Journal of Cultural Heritage 16 (2015) 790–797

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Original article

Environmental control strategies for the in situ preservation of unearthed relics in archaeology museums

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ARTICLE INFO

Article history:
Received 17 January 2015
Accepted 31 March 2015
Available online 23 April 2015

Keywords:
Archaeology museum
Preservation environment
Local environmental control
Relics preservation
Capillary tube radiant panel

ABSTRACT

Archaeology museums play an important role in protecting unearthed cultural relics from natural weathering. However, many of the unearthed relics are still suffering from deterioration or even ruin due to improper environmental control in archaeology museums. In this study, we demonstrate that the disregard of environmental control for relics and the imbalances of energy and mass across in situ air-relic-soil interfaces in pits are important causes for the deterioration of relics. Thus, individual environmental management strategies for visitor passages and relic preservation are proposed for the long-term preservation of unearthed relics. Experimental investigations using the test pit, with radiant panels for control of the environmental interfaces, validated these management strategies for the preservation and display of relics in archaeology museums. These results have significant implications for understanding the mechanism of relic deterioration and for formulating appropriate strategies to create sustainable environments for long-term preservation of unearthed relics in archaeology museums.

1. Research aims

The environmental requirements for appropriate preservation of unearthed relics are usually inconsistent with those for visitors in an archaeology museum. The primary purpose of this research is to develop and evaluate the stabilization of microclimate for the long-term preservation of unearthed relics in archaeology museums. We also identify how the unearthed relics deteriorate in archaeology museums, and the crucial considerations in developing environmental control strategies for the design of archaeology museums.

2. Introduction

The cultural value of the conservation of ancient sites is recognized and treasured by every government in the world, allowing visitors worldwide to learn about the development of human civilization. However, effectively protecting ancient sites is becoming a global problem [1–3]. An immense quantity and variety of cultural relics have been excavated and preserved in China, as it is one of the birthplaces of ancient civilizations. Until now, more than 400,000 unmovable cultural relics have been discovered and exposed on the ground and in the earth [4]. Archaeologists have proposed various protection modes, such as excavation, backfill, and construction of archaeology museums, to preserve the unearthed relics and earthen sites. Construction of archaeology museums is considered the most effective way to preserve unearthed relics. Hundreds of archaeology museums are open in China, and more than 50 archaeology museums are being constructed [5].

However, long-term appropriate conservation of relics is far from a reality in archaeology museums. This is still a challenging goal for environmental scientists and technologists to develop a sustainable, long-term preservation strategy that is also appropriate for displaying relics to the general public. Many unearthed relics are suffering from severe deterioration; for example, in the Emperor Qin's Terra-Cotta Warriors and Horses Museum, the appearances of relics in the pits have gradually changed after their unearthing due to the lack of available environmental management approaches [6,7]. Even in the underground exhibition hall of Hanyangling Museum, China, opened in 2006, where physical divisions exist between visitor passages and the exhibition hall and many other technical measures have been utilized for the preservation of relics, the relics are still not preserved as well as expected. Slight surface cracking and weathering have been found on the pottery figurines, and air pollutants such as SO_2 and NO_x have been found on the relics' side of the enclosed hall [8–10]. An investigation organized by China's State Administration of Cultural Heritage

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http://dx.doi.org/10.1016/j.culher.2015.03.013
1296-2074/

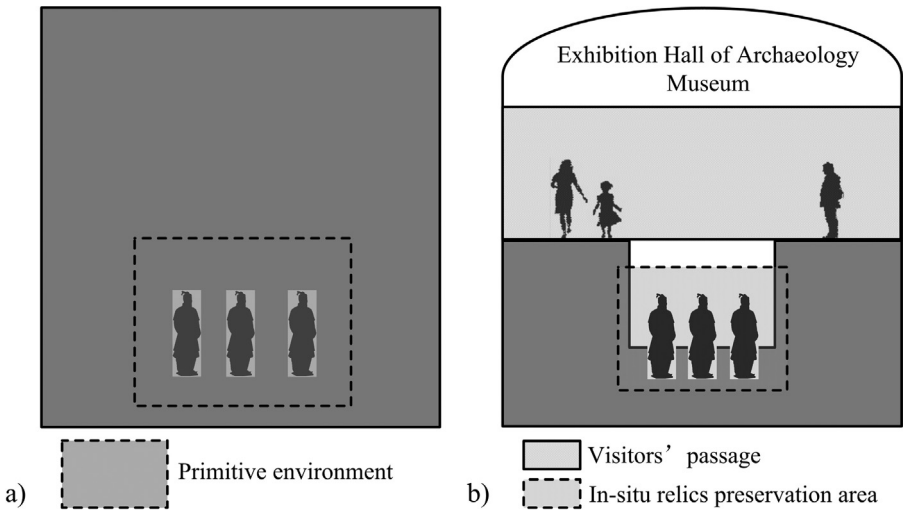

Fig. 1. The surrounding environments of relics before and after being unearthed: a: relics before being unearthed; b: unearthed relics in exhibition environment.

reveals that there are more than 3000 museums in China, among which approximately 51% of the collections are suffering deterioration or even ruin due to improper preservation environments [11,12].

After hundreds of years of being underground, relics and their surrounding earthen environment have reached a mass and energy equilibrium, so that the buried relics are well-preserved in a stable, primitive environment (Fig. 1a). After being excavated, however, the closed and balanced environment of the buried relics is disturbed, and the relics are being displayed in an open in situ exhibition environment, as shown in Fig. 1b. Much deterioration occurs in such an open environment; for example, the fading of the fresh orange color of relics in the Emperor Qin's Terra-Cotta Warriors and Horses Museum since being unearthed [6]. These deteriorations can be attributed to an improper environmental control strategy and to unique features of the conservation environment of the archaeology museum.

Environmental fluctuations are crucial considerations for the conservation of relics, and many specifications have been established for the indoor-display of collections in museums [13–15]. Additionally, novel and energy-efficient heating systems have been proposed and successfully applied to in historic buildings to reduce the risks due to environment fluctuation in artworks and improve the thermal comfort for visitors [16–18]. Very few studies of environmental preservation strategies for unearthed relics in archaeology museums have been published [5]. Maintaining a stable environment in an archaeology museum is more difficult than in an indoor-display museum. In this study, we argue that imbalances of energy and mass between the complex air-relic-soil interfaces of unearthed relics, along with disregard for the different indoor environmental demands between visitor passages and relic preservation, are the important causes of deterioration. We propose restoring the air-relic-soil balance and separate independent environmental controls for visitor passages and in situ relic preservation as strategies to create appropriate, sustainable environments for the long-term preservation of unearthed relics in archaeology museums. A series of experimental tests were performed to validate these strategies and confirm our arguments.

3. Problem description

We first explain how the unearthed relics deteriorate in archaeology museums, and the crucial considerations in developing environmental control strategies for the design of archaeology museums. Existing archaeology museum buildings usually have an open and large-space layout, such that both visitors and relics share the same indoor environment, as shown in Fig. 1b. However, the environmental requirements for appropriate preservation of unearthed relics are usually inconsistent with those for visitors in an archaeology museum; for example, the recommended thermal comfort standard for visitors is in a temperature range of 24 to 28 °C and 40-65% relative humidity (RH) [19]. The necessary environmental conditions for unearthed relics vary widely, depending on material properties and the soil environment [13]. Therefore, it is very difficult for the all-encompassing environmental management presently used in archaeology museums to simultaneously satisfy the different needs of all aspects of the museum. Additionally, the operating mode of the present environmental control system designated for visitors is quite different from that required for relics. The visitor facility operating hours are from 9 A.M to 5 P.M. The special needs of the unearthed relics are still ignored in many archaeology museums because a steady, conservative environment requires the environmental control system to operate all day.

For the display of unearthed relics in archaeology museums, an in situ air-relic-soil complex is adopted, in which the majority of the relics are exposed to the visitors (air) and the others still lie in their primitive environment (soil), as shown in Fig. 2. As a result, an imbalance of energy, moisture and chemical potential occurs at the air-soil interface and the air-relic-soil complex interfaces, causing not only the fluctuation of environmental parameters where relics are exposed but also the deterioration of relics due to mass and energy transfer. For example, the migration of moisture from the air-relic-soil complex into the air would cause carbonation, which is deposited on the relic's surface, and some carbonates would further react with the penetrating SO_2 to form sulphates [6]. Ignoring the effects of solar radiation, the heat and mass flux through the interfaces (Fig. 2b) can be described by the following equations [20–23] as:

$$G_m = h_m \Delta \rho_v = h_m (\rho_{v2} - \rho_{v1}) \quad (1)$$

$$G_h = h_o \Delta T + h_m \Delta \rho_v \lambda_{water} = h_o (T_2 - T_1) + h_m (\rho_{v2} - \rho_{v1}) \lambda_{water} \quad (2)$$

Meanwhile, from the viewpoint of heat conducting through the soil media, the left side of Eq. (2) can be written as:

$$G_h = k_{soil} \frac{\partial T}{\partial z} = -k_{soil} \frac{T_2 - T_3}{\Delta z_1} \quad (3)$$

where G_m, G_h, h_m and h_o are the mass flux, heat flux, mass transfer coefficient and heat transfer coefficient, respectively. T_1, T_2 and T_3