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The integrated archaeological shelter: a new method for on-site conservation

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Abstract. Archaeological sites have been affected by environmental changes during the excavation stage for a long time. At present, the construction of protective shelters and archaeological site museums is a common method of site conservation; however, both approaches remain inadequate in terms of micro-environmental control during excavation process. Taking the Sanxingdui Integrated Archaeological Shelter as an example, this paper analyzes its structures, functions and system configuration, thereby proposing the core concept of the Integrated Archaeological Shelter. Integrated Archaeological Shelter is a protective structure used at archaeological excavation sites. It possesses five features, including on-site applicability, customizability, enclosure with environmental control, temporary and reversible nature, and integration. It has four functions: micro-environmental regulation, data collection, integrated on-site operations and public education. In addition, it can be classified into three types: excavation-oriented, public exhibition-oriented and emergency-oriented. During the construction stage, Integrated Archaeological Shelters should comprehensively consider both functions and features, which should be designed as high-performance structures that meet the customized needs of specific sites. Archaeological conservation Integrated Archaeological Shelters demonstrate innovative value at both theoretical and practical levels, providing a conceptual basis and reference framework for future related research and applications.

Keywords: archaeological sites, on-site conservation, Integrated Archaeological Shelter, micro-environmental control

1. Introduction

Cultural heritage is the common and precious wealth of all humanity. The principle of authenticity, the principle of minimal intervention [1], and the principle of precautionary conservation [2] should be observed during the process of excavation and conservation. Archaeological excavations are not only conducted to obtain historical information and advance scientific research, but also to protect cultural heritage. During the excavation process, the information contained within the archaeological site should be reflected as comprehensively as possible to facilitate subsequent scientific research and heritage conservation. Although archaeological sites vary in type, excavation is inherently destructive and non-renewable. Therefore, the principle of minimum intervention should be followed throughout the excavation process to minimize damage to the site itself and the unearthed remains.

Environmental variation is one of the key factors in the deterioration of archaeological remains. This is because when archaeological excavations uncover these remains, they simultaneously disrupt the burial environment that had preserved them over long periods. Sudden changes in external conditions expose a number of fragile archaeological artifacts to the risk of damage the instant they are unearthed [3]. Taking earthen heritage sites as example, their conservation has been a major challenge for the academic field. Affected by the inherent properties of soil and the storage environment, natural deterioration persists over time. Forms of damage include sheet erosion , hollow-out erosion, fissures, gully erosion and biological damage [3, 4]. In addition to natural degradation, human factors such as agricultural irrigation also constitute significant destructive elements. Therefore, after assessing the environmental conservation conditions of archaeological sites and analyzing protective factors, controlling the site environment to reduce natural degradation on earthen heritage sites can be the more effective measure for their protection. Moreover, this measure aligns with the principles of the principle of minimal intervention and preventive conservation in cultural heritage conservation.

Archaeological sites, as an important component of cultural heritage, the public education is one of their key functions [1, 5]. To ensure the sustainable preservation, research and display of archaeological sites and excavated artifacts, subsequent exhibition considerations should be integrated into the excavation and on-site conservation processes [6]. In practice, protective structures erected during the excavation phase are often converted into permanent conservation facilities for long-term protection and public exhibition of the site after completion. Thus, archaeological site conservation facilities typically serve a dual purpose of conservation and site exhibition.

This research takes the sacrificial areas at the Sanxingdui site as the case study. Based on photographs of the completed Integrated Archaeological Shelter and other open-source materials, it analyzes the Integrated Archaeological Shelter's functions and facilities. By contrasting it with widely existing site protective structures, this research proposes the new concept of Integrated Archaeological Shelter for the first time. It illustrates its characteristics, core functions and required facilities, while discussing its application models and potential issues. The core contribution of this research lies in establishing the Integrated Archaeological Shelter as a new paradigm for on-site conservation of heritage sites, grounded in both theoretical and practical perspectives.

2. Literature review

The preservation and display methods for archaeological sites encompass seven categories: backfilling protection, physical and chemical reinforcement, in-situ exhibition, signage display, reconstruction exhibition, site museums and protective shelters. Among these, site museums and protective shelters meet the dual requirements of concurrent preservation and exhibition at excavation sites, representing common approaches in on-site preservation of archaeological remains. Their shared characteristic lies in preserving heritage through environmental control while facilitating public display.

During excavation stage, archaeological sites are protected by erecting shelters to control the site environment and minimize damage caused by drastic environmental changes. Most archaeological sites are open-air sites that face prolonged exposure to natural elements such as rain erosion, wind erosion and ultraviolet radiation during excavation, causing significant damage to both the site and cultural relics [7]. Protective shelters can be categorized into simple protective shelters, traditional-style protective shelters and modern protective shelters [8]. At present, erecting temporary protective shelters at archaeological sites is widely recognized as an effective method to reduce natural environmental impacts. These shelters are increasingly being replaced by modern protective structures designed for long-term use and subsequent exhibition purposes. The 2013 Workshop on Archaeological Site Protection Facilities in Italy thoroughly examined multiple aspects of archaeological protective shelter design, maintenance and management. It emphasized that the design and construction of archaeological protective shelters should balance reversibility, environmental adaptability, landscape harmony and maintenance feasibility [9]. Some scholars have evaluated the practical effectiveness of archaeological protective shelters based on exposure experiments. Through investigative analysis, they found that while these shelters are widely recognized as effective protective structures, their protective performance gradually diminishes over time. This degradation is closely linked to the design and maintenance conditions of the shelters [10]. While protective shelters can safeguard archaeological sites during excavation, their long-term effectiveness still requires further consideration.

For archaeological sites with significant value, the common approach is to construct a site museum on itself. Unlike protective shelters that focus mainly on-site conservation, site museums serve dual functions of preservation and exhibition, undertaking the important tasks of controlling the site environment and providing public education [11]. Site museums are typically designed after archaeological excavations complete, with the museum architecture integrated into the surrounding environment [12].

Archaeological shelters and site museums focus on different stages of site preservation but have inherent limitations. Site museums are typically constructed after excavation has been completed, leaving artifact security vulnerable during active excavation phases. Shelter effectiveness falls below ideal standards, with limited environmental control capabilities that leave organic artifacts highly vulnerable to environmental factors. Reviewing past approaches to site preservation and display reveals distinct limitations in methods like shelter construction and site museums. In the era of meticulous, scientific archaeological excavation and conservation, novel protective facilities capable of microenvironmental control are urgently needed to meet the demands of contemporary archaeological work.

3. Methodology

3.1. Research design

Based on structural observation and documentary analysis of the Sanxingdui site Integrated Archaeological Shelter, this study proposes a framework defining its facilities, characteristics and functions, addressing the current lack of a unified conceptual understanding. The primary data consists of 12 photographs partly taken in June 2025, supplemented by officially released documentaries and media reports from Xinhua and CCTV that provide technical insights into construction materials, ventilation systems and environmental monitoring.

To ensure the rigor of this research, a three-pronged complementary approach is adopted: First, a case study of the Sanxingdui archaeological preservation chamber; second, a systematic analysis deconstructing its structural design; and third, cross-referencing the findings with press releases and museum descriptions.

The specific methodology is as follows: First, photographic information is converted into comparable analytical units. Each photograph is analyzed and documented based on the visible details it displays. Second, the functional attributes of the protective enclosures are inferred from their appearance and structural characteristics. For instance, transparent or translucent cover materials indicate strong natural light regulation capabilities; the connection methods between steel frames and trusses affect the facility's reversibility and maintenance complexity; while internal spatial layouts determine whether they also serve public viewing functions. Third, to diminish potential errors inherent in photo analysis, this study employs triangulation verification. Building upon photographic analysis, official museum records are consulted to validate the accuracy of inferences.

As excavation of the sacrificial pits within the Sanxingdui Integrated Archaeological Shelter has been completed, this paper focuses solely on a conceptual analysis of the conservation shelter itself. It does not include long-term environmental monitoring or data analysis, nor does it provide a comprehensive evaluation of its actual conservation effectiveness.

3.2. Case selection

This study selects the Sanxingdui Integrated Archaeological Shelter as a case analysis for two main reasons: First, the Sanxingdui Integrated Archaeological Shelter is the first of its kind and serves as a model for such structures. Second, the excavation work inside the Sanxingdui Integrated Archaeological Shelter has been completed, and the process was accompanied by extensive media coverage, resulting in a wealth of visual materials.

The Sanxingdui site is located in Sanxingdui Village, Sanxingdui Town, Guanghan City, Sichuan Province, on the south bank of the Yazi River (Figure 1) [12, 13]. The sacrificial area is situated on the Sanxing Terrace in the south-central part of the ancient city of Sanxingdui, which is the core excavation zone of the site. Archaeological work commenced here in 1980, when the Sichuan Provincial Cultural Relics Administration and the Sichuan Provincial Cultural Relics and Archaeology Research Institute excavated Sacrificial Pits No. 1 (K1) and No. 2 (K2) [15, 16], unearthing a significant quantity of precious cultural relics. Due to its unique cultural characteristics, it has quickly attracted widespread attention from society. In 2020, archaeological excavations were re-started at the Sanxingdui sacrificial area, uncovering a total of six sacrificial pits numbered K3-K8. These sacrificial pits excavated numerous artifacts, including large quantities of ivory, bronze ware, pottery, jade objects, gold items and more, possessing immense historical, artistic and scientific value. Based on excavated artifacts and combined with radiocarbon dating results from K4, archaeologists have concluded that the sacrificial area dates back to the fourth phase of the Yinxu culture in China, with an absolute chronology of approximately 3,200–3,000 years ago [13].

Based on the artifact types from K1 and K2, as well as the survey findings before the excavation, the protection and exhibition during the site's re-excavation requires a new facility that can both stabilize the environment and accommodate public exhibition. Therefore, four Integrated Archaeological Shelters were constructed over the six sacrificial pits (K3-K8) at the Sanxingdui site, officially put into use in July 2021. The layout of the Integrated Archaeological Shelters strictly follows the practical requirements of the excavation work. Since the three sacrificial pits K5, K6 and K7 are adjacent, a single Integrated Archaeological Shelter was established to efficiently utilize space and resources (Figure 2). The approach of 'archaeological protective shelter + Integrated Archaeological Shelter' was adopted to ensure the scientific work and the safety of cultural relics during the excavation period. As a new type of protective structure, the Integrated Archaeological Shelter differs from both conventional archaeological shelters and site museums, emphasizing a highly stable environment.

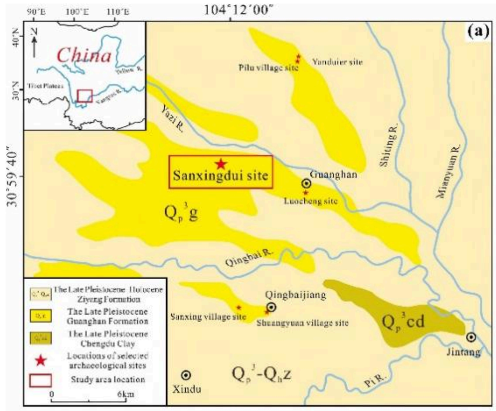

Figure 1. Schematic map of the Sanxingdui site location [14]

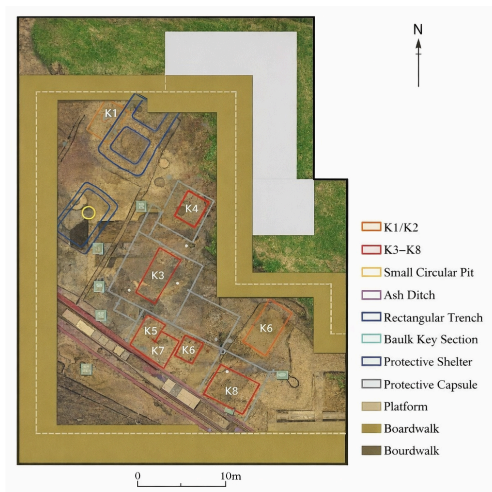

Figure 2. Site distribution map within the Sanxingdui protective structures [17]

4. Results

The Sanxingdui Integrated Archaeological Shelter is designed with a transparent glass and steel frame structure (Figure 3). Its exterior features a regular geometric cube shape with a distinctly modern aesthetic, serving two core functions: environmental control and public engagement. Firstly, the transparent enclosure provides essential conditions for public visiting during excavation, enabling visitors to visit the site without disrupting the excavation work of the sacrificial pits. This allows them to gain intuitive and immersive experience. This not only reflects the public education function of archaeological work but also enhances the social effectiveness of cultural heritage propagation. Secondly, the translucency of the glass material ensures adequate lighting conditions within the Integrated Archaeological Shelter. This allows excavation work to utilize a combined lighting scheme of natural and artificial light sources, which not only conserves energy but also provides an optimal lighting environment for site excavation. The design and application of the protective chamber form an integrated system with the external Integrated Archaeological Shelter (Figure 4). The archaeological protective shelter employs a large-span steel structure to provide a semi-enclosed space, equipped with a dynamically operating shutter system around its walls [17]. This system already provides fundamental environmental regulation capabilities against wind, sand and rain at the macro-site level.

Consequently, the Integrated Archaeological Shelter is not required to undertake basic environmental control tasks, allowing it to focus on creating and maintaining a more precise and stable archaeological microenvironment within its interior. The exterior design of the Sanxingdui Integrated Archaeological Shelter reflects the Sanxingdui Site Archaeological Team's emphasis on public education functions and its implementation of a precise, grading-based cultural heritage protection concept: macro-level protection (archaeological protective shelter) + micro-level regulation (Integrated Archaeological Shelter).

Figure 3. Exterior of the Sanxingdui Integrated Archaeological Shelter

Figure 4. Exterior of the Sanxingdui Archaeological Conservation Shelte

The main structure of the Sanxingdui Integrated Archaeological Shelter is a steel structure truss system, featuring bolted connections that provide excellent mechanical performance, spatial flexibility and ease of construction. The steel framework offers robust support for the Integrated Archaeological Shelter, enabling a large-span, column-free interior space (Figure 5). The Sanxingdui Integrated Archaeological Shelters adopts a modular design, enabling rapid assembly and installation at the excavation site. This minimizes disruption to the archaeological work and allows for easy dismantling later, embodying the principle of reversibility in archaeological protective structures. The large-span, column-free spatial design ensures no internal support within each Integrated Archaeological Shelter, providing a wide-angle, unobstructed operational view for excavation and full flexibility for equipment and personnel movement. The supporting structure with translucent glass combines optimally to meet public archaeology requirements. The robust steel framework carries all structural loads, while the exterior glass acts merely as an envelope system without bearing structural forces. Its weight is fully supported by the main steel skeleton, ensuring overall safety while providing a reliable foundation for installing various equipment.

(a) Internal Structure. (b) Internal Steel Structure. (c) Bolt Joints.

Figure 5. The internal structures of the Sanxingdui Integrated Archaeological Shelter

Sanxingdui site is located in the Sichuan Basin, characterized by a subtropical humid climate with abundant rainfall. The drainage functionality of the Integrated Archaeological Shelter is designed with importance. The archaeological shelter provides environmental control for the site. Its large-span roof effectively prevents most rainfall penetration, and the design fully addresses waterproofing requirements: the shelter uses a closed structure beneath the roof, with adjustable shutters positioned in the upper-middle section to minimize rainwater ingress (Figure 6). Exterior drainage channels and slope design facilitate rapid removal of rainwater from the excavation area. Therefore, the base design of the Integrated Archaeological Shelter does not need to account for large-scale precipitation but rather serves to ensure microenvironmental stability and operational safety. The interior base employs a raised structure with wooden joists as the load-bearing framework, topped with protective panels (Figure 7). This provides a safe working and viewing platform for staff and visitors, preventing direct foot traffic on the excavation area and avoiding collapse or damage to the site caused by stepping. Additionally, the elevated structure effectively blocks moisture penetration, aiding humidity control within the Integrated Archaeological Shelter. The Integrated Archaeological Shelter and its base implement a graded protection system: the Integrated Archaeological Shelter serves as primary protection against external precipitation, while the base provides secondary protection to ensure personnel activities and assist in humidity control.

Figure 6. Exterior design of the shelter

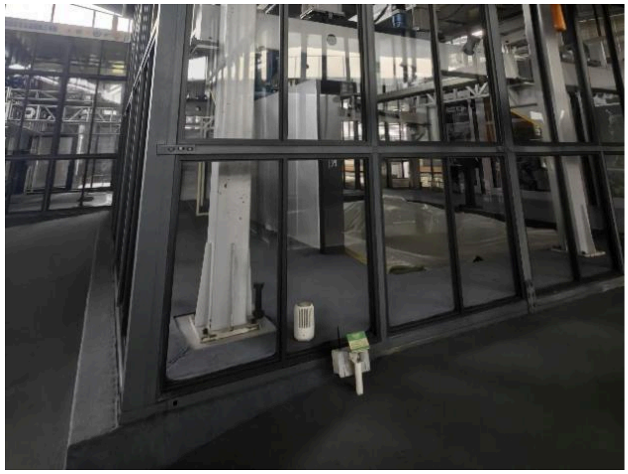

Figure 7. Base of the Integrated Archaeological Shelter

Microenvironment control is the core function of the Sanxingdui Integrated Archaeological Shelter and the primary objective of building it. The sacrificial pits at the Sanxingdui site contain large quantities of organic objects such as ivory and silk, which are extremely sensitive to environmental changes. Any alteration in factors like temperature, humidity, or ultraviolet light will rapidly cause organic objects to deteriorate. Therefore, the core function of the Integrated Archaeological Shelter is to create a stable microenvironment which is isolated from the outside environment and where the environmental parameters (temperature, humidity, light) are measurable, controllable and adjustable, ensuring the safety of cultural relics throughout the entire process from excavation to extraction. The Sanxingdui Integrated Archaeological Shelter is designed with a complete set of microenvironment control equipment, including an environmental monitoring system, ventilation system, temperature and humidity control system, and illumination system. The environmental monitoring system monitors all parameters within the entire Integrated Archaeological Shelter, including core data such as temperature, humidity, oxygen levels, air quality, light intensity and soil conditions. Utilizing AI algorithms, it automatically regulates the microenvironment within the Integrated Archaeological Shelter (Figure 8). Ground is equipped with multifunctional sensors that wirelessly transmit data such as soil temperature and moisture content to the cloud platform (Figure 9).

Figure 8. Sanxingdui Intelligent Control Cloud Platform

Figure 9. Microwise system

The ventilation system ensures that air circulation within the Integrated Archaeological Shelter is purified. Equipped with an air purification system, it prevents microorganisms and pollutants from damaging the fragile artifacts within the sacrificial pits. The temperature and humidity control system, used with monitoring system, maintains the temperature within the Sanxingdui Integrated Archaeological Shelter at 20 ± 2 °C and humidity at 80 ± 5% RH [17], balancing with the pit's ambient conditions (Figure 10). The lighting system combines natural light with artificial illumination. By installing specialized low-ultraviolet lamps on the beams, it ensures sufficient illumination for excavation work while eliminating photoaging issues caused by ultraviolet radiation and other forms of light radiation (Figure 11).

Figure 10. Sanxingdui air-conditioning system

Figure 11. Sanxingdui illumination facilities

Traditional archaeological excavations often face the problem of stepping directly on the ground surrounding artifacts. Within the Sanxingdui sacrificial pits, numerous precious artifacts were stacked in layers. Direct stepping would cause severe damage to these fragile relics. To address this, the Sanxingdui Integrated Archaeological Shelter is equipped with a rail-guided operating platform (Figure 12). This integrated steel structure platform combines load-supporting, stabilizing, mobile and safety functions. It provides archaeologists with a stable working surface that fully covers the pit opening while allowing flexible adjustments in height and angle. This enables precise, site-specific operations without causing any pressure damage to the burial pit's remains. The Sanxingdui Integrated Archaeological Shelter is equipped with panoramic cameras, enabling excavation personnel to document materials from optimal angles and ensure the scientific integrity of the visual records.

Figure 12. Operating platform

In a word, the Sanxingdui Integrated Archaeological Shelter represents a new paradigm for on-site conservation during archaeological excavation. Its enclosed, intelligent and secure design safeguards both the excavation process and public archaeology initiatives, thereby establishing a benchmark for empirical analysis and offering a valuable reference for the design and implementation of Integrated Archaeological Shelters at other heritage sites.

5. Discussion

5.1. Conceptual analysis of Integrated Archaeological Shelters

5.1.1. The concept of the Integrated Archaeological Shelter

Integrated Archaeological Shelters have been pioneered in China. Although consensus on their conceptual framework remains elusive, several archaeological sites have already implemented Integrated Archaeological Shelters to safeguard cultural relics. These include the Sanxingdui Sacrificial Area in Guanghan, Sichuan; the Beibai'e Cemetery in Yuanqu, Shanxi; the Wuwangdun Cemetery in Huainan, Anhui; and the Qin Dongling in Xi'an, Shaanxi. Among these, the Sanxingdui Sacrificial Area is the first site to have deployed Integrated Archaeological Shelters.

Based on explorations into the conservation needs of artifacts at archaeological excavation sites and observations of existing Integrated Archaeological Shelters, this paper introduces the concept of an Integrated

Archaeological Shelter. This facility, deployed at excavation sites, employs environmental control measures to create a stable and controllable microenvironment for the conservation of artifacts during the excavation phase. This enables meticulous site excavation, preventive conservation of remains, and fulfills public accessibility requirements.

The Integrated Archaeological Shelter represents a revolutionary conservation facility and embodies a new conservation paradigm, distinct from similar structures such as shelters and site museums. While most protective shelters are also deployed from the excavation stage, their environmental control primarily addresses the broader surroundings of the site, such as preventing rainwater erosion and UV, induced deterioration of artifacts. Structurally, these shelters employ open or semi-open beam-and-frame designs, which inherently fail to create a microenvironment within the shelter. Consequently, they lack the capability for precise regulation of the site's microenvironment. Numerous site museums are constructed after excavation work concludes, targeting archaeological sites of exceptional value. Consequently, they cannot safeguard artifacts during excavation and share the same environmental control limitations as protective shelters.

Archaeological sites with significant value or highly fragile artifacts often require meticulous excavation, which protective shelters and site museums struggle to accommodate. This has led to the development and application of Integrated Archaeological Shelters. Compared to shelters, Integrated Archaeological Shelters emphasize high-precision environmental control and integrated facilities. Compared to site museums, Integrated Archaeological Shelters are deployed during excavation phases, prioritizing on-site operational capabilities and flexibility. The demand for high-precision environmental control and integrated operations in Integrated Archaeological Shelters reflects emerging principles in cultural heritage conservation, driven by sustainable development, preventive conservation and the principle of minimal intervention.

5.1.2. Features of the Integrated Archaeological Shelter

Integrated Archaeological Shelters primarily address the issue of object preservation during the excavation phase. Based on China's archaeological excavation procedures, characteristics, site properties and relic types, this paper proposes that such shelters should possess five essential features: on-site deployment capability, customizability, environmental containment and controllability, temporary and reversible design, and integrated functionality.

First, the Integrated Archaeological Shelter is characterized by its on-site nature. Both the construction and operational context of the shelter are confined to the archaeological excavation site, meaning its use must ensure both the scientific integrity and safety of the excavation. The scientific rigor of excavation work requires that the shelter enables meticulous excavation by staff and precise data collection. Safety requirements mandate that the integrated shelter safeguards both artifacts and personnel throughout the entire process, from cleaning to extraction, while ensuring the physical safety of workers during excavation.

Second, Integrated Archaeological Shelters are characterized by their customizable nature. Archaeological excavation sites and contexts are diverse, with numerous sites found across plains, plateaus, caves and underwater environments. Different site types, such as earthen and stone structures, face distinct protection challenges, and the preservation status of remains varies significantly across sites. Therefore, comprehensive consideration across multiple dimensions is required to design Integrated Archaeological Shelters that align with excavation conditions and cultural heritage protection needs, thereby addressing site-specific conservation issues.

Third, Integrated Archaeological Shelters feature enclosed spaces with controllable environments. By enclosing the site area, these shelters create a sealed interior space—the foundation for establishing a stable microenvironment within the site. This enables precise environmental regulation by archeological personnel, thereby preventing cultural relic deterioration caused by sudden environmental shifts through controlled environmental measures.

Fourth, Integrated Archaeological Shelters are temporaneous and reversible structures. Primarily serving the excavation phase, these shelters function as temporary site protection facilities. Whether they remain in place after excavation depends on the specific site conditions. Therefore, their construction must ensure reversibility, they should be capable of being dismantled at the excavation site after completing their protective duties, and they shall avoid causing alterations to the site or its surrounding environment.

Fifth, the Integrated Archaeological Shelter exhibits an integrated design. Modern archaeological excavations require equipment that extends beyond basic excavation tools. To meet environmental control demands, the shelter interior needs to incorporate a wide variety of facilities, including environmental monitoring systems, climate control systems and operational equipment. The shelter serves as a multifunctional, integrated conservation facility, and this integrated character is a distinctive feature that sets it apart from other site protection methods.

5.1.3. Functions of the Integrated Archaeological Shelters

As a innovative facility, the core distinction of the Integrated Archaeological Shelter from previous protection measures lies in its multifunctional capabilities. Only through diverse functions can the integrated shelter support meticulous excavation operations while ensuring artifact security. To meet the demands of cultural heritage conservation and exhibition, this paper proposes that the integrated shelter should incorporate four essential functions: microenvironment regulation, data acquisition, integrated operations and public education.

First, the Integrated Archaeological Shelter shall possess microenvironmental regulation capabilities, which constitute its core function distinguishing it from protective shelters and site museums. Due to its enclosed structure, the shelter creates a microclimate within its interior. Equipped with environmental monitoring and control systems, it maintains stable environmental parameters through automated regulation and manual intervention, thereby ensuring the safety of cultural relics.

Secondly, the Integrated Archaeological Shelter should incorporate data collection capabilities. Documenting excavations is a critical task of archaeological work, including on-site data collection of archaeological features and photographic documentation of artifacts and sites. Taking feature photography as an example, open-air archaeological sites can be photographed using drones or elevated aerial photography. However, the shelter's limited height necessitates design considerations for data collection during excavations. Beyond excavation data collection, the integrated shelter should also collect environmental data within the integrated shelter to support subsequent cultural heritage conservation and research efforts.

Furthermore, the Integrated Archaeological Shelter should incorporate integrated operational capabilities. It must simultaneously address the dual requirements of archaeological excavation and cultural relic conservation, necessitating a highly integrated design within the shelter. For instance, to facilitate excavation work, it should provide a stable and position-adjustable working surface. To ensure the normal operation of equipment and instruments inside the shelter, power wiring and equipment interfaces should be pre-planned.

Finally, Integrated Archaeological Shelter should incorporate features conducive to public education. In recent years, public curiosity about archaeological work has steadily grown. Taking the Sanxingdui Integrated Archaeological Shelter as an example, the unique cultural characteristics of Sanxingdui have given its excavations extensive social reach. Recognizing this phenomenon, the Sanxingdui team designed the sacrificial area integrated shelter with fully transparent glass. This facilitates live media broadcasts and news interviews during excavations, while also allowing the public to observe the site closely from outside the shelter.

5.1.4. Types of the Integrated Archaeological Shelter

Since protective integrated shelters are applied in different situations, this paper categorizes Integrated Archaeological Shelters into three types: excavation-oriented, public display-oriented, and emergency-oriented.

The first category is excavation-oriented Integrated Archaeological Shelters. Designed exclusively for archaeological excavations with limited public display functionality, these integrated shelters feature non-transparent enclosures, exemplified by the Qin Dongling Integrated Archaeological Shelter. Highly enclosed structures facilitate precise microenvironment control within the Integrated Archaeological Shelter, providing optimal conservation conditions for fragile artifacts. They are suitable for fragile sites with poor conservation conditions and high environmental sensitivity, deep pits or burial rooms with narrow openings and limited internal space, as well as major scientific research projects involving extended excavation periods, complex technical procedures and the need to minimize external interference.

The second category is public-display archaeological integrated shelters. Designed to balance conservation and exhibition, these shelters feature transparent enclosures, exemplified by the Sanxingdui sacrificial area integrated shelter. While maintaining precise environmental control capabilities, these integrated shelters regard public access as a core function. They permit visitors to observe excavation sites from close proximity outside the enclosure, enhancing the visitor experience while also providing facilities for media interviews and live broadcasts. Such shelters are suitable for sites with high environmental sensitivity, moderate conservation status, and where public display on a certain scale is permitted, such as purpose-driven excavation projects of significant academic value and high public attention.

The third category comprises emergency Integrated Archaeological Shelters. These integrated shelters are designed to respond to sudden incidents, providing rapid and timely basic protection for sites. The design principle prioritizes immediate deployment at excavation sites, aiming for rapid assembly to create temporary integrated shelters that isolate the site from external elements. This allows time for developing detailed conservation plans. These integrated shelters are suitable for urgent rescue excavations involving exceptionally valuable and fragile archaeological remains.

5.2. The establishment of the Integrated Archaeological Shelter

Through the exploration of the Integrated Archaeological Shelter concept above, it is evident that the Integrated Archaeological Shelter serves as a high-performance and comprehensive site protection facility. This paper designs a performance evaluation scale for the Integrated Archaeological Shelter to systematically assess its overall capabilities, providing a reference for subsequent shelter construction (Table 1).

Before designing an integrated shelter, the team should investigate the climate and geological conditions of the site's location, analyze the types of remains and potential cultural heritage deterioration that may exist during the excavation phase, and fully understand the site's customized requirements. This enables the design and construction of a high-performance integrated shelter that meets archaeological excavation needs. Considering the characteristics and functions of the integrated shelter, its construction should be designed, built and evaluated based on five key aspects: on-site adaptability, environmental control capabilities, integration, customization and public participation.

Table 1. Integrated Archaeological Shelter performance evaluation scale

Feature/ Function	Requirement	Assessment Criteria
In-site Adaptability	Rapid on-site assembly; Facilitates artifact transport	Assembly Duration (Hour) Power Supply (Input) Communication (4G/5G/Satellite) Load Capacity & Transportability (KG)
Environmental Controllability	Precise micro-environment control via enclosed space & technology	Temperature Control Accuracy (± °C) Humidity Control Accuracy (± %RH) Illuminance (Lux) UV Intensity (μW/lm) Air Cleanliness (PM2.5/Pollen Concentration)
Integration Capability	Integrated platform with environment control & power systems	Intelligent multi-system linkage Adjustable & load-bearing platform
Customizability	Customized design based on site features predicted remains & excavation needs	Site Compatibility Conservation Demand Responsiveness
Public Participation	Public Engagement & Media Dissemination; Educational Enablement	Visual Connectivity Optimized Visitor Circulation Comprehensive Media Infrastructure

First, design and evaluate Integrated Archaeological Shelters from the perspective of on-site adaptability. Given that archaeological excavations span extended timelines, integrated shelter construction should not consume excessive time and should possess rapid deployment capabilities. Deployment capability can be measured by calculating the assembly time in hours, from the arrival of all components at the site to the completion of the integrated shelter. Minimizing assembly time reduces disruption to ongoing excavations. Modular alloy components should be selected to enable rapid construction. Secondly, due to the integrated shelter's enclosures and environmental control systems, numerous facilities require installation inside. The operation of these facilities demands a reliable energy supply, particularly one capable of supporting simultaneous operation. Therefore, the maximum power requirement per unit time needs to be calculated in advance. Furthermore, considering that many archaeological sites are located in remote areas far from urban centers, the design of the integrated archaeological shelter must account for unexpected situations such as power outages. It is essential not only to ensure the stability of the power system during routine use but also to prepare emergency power solutions to prevent damage to cultural relics caused by unforeseen circumstances. Third, the operation of the facilities within the integrated shelter relies on communication networks. Given the special characteristics of archaeological excavation areas, the integrated shelter must have a stable network connection to ensure the reliable transmission of network data. Furthermore, while archaeological sites vary in the types of remains they contain, the possibility of large-scale discoveries exists. The design of the integrated shelter requires consideration for excavation convenience, incorporating a load-bearing support system to ensure stability during static operations on the work platform. It is also essential to guarantee the safe and efficient transportation of artifacts and personnel movement within the shelter.

Second, this study examines the construction of Integrated Archaeological Shelters from the perspective of environmental control. Crucially, to ensure precise regulation of the internal environment, the integrated shelter should possess exceptional enclosure integrity. This allows for the establishment of a buffer zone between the external macro-environment and the internal micro-environment, thereby preventing direct exchange between the two. Next, abrupt changes in temperature and humidity, intense ultraviolet radiation and particulate matter (PM2.5) deposition are common factors causing deterioration in cultural relics.

Environmental control within the integrated shelter should address these aspects to regulate the microenvironment. To achieve this, various sensors should be strategically placed throughout the shelter to collect environmental data. Additionally, high-precision constant temperature and humidity air conditioning units should be installed to enable timely adjustments when environmental values exceed set parameters. For UV and lighting, UV-free illumination systems should be employed to prevent photo-degradation. Regarding atmospheric pollution and particulate matter, a fresh air system is essential. This system facilitates air exchange between the integrated shelter and the exterior while simultaneously purifying the air of microorganisms and impurities, thereby preventing damage to cultural relics from dust particles and microbial contamination.

Third, the construction of the integrated shelter should be approached from the perspective of integrated shelter facilities. Although the equipment within the integrated shelter belongs to different systems, its functions should be interconnected as a unified whole. Taking the Sanxingdui integrated shelter as an example, the Sanxingdui team developed the "Sanxingdui Smart Air Cloud Platform". This intelligent platform enables clear access via PC to metrics such as operational uptime, real-time temperature and humidity, PM2.5, CO2, tVOC, soil temperature fluctuation range, soil moisture content fluctuation range, soil conductivity range, and integrated shelter air quality compliance rate. This successfully integrates all internal facilities into an organic whole. During construction, integrated shelters can incorporate such centralized intelligent management platforms to aggregate environmental monitoring data. When readings fall outside preset safety ranges, the platform automatically issues adjustment commands to control systems, intelligently managing the internal environment and enhancing microenvironmental control precision. Additionally, another aspect of integration concerns archaeological excavation work. This requires that the rail-guided work platforms used by excavation personnel not only possess high equipment load-bearing capacity but also align structurally with other environmental control systems. This prevents environmental control facilities from interfering with excavation activities, thereby creating an efficient, obstacle-free environment for meticulous excavation.

Fourth, examining the construction of integrated shelters from a customized perspective. Integrated Archaeological Shelters should adhere to targeted design principles, ensuring their spatial distribution precisely aligns with the site's excavation scope, depth and distribution. This minimizes the microenvironment control area, thereby reducing maintenance costs. Building upon this foundation, functional priorities should be established based on the site's conservation status and excavation objectives. For instance, sites with poor condition and narrow openings should adopt excavation-oriented designs, concentrating resources on environmental control and safety measures while limiting public display functions. Such customization requires integrating archaeological survey data to predict potential remains, ensuring the Integrated Archaeological Shelter possesses compatible functions during excavation.

Fifth, this research explores the construction of integrated shelters from the perspective of public participation. It is worth noting that while some sites possess a certain capacity, demand and potential for public display, safeguarding cultural relics and ensuring the progress of excavation work still remain the primary purpose of integrated shelters. Different types of integrated shelters may have varying requirements for public participation. For instance, public display-oriented Integrated Archaeological Shelters have a need for public exposure, thus their construction can incorporate transparent exteriors to facilitate on-site visits and media coverage. In contrast, emergency and excavation-oriented integrated shelters have less need for public display functions, allowing their design and construction to focus less on exhibition capabilities. Furthermore, integrated shelters requiring public display should incorporate design measures to separate visitor pathways from archaeological work zones, preventing visitor activity from disrupting excavation operations.

6. Conclusion

This research first identifies limitations in existing site protection methods through literature and case analysis, introducing the new concept of archaeological integrated shelters. These are clearly defined as protective facilities deployed at excavation sites. Centered on this definition, the paper systematically constructs the theoretical and practical framework for Integrated Archaeological Shelter. It proposes five defining characteristics, on-site deployment, customization, enclosure with environmental control, temporary and reversible nature, and integration, laying the theoretical foundation for future development. Furthermore, it identifies four core functions: microenvironment regulation, data collection, integrated operations and public education, clarifying the multifunctional attributes of Integrated Archaeological Shelter. Additionally, based on varying application scenarios, the integrated shelter is categorized into three types: excavation-oriented, public exhibition-oriented and emergency-oriented, to accommodate the conservation needs of different sites. Finally, a performance evaluation scale for Integrated Archaeological Shelters is developed, accompanied by construction recommendations. This transforms theoretical concepts into practical design and assessment tools, providing methodological support for subsequent research and practice.

The significance of this study lies in elevating the Integrated Archaeological Shelter from a vague concept in practice to an academic concept and tool with clear theoretical implications and well-defined technical standards. This represents not only a further shift in field archaeology's on-site preservation approach toward precision, standardization and preventive conservation, but also provides new practical and developmental directions for collaboration among field archaeology, cultural heritage conservation and construction engineering. Subsequent research urgently requires expanding the range of site samples, refining the types and functions of Integrated Archaeological Shelters, and conducting long-term monitoring studies to evaluate their effectiveness in practical applications. This will further guide the development of more effective, lower-cost and more universally applicable Integrated Archaeological Shelters, thereby driving their sustainable advancement.

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