An Evaluation System Based on AHP Method for Preserve Situation in Guangyuan Thousand-Buddha Grotto of Tang Dynasty in Sichuan, China

Xue Yao (yaozhibushixue0726@126.com)
Southwest Minzu University https://orcid.org/0000-0002-5287-6384
Fan Zhao
Institute of Cultural Relics and Archaeology of Sichuan Province

Research article

Keywords: Grotto, Preserve situation, AHP method, Evaluation system, Hierarchy structure

Posted Date: July 23rd, 2021

DOI: https://doi.org/10.21203/rs.3.rs-735911/v1

An Evaluation System Based on AHP Method for Preserve Situation in Guangyuan Thousand-Buddha Grotto of Tang Dynasty in Sichuan, China

Xue Yao*[1], Fan Zhao[2]

Abstract

Guangyuan thousand-buddha grotto is of great value in researching Buddhism spread in China. By joint effect of various factors, the grottos have developed serious diseases, which threaten the long-term preservation. To date, the existing study can neither reveal the contribution each disease makes to nor the grottos' preserve situation in a quantized way. Therefore, establishing a scientific evaluation system to explore the effection of each disease and assess grottos' preserve situation degree has been a significant topic for grotto's conservation. In this research, the authors selected 11 grottos of middle Tang dynasty in Guangyuan thousand-buddha grotto as survey objects, traditional diseases investigation was taken and analytic hierarchy process (AHP method) was applied to build a system to calculate weight of 15 diseases and evaluate grottos' preserve situation. The result shows, 15 diseases can be classified as two risk categories, and every disease has its own weight on effecting grotto's preserve situation. AHP method is suitable for heritage assessment with complex structure.

Key words: Grotto, Preserve situation, AHP method, Evaluation system, Hierarchy structure

Introduction

Grotto is a kind of valuable heritage in China with high history, art and science value, which is

* Correspondence: yaozhibushixue0726@126.com

[1] Department of Tourism and History Cultural, Southwest Minzu University, Chengdu 610041, Sichuan, People' s republic of China.

[2] E-mail: zhaofan_163@163.com. Cultural Relics and Archaeology institute of Sichuan, Chengdu 610041, Sichuan, People' s republic of China.

started from Han dynasty, and thriven from North Wei dynasty to Tang dynasty. It can be classified as Xinjiang grotto, north grotto, south grotto and Tibetan grotto according to the characteristic [1]. Among these four parts, the south grotto is account for 42.9%, and grotto in Sichuan and Chongqing is account for more than 80% of south grotto. A large number of grottoes with high value distributed in Sichuan province, southwest China. They are the outstanding representative of grotto in late time in Chinese history, which is meaningful to reconstruct the local history of southwest China [2]. After experiencing hundreds years of natural erosion and human destruction, most of these grottoes have developed serious deterioration that threaten their long term existence and preservation. The existing research reveals that most of grotto in Sichuan is suffering dangerous rock mass, sandstone degradation, water disease and biological disease, due to wet and rainy climate, soft property of sand stone and dense seismic zones [3]. Conservation research on sandstone grotto is in the primary stage. Grotto's deterioration is the result of the combined function of varies factors, such as sandstone properties, grotto's preserve situation and surrounding [4]. Among these factors, sandstone properties and grotto's preserve situation are internal causes and the surrounding is the external cause.

Vulnerability evaluation is derived from natural disaster risk assessment, which is widely used in assessing the loss caused by earthquake, debris flow, landslip and rainstorm [5-8]. Currently, the research on risk management in cultural heritage is still in the exploratory stage. Studies of risk forecast on specified types heritage to single factor were taken, such as rainstorm to historic building, flood to earthen site and earthquake to grotto [9-11]. These studies provide a good foundation to this research and emphasize the disaster' development degree and frequency, but they are unaware of the center position of cultural relics in risk event.

From dynamics aspect, the grotto's preserve situation is the result of the combined effect of varies factors, and from the performance is the joint contribution of the multiple diseases. Grotto's preserve situation is represented in kinds of diseases or quantity of diseases [12]. Neither of them can show the contribution of each disease to grotto's deterioration nor the grotto's preserve situation in a quantized way. So far, the research on grotto's preserve situation makes little contribution to assess the grotto's conserve necessary scientifically.

In this research, the authors selected 11 grottoes of Tang dynasty in Guangyuan Thousand-Buddha Grotto as the study objects. To explore the vulnerability evaluation mode and the quantification of preserve situation, the geological disaster risk assessment method is used for reference [13]. By the traditional diseases surveying and taking analytic hierarchy process (AHP method), the contribution of each disease to the grotto's preserve situation is determined. Furthermore, the vulnerability evaluation mode, including grotto's value, sandstone properties, preserve situation and management, is basically established. This research proposes a new evaluation system to grotto's preserve situation, and is an important component of grotto's risk assessment, which is benefit for judging the urgency of the grotto's preserve situation in a quick and effective way and offering evidence for grotto's conservation and consolidation.

Study object

Guangyuan Thousand-Buddha Grotto is located in Guangyuan, Sichuan province, which was excavated from NorthWei to Qing dynasty [14]. The Grotto distributed on the face of the cliff beside the east bank of Jialing River (Figure 1). The Jinniu road was under the cliff, which is the important path that Buddhism was spread from center plains area to Shu area. By the digital investigation, 949 caves and more than 7000 stone sculptures were found, most of which were made from Tang dynasty, presenting high level of history, art and science value in the southern part of China. Owing to the high value and serious preservation, Guangyuan Thousand-Buddha Grotto was honored as the first state-level key cultural relic preservation organ in 1961, and urgent repairing treatments were needed [14]. However, several important questions must be answered before starting the work: Which disease is the most common and which is the most serious? Which one affected the stability of the grotto and which one affected the value loss? Which conservation project should be conducted first? Therefore, it is very necessary to conduct a systematic and quantized diseases investigation on the grotto, not only for answering these questions, but also for offering a decision basis to conservation.

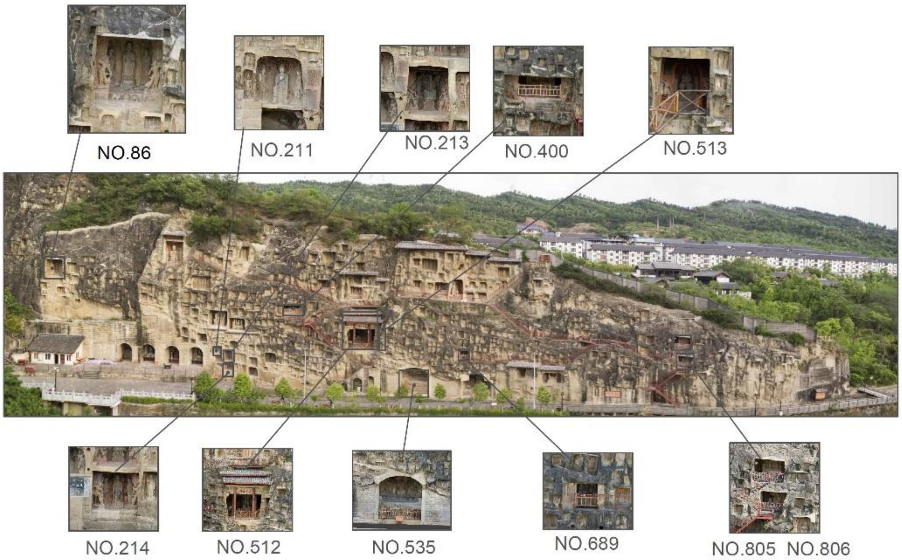
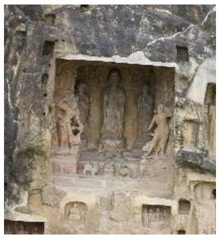


Fig.1 The location of study object in Guangyuan Thousand Buddha grotto

In this research, we selected 11 caves excavated in middle Tang dynasty as research objects, because of their outstanding value and representative art styles. They are NO.86, NO.211, NO.213, NO.214, NO.400, NO.512, NO.513, NO.535, NO.689, NO.805, NO.806. The basic information about these caves is listed in Tab. 1.

Table 1 The basic information of caves excavated in middle Tang dynasty

NO.	Name	Basic information	Figure
86	Amitabha grotto	This grotto was excavated in middle Tang dynasty, with the height of 3.6m and the depth of 1.4m. The preserve situation is well.	
211	Suting grotto	This grotto was excavated in 723AD by the current officer Suting. It’s a circle arch grotto with height of 1.8m, width of 1.64m, and depth of 0.85m.	

213	/	NO.213 cave was excavated in middle Tang dynasty, and the detail time is not clear.	
214	Vairocana Buddha cave	This cave was excavated in early stage of Tang Kaiyuan.	
400	Central stupa grotto	This is an uncompleted grotto. The outer cave is a horizontal rectangle. In the center, a square column was planned to be excavated but unfinished.	
512	Dayun old cave	This cave and NO.513 were both excavated by Weikang, the current government officer from 715AD to 722AD. This cave is located in the center of whole Thousand Buddha grotto, and is the largest grotto.	
513	Weikang grotto	This cave and NO.512 were both excavated by Weikang, the current government officer from 715AD to 722AD.	
535	Lotus cave	This cave was excavated in Wuzhou period (690AD-697AD), and is located in the middle of the bottom of Thousand buddha grotto (NO.689). At the inner top of the cave there is a lotus, so it was named “Lotus cave”.	

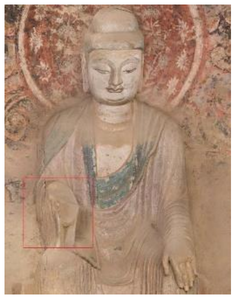
689	Thousand buddha cave	This cave was excavated in middle Tang dynasty and the detail time is unclear. Since of the surrounding wall was sculptured thousands of small buddhas, it was named “Thousand buddha cave”.	
805	Benefactors grotto	This grotto is under the NO.806, and there were 6 couples of benefactors sculptured in the grotto, so it was called “Benefactors grotto”.	
806	Shakyamuni and Prabhuta -ratna grotto	This grotto is located in the south end of the cliff, and is named for its elegant sculpture.	

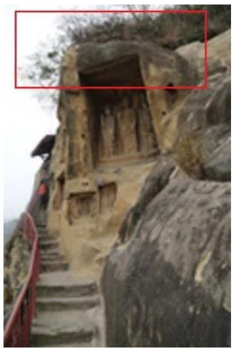
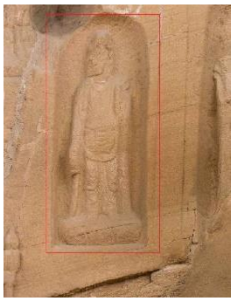
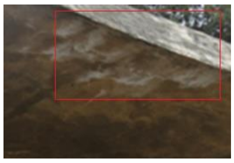
Method

Field investigation

In this research, the authors surveyed the diseases on the grottos but didn’t involve the dangerous rock of the surrounding. The diseases were named by referring the classification and legend on the deterioration of ancient stone objects (WW/T 0002-2007), issued by the State Administration of Cultural Heritage of People’s Republic of China [15]. Based on the investigation, all the diseases can be classified as two major categories according to the risk. The one may cause safety risk involving scaling off, detachment, water disease, body loss, cracks and plant damage. These diseases may affect the grotto’s safety directly, leading to the grotto’s loss or disappearance. They have small quantity but develop fast and destructively. And the other one may cause value loss including rock powdering weathering, deep loss, salt crystallization, pigment layer peeled off, paint layer craquelure, scratch or graffiti, improper repairing, human pollution, microorganism pollution. These diseases exist on the grotto for a long time, and do not affect the grotto's safety in a short term, but will lead to the value loss for a long time. They distribute widely with slow development and have weak destructive. All these typical diseases almost exist all the survey objects (Table 2). The diseases data were investigated and analyzed in Table 3 and Table 4. All data are from Guangyuan Thousand buddha Museum.

Table. 2 Typical diseases in Guangyuan thousand buddhas grottos

Category	Disease	Description	Figure
Safety risk	scaling off	Surface of stone was peeled off as slice or crust due to salt dissolute and crystallize, temperature fluctuation, frozen and weathering.	
	detachment	Surface of stone was out of the grotto body, and formed a cavity but not peeled off.	
	water disease	Water leakage, water incrustation inside the grotto due to rainfall, surface runoff and capillary water.	
	body loss	The grotto or sculpture showed a certain volume loss than its initial state.	
	cracks	Including three types: one is weathering fracture, often occurring on the surface, second one is stress fracture, often extending to the inner of stone, and may cause body loss or completely broken, last one is structural fracture, often closing, smoothing and appearing as a	

		group.	
	plant damage	Plants grow in the cracks of grotto; the root may lead to more cracks.	
	rock powdering weathering	Surface of stone was softened and peeled off because of temperature and humid fluctuation, frozen and thaw, water and salt activity.	
	deep loss	The plaster layer of paint in the grotto peeled off from the stone.	
Value loss risk	salt crystallization	Soluble salt dissolved and crystallized because of temperature and humid change.	
	pigment layer peeled off	Paint layer of grotto flaked and broke away from grotto or sculpture.	
	Paint layer craquelure	Paint layer of grotto cracked but not peeled off from grotto or sculpture.	

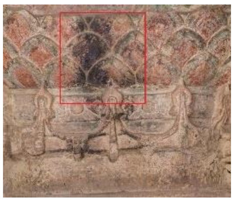
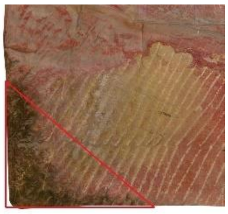
scratch or graffiti	Scratch or graffiti by human's activity.	
improper repairing	The grotto was repaired by improper material or method in the history.	
human pollution	Sootiness on the grotto or sculpture by smoke in the history.	
microorganism pollution	Microorganism grow on the grotto.	

Table 3 Data of diseases lead to safety risk

Number	**Name**	**Safety risk**					
		scaling off（m²）	**detachment（m²）**	**water disease（m²）**	**body loss（m²）**	**cracks（m）**	**plant damage（m²）**
86	Amitabha grotto	3.05	0.32	0.46	0.06	10.04	0.00
211	Suting grotto	0.02	0.00	0.00	0.01	0.82	0.00
213	/	0.47	0.07	0.00	0.03	5.36	0.00
214	Vairocana Buddha cave	0.00	0.64	0.00	0.43	5.83	0.43
400	Central stupa grotto	0.13	0.33	3.06	0.01	15.20	0.00

512	Dayun old cave	10.28	0.19	0.64	0.95	27.12	0.01
513	Weikang grotto	0.83	0.00	0.00	0.57	4.52	0.00
535	Lotus cave	1.98	1.04	0.00	0.14	21.89	0.00
689	Thousand buddha cave	5.06	0.00	0.00	0.14	5.76	0.00
805	Benefactors grotto	0.52	0.20	0.00	0.03	9.83	0.00
806	Shakyamuni and Prabhuta-ratna grotto	2.29	0.09	0.00	0.04	4.00	0.00

Table 4 Data of diseases lead to value loss risk

No.	**Name**	**Value loss risk**				
		rock powdering weathering （m²）	**deep loss （m²）**	**salt crystallization （m²）**	**pigment layer peeled off （m²）**	**Paint layer craquelure （m²）**
86	Amitabha grotto	7.67	0.01	0.60	2.76	1.59
211	Suting grotto	0.15	0.00	0.09	0.13	0.00
213	/	2.95	0.03	0.13	1.14	0.31
214	Vairocana Buddha cave	0.10	0.07	0.00	0.36	0.48
400	central stupa grotto	15.92	0.58	5.91	0.26	0.06

512	Dayun old cave	19.16	0.06	4.98	1.92	0.01
513	Weikang grotto	4.49	0.02	0.00	2.24	0.00
535	Lotus cave	12.47	0.01	1.71	5.25	0.09
689	Thousand buddha cave	7.62	0.01	0.86	4.27	0.00
805	Benefactors grotto	18.67	0.00	0.72	0.12	3.27
806	Shakyamuni and Prabhuta-ratna grotto	17.69	0.00	0.14	5.27	0.78

No.	**Name**	**Value loss risk**			
		scratch or graffiti (m)	**improper repairing （m^2）**	**human pollution （m^2）**	**microorganism pollution （m^2）**
86	Amitabha grotto	0.00	0.10	5.79	0.01
211	Suting grotto	0.00	0.00	1.48	0.00
213	/	0.00	0.63	1.46	0.00
214	Vairocana Buddha cave	5.90	0.12	0.00	0.01
400	central stupa grotto	36.94	0.07	2.61	1.35
512	Dayun old cave	15.15	3.00	10.86	0.37
513	Weikang	21.07	0.05	1.27	0.05

	grotto				
535	Lotus cave	12.83	0.84	8.60	5.70
689	Thousand buddha cave	88.53	0.09	3.18	0.01
805	Benefactors grotto	58.17	0.01	3.57	1.86
806	Shakyamuni and Prabhuta-ratna grotto	70.65	0.05	3.01	1.70

AHP method

The AHP method is a multi-objective decision analysis method combined qualitative and quantitative analysis, applying to the large complex system with complex target structure, or lack of certain data [16,17]. The basic principle is to decompose the decision goal according to different standard, then calculate the weight each element to a specific element in the above layer through calculating the matrix and eigenvector, finally conclude the weight of every element in this system [16]. The specific procedure includes 5 necessary steps [6-8,11,16]: clarify the decision goal, build hierarchical structure, construct judgment matrix, check consistency and make judgment. The finally goal of AHP method is to determine the relative weight every element in the system. The specific procedure of this method is shown in Figure 2.

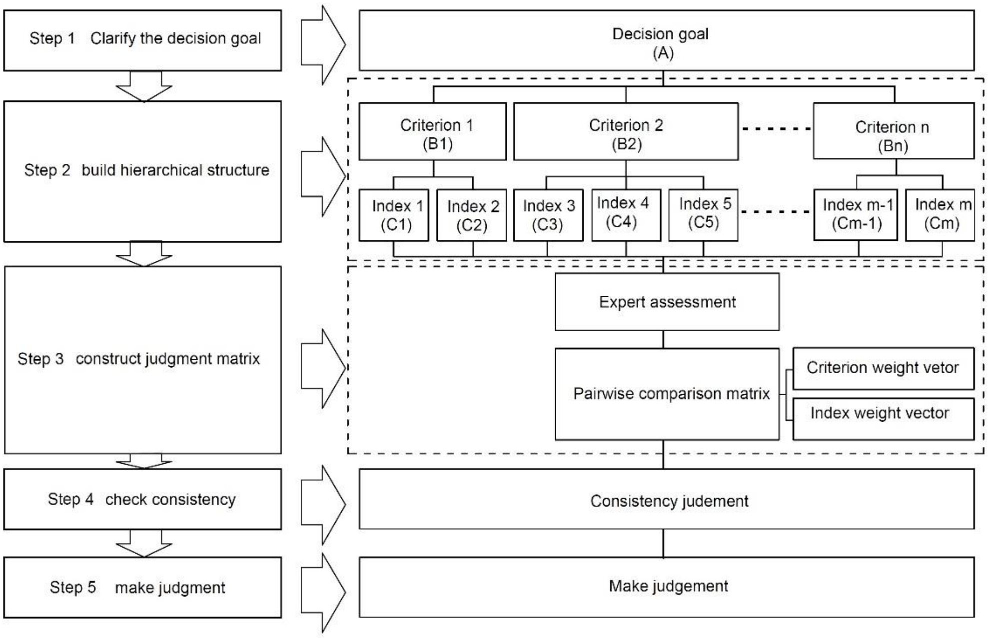


Fig. 2 AHP Method procedure

In existing investigation, the grotto's preserve situation is often characterized through quantity and variety of diseases [12], this expression depends on the investigator's subjective judgement. Although most of the investigators are professional, the disease data is lack of objective. Since of the significant value of these survey objects, it is very important to consider experts' opinions when studying the preserve situation and conservation. In this research, we selected AHP method because it can reflect the subjective intension of the decision maker, provide the hierarchical structure, facilitate decomposition and pairwise comparison, reduce inconsistencies and generate priority vectors [11,16]. The AHP method was used to establish a system for evaluating the grotto's preserve situation, in order to calculate its degree of disease development in each grotto, because of its combination of subjectivity and objectivity in this research.

The AHP method procedures are as follow:

Step 1: Clarify the decision goal. In this research, the decision goal is to evaluate all survey subjects' preserve situation in a quantized way.

Step 2: Build hierarchical structure. According to the grotto's diseases, the hierarchical structure of the grotto's preserve situation is established.

Step 3: Construct judgement matrix. In this step, the weight of the indexes in the hierarchical structure are calculated.

First, compare the element of particular layer pairwise in accordance with the experts' opinion, then the matrix A can be given as follows (Eq 1):

$$A = \left(a_{ij}\right)_{n\times n} \quad (1)$$

n is the number of elements compared, and a_{ij} is governed by the rules: a_{ij} >0; $a_{ij} = {}^{1}/_{a_{ij}}$ (i≠ j), $a_{ij} = 1$ $(i = j = 1,2 \dots n)$.

a_{ij} is the element of the matrix A, and the value of a_{ij} is from the judgement of a pair of elements A_i and A_j , which indicate the relative importance between two elements. The value of a_{ij} is defined from a 9-point scale (Table 5). In this table, the value of relative importance is expressed as pairwise weight of 1, 3, 5, 7 and 9, which means the relative importance between elements is equally, moderately, strongly, very strong and extremely. While the value of 2, 4, 6, and 8 are intermediate value [17].

Table 5 Relative importance meaning of pairwise value

Value	Meaning
1	The relative importance of A_i and A_j is equal
3	A_i is moderately important than A_j
5	A_i is strongly important than A_j
7	A_i is much strongly important than A_j
9	A_i is extremely strong important than A_j
2, 4, 6, 8	The relative importance between 1, 3, 5, 7, 9 in turns

Second, calculate the weight of each index to particular criterion in above layer. Normalizing each column of matrix A, the matrix A' can be calculated according to the Eq (2).

$$A'_{ij} = \frac{A_{ij}}{\sum A_{ij}} \quad (2)$$

In equation (2), A'_{ij} is the element of matrix A' which is normalized from matrix A, A_{ij} is the relative importance value of A_i and A_j in matrix A, $\sum A_{ij}$ is the sum of each column in matrix A.

The eigenvector of each column in matrix A can be calculated according to Eq (3).

$$\overline{Wi} = \sum_{j=1}^{n} \overline{Wij} \quad (3)$$

In equation (3), $\overline{W_i}$ is the eigenvector of each column, $\sum_{j=1}^{n} \overline{Wij}$ is the sum of each column in matrix A'.

Finally, normalizing the eigenvector of each column according to Eq (4), the weight of each index can be calculated.

$$Wi = \frac{\overline{\mathrm{Wi}}}{\sum \mathrm{Wi}} \quad (4)$$

In equation (4), $\overline{W_i}$ is the eigenvector of each column, $\sum W_i$ is the sum of eigenvalue in matrix A.

Step 4: Check consistency. To avoid the inconsistency of the decision system, it is necessary to verify the consistency of the matrix. When the coincidence indicator (C.I) and the random consistency index (C.R) are both less than or equal to 0.1, it means the matrix can be regarded as consistent. The C.I can be calculated according to Eq (5), and C.R can be calculated according to Eq (6) [16].

$$C.I. = {}^{(\lambda_{max} - n)}\!\big/_{(n-1)} \quad (5)$$

$$C.R. = {}^{C.I.}\!\big/_{R.I} \quad (6)$$

In equation (5), λ_{max} is the largest eigenvalue of matrix A, n is the scale of matrix, R.I is average random consistency index which is a constant according to the scale of matrix (Table 6).

Table 6 The random index (R.I) values

Scale	1	2	3	4	5	6	7	8	9	10
R. I	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Step 5: Make judgement. By calculating the weight and normalizing the quantity of disease in each grotto, the grottos' preserve situation can be calculated in a subjective and objective way, and the grottos' vulnerability assessing mode can be established primarily.

Result

In this part, the authors established a hierarchical structure of the grottos' preserve situation, calculated the weight of the indices in the hierarchical structure and finally obtained the preserve situation of each grotto.

Building hierarchical structure

The grottos' degradation is the joint effect of various diseases. According to the survey, the diseases may lead to safe risk, have less quantity, but develop fast and more dangerously, while the diseases resulting in value loss distribute widely but develop at a low speed, exiting in a long term. The two categories' diseases have different contribution to grottos' preserve situation and further effecting. It is necessary to consider both the quantity and the weight of disease when defining the grottos' preserve situation. The authors build the hierarchical structure of 15 diseases two categories (Figure 3). By calculating the weight, the contribution of each disease to grottos' preserve situation can be determined. Combined with the quantity of each disease, the grottos' preserve situation can be characterized in a respect quantitively way. And then the vulnerability of each grotto is determined which offers the evidence of priority level of conservation.

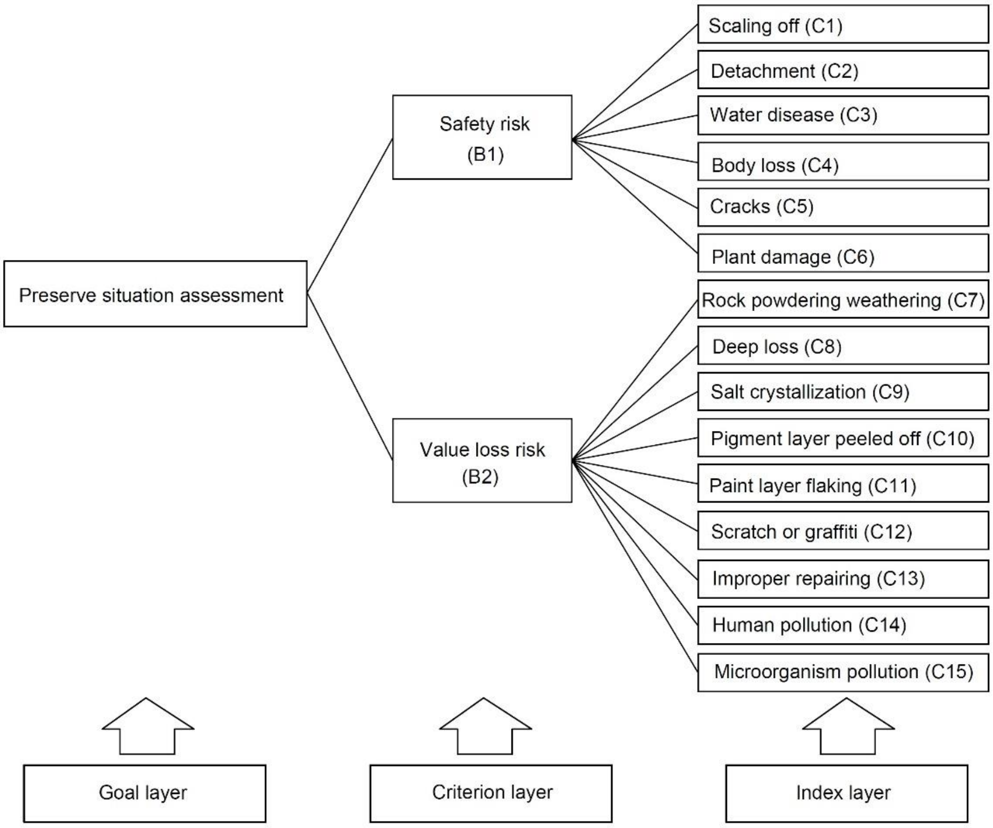


Fig. 3 The hierarchical structure of grotto's preserve situation assessment

Constructing judgement matrix

In this research, the grottos' preserve situation is the goal layer, the safety risk and value loss risk are criterion layer. The index layer includes scaling off, detachment, water disease, body loss, cracks and plant damage, rock powdering weathering, deep loss, salt crystallization, the pigment layer peeled off, paint layer craquelure, scratch or graffiti, improper repairing, human pollution, microorganism pollution.

Three experts who are well acquainted with the preservation of grottos in China were invited to provide the final comparison results for the structure pairwise comparison matrices, as shown in Table 7 to Table 9. Table 7 is the comparison result of criterion layer, and Table 8 and Table 9 are the index layer to particular criterion above.

Table 7 Pairwise comparison result of criterion layer

Criterion	B_1	B_2
B_1	1	3
B_2	1/3	1

Table 8 Pairwise comparison result of C_1~C_6 to criterion B_1

Index	C_1	C_2	C_3	C_4	C_5	C_6
C_1	1	2	2	1/2	1	4
C_2	1/2	1	1	1/3	1/2	3
C_3	1/2	1	1	1/3	1	3
C_4	2	3	3	1	2	5
C_5	1	2	2	1/2	1	4
C_6	1/3	1/3	1/3	1/5	1/4	1

Table 9 Pairwise comparison result of C_7~C_{15} to criterion B_2

Index	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}
C_7	1	2	2	3	4	4	5	5	5
C_8	1/2	1	1	2	3	3	4	4	4
C_9	1/2	1	1	2	3	3	4	4	4
C_{10}	1/3	1/2	1/2	1	2	2	3	3	3
C_{11}	1/4	1/3	1/3	1/2	1	1	2	2	2
C_{12}	1/4	1/3	1/3	1/2	1	1	2	2	2
C_{13}	1/5	1/4	1/4	1/3	1/2	1/2	1	1	1
C_{14}	1/5	1/4	1/4	1/3	1/2	1/2	1	1	1
C_{15}	1/5	1/4	1/4	1/3	1/2	1/2	1	1	1

Translate Table 7 ~ Table 9 to standard mathematic matrix, namely, matrix A, matrix B_1 and matrix B_2.

$$A = \begin{bmatrix} 1 & 3 \\ 1/3 & 1 \end{bmatrix}, B1 = \begin{bmatrix} 1 & 2 & 2 & 1/2 & 1 & 4 \\ 1/2 & 1 & 1 & 1/3 & 1/2 & 3 \\ 1/2 & 1 & 1 & 1/3 & 1 & 3 \\ 2 & 3 & 3 & 1 & 2 & 5 \\ 1 & 2 & 2 & 1/2 & 1 & 4 \\ 1/3 & 1/3 & 1/3 & 1/5 & 1/4 & 1 \end{bmatrix}$$

$$B2 = \begin{bmatrix} 1 & 2 & 2 & 3 & 4 & 4 & 5 & 5 & 5 \\ \frac{1}{2} & 1 & 1 & 2 & 3 & 3 & 4 & 4 & 4 \\ \frac{1}{2} & 1 & 1 & 2 & 3 & 3 & 4 & 4 & 4 \\ \frac{1}{3} & \frac{1}{2} & \frac{1}{2} & 1 & 2 & 2 & 3 & 3 & 3 \\ \frac{1}{4} & \frac{1}{3} & \frac{1}{3} & \frac{1}{2} & 1 & 1 & 2 & 2 & 2 \\ \frac{1}{3} & \frac{1}{3} & \frac{1}{3} & \frac{1}{2} & 1 & 1 & 2 & 2 & 2 \\ \frac{1}{5} & \frac{1}{4} & \frac{1}{4} & \frac{1}{3} & \frac{1}{2} & \frac{1}{2} & 1 & 1 & 1 \\ \frac{1}{5} & \frac{1}{4} & \frac{1}{4} & \frac{1}{3} & \frac{1}{2} & \frac{1}{2} & 1 & 1 & 1 \\ \frac{1}{5} & \frac{1}{4} & \frac{1}{4} & \frac{1}{3} & \frac{1}{2} & \frac{1}{2} & 1 & 1 & 1 \end{bmatrix}$$

Then, normalizing each column of every matrix according to Eq (2), the normalized matrix A’, matrix B1’ and matrix B2’ can be calculated.

$$A` = \begin{bmatrix} 0.751 & 0.750 \\ 0.248 & 0.250 \end{bmatrix}, B1` = \begin{bmatrix} 0.188 & 0.214 & 0.214 & 0.174 & 0.174 & 0.200 \\ 0.0938 & 0.107 & 0.107 & 0.116 & 0.0870 & 0.150 \\ 0.0938 & 0.107 & 0.107 & 0.116 & 0.174 & 0.150 \\ 0.375 & 0.321 & 0.321 & 0.349 & 0.348 & 0.250 \\ 0.188 & 0.214 & 0.214 & 0.174 & 0.174 & 0.200 \\ 0.0625 & 0.0357 & 0.0357 & 0.0697 & 0.0435 & 0.0500 \end{bmatrix},$$

$$B2` = \begin{bmatrix} 0.291 & 0.338 & 0.338 & 0.300 & 0.258 & 0.258 & 0.217 & 0.217 & 0.217 \\ 0.146 & 0.169 & 0.169 & 0.200 & 0.194 & 0.194 & 0.174 & 0.174 & 0.174 \\ 0.146 & 0.169 & 0.169 & 0.200 & 0.194 & 0.194 & 0.174 & 0.174 & 0.174 \\ 0.0971 & 0.0845 & 0.0845 & 0.100 & 0.129 & 0.129 & 0.130 & 0.130 & 0.130 \\ 0.0728 & 0.0563 & 0.0563 & 0.0500 & 0.0645 & 0.0645 & 0.0870 & 0.0870 & 0.0870 \\ 0.0728 & 0.0563 & 0.0563 & 0.0500 & 0.0645 & 0.0645 & 0.0870 & 0.0870 & 0.0870 \\ 0.0583 & 0.0423 & 0.0423 & 0.0333 & 0.0323 & 0.0323 & 0.0435 & 0.0435 & 0.0435 \\ 0.0583 & 0.0423 & 0.0423 & 0.0333 & 0.0323 & 0.0323 & 0.0435 & 0.0435 & 0.0435 \\ 0.0583 & 0.0423 & 0.0423 & 0.0333 & 0.0323 & 0.0323 & 0.0435 & 0.0435 & 0.0435 \end{bmatrix}$$

According to the Eq (3), the eigenvector $\overline{W_i}$ of each column in matrix A’, matrix B1’ and matrix B2’ can be calculated. And according to Eq (4), the normalized eigenvector $\overline{W_i}$ and comprehensive weight of every criterion and index can be calculated. The result in this research is shown in Table 10.

Table 10 Comprehensive weight acquired by AHP

Criterion layer	Criterion layer weight (W_{bi})	Index layer	Index layer weight (W_{ci})	Total sequencing weight ($W_n=W_{bi}\times W_{ci}$)	Weight ranking in system
Safety Risk	0.75	C_1	0.194	0.146	2

B_1		C_2	0.110	0.083	4
		C_3	0.125	0.094	3
		C_4	0.327	0.246	1
		C_5	0.194	0.146	2
		C_6	0.050	0.037	7
		C_7	0.271	0.068	5
		C_8	0.177	0.044	6
		C_9	0.177	0.044	6
Value loss		C_{10}	0.113	0.028	8
Risk	0.25	C_{11}	0.069	0.017	9
B_2		C_{12}	0.069	0.017	9
		C_{13}	0.041	0.010	10
		C_{14}	0.041	0.010	10
		C_{15}	0.041	0.010	10

Checking consistency

Avoiding to the inconsistency of the index pairwise in the system, the consistency checking is necessary. Only the C. I and C. R both less than or equal to 0.1, the result above is approved. When the matrix is a second order matrix (scale n=2), its' C.I and C. R both are 0, and the matrix is naturally consistent. According to Eq (5) and Eq (6), the consistency of matrix B_1 and matrix B_2 is checked (Table 11).

Table 11 Consistency checking result

Matrix	C.I	C.R	Consistency
Matrix B_1	0.0518	0.0417	consistent
Matrix B_2	0.0134	0.00924	consistent

Assessing the preserve situation

The weight shows the contribution of each disease makes to the grotto's preserve situation. Here, the authors started to evaluate the grottos' preserve situation. Owing to the various units of 15 diseases, there are no comparability between different diseases, and the disease data cannot be weighted sum. It is necessary for dimensionless process of diseases data to solve the incomparable between different diseases. In this research, equalization method is adopted according to Eq (7).

$$x_i` = \frac{x_i}{\bar{x_i}} \qquad (7)$$

In equation (7), x_i` is the dimensionless processing data, x_i is the initial disease data from Table 3 and Table 4, and $\bar{x_i}$ is average of every column in Table 3 and Table 4. The proceed data are in Table 12 and Table 13.

Tab. 12 Dimensionless processing data of safety risk

No.	Safety risk					
	scaling off	detachment	water disease	body loss	cracks	plant damage
86	1.36	1.22	1.22	0.27	1.00	0.00
211	0.01	0.00	0.00	0.05	0.08	0.00
213	0.21	0.27	0.00	0.14	0.53	0.00
214	0.00	2.44	0.00	1.96	0.58	10.75
400	0.06	1.26	8.10	0.05	1.52	0.00
512	4.59	0.73	1.69	4.34	2.70	0.25
513	0.37	0.00	0.00	2.60	0.45	0.00
535	0.88	3.97	0.00	0.64	2.18	0.00
689	2.26	0.00	0.00	0.64	0.57	0.00
805	0.23	0.76	0.00	0.14	0.98	0.00
806	1.02	0.34	0.00	0.18	0.40	0.00

Tab. 13 Dimensionless processing data of value loss risk

No.	Value loss risk				
	rock powdering	deep loss	salt crystallization	pigment layer peeled	paint layer

	weathering			off	craquelure
86	0.79	0.14	0.44	1.28	2.65
211	0.02	0.00	0.07	0.06	0.00
213	0.30	0.42	0.09	0.53	0.52
214	0.01	0.97	0.00	0.17	0.80
400	1.64	8.08	4.30	0.12	0.10
512	1.97	0.84	3.62	0.89	0.02
513	0.46	0.28	0.00	1.04	0.00
535	1.28	0.14	1.24	2.44	0.15
689	0.78	0.14	0.63	1.98	0.00
805	1.92	0.00	0.52	0.06	5.46
806	1.82	0.00	0.10	2.44	1.30

No.	Value loss risk			
	scratch or graffiti	improper repairing	human pollution	microorganism pollution
86	0.00	0.22	1.52	0.01
211	0.00	0.00	0.39	0.00
213	0.00	1.40	0.38	0.00
214	0.21	0.27	0.00	0.01
400	1.31	0.16	0.69	1.34
512	0.54	6.65	2.86	0.37
513	0.75	0.11	0.33	0.05
535	0.46	1.86	2.26	5.67
689	3.15	0.20	0.84	0.01
805	2.07	0.02	0.94	1.85
806	2.51	0.11	0.79	1.69

Grottos' preserve situation is characterized by the quantity and weight of every disease. So, the grottos' preserve situation can be calculated as Eq (8) below.

$$D = C1 \cdot \eta_1 + C2 \cdot \eta_2 + \cdots + C15 \cdot \eta_{15} \qquad (8)$$

C_1, C_2, C_3…C_{15} is dimensionless processing disease data, and η_1、η_2…η_{15} is the weight of disease. D is grottos' preserve situation. Using the procedure and equations above, the value of preserve situation of 11 grottos can be calculated and result is shown in Table 14.

Table 14 The value of preserve situation of 11 grottos

NO.	86	211	213	214	400	512
Value of preserve situation	0.80	0.03	0.25	1.24	1.81	2.82
NO.	513	535	689	805	806	
Value of preserve situation	0.85	1.26	0.78	0.59	0.57	

Vulnerability assessment

Vulnerability is origin from risk management [18-20]. In this research, the authors define the grotto's risk, which is the possibility of grotto destructed by various factors, including the possibility, and the loss destruction may lead to geological hazard. All the behaviors may lead to safety risk or value loss to grotto and its' surrounding can be treated as risk, and we use risk degree to characterize its' value, and the expression of risk degree is as Eq (9) [5,13].

$$R = H \times V \qquad (9)$$

In equation 9, R means risk degree and H stands for hazard. In this research, hazard, referring to the external causes, may lead to grotto's degradation, such as geologic environment, meteorological environment, biological environment, and these factors does not involve in this research. V is vulnerability, and we define it as the internal causes resulting in the grotto's degradation, including value (E), rock properties (T), preserve situation (D) and management (M). The expression of vulnerability can be expressed as Eq (10) primarily.

$$V = f(E, T, D, M) \qquad (10)$$

In this research, the 11 survey objects are the same time and the position in the cliff is nearby, so the value (E), rock properties (T) and management (M) are similar without further discussion. Only the preserve situation (D) is the crucial factor affecting grotto's vulnerability. Substituting our research result into Eq (10), the vulnerability of the 11 caves in middle Tang dynasty of Guangyuan thousand buddhas grottos can be expressed as Eq (11) primarily.

$$V = f[E, T, (C1 \cdot \eta_1 + C2 \cdot \eta_2 + \cdots + C15 \cdot \eta_{15}), M] \quad (11)$$

Discussion

The result shows 15 diseases make different contribution to grottos' preserve situation, and the descending order by weight in the system is: body loss (C_4), scaling off (C_1), cracks (C_5), water diseases (C_3), detachment (C_2), rock powdering weathering (C_7), deep loss (C_8), salt crystallization (C_9), plant damage (C_6), pigment layer peeled off (C_{10}), paint layer craquelure (C_{11}), scratch or graffiti (C_{12}), improper repairing (C_{13}), human pollution (C_{14}), and microorganism pollution.

According to the analysis, safety risk has more effect on grottos' preserve situation, and value of safety risk weight in the system is 0.75. While value loss risk affects grottos' preserve situation less, effect weight is 0.25. In fact, safety risk in these 11 survey objects often develop fast with a small quantity, which means they are more destructive than other diseases. All of them may directly or indirectly lead to grottos' stability problems. Especially Guangyuan is near to the Longmenshan fault zones, it means once earthquake occurs, the safety risk may result in grottos' destructive damage or disappearance. The physical remains of grottos is the most important physical carrier of value. Value loss risk affects the grotto at a low speed with a long time and distributes widely. In short terms, it will not bring an obvious change to grottos' appearance, but in a long term, this risk may lead to grottos' weathering and value loss even disappearance.

Grottos' vulnerability is a multi-factor, hierarchical structure complex system which involves grottos' value, stone property, existed preserve situation and management. When assessing the grottos' vulnerability, every factor should be considered and the factors are interacted with each other. In this research, we try to explore the vulnerability evaluate mode primarily and under current research condition, the specific expression of the function in equation 10 and 11 is not clear which is for further research.

The AHP method can be used for studying other parameters of grottos' vulnerability or hazard, and this research can offer a useful reference for further study. The grottos' preserve situation assessment mode and vulnerability evaluation mode is still needed to be verified by using other grottos' diseases data. Only keeping adjusting the construction and constitute of matrix in further practice, the assessing indexes and weight can be more reasonable and the evaluation mode can be more reliable. The result can reflect the degree of vulnerability and hazard more effectively, while offering effective evidence for conservation.

There are some deficiencies in this research. One important aspect is geologic environment. Geologic environment plays a crucial role in determining grottos' vulnerability because of most grottos in Sichuan excavated in mountains. In this study, we treat it as the external cause of grottos' degradation, which may lead to dangerous rock mass problem. And then reducing the degree of vulnerability to a certain extent. So, in the future study, it is necessary to research the mode of hazard. Only combining the grottos' vulnerability and hazard, can the risk grottos' facing to be reflected reliably and objectively.

Conclusion

The authors surveyed 11 grottos of middle Tang dynasty in Guangyuan thousand-buddhas grottos in the field to determine the contribution of each disease, making to grottos' preserve situation. By building hierarchical structure and constructing judgement matrix, weight of every disease is calculated, and the preserve situation degree of 11 grottos can be shown in a quantized way. From the result, we can conclude the following:

1. A hierarchical structure of the preserve situation is established: the preserve situation of grotto is defined as goal layer, two categories' risks made up criterion layer, the index layer includes 15 diseases, namely, body loss (C_4), scaling off (C_1), cracks (C_5), water diseases (C_3), detachment (C_2), rock powdering weathering (C_7), deep loss (C_8), salt crystallization (C_9), plant damage (C_6), pigment layer peeled off (C_{10}), paint layer craquelure (C_{11}), scratch or graffiti (C_{12}), improper repairing (C_{13}), human pollution (C_{14}), and microorganism pollution (C_{15}). The weight in the evaluate system is descending order.

2. The preserve situation degree of 11 survey objects is ascended by the order of severity, namely, No.512 (Dayun old cave), No.400 (Central stupa grotto), No.535 (Lotus cave), No.214 (Vairocana Buddha cave), No.513 (Weikang grotto), No.86 (Amitabha grotto), No.689 (Thousand buddha cave), No.805 (Benefactors grotto), No.806 (Shakyamuni and Prabhutaratna grotto), No.213 cave, No.211 (Suting grotto).

3. This research characterizes the preserve situation in a quantized way of 11grottos of middle Tang dynasty in Guangyuan thousand-buhhdas grottos, and explores the vulnerability evaluate mode primarily. The result shows that AHP method can be used for the grottos' preserve situation evaluation, and in the future study, it is necessary to take a consideration of the interaction of each factor.

Abbreviations

AHP: the analytic hierarchy process; C.I: the consistency index; R.I: the random index; C.R: the consistency ratio; H: hazard; R: risk; V: vulnerability; E: value; D: preserve situation; T: stone property; M: management.

Author's contribution

XY and FZ designed the research project; FZ was responsible for investigation and data collection. XY analyzed the data and wrote this publication. All authors read and approved the final manuscript.

Author details

1. Department of Tourism and History Cultural, Southwest Minzu University, Chengdu 610041, Sichuan, People's republic of China. 2. Cultural Relics and Archaeology institute of Sichuan, Chengdu 610041, Sichuan, People's republic of China.

Acknowledgement

The authors would like to thank the Guangyuan Thousand-buddha Grotto Art Museum for their support with this research.

Competing interest

The authors declare that they have no competing interests.

Availability of data and materials

The data used in this research are published in this paper, they are all available from corresponding author on reasonable request.

Funding

This research is supported by “the Fundamental Research Funds for the Central Universities”, Southwest Minzu University (Grant Number: 2020SYBPY08) and National Key R&D Program of China (Grant Number: 2020YFC1522903).

References

1. Su Bai. Chinese grotto study. Cultural relic Press.1998 :1-3. **(in Chinese).**

2. Yu Hua Lei. Preliminary Discussion of partition and stage of Sichuan Grotto. Chengdu Archaeology Study. 2016(00):347-373. **(in Chinese).**

3. Jin Huan Wang, Jia Qi Chen. Current Status and Future Development of Cave Temples Protection in China. Southeast Cultural. 2018 (01): 06-14. **(in Chinese).**

4. Jingke Zhang, Zhen Li, Li Li, Jianhui Liu, Dun Liu & Mingshen Shao. Study on weathering mechanism of sandstone statues in Southwest China: example from the sandstone of Niche of Sakyamuni Entering Nirvana at Dazu Rock Carvings. Nat Hazards (2021).

5. RJ Blong. Some perspectives on geological hazards. Springer Netherlands. 1992.01:23-25.

6. Longqing Shi, Mei Qiu, Chao Teng, Ying Wang, Tianhao Liu， Xingyue Qu. Risk assessment of water inrush to coal seams from underlying aquifer by an innovative combination of the TFN-AHP and TOPSIS techniques. Arab J Geosci 13, 600 (2020).

7. Eskandari, S. A new approach for forest fire risk modeling using fuzzy AHP and GIS in Hyrcanian forests of Iran. Arab J Geosci 10, 190 (2017).

8. Shifa Chen, Wen Liu, Yonghui Bai, Xiaoying Luo, Hangfei Li, Xuan Zha. Evaluation of watershed soil erosion hazard using combination weight and GIS: a case study from eroded soil in

Southern China. Nat Hazards (2021).

9. Long Liang, Adu Gong, Yan Zhong Sun, Yun Hao Chen. Seasonal rainstorm and flood risk assessment method for immovable cultural relics: A case study of national ancient sites in Fujian province. Geomatics and Information Science of Wuhan University. 2020 (01): 1-17. **(in Chinese).**

10. Chuan Ge, Li Qian Zhang. The research of earthquake risk assessment method on Chinese Buddhist cave temples. Architecture and Cultural. 2013 (4)：104-107. **(in Chinese).**

11. Kai Cui, Yumin Du, Yinghui Zhang, Guopeng Wu, Li Yu. An evaluation system for the development of scaling off at earthen sites in arid areas in NW China. Herit Sci 7, 14 (2019).

12. Ren Zhi Liu, Bing Jian Zhang, Hui Zhang, Mei Feng Shi. Deterioration of Yungan Grottos: Diagnosis and research. Journal of Cultural Heritage 12 (2011): 494-499.

13. Yuanhua Luo, Liang Zhang, Yecheng Zhang. Method for risk assessment of geological hazards. Cent Geology. 1998; 8: 123-125. **(in Chinese).**

14. Ling He, Na Wang, Xiang Zhao, Tie Zhou, Yin Xia, Junyan Liang, Bo Rong. Polychromic structures and pigments in Guangyuan thousand-buhhda grotto of Tang dynasty (China). Journal of Archaeological Science 39 (2012):1809-1820.

15. State Administration of Cultural Heritage of People's Republic of China. Classification and legend on the deterioration of ancient stone objects (WW/T 0002-2007). **(in Chinese)**

16. Saaty TL. The analytic hierarchy process: a 1993overview. Cent Eur J Oper Res Econ.1993;2:119-37.

17. Saaty TL. Rank from comparisons and from rating in the analytic hierarchy/ network processes. Eur J Oper Res. 2006; 168:557-70.

18. ICCROM, CCI. A Guide to Risk Management of Cultural Heritage. 2016.

19. Pierfrancesco Fiore, Enrico Sicignano, Giuseppe Donnarumma. An AHP-Based Methodology for the Evaluation and Choice of Integrated Interventions on Historic Buildings. Sustainability 2020, 12.

20. Elena Sesana, Alexandre S. Gagnon, Alessandra Bonazza, John J. Hughes. An integrated approach for assessing the vulnerability of world heritage site to climate change impact. Journal of Cultural Heritage 41(2020): 211-224.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- graphicalabstract.jpg