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Measurement of Conservation Value of Ancient Buildings from the Perspective of Climate Risk Based on the Entropy Weighting Method

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Abstract. Modern society is characterized by high levels of human activity and pollution, triggering numerous extreme weather events. This has resulted in numerous disaster losses, and ancient buildings of conservation value are often damaged by extreme weather. To mitigate the crisis caused by the increasingly severe climate risk to the protection of ancient buildings, this paper will measure the level of exposure of ancient buildings to climate risk this paper constructs a comprehensive evaluation index system that includes eight factors affecting the level of architectural protection from the aspects of history and culture, economic and social, and natural environment. On this basis, the Entropy Weighting Method and Delphi Method are used to establish a Building Conservation Model, and the weights of the subjective and objective factors are combined to prioritize the indicators, and the model is used to help regional leaders determine to what extent measures should be taken to protect buildings. In our model, the USA ranked first with a score of 0.116, followed by China with 0.005. This paper will provide a decision-making basis for the units responsible for the conservation of ancient buildings, and help them to identify and prevent climate risks to ancient buildings.

Keywords: Climate risk level; Conservation of ancient buildings EWM; Delphi.

1. Introduction

In recent years, the frequency of extreme weather events triggered by increased global climate change has posed unprecedented challenges to the safety of human life and property. According to a new report from the United Nations, there has been a "staggering increase" in the number of extreme weather events over the past 20 years. From 2000 to 2019, there have been 7,348 extreme weather disasters globally, resulting in 1.23 million deaths and global economic losses of US$2.97 trillion [1]. The close interrelationship between sustainability and natural disasters is both bidirectional and complex, holding paramount significance within the realm of the economics of natural disasters [2]. Frequent extreme weather events can lead to significant economic losses, especially for the property insurance industry, and this trend has led to a significant increase in insurance claims, with a 115% increase in natural disaster claims in 2022 compared to the average of the past 30 years. With the projected increase in severe weather events, rising insurance costs, and widening insurance coverage gaps, the property insurance industry faces significant challenges.

Existing studies on climate risk and the conservation of ancient buildings provide the basis for our analysis. From the lineage of literature development, one strand of literature focuses on the impact of climate risk. Climate risk has a significant impact on the global economy. Burke et al. point out that global warming has an inverted U-shape effect on economic output [3], and that continued deterioration of the climate will lead to a sharp 23% reduction in global GDP by the end of the century, accompanied by regional variability. Climate risk can increase loan and bond defaults and investment losses in the short term, thereby affecting financial institutions' operations and causing capital losses [4]. Climate risk can cause damage to production and supply chains and result in damage to corporate assets, increasing the risk of corporate default and raising the cost of corporate finance [5]. Another strand of literature has focused on the preservation of ancient buildings. Most of the literature talks about the many aspects of the conservation of ancient buildings [6], such as the aging of building materials [7] and the ability of buildings to resist fire [8]. There are also numerous references to measures for the application of science and technology in the conservation of ancient buildings [9]. There are also numerous literatures mentioning the application measures of science and technology in the conservation of ancient buildings [10], such as the use of 3D printing technology for the restoration of cultural relics [11], and the use of BIM technology for the repair of ancient buildings [12].

Although the existing literature has been very rich in the field of climate risk and ancient building conservation, few scholars have been able to combine the two and consider the problems and difficulties faced by ancient building conservation from the perspective of climate risk. Most scholars only consider the conservation value of ancient buildings from the perspective of the buildings themselves [13], but not from the perspective of the geographic location of the ancient buildings and the climate risk they face. In addition, most of the literature is based on the micro perspective, with only one ancient building as an example to analyze, but not from the overall macro point of view to consider the problems faced by ancient buildings worldwide and the measures to deal with them. This paper combines the two to examine the conservation value of ancient buildings around the world in the face of climate risk from a macro perspective.

2. Building protection rating based on the entropy power method

2.1. Indices Definition

We searched for relevant studies and evaluated relevant articles to create a logical methodology for assessing historic structure conservation in each country. We choose to consider history and culture, economy and society, and environmental protection. We then chose supplementary indicators for each variable to improve model precision. The entropy weight method (EWM) and Delphi were used to determine indication importance.

According to Purvis, B. and Mao, Y. (2019), “the three-pillar conception of (social, economic and environmental) sustainability has become ubiquitous” [14]. To enhance the accuracy of our model, we selected eight crucial and illustrative factors that encompass three distinct dimensions: historical and cultural, economic and social, and environmental preservation. Through a thorough examination of the literature, we initially discovered the advantages of these indicators in relation to the preservation worth of structures. These indicators include factors that reflect the conservation value of the building itself, as well as indicators that reflect the state of the local environment to consider its exposure to climate risk. Carbon dioxide emissions are often considered the most important indicator of climate risk. Table 1 provides a comprehensive discussion of these indicators.

Table 1. The variants of 3 dimensions

Dimension	Variant	Symbol	Effect
History and culture	Per capita expenditure on cultural and natural heritage	*ECN*	+
	History museums per million population	*HM*	+
Economic society	GDP per capita	*GDP*	+
	Population density	*Density*	-
	Industrial structure (Value added of secondary industry as a share of gdp)	*Industry*	-
	Green Technology Innovation (Number of patents for green inventions)	*Invent*	+
Environment	Carbon dioxide emissions	*CO2*	-
	Environmental regulation	*ER*	+

The "+" symbol in the Table 1 denotes a benefit-type index, with higher values being better. The symbol "-" represents a cost-type index, where a lower number is better.

To build our model, we gathered data from a total of 37 countries, encompassing both developed and developing nations.

$$Y_{mn}=\begin{pmatrix} y_{1,1} & \cdots & y_{1,8} \\ \vdots & \ddots & \vdots \\ y_{37,1} & \cdots & y_{37,8} \end{pmatrix} \tag{1}$$

Where $y_{i,j}$ represents the value of the jth variable for the ith country.

2.2. Data Normalization

To standardize the acquired data, we choose to normalize it by transforming all values to a range between 0 and 1, so achieving data harmonization.

The data were normalized for the positive indicators using the following methods:

$$y_{ij}^{*}=\frac{y_{ij}-\min\{y_{1j},\cdots,y_{nj}\}}{\max\{y_{1j},\cdots,y_{nj}\}-\min\{y_{1j},\cdots,y_{nj}\}} \tag{2}$$

The data normalization method for negative indicators is:

$$y_{ij}^{*}=\frac{\max\{y_{1j},\cdots,y_{nj}\}-y_{ij}}{\max\{y_{1j},\cdots,y_{nj}\}-\min\{y_{1j},\cdots,y_{nj}\}} \tag{3}$$

2.3. Weight Calculation

Note that different indices affect their dimensions, which affect the model's evaluation. To avoid subjective bias, we compute the weight using the Entropy Weight Method (EWM).

Weighting values with the Entropy Weight Method (EWM) is a common way to assess decision-making spread. This statement assumes that dispersion increases differentiation and information extraction. Thus, the index should be prioritized. This method calculates second-level indicator weights.

Seeing each dimension, for the country i and index j, the weight of it is named q_{ij}, calculated as the following:

$$q_{ij}=\frac{y_{ij}}{\sum_{i=1}^{m} y_{ij}} \tag{4}$$

Where m represents the amount of the country we selected for calculation.

Meanwhile, the function of information entropy, M_j, is calculated as the following:

$$M_j=-\frac{1}{\ln m}\sum_{i=1}^{m} q_{ij}\ln q_{ij} \tag{5}$$

Because of the content above, we finally attain the weight of index j in each dimension, N_j, calculated as the following:

$$N_j = \frac{1 - M_j}{\sum_{j=1}^{n} \left(1 - M_j\right)} \tag{6}$$

Subsequently, the weights of 8 comprehensive evaluation indicators can be calculated by the entropy weight method. Based on these calculated weights, we have:

$$\begin{cases} History\_and\_culture = N_1 \cdot ECN + N_2 \cdot HM \\ Economic\_society = N_3 \cdot GDP + N_4 \cdot Density + N_5 \cdot Industry + N_6 \cdot Invent \\ Environment = N_7 \cdot CO_2 + N_8 \cdot ER \end{cases} \tag{7}$$

The Delphi technique [15], referred to as the expert scoring method, is extensively utilized in the domains of decision-making and systems analysis. The system gathers expert opinions anonymously and uses information communication and feedback to align and bring them closer to the actual values.

When it comes to assigning weights based on the intents of decision-makers, the Delphi method is more advantageous than the entropy weighing method. However, it is also less objective and more subjective. Although the entropy weighting approach has an objective benefit, it does not capture the participation Thus, when weighting indicators, one should consider statistical laws and authority values in indicator data. To minimize the disadvantages of a single assignment, decision-making indicators should be weighted using a combination of Delphi and entropy weighting techniques. Combination assignment is the weighting that combines the two assignment systems. The subject-object combination weights W_j are:

$$W_j = \frac{\sqrt{\alpha_j \beta_j}}{\sum_{j=1}^{n} \sqrt{\alpha_j \beta_j}} \tag{8}$$

Where, α_j represents the weights derived from the entropy weighting method and β_j represents the weights derived from the Delphi method.

3. Results

3.1. The establishment of simulation model

By using MATLAB, we get the final weight by EWM of the three dimensions are shown as the following.

$$N = \left[N_1, \cdots N_8\right] = \left[0.1239, 0.1227, 0.1225, 0.1287, 0.1210, 0.1293, 0.1302, 0.1217\right] \tag{9}$$

To see the weight more clearly, we first make Table 2 showing the proportion of each index in every dimension.

Table 2. Entropy weights for building conservation system

Model	Indicators (I)	Weight	Indicators (II)	Weight
Building Conservation Model	History and culture	0.2466	*ECN*	0.1239
			HM	0.1227
	Economic society	0.5015	*GDP*	0.1225
			Density	0.1287
			Industry	0.1210
			Invent	0.1293
	Environment	0.2519	*CO2*	0.1302
			ER	0.1217

Based on the provided Table 2, it is evident that the variable ECN carries more significance in the historical and cultural aspect, the variable Invent holds larger importance in the economic and social aspect, and the variable CO2 has a higher level of significance in the environmental protection aspect. It is reasonable to assume that an increase in per capita expenditure on natural heritage culture will significantly increase the level of protection and awareness of the local people towards the conservation of ancient buildings. The reason why the level of technology plays a greater role in the preservation of ancient buildings in the economic and social neighborhood is that we need more advanced technology to carry out restoration work on ancient buildings. Carbon dioxide is a measure of climate risk, and the higher the carbon dioxide emissions, the higher the climate risk. Next, we display the radar chart in Figure 1 to enhance the visibility of the weights.

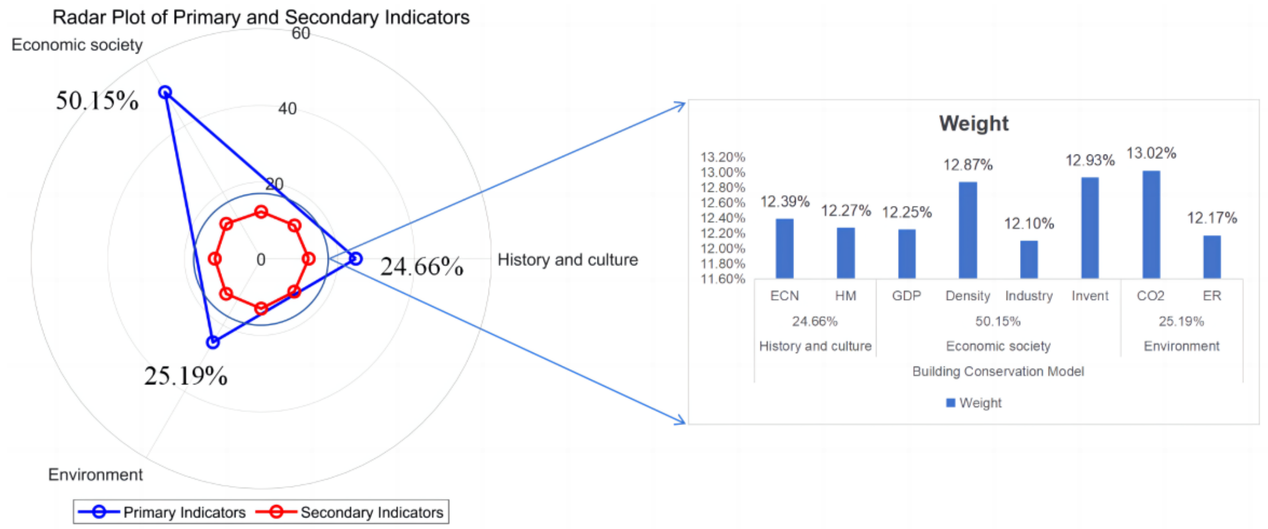

Figure 1. Weight for 3 dimensions

The thesis team sent questionnaires to university students, international students, professors specializing in ancient architecture, and other professionals in the field. The decided indicators were dispersed through these surveys. Subsequently, the subjective weights were obtained by organizing and calculating the collected data. The specific weighting data for each variable is shown in Table 3.

Table 3. Delphi weights for building conservation system

Variant	*ECN*	*HM*	*GDP*	*Density*	*Industry*	*Invent*	*CO2*	*ER*
Delphi Weight	0.12	0.13	0.11	0.14	0.16	0.13	0.07	0.14

Based on the construction process of the entropy weighting method model described above, it is calculated that the final weights of the indicators combined in the model for the conservation of ancient buildings are shown in Table 4.

Table 4. Final weights for building conservation system

Variant	*ECN*	*HM*	*GDP*	*Density*	*Industry*	*Invent*	*CO2*	*ER*
Final weights	0.1228	0.1271	0.1169	0.1351	0.1401	0.1305	0.0961	0.1314

Ultimately, we developed a complete assessment criterion for quantifying the historical and cultural, economic and social, and environmental conservation aspects of a nation's system for preserving ancient buildings. The formula will help in measuring the conservation value of ancient buildings by considering climate risks. This criterion is determined using the following formula (Standardization converts negative indicators into positive ones, and the composite assessment value is produced by cumulatively multiplying direct weights by converted indicator values.):

$$\begin{aligned} & BuildingConservationValue = 0.1228ECN + 0.1271HM + 0.1169GDP \\ & +0.1351Density + 0.1401Industry + 0.1305Invent + 0.0961CO_2 + 0.1314ER \end{aligned} \tag{10}$$

3.2. Analysis of experimental results

We have completed the building conservation system model and applied it to 37 countries for which we collected data, Substituting the data into the model and solving it, the conservation value of the ancient buildings in a certain place under the consideration of climate risk can be obtained. In Figure 2 we show the collected conservation values of ancient buildings in 37 major countries and rank them from high to low, thus giving a clear picture of the global distribution of national conservation values of ancient buildings. In addition, we have analyzed the value of their building and show specific results for the top ten versus the bottom ten of them in Table 5, and the results are visualized in Figure 3. In the following analysis, we will try to analyze the plausibility of the model results through the conservation values of ancient buildings between each country and the characteristics of that country.

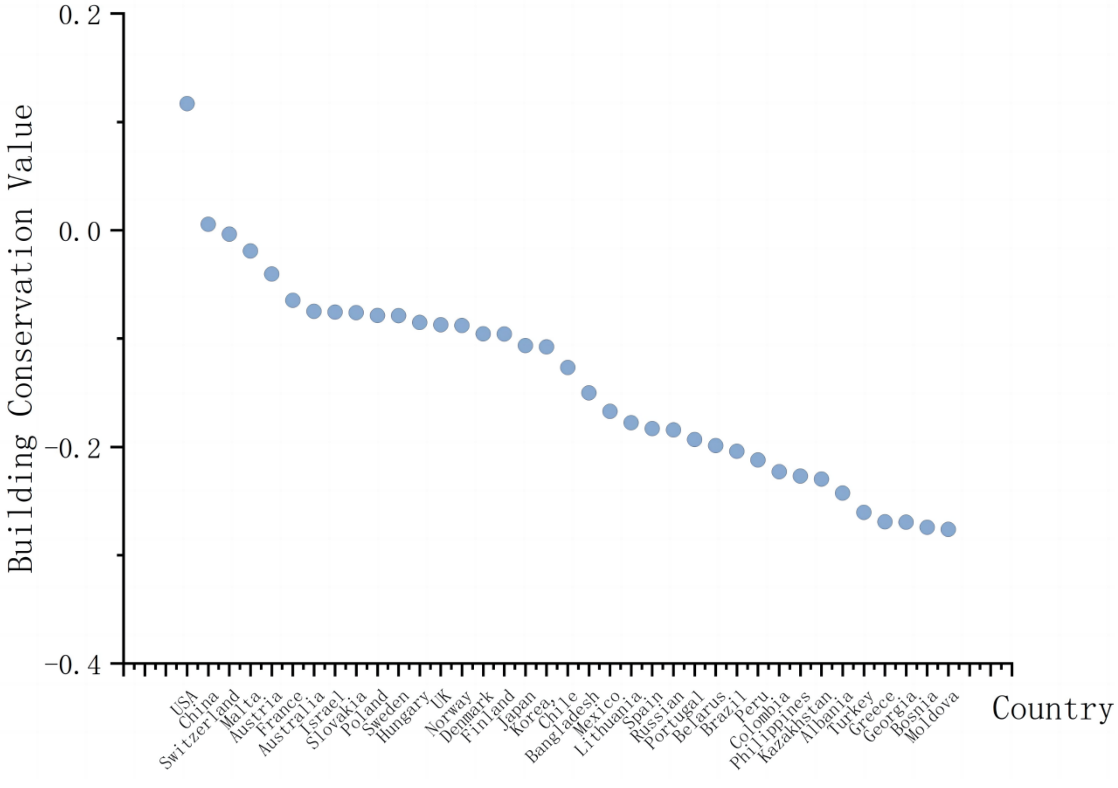

Figure 2. Bubble chart of all country scores

Table 5. Assessment of the conservation value of ancient buildings in selected countries

Top 10 countries	Score	Bottom 10 countries	Score Index
USA	0.116886279	Belarus	-0.198749013
China	0.005479004	Brazil	-0.20408385
Switzerland	-0.003595726	Peru	-0.212086469
Malta	-0.019133961	Colombia	-0.222980794
Austria	-0.040393476	Philippines	-0.226866559
France	-0.064700801	Kazakhstan	-0.22970888
Australia	-0.074907466	Albania	-0.242623168
Israel	-0.075481223	Turkey	-0.260428151
Slovakia	-0.076027139	Greece	-0.269250306
Poland	-0.078717358	Georgia	-0.269626192

According to the data provided, the United States obtained the highest ranking in our approach for evaluating the conservation value of ancient buildings. China, Switzerland, Malaysia, Austria, and France followed in that order. The remaining three countries or areas with the lowest scores are Moldova (with the lowest score), Bosnia and Herzegovina, and Georgia.

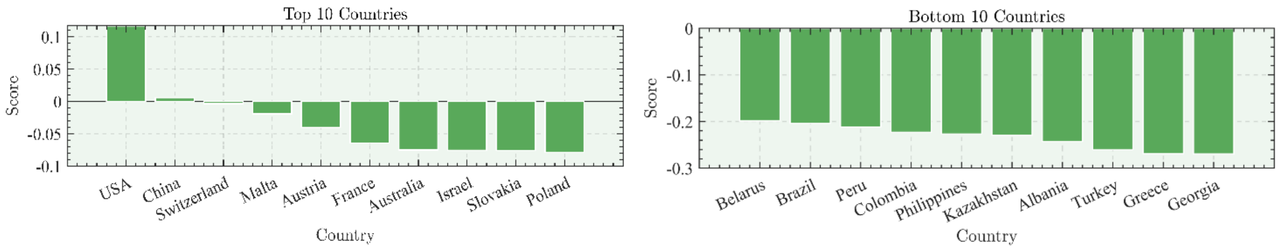

Figure 3. Score schematic

Using the ranking of countries in the model for evaluating the preservation worth of historic structures, we may conduct the subsequent analysis:

(1) The United States and China possess superior scores. The United States demonstrates a significant level of per capita spending on cultural heritage (ECN) and green technology innovation (Invent), suggesting a substantial investment in the preservation of cultural heritage and the advancement of environmental technology. China, despite its dense population, has made notable advancements in green technology innovation and has made substantial progress in environmental legislation and cultural heritage preservation in recent times [16].

(2) Countries with the highest rankings. Despite certain negative effects on certain indicators like Population Density, countries such as Switzerland, Malta, and Austria demonstrate superior performance in Environmental Regulation (ER) and GDP per capita (GDP). This suggests that they possess adequate economic power and strict policies to safeguard ancient structures. Conversely, countries like France and Australia possess abundant historical and cultural assets, and likely allocate a higher amount of money per person towards preserving cultural heritage (ECN), in addition to having a greater number of history museums (HM).

(3) Countries of lower rank. Belarus, Brazil, and Peru received low marks due to industrial structures damaging historic architecture or insufficient environmental laws. Historic structures may be threatened by high population density in Colombia and the Philippines. The low scores given to Colombia, the Philippines, Kazakhstan, and Albania may indicate their serious environmental issues, particularly CO_2 emissions, and their inadequate resource allocation for environmental conservation and cultural preservation.

(4) Countries with notably low scores, such as Georgia, Bosnia and Herzegovina, and Moldova, face various challenges across multiple indicators. These challenges are particularly evident in cases where

the economic power, as measured by GDP, is inadequate to support the preservation of cultural heritage. Additionally, the neglect of ancient buildings during the process of industrialization exacerbates these challenges.

4. Conclusions and Outlooks

In this paper, a combined assignment model (entropy weight method and Delphi method) is used to determine the value of building protection within a country, region, or community. Our model inherits the advantages of EWM and Delphi. In the old-fashioned architectural conservation model, we use the combined subjective and objective empowerment method (SOEM), which combines the model's subjectivity with the objectivity of the model. The weights and final calculation results determine the priority of each indicator and the ranking of the relevant countries, which is used to guide ancient building protection. The governments can develop and enforce strict building standards to improve climate resilience and adaptability, offering tax incentives and subsidies for sustainable construction materials and technology. Besides, governments should identify, register, and protect cultural and historical buildings, creating regulations and funding to restore and maintain them.

There are some shortcomings in this paper. Possibility of missing variables: Due to the problem of data availability, the comprehensive index assessment model in this study does not include all variables related to the objectives, so some key variables may be missed, resulting in the possibility of a slight bias in the model's calculation results. The generalizability of the model needs to be further studied: Due to the scarcity of city data, the modeling uses national-level data. The generalizability of the model may vary from the national level to the city level. Some countries with small land areas or geographic locations that do not have significant climatic differences may be better suited, while some countries with large land areas and significant climatic differences within a country may not be as well suited.

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