the operative driver of outcomes; closing that distance requires the very procedural infrastructure the importance–performance analysis identifies as deficient. The same logic underlies value-based conservation

of comparable bridge monuments elsewhere, where explicit value statements are used to govern technical choice rather than follow it (Chen et al., 2026; Yang et al., 2025).

Setting as a determinant of intervention logic

The two settings impose different technical agendas. The riverine bridge-dam operates within a managed hydraulic system: its risks are sedimentation, altered base flow, pier scour under seasonal flood, and encroachment on the visual buffer. Its conservation is therefore inseparable from water management, and the jurisdictional tension identified in its SWOT profile is not incidental but structural. The gorge-bound bridge faces a narrower but more acute set of forces: high-energy seasonal flow in a confined channel, freeze–thaw cycling, and progressive scour at the piers with no monitoring in place. Scour is the dominant failure mechanism for bridges in such regimes, and the monitoring techniques that would detect its progression are well developed (Prendergast & Gavin, 2014) yet entirely absent here; the hydrodynamic loading imposed by floating debris during flood events compounds the risk (Majtan et al., 2022). This divergence argues against uniform prescription. The tiered pathway structure adopted here — light, standard and full, assigned by composite index is a direct response, and it aligns with hydrologically informed approaches to riverine bridge heritage developed elsewhere (Ccanccapa Puma et al., 2024) and with the structural-assessment literature that conditions intervention on demonstrated capacity rather than on categorical status (Addessi et al., 2021; Simoncello et al., 2020). It also reframes the remote case. Pol-e Dokhtar's intact setting is a conservation asset of the kind that landscape-scale heritage thinking explicitly values (Palang & Fry, 2003; Rössler & Lin, 2018), and one that the managed site is progressively losing. A tiered framework that treats the unlisted bridge purely as a deficit case would miss this; an indicator set that scores environmental setting independently does not.

Implications for practice

Three implications follow. First, resource allocation for historic-bridge landscape restoration in Iran should prioritise systemic investment a national documentation bank, an explicit restoration standard for bridge structures, and defined process gates over additional fabric intervention at already well-managed sites. The importance–performance analysis identifies precisely these as the high-importance, low-performance indicators, and the comparative case analysis shows the gap between the cases concentrated there. Second, documentation should be treated as the entry condition rather than the culmination of the conservation process. Contemporary workflows integrating terrestrial laser scanning and building information modelling for heritage bridges (León-Robles et al., 2019; Willkens et al., 2024) and photogrammetric approaches suited to constrained-resource contexts (Hassani & Rafiee, 2013) make baseline geometric and material records achievable without prohibitive cost, and such records are the precondition for any defensible judgement of intervention necessity. Third, landscape buffers require statutory definition independent of inscription status. The ecological-protection reversal demonstrates that inscription alone does not protect setting, while the absence of any buffer instrument at the unlisted site leaves an intact landscape exposed to the first development pressure that reaches it. Heritage impact assessment methods now applied to Iranian World Heritage contexts (Ashrafi et al., 2024) and visual-impact methods developed for cultural landscape properties (Kou et al., 2024) provide operational precedent.

Transferability of the framework

The framework's structure is separable from its calibration. Its architecture a small set of indicators distributed across physical, landscape, heritage, environmental and managerial dimensions, weighted by expert elicitation, validated against an outcome construct, and mapped onto tiered intervention pathways makes no assumption

specific to Sassanid bridges or to Iran. What is context-specific is the numerical calibration: the particular eight indicators surviving the Delphi filter, their weights, and the thresholds separating the pathways. This distinction matters for how the results should be read elsewhere. Re-estimating the framework for another bridge culture would almost certainly yield a different indicator set and different weights, because the factors that experts judge salient are conditioned by the prevailing construction tradition, hydrological regime and governance arrangement. What can be tested across contexts is the structural finding: whether, once indicators are weighted and applied comparatively, measured performance separates along managerial rather than material lines. Evidence from value-based conservation of monumental bridges in East Asia (Chen et al., 2026; Yang et al., 2025) and from hydrologically framed conservation in Latin America (Ccanccapa Puma et al., 2024) suggests the managerial dimension is consistently decisive, but no study has yet isolated it comparatively across a status gradient within a single heritage stock. A second transferable element is the tiered-pathway logic itself. Proportioning intervention depth to a measured composite index, rather than to categorical status, offers a defensible basis for triage wherever a heterogeneous stock exceeds available conservation capacity a condition that describes most national inventories of vernacular and infrastructural heritage, not only Iran's.

Finally, this study developed an eight-indicator, empirically weighted framework for assessing the landscape restoration of historic bridges and applied it comparatively to three Sassanid-associated case studies in Iran spanning a deliberate gradient of setting and statutory status. The framework was derived through qualitative content analysis, three rounds of fuzzy Delphi and fuzzy analytic hierarchy process, and its dimensional structure was confirmed by partial least squares structural equation modelling explaining 54 per cent of variance in restoration sustainability with acceptable predictive relevance. Applying the weighted indicators yielded composite condition indices of 80.5 for the riverine, World-Heritage-listed Band-e Kaisar at Shushtar, 67.7 for the valley-bound, nationally registered Pol-e Mehr Narseh at Tangab and 63.2 for the gorge-bound, unlisted Pol-e Dokhtar at Mianeh, placing the three cases in three distinct intervention pathways. The decisive result is the composition rather than the size of this spread: it is concentrated in restoration standards, process design and architectural-element conservation, while the three bridges differ only marginally on landscape and aesthetic indicators, and the remote unlisted case outperforms the inscribed monument on ecological protection. The intermediate case shows that the spread is not evenly distributed along the status gradient: most of it opens between inscription and national registration. Three conclusions follow. Measured restoration performance in this sample is driven principally by statutory status and the managerial infrastructure accompanying it, not by intrinsic material condition. Inscription does not by itself protect landscape setting, and may coincide with its erosion where development and visitor pressure concentrate. And the divergence between the normative primacy experts assign to authenticity and the empirical dominance of physical–structural factors marks the distance that procedural reform must close. For policy, the implication is that landscape-restoration effort for historic bridges should be tiered by measured condition rather than applied uniformly, and that systemic investment in documentation, standards and process infrastructure will yield more than additional fabric intervention at already well-managed sites. The framework presented here is transferable in structure if not in calibration: the indicator set, weighting procedure and tiered-pathway logic can be re-estimated for other bridge cultures, and doing so would test whether the status-driven performance pattern identified in Iran is a local artefact or a general feature of heterogeneous heritage stocks.

REFERENCES

Addessi, D., Gatta, C., Nocera, M., & Liberatore, D. (2021). Nonlinear dynamic analysis of a masonry arch bridge accounting for damage evolution. Geosciences, 11(8), 343. https://doi.org/10.3390/geosciences11080343

Ashrafi, B., Kloos, M., & Reicher, C. (2024). Heritage impact assessment index within urban development context: The case of Masjed-e Jame of Isfahan in Iran. Heritage, 8(1), 3. https://doi.org/10.3390/heritage8010003

Avrami, E., Macdonald, S., Mason, R., & Myers, D. (Eds.). (2019). Values in heritage management: Emerging approaches and research directions. Los Angeles: Getty Conservation Institute. https://www.getty.edu/publications/heritage-management/

Buckley, J. J. (1985). Fuzzy hierarchical analysis. Fuzzy Sets and Systems, 17(3), 233–247. https://doi.org/10.1016/0165-0114(85)90090-9

Ccanccapa Puma, J., Hidalgo Valdivia, A. V., Espinoza Vigil, A. J., & Booker, J. (2024). Preserving heritage riverine bridges: A hydrological approach to the case study of the Grau Bridge in Peru. Heritage, 7(7), 3350–3371. https://doi.org/10.3390/heritage7070158

Chang, D.-Y. (1996). Applications of the extent analysis method on fuzzy AHP. European Journal of Operational Research, 95(3), 649–655. https://doi.org/10.1016/0377-2217(95)00300-2

Chen, S., Pintus, V., & Li, C. (2026). Value-based conservation of Zhaozhou Bridge: Inspiration from World Heritage bridges. Journal of Highway and Transportation Research and Development, 20(2), 54–64. https://doi.org/10.26599/HTRD.2026.9480097

Council of Europe. (2000). European Landscape Convention (ETS No. 176). Florence: Council of Europe. https://www.coe.int/en/web/landscape

Fornell, C., & Larcker, D. F. (1981). Evaluating structural equation models with unobservable variables and measurement error. Journal of Marketing Research, 18(1), 39–50. https://doi.org/10.1177/002224378101800104

Hair, J. F., Risher, J. J., Sarstedt, M., & Ringle, C. M. (2019). When to use and how to report the results of PLS-SEM. European Business Review, 31(1), 2–24. https://doi.org/10.1108/EBR-11-2018-0203

Hassani, F., & Rafiee, M. (2013). An experience in cultural heritage documentation in Iran using a low-cost technique. ISPRS Archives, XL-5/W2, 313–318. https://doi.org/10.5194/isprsarchives-XL-5-W2-313-2013

Henseler, J., Ringle, C. M., & Sarstedt, M. (2015). A new criterion for assessing discriminant validity in variance-based structural equation modeling. Journal of the Academy of Marketing Science, 43(1), 115–135. https://doi.org/10.1007/s11747-014-0403-8

Historic England. (2008). Conservation principles, policies and guidance for the sustainable management of the historic environment. London: English Heritage. https://historicengland.org.uk/images-books/publications/conservation-principles-sustainable-management-historic-environment/

Hsu, Y.-L., Lee, C.-H., & Kreng, V. B. (2010). The application of fuzzy Delphi method and fuzzy AHP in lubricant regenerative technology selection. Expert Systems with Applications, 37(1), 419–425. https://doi.org/10.1016/j.eswa.2009.05.068

Huff, D., & Kleiss, W. (1989). Bridges. In Encyclopædia Iranica (Vol. IV, Fasc. 5, pp. 449–455). London: Routledge & Kegan Paul. https://www.iranicaonline.org/articles/bridges/

ICOMOS. (1964). International charter for the conservation and restoration of monuments and sites (The Venice Charter). Venice: ICOMOS. https://www.icomos.org/images/DOCUMENTS/Charters/Venice_Charter_EN_2023.pdf

ICOMOS. (1994). The Nara document on authenticity. Nara: ICOMOS. https://www.icomos.org/en/179-articles-en-francais/ressources/charters-and-standards/386-the-nara-document-on-authenticity-1994

Ishikawa, A., Amagasa, M., Shiga, T., Tomizawa, G., Tatsuta, R., & Mieno, H. (1993). The max–min Delphi method and fuzzy Delphi method via fuzzy integration. Fuzzy Sets and Systems, 55(3), 241–253. https://doi.org/10.1016/0165-0114(93)90251-C

Kou, H., Zhang, L., & Zhang, S. (2024). Visual impact assessment method for cultural heritage: West Lake cultural landscape in Hangzhou, China. Land, 13(10), 1596. https://doi.org/10.3390/

land13101596

León-Robles, C. A., Reinoso-Gordo, J. F., & González-Quiñones, J. J. (2019). Heritage building information modeling (H-BIM) applied to a stone bridge. ISPRS International Journal of Geo-Information, 8(3), 121. https://doi.org/10.3390/ijgi8030121

Majtan, E., Cunningham, L. S., & Rogers, B. D. (2022). Experimental and numerical investigation of floating large woody debris impact on a masonry arch bridge. Journal of Marine Science and Engineering, 10(7), 911. https://doi.org/10.3390/jmse10070911

Palang, H., & Fry, G. (Eds.). (2003). Landscape interfaces: Cultural heritage in changing landscapes. Dordrecht: Kluwer Academic Publishers. https://doi.org/10.1007/978-94-017-0189-1

Prendergast, L. J., & Gavin, K. (2014). A review of bridge scour monitoring techniques. Journal of Rock Mechanics and Geotechnical Engineering, 6(2), 138–149. https://doi.org/10.1016/j.jrmge.2014.01.007

Ringle, C. M., & Sarstedt, M. (2016). Gain more insight from your PLS-SEM results: The importance-performance map analysis. Industrial Management & Data Systems, 116(9), 1865–1886. https://doi.org/10.1108/IMDS-10-2015-0449

Rössler, M., & Lin, R. C.-H. (2018). Cultural landscape in World Heritage conservation and cultural landscape conservation challenges in Asia. Built Heritage, 2(3), 3–26. https://doi.org/10.1186/BF03545707

Sacco, G. L. S., Ridella, M., & Calderini, C. (2026). A parametric HBIM approach to geometric uncertainty modelling for heritage bridge structural analysis. Buildings, 16(15), 3054. https://doi.org/10.3390/buildings16153054

Simoncello, N., Zampieri, P., Gonzalez-Libreros, J., Perboni, S., & Pellegrino, C. (2020). Numerical analysis of an FRP-strengthened masonry arch bridge. Frontiers in Built Environment, 6, 7. https://doi.org/10.3389/fbuil.2020.00007

UNESCO. (2011). Recommendation on the Historic Urban Landscape. Paris: UNESCO. https://whc.unesco.org/en/hul/

UNESCO World Heritage Centre. (2009). Shushtar Historical Hydraulic System (World Heritage List No. 1315). Paris: UNESCO. https://whc.unesco.org/en/list/1315/

UNESCO World Heritage Centre. (2018). Sassanid Archaeological Landscape of Fars Region (World Heritage List No. 1568). Paris: UNESCO. https://whc.unesco.org/en/list/1568/

Vafadari Komarolya, D., & Sajedi, S. (2026). Power, consensus, and conflict in urban heritage governance: A MACTOR analysis of stakeholder networks in Tabriz, Iran. Journal of Urban Management, 15(3), 1430–1449. https://doi.org/10.1016/j.jum.2026.02.009

Willkens, D. S., Liu, J., & Alathamneh, S. (2024). A case study of integrating terrestrial laser scanning (TLS) and building information modeling (BIM) in heritage bridge documentation: The Edmund Pettus Bridge. Buildings, 14(7), 1940. https://doi.org/10.3390/buildings14071940

Yang, C., Hu, Y., Su, Q., Li, X., & Zhu, M. (2025). Empirical methods for recognizing and evaluating cultural heritage value of timber-arched lounge bridge from the perspective of cultural memory. Journal of Asian Architecture and Building Engineering, 24(5), 3575–3592. https://doi.org/10.1080/13467581.2024.2399689

Zhou, J., Wang, W., Zhou, J., Zhang, Z., Lu, Z., & Gong, Z. (2022). Management effectiveness evaluation of world cultural landscape heritage: A case from China. Heritage Science, 10(1), 1–9. https://doi.org/10.1186/s40494-022-00660-2

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