

Supplementary Table S1 | Archival source collection and documentary-form inventory

Source ID	Document type	Date	Content	Use in study	Access status
A1	Completion and acceptance report	December 2015	Overall architectural information, pre-maintenance condition, project background, conservation principles, intervention summary, and completion information	Establishes the overall project context and supports reconstruction of the 2015 maintenance campaign	Selected evidence is reproduced in the Supplementary Information; the complete report is subject to project, institutional, heritage-protection, and third-party restrictions.
A2	As-built drawings and technical drawings	2015	Plans, elevations, local construction details, lightning-protection layouts, repair locations, and intervention extents	Supports spatial localisation of interventions and cross-checking of locations and technical details described in textual records	Not publicly redistributed in full because of project and heritage-management restrictions; selected information is summarized in the manuscript and supplementary files.
A3	Construction and intervention records	2015	Intervention procedures, materials, dimensions, process parameters, and records of lightning protection, steel-plate treatment, repointing, local reinforcement, surface treatment, and drainage improvement	Used to reconstruct intervention procedures and map treatments to documented deterioration conditions and conservation objectives	Selected procedures are summarized in Supplementary Table S3 and illustrated in the Supplementary Information; complete records remain restricted.
A4	Site and construction photographs	2015	Pre-maintenance deterioration, work-in-progress conditions, component-level treatment, and before-and-after visual documentation	Provides visual corroboration of deterioration manifestations, intervention locations, treatment stages, and post-intervention condition	Selected photographs are reproduced in the manuscript and Supplementary Information; high-resolution originals are subject to permission restrictions.
A5	3D laser-scanning and digital-model records	2015	Exterior and interior geometric documentation, component-level digital records, and three-dimensional representations generated during the maintenance project	Provides a spatial baseline and supports interpretation of component location, geometry, and digital traceability	Described in the manuscript; complete raw scanning and model datasets are not publicly redistributed.
A6	Preventive-monitoring documentation	2020 and available later records	Monitoring-system configuration, sensor categories, monitored variables, and available monitoring information for structural and environmental condition assessment	Used to characterize the monitoring layer and to compare existing monitoring coverage with intervention-specific verification needs	System configuration and derived monitoring indicators are reported in the manuscript and Supplementary Table S4; no complete long-term time-series dataset was available.
A7	Historical conservation information reproduced or referenced in later project records	1957 and 1986/1987 campaigns, as documented retrospectively	Historical descriptions of earlier stabilization and foundation-strengthening campaigns, including intervention objectives and reported outcomes	Supports reconstruction of the long-term conservation trajectory and comparison of changing conservation priorities	Used as retrospective archival evidence. The 1986/1987 date discrepancy is retained rather than harmonized because different project records report different completion dates.

Note: A1–A7 represent distinct documentary forms within or associated with the Yunyan Temple Pagoda project archive. They are not treated as independent institutional sources. In this study, cross-document validation refers to corroboration across distinct documentary forms, with discrepancies retained explicitly rather than silently harmonized.

Supplementary Table S2 | Deterioration classification based on archival evidence

ID	Deterioration condition	Evidence source	Analytical classification	Conservation implication
D01	Incomplete lightning-protection system	Archival description and construction photographs	Preventive-safety deficiency	Increased risk of lightning-related damage to the pagoda and associated safety hazards
D02	Corrosion and expansion of corner steel plates	Archival description, close-range photographs, and construction records	Corrosion-induced deterioration	Expansion of corroded steel may cause cracking, separation, and loss of surrounding masonry
D03	Poor waterproofing capacity of the masonry	Archival condition assessment and photographic evidence	Moisture-related deterioration	Rainwater may penetrate open joints and accelerate internal material loss and masonry deterioration
D04	Freeze-thaw damage and loss of eave bricks	Archival damage inventory and photographs	Freeze-thaw and surface-weathering deterioration	Repeated freezing and thawing may cause scaling, detachment, and falling masonry components
D05	Vegetation and root growth in masonry joints	Archival photographs and maintenance records	Biological deterioration	Root growth may enlarge joints, retain moisture, and locally displace masonry units

D06	Cracking associated with corroded reinforcement and rainwater penetration	Archival description and photographic evidence	Coupled corrosion-moisture deterioration	Cracks facilitate further water ingress and may accelerate corrosion and local masonry damage
D07	Deformation and partial collapse of arched openings	Archival photographs and intervention records	Local masonry deformation	Local instability may disrupt the load path and increase the risk of progressive deformation
D08	Severe loss and weathering of bricks beneath the eaves	Archival damage inventory and photographs	Surface weathering and local component loss	Continued material loss may create falling-debris hazards and reduce the integrity of projecting masonry elements
D09	Poor drainage around the base of the pagoda	Archival description and site photographs	Moisture-related environmental deficiency	Surface ponding and prolonged damp exposure may increase moisture accumulation in the lower masonry

Supplementary Table S3 Intervention records reconstructed from the 2015 maintenance archive				
Intervention	Location	Procedure	Conservation objective	Supporting evidence
Custom scaffolding installation	Entire external surface of the leaning pagoda	A specialist scaffolding system was designed to accommodate the inclined geometry and octagonal form of the pagoda	Provide safe construction access while limiting disturbance to the historic fabric	Construction photographs and project description
Lightning-rod maintenance	Pagoda finial	Corrosion products were removed from the existing lightning rod by polishing	Restore electrical conductivity and improve lightning-protection performance	Construction photographs and archival description
Down-conductor replacement	External lightning-conduction route	The original thin bare copper conductor was replaced with two 100 mm² copper down conductors	Increase conductivity, reliability, and redundancy of the lightning-protection system	Construction records and photographs
Installation of circumferential lightning bands	Finial, seventh level, and fifth- and sixth-level eave-brick zones	Four circumferential lightning bands were installed at key levels of the pagoda	Reduce the risk of side flashes and improve the continuity of the lightning-protection system	Construction photographs and archival description
Step-voltage protection	Grounding area surrounding the pagoda	Excavation, exothermic welding, insulated backfilling, and installation of an inspection box were undertaken	Reduce step-voltage risk and facilitate later inspection of the grounding system	Construction photographs and technical records
Vegetation removal	Masonry joints and upper external surfaces	Vegetation was inactivated, roots were removed, and loose organic material was cleared	Reduce biological disturbance, moisture retention, and local joint opening	Before-and-after photographs

Pagoda-top repair	Finial and upper plastered surfaces	Detached and cracked plaster was repaired using crack-resistant and water-resistant mortar, followed by local replastering	Control leakage and restore the protective surface of the pagoda top	Construction photographs and archival description
Treatment of mildly corroded corner steel plates	Corner masonry columns	Surface rust was removed, dust was cleaned, two coats of anti-rust paint were applied, and the masonry was rebuilt with custom-made bricks	Retain serviceable historic reinforcement while restoring corrosion protection and masonry cover	Construction photographs and process records
Treatment of severely corroded corner steel plates	Selected corner masonry columns	The original steel-plate dimensions were recorded, a new steel plate of the same size was welded to the existing plate, anti-rust coatings were applied, and the masonry was rebuilt	Restore local reinforcement continuity and reduce the risk of further corrosion-induced cracking	Construction photographs and process records
Wire-mesh and tie-bar strengthening	Masonry surrounding corner steel plates	Steel wire mesh was installed on both sides of the steel plate, and two tie bars were welded at approximately 500 mm vertical intervals	Improve connection between the masonry and the steel plate and reduce recurrent cracking	Construction details and photographs
Steel-dowel insertion	Local projecting masonry elements and brick joints	Holes deeper than 40 mm were drilled in the joints, adhesive was injected, and steel dowels were inserted and concealed	Improve local anchorage while minimizing visible alteration	Construction photographs and archival description

Masonry repointing	Open joints across the external masonry	Loose material was removed, joints were cleaned using a handheld blower, preliminary pointing was completed, and the surface was finished and cleaned	Reduce rainwater ingress and prevent the loss of internal earthen material	Before-and-after photographs and process records
Arched-opening reinforcement	Deformed arched openings	Temporary timber supports were installed, seven grooves were cut along the masonry joints, two steel bars were inserted into each groove, and the grooves were concealed with mortar	Improve local stability without extensive dismantling of the historic masonry	Construction photographs and reinforcement schematic
Repair of cracks around existing hoops	Areas adjacent to earlier circumferential reinforcement	Local cracks around the hoop-reinforcement zones were repaired and sealed	Reduce moisture ingress and maintain the protective continuity of the masonry cover	Construction photographs
Surface consolidation	Weathered external masonry surfaces	KSE300 consolidant was sprayed onto the external masonry surface	Improve the cohesion of weathered and weakened surface material	Material photographs and application records
Water-repellent treatment	External surface of the pagoda	SNL water-repellent material was sprayed onto the surface, and the treated areas were protected from rainfall for seven days	Reduce surface water absorption and rainwater penetration	Material photographs and construction records
Drainage improvement	Ground surface around the pagoda	The original poorly draining brick paving was replaced with stone-slab paving	Improve surface runoff and reduce prolonged damp exposure around the base of the pagoda	Before-and-after site photographs

Supplementary Table S4 | Monitoring indicators derived from the diagnosis–intervention relationship

Intervention or risk group	Suggested monitoring indicator	Conservation issue addressed	Verification purpose
Lightning-protection system	Electrical continuity, grounding resistance, and visual condition of conductors and connections	Lightning-related safety risk	Verify that the renewed lightning-protection system remains functional and continuous
Corner steel-plate treatment	Crack width, visible corrosion, local deformation, and separation at the steel–masonry interface	Corrosion recurrence	Detect renewed corrosion expansion or deterioration of the surrounding masonry
Masonry repointing	Joint opening, mortar detachment, moisture penetration, and local leakage	Rainwater ingress through open joints	Evaluate the durability and moisture-control performance of the repointing
Pagoda-top repair	Crack recurrence, plaster detachment, and visible leakage	Water penetration at the finial and upper surfaces	Assess whether the repaired protective surface continues to prevent leakage
Vegetation removal	Vegetation recurrence, root growth, and moisture-retaining zones	Biological deterioration	Determine whether biological growth has re-established in masonry joints
Arched-opening reinforcement	Local displacement, crack development, and condition of the mortar-concealed grooves	Local masonry deformation	Verify the continued stability of the reinforced arched opening

Surface consolidation	Surface powdering, scaling, material loss, and surface cohesion	Surface weathering	Evaluate whether the consolidant continues to improve the stability of weakened surface material
Water-repellent treatment	Surface water absorption, moisture content, visible staining, and treatment ageing	Rainwater penetration	Assess the long-term effectiveness and compatibility of the water-repellent treatment
Drainage improvement	Surface ponding, runoff path, drainage time after rainfall, and moisture condition of the lower masonry	Poor site drainage	Determine whether the revised paving system effectively reduces damp exposure
Eave-brick and projecting masonry repairs	Component displacement, new material loss, and crack development	Freeze-thaw damage and falling components	Identify renewed deterioration or instability of projecting masonry elements
Overall pagoda condition	Inclination, settlement, crack development, and changes in local deformation	Global and local structural stability	Distinguish long-term structural movement from local maintenance-related deterioration

Note: The monitoring indicators listed in Supplementary Table S4 were derived from the documented relationship between deterioration mechanisms and conservation interventions. They are proposed as variables for the subsequent verification of intervention performance and are not presented as raw monitoring data collected during the 2015 maintenance project. No complete time-series monitoring dataset was available in the archival source used for this study.