ISSN 2228-9860 eISSN 1906-9642 CODEN: ITJEA8

International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies

http://TuEngr.com

Anastylosis with Technical Analysis of the Restoration of Phimai Historical Park in Thailand

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Paper ID: 17A1F

Volume 17 Issue 1

Received 25 February 2026
Received in revised form 24 April 2026
Accepted 30 April 2026
Available online 06 May 2026

Keywords:
Corbel method; Angkor; Anastylosis process; Prasat Hin Phimai; Korean-Thai joint research; French-Thai collaboration; Prang restoration; Structural safety evaluation; Nakhon Ratchasima; Thailand's Fine Arts Department; Cultural heritage protection; The Venice Charter (1964); Heritage deterioration; The Athens Charter (1931).

Abstract

Phimai Historical Park (Prasat Hin Phimai) (PHP) is the largest and most significant Khmer temple complex in Thailand. The restoration of PHP is a landmark achievement using anastylosis combined with civil/architectural engineering methodologies. This paper analyzes the multi-phased restoration of PHP. Also, this work studies the technical approaches, innovations, and conservation philosophies used from the French-Thai collaboration (1964-1969) and the Korean-Thai joint research (2016-2020). This study uses restoration archives, technical reports, historical documents, and conservation literature. This study uses five key aspects. First, this study learns the historical background of the anastylosis. Second, the engineering difficulties are associated with the reassembly of stone via the corbel technique. Third, the material science related to the deterioration of sandstone and laterite. Fourth, the safety assessment and classification system. Fifth, the formulation of comprehensive conservation frameworks. The key findings indicate that anastylosis is the standard restoration practice for the conservation of Khmer monuments in Thailand, with dismantling, coding, and reassembling the central prang using original materials. The Korean-Thai joint research identified many points required systematic safety evaluation, with Prang Hin Daeng receiving the most critical classification requiring immediate intervention. The structural damage identified patterns as separation, tilt, swelling, differential settlement, breakage, dropout, and collapse. Also, this work learns material deterioration mechanisms (weathering, abrasion, cracking, peeling). This research prioritized restoration stages, enhancements in visitor management, and the creation of a thorough maintenance system via modern conservation technology.

Discipline: Multidisciplinary (Archaeology, Civil & Architectural Engineering, Heritage Conservation & Management).

Cite This Article:

Boonthai, W., Witchayangkoon, B., Arab, Y., and Hassan, A.S. (2026). Anastylosis with Technical Analysis of the Restoration of Phimai Historical Park in Thailand. *International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies, 17*(1), 17A1F, 1-23. http://TUENGR.COM/V17/17A1F.pdf DOI: 10.14456/ITJEMAST.2026.6

1 Introduction

Phimai Historical Park (PHP) is a Khmer temple complex in Thailand, see Figure 1. It is also known in Thai as Prasat Hin Phimai. It is in Phimai town, Nakhon Ratchasima province, Northeast of Thailand. PHP marks the end of the Ancient Khmer Highway that links Angkor to the Khorat Plateau. The PHP area is 1,020 by 580 meters; thus, this is similar to Angkor Wat. This shows that Phimai is important in the Khmer empire and architectural history.

Figure 1: Landscape/bird-eye view of Phimai Historical Park (PHP).

PHP was built between the late 11th and late 12th centuries during the reigns of King Jayavarman VI and King Jayavarman VII. Unlike Khmer temples, which were dedicated to Hindu gods, Phimai was built as a Mahayana Buddhist temple. The inscriptions call the site "Vimayapura" or City of Vimaya, which later became Phimai (Museum Thailand, 2023; Thai PBS World, 2024).

A 1108 CE inscription from Prakhon Chai mentions "Kamrateng Chakata Vimaya". Talks about creating a sacred image called "Kamrateng Chakata Senapati Trilokayavijaya". This gives evidence for the temple's founding and royal support.

The design of Phimai follows the principles of Angkorian temples, with the central prang representing Mount Meru, the center of the universe in Hindu-Buddhist beliefs. The complex has two layers of corridors in a shape with gopuras or gateway towers at the north, south, east, and west of both corridors. Inside the corridor, the Main Tower is in the center along with other structures like Prang Phrommathat and Prang Hin Daeng. The whole temple faces south toward Angkor, showing its importance as a stop on the pilgrimage route (Baike, 2026).

Figure 2: The ruined PHP before the restoration. (digitally remastered image).

1.1 Historical Context of Rediscovery and Protection

The first systematic inventory of the Phimai ruins (Figure 2) was conducted in 1901 by the French geographer and archaeologist Étienne Aymonier. Aymonier, who had previously documented Khmer sites throughout present-day Cambodia and Thailand, recognized Phimai as one of the most significant Khmer monuments outside Angkor. His documentation laid the foundation for subsequent scholarly attention and eventual legal protection.

The site was officially placed under governmental protection by announcement in the Government Gazette, Volume 53, section 34, dated 27 September 1936. This designation empowered Thailand's Fine Arts Department (FAD) to regulate activities within the monument zone and to allocate resources for conservation. The FAD has been the primary agency responsible for archaeological site protection and restoration in Thailand since its establishment in 1912.

1.2 The Anastylosis Technique and Its Origins

Anastylosis is derived from the Greek words "ana" (again) and "stylosis" (to erect a column). It is a reconstruction technique that uses original architectural material to the greatest degree possible when restoring a ruined building or monument. The methodology is commonly used for cultural heritage repair in Thailand and Cambodia and has become the gold standard for Khmer monument conservation.

The fundamental principle of anastylosis is that the authenticity and historicity of a monument can be preserved only by retaining original materials. The 1964 Venice Charter, which established international standards for monument conservation, codified anastylosis as an

acceptable intervention provided that reassembly does not constitute creative reconstruction and is justified by sufficient archaeological evidence.

At Phimai, the anastylosis process followed a meticulous protocol (Figure 2):

1. Dismantling: The collapsed or unstable structure was carefully taken apart, block by block

2. Coding: Each stone block was numbered, and its position in the original structure was recorded

3. Ground Assembly: Fragments were assembled on the ground to confirm fit and identify missing pieces (Figure 7)

4. Consolidation: Damaged stones were cleaned and treated for deterioration

5. Reassembly: Blocks were restored to their original positions based on archaeological evidence.

The technique requires not only archaeological expertise but sophisticated civil/architectural engineering capabilities. The reassembly of thousands of stone blocks, some weighing more than 1,000 kilograms, demands careful planning for load distribution, foundation stability, and long-term structural integrity.

1.3 Research Questions

This paper addresses the following research questions:

1. How was the anastylosis technique applied during the 1964-1969 French-Thai restoration of Phimai Historical Park, and what engineering innovations were developed for this project?

2. What civil engineering technologies have been employed in subsequent conservation efforts, particularly the 2016-2020 joint research between Korea and Thailand?

3. How have structural assessment and safety classification methodologies been developed and applied to the Phimai ruins?

4. What have been the primary patterns of structural and material deterioration documented at the site, and what conservation responses have been developed?

5. What integrated conservation frameworks have emerged from the Phimai experience, and how can these inform practice at other Khmer monuments in Southeast Asia?

1.4 Paper Structure

Section 2 reviews the literature on Khmer architecture, anastylosis methodology, stone conservation, and international restoration standards. Section 3 describes the mixed-methods, including archival research, site documentation, & analysis of technical reports. Section 4 presents results organized in chronological and thematic restorations. Section 5 discusses the implications for heritage conservation practice and future research. Section 6 gives concluding remarks.

2 Literature Review

2.1 Khmer Architecture: Construction Systems and Materials

Understanding the restoration of Phimai requires detailed knowledge of traditional Khmer construction systems. Khmer builders developed a distinctive architectural technology that was

unparalleled in pre-industrial Southeast Asia, yet fundamentally different from Western systems of stone construction (Ektanitphong, 2014; IPFS, 2015; Alchetron, 2017).

The most significant technical limitation of Khmer architecture was the absence of the true arch. As documented in technical analyses of Phimai and other Khmer temples, builders had not developed the technique of true vault architecture; thus, they used the application of the corbel principle (Figure 5) to create "triangular and wedge-shaped structures". Lintels and roof slabs were cut at 45-degree angles to produce a triangular wedge, creating a self-supporting structure through the interlocking of angled stone blocks.

This corbelling technique, while effective for spanning relatively short distances, creates inherent structural vulnerabilities. The system relies entirely on the compressive strength of stone and the friction between blocks. Unlike true arches, which direct loads downward into supporting walls, corbel vaults exert significant lateral thrust outward. Over centuries, this thrust can cause walls to bulge, stones to shift, and ultimately, vaults to collapse.

The Khmer employed three principal construction materials, each serving distinct functions:

Brick: Used predominantly in earlier structures (pre-11th century) and for subsidiary elements. The Phimai site contains brick structures from earlier phases of construction.

Sandstone: The most prestigious material, reserved for visible outer layers, decorative carving, and primary sacred spaces. At Phimai, sandstone was used for the central prang, lintels, pediments, and door frames. The stone was quarried from sources approximately 20-40 kilometers from the site, with transport representing a major logistical achievement.

Figure 3: Current Phimai Historical Park (PHP) (Prasat Hin Phimai)

Laterite: An iron-rich claystone that hardens upon exposure to air, laterite was used for inner walls, foundations, and hidden structural elements. At Phimai, the outer enclosure wall and some subsidiary structures are built of laterite.

The combination of sandstone facing with laterite core created a composite structure that optimized material properties while managing quarrying and transport costs. However, differential material behavior—particularly differential thermal expansion and moisture movement—has contributed to long-term deterioration patterns.

2.2 The Historical Development of Anastylosis

Anastylosis as a formal conservation methodology emerged from European practice in the 19th century but achieved international recognition through the Athens Charter (1931) (ICOMOS, 2022) and subsequently the Venice Charter (1964) (ICOMOS, 2003). The technique was extensively developed at Mediterranean sites, including the Parthenon in Athens and the Roman ruins of Baalbek in Lebanon.

The application of anastylosis to Khmer architecture began at Angkor under the French École Française d'Extrême Orient (EFEO, 2016). Scholars such as Henri Marchal and Maurice Glaize developed systematic approaches to dismantling and reassembling collapsed stone structures, including the Banteay Srei temple (restored 1921-1936) and the Bayon (1930s). These projects established the precedent for subsequent work at Phimai.

According to Khanjanusthiti (1998), in 1964, PHP restoration work using anastylosis started in Thailand. This was the first joint project between the French and the FAD. Groslier organized the restoration process using the anastylosis method that had worked well on several stone structures in Cambodia. Initially, the French method of anastylosis was implemented in Thailand without any issues. It focused solely on restoring stone architecture and was later recognized by the authorities as the most effective method for restoring stone monuments. Although this method does not apply to brick and stucco buildings, the concept of complete restoration was also applied to brick ruins.

Thumwimol (2016) of the FAD, in a presentation at the Siam Society, documented the "Introduction and evolution of anastylosis in Thailand" as directly influenced by French experience at Angkor. The French-Thai collaboration at Phimai (1964-1969) represented the first systematic application of anastylosis to a Khmer monument.

2.3 Stone Deterioration Mechanisms in Tropical Environments

The conservation of sandstone monuments in tropical Southeast Asia faces particular challenges derived from the region's climate. Research conducted during the 2016-2020 joint Korea-Thailand project documented multiple deterioration mechanisms.

2.3.1 Salt Crystallization

Salt Crystallization is the most significant deterioration agent. Moisture migrating through the porous sandstone matrix dissolves soluble salts—derived from groundwater, atmospheric pollution, and biological sources—and transports them to evaporation surfaces. When moisture

evaporates, salts crystallize, generating expansive pressures within the stone's pore structure. The cyclic crystallization & dissolution cause progressive micro-fracturing and ultimately surface loss.

The Phimai sandstone has been characterized by petrographic analysis as a relatively coarse-grained material with porosity typically ranging from 10-20%. This porosity facilitates moisture movement while providing limited resistance to crystallization pressures.

2.3.2 Biological Colonization

Biological colonization by lichen, algae, moss, and higher plants is ubiquitous in the humid tropical environment. While some epilithic communities may provide protective benefits by stabilizing surfaces and moderating thermal extremes, aggressive root penetration can mechanically disrupt stone fabric. The presence of biological growth also complicates conservation decisions, as chemical treatments for removal may damage stone surfaces.

2.3.3 Atmospheric Pollution

Atmospheric pollution is less severe at Phimai than at urban monuments in Bangkok, but nevertheless contributes to stone deterioration. Nitrogen oxides and sulfur dioxide from vehicle emissions combine with atmospheric moisture to form acids that attack carbonate and silicate minerals.

2.3.4 Structural Damage

Structural damage results from seismic activity, foundation settlement, and the inherent behavior of corbel-vaulted structures has been documented throughout the Phimai complex. These mechanisms are addressed in Section 5 below.

2.4 The Fine Arts Department: Mandate and Evolution

The Fine Arts Department of Thailand (FAD) has been the primary state agency responsible for cultural heritage protection since its establishment in 1912 under the Ministry of Palace Affairs (later the Ministry of Education, and subsequently the Ministry of Culture). The Department's mandate includes archaeological excavation, monument restoration, museum management, and heritage site administration.

The Department's approach to monument restoration has evolved significantly over its century of operation. Early interventions focused primarily on vegetation clearance and emergency shoring, with limited reconstruction. The Phimai restoration (1964-1969) marked a transition toward systematic, internationally-informed conservation practice. The 1989 establishment of the Phimai Historical Park, officially opened by Her Royal Highness Princess Maha Chakri Sirindhorn on April 12, 1989, represented the culmination of this approach.

Since 1989, the FAD has continued to refine its conservation methodologies, integrating scientific material analysis, structural monitoring, and international collaborative partnerships. The 2016-2020 joint research with Korean institutions exemplifies this evolution toward evidence-based, multidisciplinary conservation.

2.5 International Conservation Charters and Standards

The restoration of Phimai has been guided by international standards codified in a series of conservation charters:

2.5.1 The Athens Charter (1931)

The Athens Charter (1931) (ICOMOS, 2022), adopted at the First International Congress of Architects and Technicians of Historic Monuments, established principles of minimal intervention, reversible treatments, and respect for original materials.

2.5.2 The Venice Charter (1964)

The Venice Charter (1964) (ICOMOS, 2003), adopted by the Second International Congress of Architects and Technicians of Historic Monuments, represented a significant advance in conservation philosophy. Articles governing restoration state that: "The process of restoration is a highly specialized operation. It aims to preserve and reveal the aesthetic and historic value of the monument and is based on respect for original material and authentic documents."

2.5.3 The Nara Document on Authenticity (1994)

The Nara Document on Authenticity (1994), developed by UNESCO, ICCROM, and ICOMOS, addressed the cultural diversity of authenticity criteria. The document recognized that different cultural traditions may legitimately employ different conservation approaches, provided they respect fundamental principles of authenticity.

The Phimai restoration has generally aligned with these international standards, though local contextual factors have required adaptation. The site's continued religious function (unlike at Angkor, which is largely secularized) has required particular sensitivity to living heritage values.

2.6 The 2016-2020 Korea-Thailand Joint Research Project

The 2016-2020 joint research project between the National Research Institute of Cultural Heritage (NRICH, 2020) of Korea and the FAD of Thailand represented the most comprehensive scientific investigation of Phimai since the 1960s restoration. The project's scope encompassed architecture, conservation science, safety evaluation, and maintenance planning.

Experts from Korea in architecture, safety, and conservation collaborated with Thai experts from the FAD. The research was motivated by recognition that natural and artificial factors continue to cause damage to the site even after the restoration, necessitating ongoing monitoring and intervention.

A working-level agreement established technical exchanges in fields including archaeology, conservation science, and architecture. The project produced a comprehensive preservation plan titled "Idea for the Preservation of Phimai Historical Park in Thailand: Korea-Thailand Cultural Heritage Preservation and Management Technology Exchange".

Key components of the Korea-Thailand joint research were

1. **Stone provenance analysis**: Rock samples were collected from three major production areas (Shikiho, Lungpuradu, and Seongnoen) and compared with samples from the Phimai site to determine quarry origins and material characteristics.

2. **Safety inspection and evaluation**: Buildings were divided into 33 zones, each undergoing systematic investigation for structural and material damage.

3. **Classification system development**: A five-grade classification system (A-E) was developed to prioritize intervention needs.

4. **Monitoring program**: Two sites were selected for ongoing monitoring of wall inclination and foundation settlement.

The Korea-Thailand joint research project represents the next generation of heritage science applied to Phimai. The systematic safety inspection of 33 zones, the development of a five-grade classification system (A-E), and the comprehensive documentation of structural and material damage have created a scientific foundation for ongoing management.

2.7 Research Gaps

Despite the extensive documentation of Phimai's restoration in Thai and French-language sources, several gaps exist in English-language scholarship. The detailed technical records of the 1964-1969 anastylosis have not been systematically published in English. The 2016-2020 joint research findings remain largely in Korean-language reports. The integration of civil engineering monitoring systems with traditional conservation practice remains under-documented

3 Methods

3.1 Research Design

This study employs a multi-method case study design combining archival research, site documentation, analysis of technical reports, and comparative case analysis. The multi-method approach enables triangulation across historical, engineering, and conservation data sources.

3.2 Archival Research

Archival materials reviewed include EFEO restoration documentation from the 1964-1969 period, including field notes and photographic records, and FAD monument files for Phimai Historical Park. Also, the 2020 publication "Idea for the Preservation of Phimai Historical Park in Thailand" documents the Korea-Thailand joint research. Further, this study learned information from the 2016 Siam Society seminar on anastylosis in Thailand. Other information includes the Gazette notifications of monument protection. Moreover, this study finds historical documentation, including Étienne Aymonier's 1901 inventory.

3.3 Site Documentation

Site visits and documentation conducted with multiple visits (2020-2025) included photographic documentation and measured drawings of key structures where accessible. Also, it is to verify previous restoration documentation. Further, it assesses visitor infrastructure and management.

3.4 Technical Report Analysis

Technical documentation reviewed includes:

- The five-year joint research final report (NRICH, 2020)
- Safety inspection protocols and evaluation criteria
- Classification system documentation (Grades A-E)
- Material analysis results from the stone provenance study
- Structural monitoring data

3.5 Limitations

Access to certain FAD restoration records was restricted. The 2016-2020 joint research findings are primarily documented in Korean-language reports, limiting accessibility. The COVID-19 pandemic prevented some planned fieldwork during 2020-2021. Finally, the author acknowledges that some interpretations—particularly regarding the 1964-1969 restoration techniques—are provisional pending access to primary documentation.

4 Results

4.1 Phase I: Pre-Restoration Conditions (Pre-1964)

4.1.1 Condition at Time of Protection (1936)

The condition of Phimai at the time of its legal protection in 1936 reflected centuries of neglect following the decline of the Khmer Empire and the initial clearing of the site in 1901. The central prang was partially collapsed, sections of the galleries had fallen, and vegetation had extensively colonized the ruins.

Early French documentation, including Aymonier's 1901 inventory, provides the first systematic record of the site's condition. Aymonier noted that while the central tower was largely intact, subsidiary structures, including Prang Hin Daeng and parts of the outer enclosure wall, were in advanced states of ruin.

4.1.2 Excavation and Clearing (1954)

The FAD began systematic excavation and clearance at Phimai in 1954, ten years before the major French-Thai collaboration. This initial work focused on clearing accumulated debris from the central courtyard and removing vegetation threatening structural stability. Also, FAD documented architectural features and tried to identify fallen stone blocks for potential reassembly.

This excavation was essential preparation for the more extensive anastylosis that would follow. It established baseline documentation of the site's condition and identified the scope of the reassembly work required.

4.2 Phase II: The 1964-1969 French-Thai Anastylosis

4.2.1 Project Organization and Collaboration

The major restoration of Phimai was carried out between 1964 and 1969 as a joint project between the Thai and French governments. This collaboration followed the model of the French-Thai cooperation at Angkor and reflected the strong bilateral relationship in cultural heritage conservation.

The French team was led by architects and conservators from the EFEO, including Pierre Pichard, who would later serve as Director of Research at the EFEO. The Thai team was composed of architects and engineers from the FAD, with support from craftsmen and laborers from the local Phimai community. The project was originally scheduled for completion before the 100th anniversary of the foundation of the EFEO, and the restoration was completed within this ambitious timeframe.

4.2.2 The Anastylosis Process

The principal prang of Prasat Hin Phimai was restored using anastylosis. The technique involved dismantling the structure, coding each stone block, and then restoring them back to the original place (Figure 4).

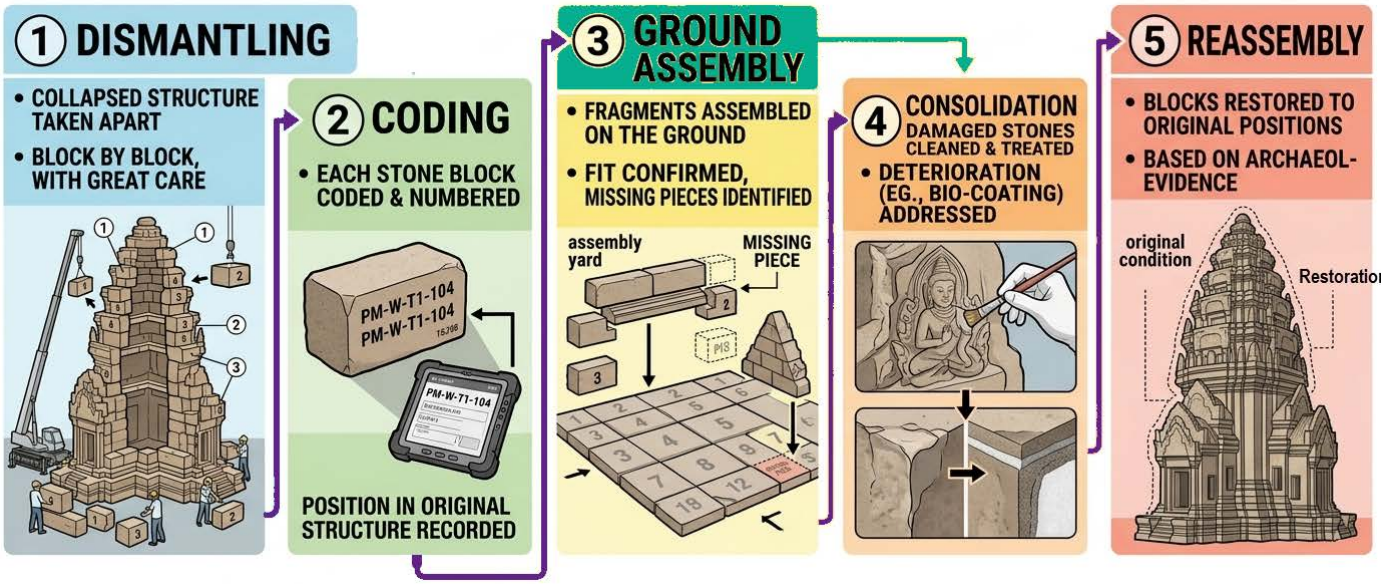

Figure 4: The anastylosis process at Prasat Hin Phimai: a meticulous protocol

Photo documentation from the period, preserved in EFEO archives, shows the meticulous ground assembly process. Blocks of the topmost motif were laid out on the ground and fitted together to confirm proper alignment before being re-erected—a practice documented by Philippe Pichard in his 1967 photographs. The process of numbering each stone and creating a key to guide reassembly required several months of preparatory work before any rebuilding could commence.

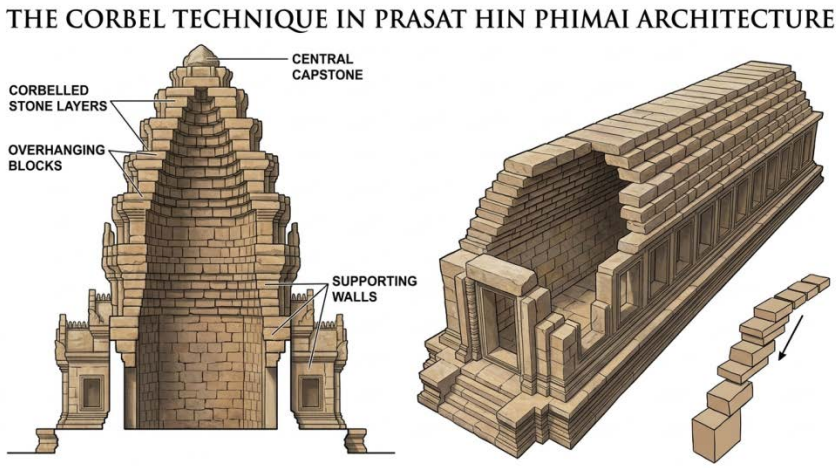

Figure 5: The corbel technique used in PHP architecture.

The assembled stones with the corbel technique (Figure 5) required careful cleaning and consolidation to address salt damage and biological growth that had developed during centuries of weathering.

4.2.3 Engineering Innovations

The reassembly of a structure of this scale presented formidable engineering challenges. Some sandstone blocks weighed more than 1,000 kilograms, requiring heavy lifting equipment that had to be carefully managed to avoid damaging delicate carved surfaces.

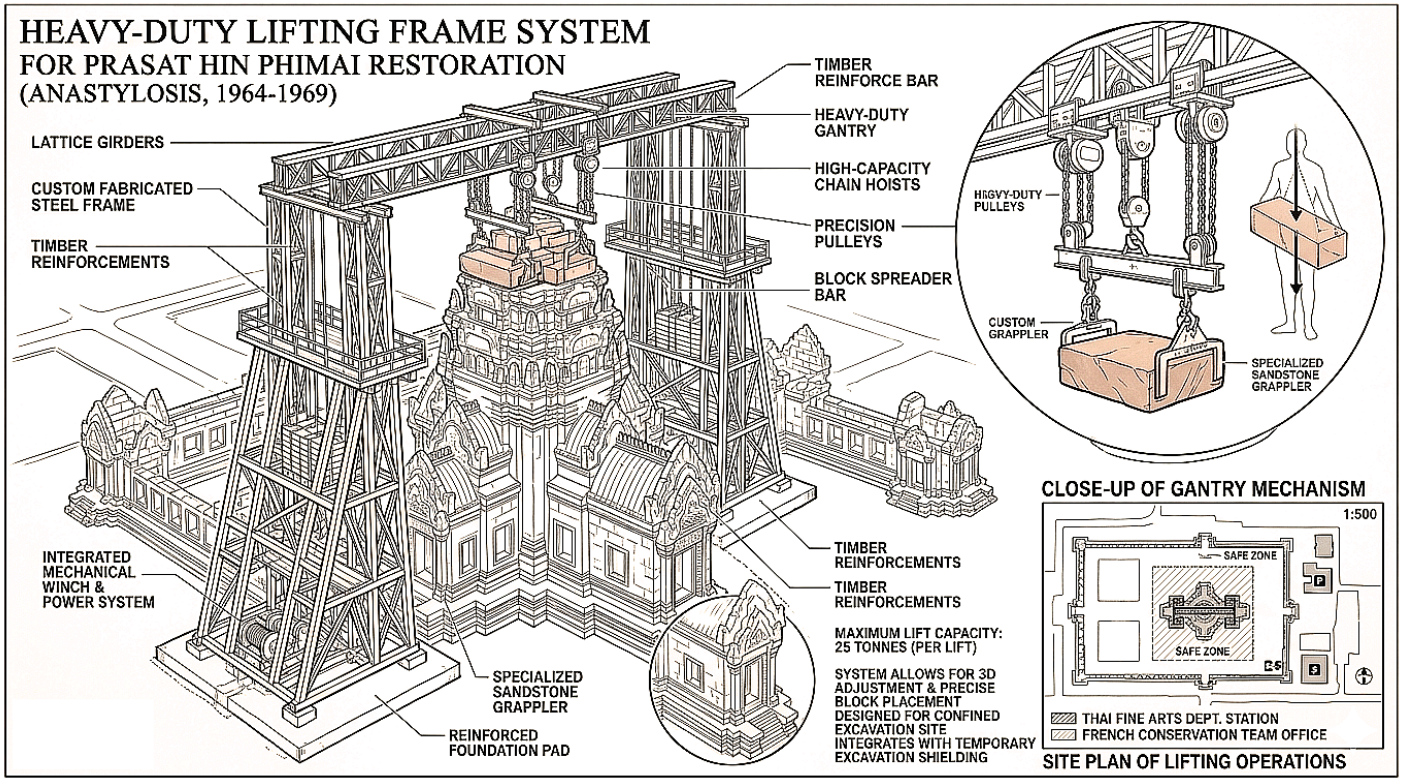

Figure 6: Heavy-duty lifting frames and handling techniques.

French and Thai engineers developed specialized lifting frames and handling techniques to address these challenges (Figure 6). Cranes were used with padded lifting slings to distribute weight

evenly across stone surfaces. For the most delicate carved elements, custom lifting frames were fabricated to support the stone at specific load-bearing points.

The reassembly also required careful attention to the structural behavior of the corbel-vaulted system. Without true arches, the stability of the prang depends entirely on the precise fit of stones and the effectiveness of the corbel wedging. Engineers analyzed the original construction logic and restored it accordingly, reinforcing connections where needed without introducing visible modern elements.

4.2.4 Interpretation and Visitor Access

The 1969 completion of the central prang restoration made possible the eventual establishment of the PHP. While the park was not officially opened until 12 April, 1989, by Her Royal Highness Princess Maha Chakri Sirindhorn, the restoration of the principal monument was largely complete by 1969.

The decision of what to restore fully—and what to leave in a state of partial ruin—reflected careful judgment informed by archaeological evidence. Structures with sufficient surviving fragments to permit confident reconstruction were restored using anastylosis. Structures where evidence was insufficient were stabilized or preserved in their existing states.

4.2.5 Documentation Legacy

The 1964-1969 French-Thai restoration produced extensive documentation of the site's condition before restoration, the anastylosis process itself, and the decisions made throughout. This documentation remains essential reference material for ongoing conservation. Phillipe Pichard's photographic record of the restoration, now housed in EFEO archives, is particularly valuable. These images capture the condition of each stone block before treatment, the ground assembly process, and the final reassembled structure.

The restoration stands as a landmark achievement in heritage engineering, demonstrating that systematic dismantling, coding, and reassembly of collapsed stone structures can produce results that are both structurally sound and archaeologically authentic. The central prang of Prasat Hin Phimai, restored through anastylosis, remains the anchor of the site's visitor experience and a testament to the durability of well-executed conservation.

4.3 Phase III: Post-Restoration Management (1969-2015)

Following completion of the major restoration, the FAD continued to manage the site with ongoing maintenance and some additional restoration of subsidiary structures. The park was officially opened to the public in 1989, and visitor facilities were gradually developed.

During this period, the Phimai National Museum was established nearby (opening in 1993) to house artifacts from the site, including the famous lintels and the sculpture of King Jayavarman VII. The museum, originally established in 1993, has long been a focal point for artifacts uncovered during the restoration of Prasat Phimai and other significant archaeological finds.

However, natural and artificial factors continued to cause damage to the site after the initial restoration, necessitating further attention.

4.4 Phase IV: The 2016-2020 Korea-Thailand Joint Research

4.4.1 Project Overview and Objectives

The 2016-2020 joint research project between the National Research Institute of Cultural Heritage (NRICH, 2022) of Korea and the FAD of Thailand represented a comprehensive scientific investigation of the park's condition. Experts in architecture, safety, and conservation participated in the five-year project.

The PHP is surrounded by two layers of corridors in a square arrangement, and a gateway (gopura) is installed in the north, south, east, and west of the inner and outer corridors, respectively. Inside the inner corridor, the Main Tower is located at the center of the east-west and north-south axis, and Prang Phrommathat is on the southeast of the Main Tower, Prang Hin Daeng is on the southeast of the Main Tower, and the Brahman Shrine is behind Prang Hin Daeng, all damaged.

4.4.2 Damage Investigation and Documentation

The joint research team conducted a systematic investigation of four main areas:

Surrounding environment and landscape: Researchers examined the historical landscape, entry into the ruins, viewing environments, and convenient facilities.

Status of major buildings: Each building was documented with photography, measured drawings, and condition assessment.

Case studies: The team studied repair status and techniques of three historical sites in Bangkok (including Wat Arun Temple) and major Khmer sites such as Phanom Rung Temple and Prasat Muang Tam Temple.

Material analysis: To estimate rock origin and investigate physical properties, the PHP stone characteristics were analyzed.

4.4.3 Stone Provenance and Material Analysis

Rock samples from the Phimai site were compared with samples from three major quarry areas: Shikiho, Lungpuradu, and Seongnoen. This comparative analysis aimed to identify the original source of construction materials.

Many methods are used, including petrographic thin-section microscopy, X-ray diffraction for mineral identification, porosity and density measurements, and salt content analysis.

This material characterization is essential for understanding original construction practices and selecting appropriate replacement stone if needed. Also, it is for developing conservation treatments compatible with original materials.

4.4.4 Safety Classification System

The Korea-Thailand joint research team developed a systematic classification system for grading the condition of each PHP structure. Table 1 gives the five-grade classification (A to E) system.

Table 1: PHP Safety classification system for grading the condition of each structure.

Grade	Description
A	Best condition without safety issues
B	Minor issues requiring monitoring
C	Moderate issues requiring attention
D	Significant issues requiring intervention
E	Critical condition requiring immediate action; cessation of use advised

Two structures in the ruins were selected to be monitored twice to see the inclination of the wall and the uneven settlement of the foundation.

Prang Hin Daeng, a tower constructed of red sandstone, represented the most urgent case. It was inspected and received the most critical assessment: Grade E. Structural deformation of Prang Hin Daeng due to differential settlement of soil was already confirmed, and materials were severely damaged due to weathering and breakage, with a high risk of parts falling off.

Table 2 shows the classification system for specific types of damage.

Table 2: Types of Structural and material damage.

Structural damage	Material damage
- Separation - Tilt - Swelling - Differential settlement - Breakage - Dropout - Collapse	- Weathering - Abrasion - Crack - Peeling off

4.4.5 Priority Classification and Staged Planning

Building on the safety classification, the joint research team developed a comprehensive maintenance plan organized in stages. In the first stage, ruins are maintained based on the order of urgent need for reinforcement, based on the safety inspection results. The access route and internal circulation route were reorganized to improve accessibility to the relic and viewing efficiency.

The second stage expands to the Phimai Historic City area, surrounded by four gateways and corridors, intending to restore the now-lost east gate and repair the overall town walls to seek the original state of the Phimai Historic City.

For conservation, the team shared the need to research similar materials to recover the authenticity of architectural materials and physical reinforcement and replacement of parts to reduce damage to the ruins.

4.5 Current Condition of Major Structures

4.5.1 Central Prang (Main Sanctuary)

The central prang, restored during the 1964-1969 anastylosis, generally remains in good condition, reflecting the quality of the original restoration work. The stone surfaces show moderate biological colonization and some salt efflorescence, but no major structural issues.

4.5.2 Prang Hin Daeng (Red Stone Tower)

Prang Hin Daeng represents the most severely damaged structure in the Phimai Historical Park. The Grade E classification indicates critical safety concerns requiring immediate action.

The tower is constructed of red sandstone, a material with distinct properties from the gray sandstone used for the main prang. The red coloration indicates higher iron oxide content, which may affect durability and weathering behavior.

The structural deformation is primarily due to the differential settlement of soil beneath the foundation. The tower is tilting and showing swelling in the lower courses of masonry. Material damage includes severe weathering, breakage, and a high risk of parts falling off.

4.5.3 Prang Phrommathat

Prang Phrommathat, located on the southeast of the Main Tower, also shows significant damage. The structure likely dates to approximately the same period as the main temple (11th-12th centuries) but was built using different materials and construction techniques.

4.5.4 Outer Corridor

The northwestern side of the outer corridor, where structures graded D and E during the safety inspection are clustered, was selected as the priority area for intervention. The FAD's approach suggested focusing on maintaining the current status of the ruins and strengthening stability using the anastylosis technique.

4.6 Visitor Management Assessment

The 2016-2020 joint research also addressed visitor management and interpretation.

The research identified that visitors are currently allowed to view the ruins freely within the site. The joint research team proposed to "overhaul the guidance system by adding more information centers, facilities for the handicapped, and information boards".

For the most damaged structures, including Prang Hin Daeng, the team suggested "creating a distant viewing environment after preparing long-term measures for restoration and preservation". This reflects concern for visitor safety while maintaining access.

4.7 Comparative Analysis with Other Khmer Monuments

The Phimai restoration can be usefully compared with other major Thai-French collaborations (Table 3).

Table 3: Comparative Analysis with Other Khmer Monuments

Phanom Rung Historical Park benefited from a similar approach, though the restoration period was later and primarily Thai-led, with French technical consultation rather than full collaboration.
Prasat Muang Tam underwent more limited anastylosis, with some areas left in a state of "ruin" to illustrate the archaeological process.
Angkor Archaeological Park (Cambodia) has seen more extensive anastylosis projects, including the celebrated restoration of Banteay Srei (1921-1936) and more recent work at Ta Prohm.

The Phimai project is distinctive in its systematic application of anastylosis to a complete temple complex within a defined timeframe (1964-1969), producing a result that is both archaeologically authentic and accessible to visitors.

5 Discussion

5.1 The Significance of the 1964-1969 Anastylosis as an Engineering/ Achievement

The 1964-1969 restoration of Phimai must be recognized as a major engineering achievement, representing not merely a conservation project but a carefully orchestrated process of architectural reconstruction from fragmentary evidence. The reassembly of the central prang required engineers to solve problems that the original Khmer builders had addressed for the first time nearly a millennium earlier.

The most significant challenge was the corbel-vaulted structure. Without access to true arch technology, the original builders had developed a system that relied on the precise interlocking of angled stone blocks. When the structure collapsed, the blocks scattered, and centuries of weathering removed or obscured some tool marks that would have indicated original positions.

Through careful archaeological analysis, the project team was able to reconstruct the original construction logic. Each block was identified, its position determined, and its fit confirmed through ground assembly. This process required not only engineering knowledge but archaeological imagination—the ability to visualize the completed structure from fragmentary evidence.

5.2 The Anastylosis Philosophy as Applied to Phimai

The anastylosis approach at Phimai embodied an "authenticity principle": the authentic monument is one composed primarily of original materials. This philosophy was audacious for its time—the site had been largely ruined, and a simpler approach might have been to clear the debris and stabilize the remaining walls rather than attempting full reassembly.

The decision to pursue full anastylosis was justified by the extraordinary amount of surviving original material. Fallen stones littered the site, many with intact tool marks and fitting surfaces. A full reconstruction of the prang was possible (Figures 7 and 8).

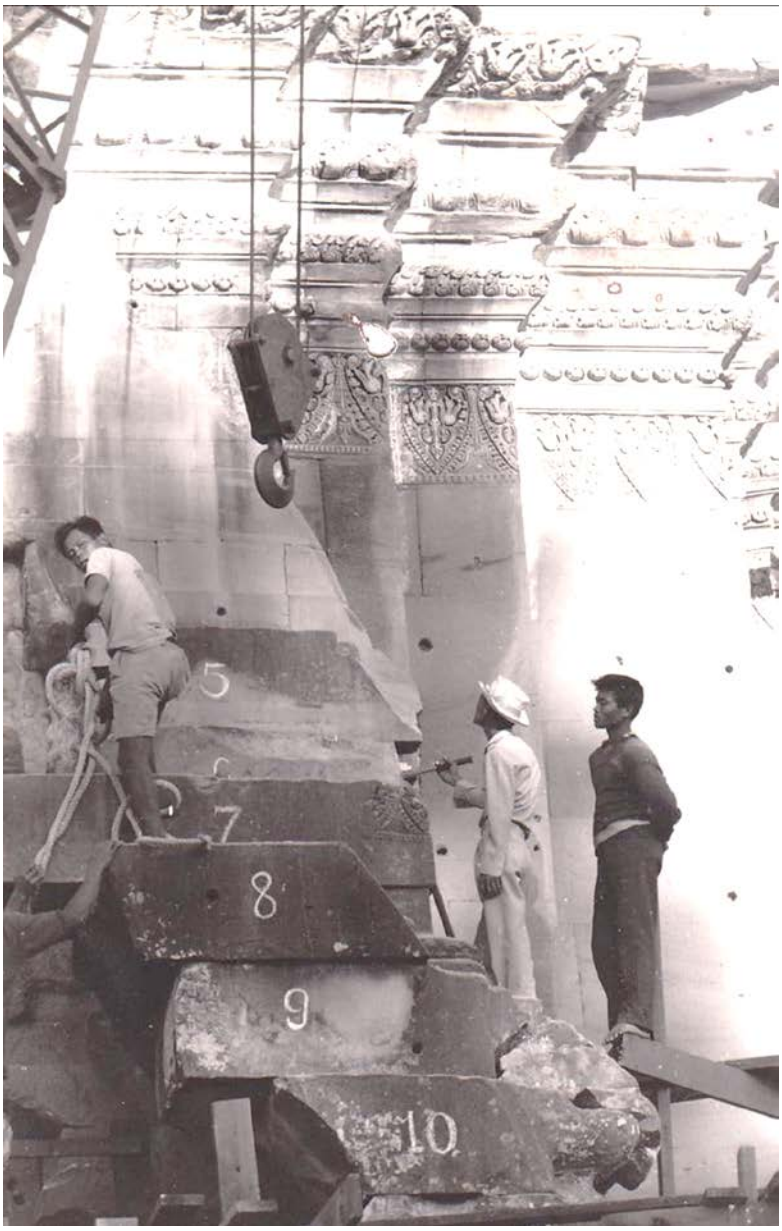

Figure 7: Anastylosis technique - reassembly based on the coding marked on the specimens. (Courtesy of Somboon Boonyawet (2020).)

The Phimai restoration also shows the complementarity of anastylosis with other conservation approaches. While the central prang was fully reassembled, other structures were stabilized but not fully reconstructed. The site incorporates both highly restored and partially ruined areas, illustrating a nuanced approach to heritage presentation.

5.3 Engineering vs Conservation

The Phimai restoration illuminates a fundamental tension in heritage engineering between structural and authenticity objectives. Engineers seek stability and durability; conservation seeks minimal intervention and maximum retention of original material. These objectives may conflict.

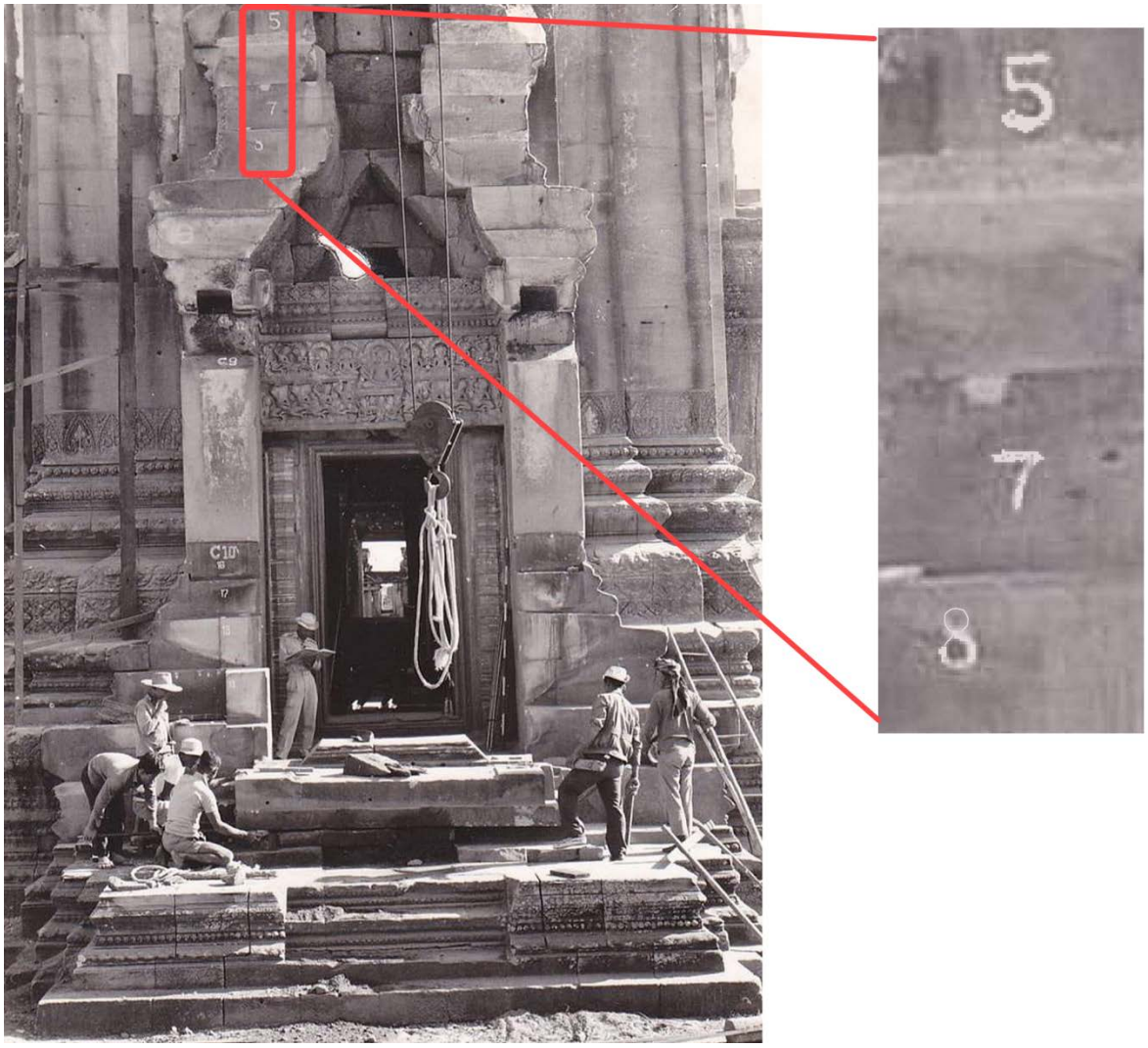

Figure 8: Anastylosis technique - reassembly based on the coding marked on the specimens. (Courtesy of Somboon Boonyawet (2020).)

Figure 9: Ground assembly before reassembly based on anastylosis. (Courtesy of Somboon Boonyawet (2020).)

For Phimai, the engineers' solution—extensive dismantling and reassembly—served both objectives (Figure 7). The reassembly made the prang more stable than it had been for centuries while preserving nearly all original material.

This approach succeeded for the central prang, where extensive evidence enabled confident reconstruction. For other structures, particularly Prang Hin Daeng, the situation is different. The

Grade E classification of Prang Hin Daeng indicates that some structures may be beyond complete anastylosis. The severe weathering and material loss create concern over reusing original materials.

Grade E shows that even well-conserved sites face ongoing deterioration. The structure's condition results from differential settlement of soil, severe weathering, and breakage, with a high risk of parts falling off. The concern over reusing original materials has led to a preference for preserving it in its current state rather than attempting full anastylosis.

5.4 The Philosophy of Long-Term Conservation: Maintenance as the Key

A major finding from the 2016-2020 joint research is that restoration is not an endpoint but a moment in a continuous process of care. Even the masterful 1964-1969 anastylosis has not prevented ongoing deterioration—indeed, the passage of 50 years has created new conservation needs.

The joint research team's classification system (Grades A-E) provides a scientific basis for ongoing management. The system enables continuous monitoring of each structure's condition, with intervention triggered at specific thresholds.

The final maintenance plan—organized into stages—reflects this philosophy. "In the first stage, ruins maintenance is conducted in the order of urgent need for reinforcement based on the result of safety inspection". Only then do second-stage activities address broader site improvements.

5.5 The Role of International Collaboration

The Phimai restoration illustrates the value of international collaboration in heritage engineering. The 1964-1969 project brought French expertise in Khmer architecture and anastylosis to bear on a Thai monument. The 2016-2020 joint research brought Korean expertise in materials science and safety engineering.

This international dimension provided not only technical benefits but also capacity building. Thai conservators trained alongside French experts, learning both specific techniques and broader conservation philosophy. The joint research demonstrated that heritage conservation benefits from the exchange of knowledge across national boundaries.

5.6 Policy and Regulatory Implications

The Phimai experience has implications for heritage policy in Thailand and beyond:

The legal framework: Phimai's registration in the Government Gazette in 1936, followed by the 1961 Ancient Monuments, Antiques, Objects of Art and National Museums Act, provided the legal basis for protection and funding. Strong legal protection is essential for major restoration.

Heritage assessment: The Korea-Thailand research demonstrates the value of systematic condition assessment as a basis for conservation planning. The classification system (Grades A-E) could serve as a model for other sites.

Sustainable management: The staged maintenance plan, with its integration of structural, safety, and visitor management components, provides a framework that could be adapted for other Khmer monuments.

5.7 Future Research Directions

The site should conduct long-term digital sensor-based monitoring to analyze inclination and settlement trends. This is to understand structural behavior.

For Prang Hin Daeng, they should conduct a critical technical assessment of the damaged structure to determine whether any form of anastylosis is feasible or whether preservation in its current state is the only responsible approach. For visitor impact assessment, the effects of visitor behavior on monument condition should be systematically studied to inform management. Further research is on 3D documentation and application of Building Information Modeling (BIM) technology to the Phimai structures, that could support both conservation planning and visitor interpretation.

The examination of Khmer/Angkor stone architecture within a similar environment built with similar materials would provide valuable insights for the conservation of Prang Hin Daeng. Also, a proposed research focuses on the material science of the red sandstone found at Prang Hin Daeng, aiming to realize its unique weathering behavior and to find suitable conservation methods.

Based on spatial technologies, the entire site should be high-precision digitally recorded via 3D laser scanning/photogrammetry. In terms of geotechnical engineering, they should assess the soil conditions beneath the entire site. This is to identify areas susceptible to differential settlement. Further, historical research will be carried out regarding the site's utilization during the 13th to 18th centuries. This may reveal the damage patterns observed in certain structures. Site climatic monitoring should be observed to correlate environmental conditions with active deterioration.

6 Conclusion

This study involves anastylosis analysis of the restoration of Phimai Historical Park via multidisciplinary cooperation of archeology, civil/architectural engineering, and conservation technology. The restoration of Phimai Historical Park represents a convergence of two traditions: the engineering tradition of structure, stability, and systems; and the conservation tradition of authenticity, material preservation, and reversibility. The 1964-1969 French-Thai anastylosis showed that these traditions need not conflict—that a structure could be completely dismantled and reassembled while retaining its original materials and historic character. The 2016-2020 Korea-Thailand joint research has shown that the completion of restoration is not an endpoint but the beginning of a new phase of monitoring, maintenance, and scientific study.

The Grade E classification of Prang Hin Daeng may be the most urgent finding of the joint research, but it also may be the most revealing. It shows that the conservation of heritage is never finished, but it is a continuous process of care, observation, and adaptation.

For the visitor walking through the PHP galleries today, the central prang stands complete and majestic. The structure is scarcely distinguishable from how it might have appeared in the 12th century, when Khmer pilgrims approached from the south along the ancient highway from Angkor. This is the achievement of the 1964-1969 restoration. The monument will survive centuries intact, but it is actually the product of meticulous reassembly.

The task for the next generation of heritage engineers and conservators is to extend this achievement to the structures that remain in an unreconstructed state—Prang Hin Daeng, the damaged outer corridors, the crumbling town walls. The goal is not to restore everything to a pristine condition but to manage the site's heritage with the same rigor, creativity, and care. Phimai has been, and remains, a model for the convergence of civil/architectural engineering and heritage conservation—a model that Thailand continues to refine and share with the world.

7 Availability of Data and Materials

All information is included in this article.

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