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Unveiling the Influencing Factors of the Residual Life of Historical Buildings: A Study of the Wuhan Lutheran Missions Home and Agency Building

Bo Huang [1,2], Xueqi Liu [2], Lanjun Liu [2,3,*], Zhiyong Li [2], Zhifeng Wu [3,4], Bin Huang [1,2] and Zimo Jia [5]

[1] Sanya Science and Education Innovation Park, Wuhan University of Technology, Sanya 572025, China; bohuang@whut.edu.cn (B.H.)
[2] School of Civil Engineering and Architecture, Wuhan University of Technology, Wuhan 430070, China
[3] School of Civil Engineering and Architecture, Wuhan Institute of Technology, Wuhan 430074, China
[4] School of Civil and Hydraulic Engineering, Huazhong University of Science and Technology, Wuhan 430074, China
[5] School of Economics, Southwest Minzu University, Chengdu 610041, China
* Correspondence: llj11090101@wit.edu.cn

Abstract: The development of a city needs the accumulation of culture, and historical buildings are the most direct witness of the rise and fall of a city. Like the human body, historical buildings have a certain life cycle, but the acceleration of urbanization and unreasonable use cause an irreversible reduction in the residual life of historical buildings. There is a notable lack of quantitative analysis regarding the residual life of historical buildings. Therefore, identifying the factors that influence their residual life is crucial for both preserving these buildings and sustaining urban culture. In order to obtain a more accurate correlation degree of influencing factors, a systematic-analysis model of influencing factors on the residual life of historical buildings based on the entropy weight method (EWM) and the grey relation analysis method (GRA) was established, so as to excavate the mechanism of the influencing factors on the residual life of historical buildings, accurately identify the main influencing factors on the residual life of historical buildings, and propose preventive measures. The results show that the structural system has the greatest influence on the residual life of historical buildings, followed by the enclosure system, and the equipment system. The research findings offer valuable insights for extending the residual life of historical buildings in the future.

Keywords: historical buildings; EWM-GRA model; residual life; disaster prevention management; resilience

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1. Introduction

The basis for the formation of a city's style and characteristics is its degree of cultural accumulation. The more accumulation of historical and cultural buildings, the higher the value of the city [1,2]. Each city has different experiences, and history has shaped their personalities and styles differently. Therefore, the cultural characteristics of each historical stage reflected in the architecture are also different. Historical buildings are a vivid carrier of historical and cultural development, a concrete manifestation of the characteristics of urban style and characteristics, and a non-renewable and precious cultural resource [3–8]. The preservation of historical buildings demonstrates the continuity of a city's culture [9,10]. Effectively strengthening the protection of historical buildings is an important part of the protection of urban historical and cultural heritage.

Buildings can be likened to human bodies: their windows are like mouths, pipelines function as blood vessels, exterior walls act as skin, beams and columns resemble bones, and foundations serve as feet [11–15]. From the moment they are constructed, buildings take on form, appearance, and purpose, much like humans. Historical buildings also follow a life cycle, evolving over time [16–23]. However, the rapid urbanization and development of cities have significantly impacted these structures. Environmental deterioration and improper usage have led to varying degrees of damage to many historic buildings, shortening their lifespan [24]. As a result, in-depth research into the factors influencing the longevity of historical buildings is essential.

Prolonging the lifespan of historical buildings is crucial for both their protection and reuse, as well as for the preservation of urban culture [25,26]. This paper uses the Wuhan Lutheran Missions Home and Agency Building as a case study, employing the entropy weight method and grey relation analysis to thoroughly examine the factors influencing the residual life of historical buildings [27–30]. The aim is to identify key issues affecting their longevity and propose targeted recommendations for improving the protection of historical buildings [31–35]. These insights contribute to advancing research in the field of historical building protection.

The process of calculating weights by the EWM requires determining the amount of information covered by each value, avoiding the non-objectivity brought by expert review. The calculation results are highly accurate and can explain the results more closely. It is an objective weighting method. The grey correlation analysis method originated from grey system theory. It analyzes the degree of correlation between all perceived factors, that is, the consistency of the development trends between various factors, so as to find out the main factors. The grey correlation degree can be used to measure the degree of proximity between different factors, that is, the correlation. The larger the grey correlation degree, the closer the two are. The grey correlation analysis method is not only a mathematical analysis tool, but also a new method for system research.

Rizal Taufiq Fauzi [36] used the attribution method and the result method to analyze the life cycle and life cycle cost of buildings, respectively, but did not analyze the influencing factors. Darya Gachkar [37] used artificial intelligence methods to evaluate the life cycle of buildings, which can achieve accurate predictions, but requires sufficient data. This paper proposes a decision-making model based on the combination of the EWM and GRA methods to analyze the influencing factors of the residual life of historical buildings, avoiding the problems encountered in previous studies. The EWM is used to reasonably determine the relative importance of each evaluation index, that is, the weight. The GRA method compares the data of each relationship index with the optimal reference sequence to obtain the relationship level of each influencing factor. It not only scientifically handles the fuzzy problem of subjective judgment of index weight in the quantification process but also takes the optimal grey correlation between the influencing factors and the reference sequence as the starting point, thereby providing a good decision-making basis.

This study focuses on the factors influencing the residual life of historical buildings. The data of 12 indicators affecting the residual life of historical buildings are sorted out, and the index system of factors affecting the residual life of historical buildings is determined. The EWM and GRA are used as the analysis methods of factors affecting the residual life of historical buildings to achieve a longitudinal comprehensive analysis [38]. Taking the Wuhan Lutheran Missions Home and Agency Building as the research object, the factors affecting the residual life of historical buildings are deeply explored [39–41]. Firstly, the EWM can calculate the indicators' weight of influencing factors affecting the residual life of historical buildings to find out the factors with a greater influence. Secondly, the ranking of factors affecting the residual life of historical buildings is calculated by the grey relation

analysis model; according to the results, the important indicators are specifically analyzed, as shown in Figure 1.

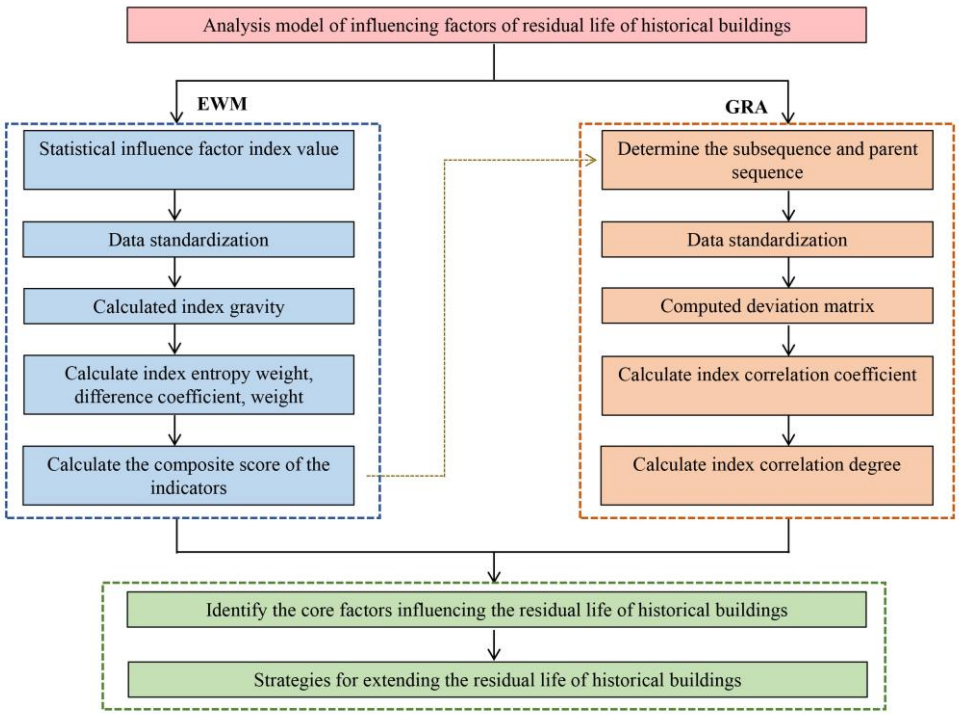


Figure 1. Analysis framework of factors affecting the residual life of historical buildings.

2. Methodology

The EWM can accurately evaluate the contribution of each indicator to the result by calculating the entropy value and the weight of the influencing factors on the residual life of historical buildings [42,43]. The grey relation analysis method is used to establish a model, analyze the correlation between factors, find the factors that have the greatest impact on the decision results, and adjust the decision-making strategy over time to deal with uncertainty and changes. The introduction of the EWM and GRA can help historical buildings identify, evaluate, and optimize the correlation of various factors, so as to manage historical buildings more reasonably [44].

2.1. Entropy Weight Method

The EWM determines the weight of known data according to the degree of discreteness of the indicator [45]. The determination of weights in traditional evaluation methods is highly subjective, while the EWM can effectively avoid the interference of subjective factors and greatly improve the objectivity of the evaluation results.

Select the data related to the factors affecting the residual life of historical buildings [46], and construct the indicator matrix:

(1) The relevant data of factors affecting the residual life of historical buildings are selected to construct the original data matrix with m evaluation indicators and n evaluation objects as follows:

$$X_{ij} = (X_{ij})_{mn} = \begin{matrix} X_{11} & \cdots & X_{1n} \\ \vdots & \cdots & \vdots \\ X_{m1} & \cdots & X_{mn} \end{matrix} \quad (1)$$

X_{ij} (i = 1, 2, 3, . . ., m, j = 1, 2, 3, . . ., n) represents the value of the j-th evaluation object on the i-th evaluation index.

Since the original data have different dimensions and orders of magnitude, the extreme value method can be used to normalize the original data matrix X to eliminate errors and obtain the standardized matrix $X' = (X'_{ij})_{mn}$ [47]. In Formulae (2) and (3), $MaxX_{ij}$ and $MinX_{ij}$ represent the maximum and minimum values of the sequence, respectively.

When the indicator is a positive indicator, its standardized formula is:

$$X'_{ij} = \frac{X_{ij} - MinX_{ij}}{MaxX_{ij} - MinX_{ij}} \ (i = 1,\ 2, \cdots, m, j = 1, 2, \cdots, n) \tag{2}$$

When the indicator is a reverse indicator, its standardized formula is:

$$X'_{ij} = \frac{MaxX_{ij} - X_{ij}}{MaxX_{ij} - MinX_{ij}} \ (i = 1,\ 2, \cdots, m, j = 1, 2, \cdots, n) \tag{3}$$

When the indicator is a moderate indicator, its standardized formula is:

$$X'_{ij} = 1 - \frac{\left| x_{ij - d_{best}} \right|}{\max \left| x_{ij} - d_{best} \right|} \tag{4}$$

where d_{best} is the determined standard value.

Calculate the proportion of the j-th eigenvalue X_{ij} to the eigenvalue of all sample data P_{ij} under the i-th indicator, as shown in Formula (5):

$$P_{ij} = \frac{X_{ij}}{\sum_{i=1}^{n} X_{ij}} (i = 1,\ 2, \cdots, m, j = 1, 2, \cdots, n) \tag{5}$$

Calculate the information entropy value e_j of the j-th eigenvalue of all n samples, as shown in Formula (6):

$$e_j = \frac{1}{In_n} \sum_{i=1}^{n} P_{ij} In P_{ij},\ (i = 1,\ 2, \cdots, m, j = 1, 2, \cdots, n),\ 0 \leq e_j \leq 1 \tag{6}$$

Calculate the redundancy d_j of the information entropy value of the j-th eigenvalue, as shown in Formula (7)

$$d_j = 1 - e_j,\ (j = 1,\ 2, \cdots\ n) \tag{7}$$

Calculate the weight value W_j of the j-th eigenvalue, as shown in Formula (8):

$$w_j = \frac{j}{\sum_{j=1}^{m} d_j},\ (j = 1,\ 2,\ \cdots,\ n) \tag{8}$$

2.2. Grey Relation Analysis Method

Grey relation analysis is a multi-factor statistical analysis method, that is, a specific project is affected by multiple factors. During the analysis, the relation degree is judged by the change trend of each factor [48]. During the analysis process, it is necessary to establish a reference series and a comparison series to solve the degree of relation between the two. The advantage of this method over traditional analysis methods is that it can be applied even if the data have no regularity.

2.2.1. Determine the Parent Sequence and the Influencing Factor Sub-Sequence

The parent sequence is referred to as the reference sequence, while the child sequence is referred to as the comparison sequence. Select relevant data for classification, use the most representative data as reference data, and other data as comparison data:

$$\text{Set reference sequence: } Y_i = \{y_i(1), y_i(2), \ldots, y_i(\mathrm{k})\} \tag{9}$$

$$\text{Set the comparison sequence: } X_i = \{x_i(1), x_i(2), \ldots, x_i(k)\}(k = 1, 2, \ldots, \mathrm{m}, i = 1, 2, \ldots, \mathrm{n}) \tag{10}$$

If a real number is given and if the real number satisfies certain norms and approximations, then it is the grey correlation degree between Y_i and X_i, and it is the correlation coefficient between Y_i and X_i at point k. In grey theory, there are no two completely independent sequences, that is, any two sequences have a greater or lesser correlation.

2.2.2. Data Preprocessing

Due to the inherent differences in the properties of each influencing factor, the data may be inconsistent in its magnitude. To ensure that all factors are comparable during numerical analysis, it is necessary to make them dimensionless [48]. This process, commonly referred to as normalization in data processing, reduces the disparity in absolute values, bringing them into a common range. It then allows for a focus on their relative changes and trends. Basic definition sequence Formulae (11)–(13) for dimensionalization are as follows:

$$X_i = x_i(1), x_i(2) \ldots \ldots x_i(\mathrm{n}) \tag{11}$$

$$f : x_i \to y_i \tag{12}$$

$$f(x_i(k)) = \mathrm{y_i}(k), k = 1, 2 \ldots \mathrm{n} \tag{13}$$

Formulae (11)–(13) are transformations of the original data, where $x_i(k)$ represents the original data value and $y_i(k)$ represents the standardized value.

For initialization, f is the initialization transformation, as shown in Formula (14) for details. Divide all data by the first value of the sequence to obtain a new matrix. This method is suitable for averaging data that is steadily increasing or decreasing.

$$f(x_i(k)) = \frac{x_i(k)}{x_i(1)} = y_i(k), \ \ (k = 1, 2 \ldots \ldots n) \tag{14}$$

where $x_i(k)$ represents the original data and $x_{\mathrm{i}}(1) \neq 0$.

When using averaging, the main purpose is to average the values, where f is the mean transformation, as shown in Formula (15) for details. That is, each number in the sequence matrix is divided by the matrix obtained by the average value of all elements of the matrix. This method is suitable for data without obvious upward and downward trends and can effectively eliminate unit differences, such as:

$$f(x_i(k)) = \frac{x_i(k)}{\overline{x_i}} = y_i(k), \ \ \overline{x_i} = \frac{1}{n}\sum_{i=1}^{n} x_i(k) \tag{15}$$

where $\overline{x_i}$ represents the mean value of the factor sequence. Its meaning is the multiple of the mean value, and the mean value is usually for all numbers greater than 0.

For percentage transformation, f is a percentage transformation, which is transformed into a number less than 1. It analyzes the direct proportional relationship between the original data and the reference data. It is suitable for emphasizing the comparative rela-

tionship with the reference sequence in grey relational analysis. As shown in Formula (16) for details.

$$f(x_i(k)) = \frac{x_i(k)}{maxx_i(k)} = y_i(k) \tag{16}$$

where max$x_i(k)$ is the maximum value of the sequence.

In multiple transformation, f is a percentage transformation, which is transformed into a number greater than 1. Details are shown in Formula (17) as follows:

$$f(x_i(k)) = \frac{x_i(k)}{\underset{k}{minx_i(k)}} = y_i(k) \tag{17}$$

where min$x_i(k)$ is the minimum value of the sequence and $\underset{k}{minx_i(k)} \neq 0$.

For normalization transformation, f is the normalization transformation, as shown in Formula (18) for details. Normalization is to scale the data to a value between 0 and 1. This method can also eliminate the directional influence of the data and the origin while maintaining the consistency of the data size.

$$f(x_i(k)) = \frac{x_i(k)}{x_0} = y_i(k) \tag{18}$$

It should be noted that $x_0 > 0$.

In maximum range transformation, f is the maximum value of the range transformation, which is suitable for processing positive and negative indicators and can unify the data into the range of [0,1] for an easy comparison. As shown in Formula (19) for details:

$$f(x_i(k)) = \frac{x_i(k) - \underset{k}{minx_i(k)}}{\underset{k}{maxx_i(k)}} = y_i(k) \tag{19}$$

where $x_i(k)$ is the original data, min$x_i(k)$ is the minimum value of the sequence, and max$x_i(k)$ is the maximum value of the sequence.

The interval value transformation is applicable when data needs to be normalized to an arbitrary interval such as $[-1, 1]$, as shown in Formula (20).

$$f(x_i(k)) = \frac{x_i(k) - \underset{k}{minx_i(k)}}{\underset{k}{maxx_i(k)} - \underset{k}{minx_i(k)}} = y_i(k) \tag{20}$$

Among them, $minx_i(k)$ is the minimum value of the sequence, and $maxx_i(k)$ is the maximum value of the sequence.

2.2.3. Calculate the Correlation Coefficient

The calculation of the correlation coefficient is shown in formula (21).

$$\varepsilon_i(k) = \frac{min_i min_k |y_i(k) - x_i(k)| + \rho \times max_i max_k |y_i(k) - x_i(k)|}{|y_i(k) - x_i(k)| + \rho \times max_i max_k |y_i(k) - x_i(k)|} \tag{21}$$

$|\, y_{\mathrm{i}}(\mathrm{k}) - x_{\mathrm{i}}(\mathrm{k}) \,|$ represents the absolute difference between the k-th index of the reference sequence and the comparison sequence, $min_i min_k |y_i(k) - x_i(k)|$ is the minimum value, and $max_i max_k |y_i(k) - x_i(k)|$ is the maximum value. The minimum value means the minimum value among all "rows + columns", and the maximum value means the maximum value among all "rows + columns".

The resolution coefficient ρ lies within the range (0,∞), where a smaller value of ρ indicates greater resolution. Typically, ρ is considered within the range (0,1), with its

specific value determined based on the context. In general, when $\rho \leq 0.5463$, the resolution is optimal. A common choice is $\rho = 0.5$.

In the case of a fixed range, that is, when the value of i is fixed, the global maximum and minimum values are used as the value range of the denominator. The obtained correlation coefficient $\xi_i(k)$ is shown in Formula (19), and its mapping is shown in Formula (22).

$$\xi_i(k) = \frac{min_i min_const + \rho \times max_i max_const}{|y_i(k) - x_i(k)| + \rho \times max_i max_const} \tag{22}$$

The fixed range formula is suitable for comparing the correlation between different series because it takes into account the global scope of all data.

In the case of an unfixed range, i when the value of i is not fixed, the maximum and minimum values of the denominator are based only on the range of the current sequence i. The mapping of the obtained correlation coefficient $\xi_i(k)$ is shown in Formula (23).

$$\xi_i(k) = \frac{min_k_const + \rho \times max_const}{|y_i(k) - x_i(k)| + \rho \times max_const} \tag{23}$$

The non-fixed range formula is more suitable for the correlation analysis between indicators within a single series because it only focuses on the range of the current series.

In Formulae (20) and (21), "min_const" and "max_const", respectively, represent the minimum and maximum absolute differences between the k-th index of the reference sequence and the comparison sequence.

2.2.4. Calculate the Correlation

The weighted average of the correlation coefficients between each indicator and the corresponding elements of the reference sequence is calculated to reflect the correlation between each influencing factor and the reference sequence, which is called the correlation degree. The specific correlation degree is shown in Formula (24) as follows:

$$R_{0i} = \frac{1}{m}\sum_{k=1}^{m} \xi_i(k) \tag{24}$$

where R_{0i} is the correlation degree and $\xi_i(k)$ is the correlation coefficient between the reference sequence and the comparison sequence. The addition of weights can obtain the effects of each indicator, as shown in Formula (25):

$$R'_{0i} = \frac{1}{m}\sum_{k=1}^{m} w_k \xi_i(k), (k = 1 \ldots, \mathrm{m}) \tag{25}$$

where W_k is the weight of the k-th data and R'_{0i} is the grey correlation degree of the i-th influencing factor on the evaluation object.

3. Empirical Research

3.1. Study Area

The Wuhan Lutheran Missions Home and Agency Building, constructed in 1923, is an example of classical architecture. Located at No. 77 Dongting Street, Jiang'an District, Wuhan, Hubei Province, it was designed by the German Shiges Architecture Office and built by the Han Xiesheng Construction Factory. The church features a three-stage layout, originally consisting of four stories, with two additional floors added later. The building was a collaborative project between the American and Swedish Methodist Churches and the Lutheran Churches of Norway, Finland, Xiangxi, and Xiangzhong. Operated by the American church, its primary function was to provide food, accommodation, and support for Lutheran missionaries traveling through central China, as well as for various inter-

national and domestic figures in modern Chinese history. It also served as a liaison and agency for various matters. The church has since become a significant material symbol for studying Wuhan's modern history, carrying high historical value and revolutionary commemorative importance. Architecturally, the Wuhan Lutheran Missions Home and Agency Building exudes a solemn and austere character, with no ornate decorations. The gray stone walls, even under sunlight, impart a sense of lifelessness, evoking feelings of isolation and melancholy. This contributes to an atmosphere of solemnity and detachment from the surrounding world.

The layout of the concave atrium of the Wuhan Lutheran Missions Home and Agency Building supports the ventilation and lighting, and at the same time it adapts to the hot and humid climate characteristics of the Wuhan area. It has important scientific value and a practical significance for the study of the characteristics of regional architecture. The main body of the house is a mixed structure. The house was originally a four-story hotel-style building, and two floors were added later. The total height of the building is 24.90 m. The walls of the house are all sintered red bricks, and the wall thickness types are 240 mm, 370 mm, 490 mm, and 620 mm. The roof is a wooden truss, and the rest of the floor panels are cast-in-place panels.

The Wuhan Lutheran Missions Home and Agency Building currently serves as the headquarters of the Wuhan Christian Association. From a historical perspective, the building is unique in that its original purpose has remained largely unchanged since its construction, a rarity among many old buildings in Hankou. In recognition of its historical and architectural significance, the Wuhan Lutheran Missions Home and Agency Building was designated as one of the first batch of outstanding historical buildings in Wuhan by the Wuhan Municipal Government in 1993. Today, it is managed by the Wuhan Christian Association and functions as the office building of the Wuhan Christian Three-Self Patriotic Movement Committee, as shown in Figure 2.



Figure 2. Location and survey map of the Wuhan Lutheran Missions Home and Agency Building.

3.2. Construction of the Indicator System

Based on the survey data, the factors affecting the residual life of historical buildings were identified and categorized into 12 factors across three dimensions. These factors were then subjected to grey correlation analysis. Drawing on the available data and the relevant literature, this paper constructs an analytical indicators system for evaluating the factors influencing the residual life of historical buildings, as shown in Table 1.

Table 1. Judgment matrix.

Dimensions	Indicators	Meaning of Indicators	Symbol
Structural system	Beam damage ratio	Number of damaged beams/total number of all beams × 100%	X_1
	Floor damage ratio	Number of damaged floors/total number of all floors × 100%	X_2
	Column damage ratio	Number of broken columns/total number of all columns × 100%	X_3
	Wall damage ratio	Number of damaged walls/total number of all walls × 100%	X_4
	Foundation damage ratio	Damaged foundation area/total foundation area × 100%	X_5
	Concrete carbonization rate	Carbonated concrete/all concrete in the building × 100%	X_6
	Building inclination	Building tilt angle/building base × 100%	X_7
Enclosure system	Roof damage ratio	Damaged roof area/total roof area × 100%	X_8
	Door and window damage rate	Number of damaged doors and windows/number of all doors and windows × 100%	X_9
	Indoor damage ratio	Indoor damaged area/total indoor area × 100%	X_{10}
Equipment system	Power supply equipment damage ratio	Number of power supply equipment failures/total number of power supply equipment × 100%	X_{11}
	Drainage equipment damage ratio	Number of drainage equipment failures/total number of drainage equipment × 100%	X_{12}

3.3. Site Survey and Test Data

3.3.1. On-Site Instruments and Equipment

When collecting data on site, in addition to visual observation, professional instruments were also required, as shown in Table 2.

3.3.2. Structural System Site Investigation

From Table 3, we can see that the beams, floor slabs, columns, and foundations of the Lutheran Missions Home and Agency Building have exposed steel bars and that the steel bars are rusted, and the situation is getting worse with the passing of years. The walls are damaged to varying degrees by weather and equipment, and there is also human damage. The structural system is equivalent to the skeleton of a building and plays a vital role in the residual life of the building. Therefore, it is necessary to analyze the specific reasons and take relevant measures.

Through the on-site survey photos of the maintenance system in 2019 and 2024, it can be found that the maintenance system of the Lutheran Missions Home and Agency Building has suffered varying degrees of damage over time. If the core factors of the damage cannot be analyzed and a scientific protection plan cannot be formulated, the residual life of the

building will be greatly reduced. The on-site survey diagram of the enclosure system is shown in Table 4.

Table 2. Professional instruments.

Instrument Name	Specifications	Instrument Number	Application
Laser rangefinder (Shanghai Xinji Instrument Co., Ltd., Shanghai, China)	SW-M100	BL-YQ-37	Measuring grid dimensions
Integrated digital rebound tester (Beijing Haichuang Hi-Tech Technology Co., Ltd., Beijing, China)	HT-225T	BL-YQ-171	Testing brick material strength
Total Station (Nanjing Huantian Precision Instrument Co., Ltd., Nanjing, China)	KTS-442ll	BL-YQ-48	Measuring the tilt of a building
Penetration mortar strength tester (Tianjin Kean Instrument Technology Co., Ltd., Tianjin, China)	SJY-800B	BL-YQ-50	Testing the strength of mortar materials
Steel measuring tape (Shenzhen Aiweiboer Tools Co., Ltd., Shenzhen, China)	(0~5) m	BL-YQ-39	Measuring building dimensions
Vernier caliper (Shanghai Qunhong Instruments Co., Ltd., Shanghai, China)	(0~200) mm	BL-YQ-40	Detecting the carbonation depth of concrete
All-in-one steel bar scanner (Beijing Dadi Hualong Technology Co., Ltd., Beijing, China)	HC-GY61T	BL-YQ-43	Detecting the spacing between steel bars
Crack Width Gauge (Beijing Haichuang Hi-Tech Technology Co., Ltd., Beijing, China)	DJCK-2	BL-YQ-51	Detection of crack width
Brick Rebound Tester(Beijing Haichuang Hi-Tech Technology Co., Ltd., Beijing, China)	ZC4	BL-YQ-52	Testing the compressive strength of bricks

Through the on-site survey photos of the equipment system in 2019 and 2024, it can be found that the equipment system of the Lutheran Missions Home and Agency Building has a negative effect on the residual life of the building. For such historical buildings in use, the equipment requirements should be reasonably planned to reduce the load of the equipment; at the same time, the damage to the historical buildings should be minimized during use. The on-site survey diagram of the equipment system is shown in Table 5.

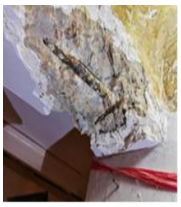
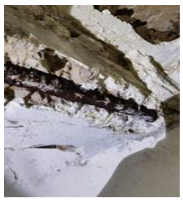
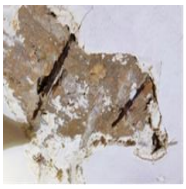
3.4. Survey Data

3.4.1. Analysis of Structural System Damage Data

The structural system is an important criterion for measuring the safety of a building. Combined with on-site inspections, the beam damage ratio, floor damage ratio, column damage ratio, wall damage ratio, foundation damage ratio, concrete carbonization rate, and building tilt rate of this historical building were investigated. The beam damage analysis of the Lutheran Missions Home and Agency Building under investigation is shown in Table 6.

From Table 6, we can find that the damage rate of beams on each floor of the Lutheran Missions Home and Agency Building increases with the years. The damage rate of beams on the first floor below ground is the highest, and the damage rate of beams on the sixth floor is the lowest. In the past six years, the damage rate of beams on the sixth floor has increased the most, and the damage rate of beams on the third floor has increased the slowest.

Table 3. On-site survey of the structural system of the Lutheran Missions Home and Agency Building from 2019 to 2024.

Position	2019	2020	2021	2022	2023	2024
Girder						
Floor						
Column						
Wall						
Foundation						

From Table 7, we can find that the floor slab on the sixth floor of the Lutheran Missions Home and Agency Building has the highest damage rate, and the floor slab on the fifth floor has the lowest damage rate. In the past six years, the damage rate of the first floor has increased the most, and the damage rate of the third floor has increased the slowest.

From Table 8, we can find that the columns on the first floor of the Lutheran Missions Home and Agency Building have the highest damage rate, while the columns on the sixth floor have the lowest damage rate. In the past six years, the damage rate of the columns on the first floor has increased the most, while the damage rate of the columns on the sixth floor has increased the slowest. Therefore, it is urgent to strengthen the protection of the columns on the first floor.

From Table 9, we can find that the wall damage rate on the first floor of the Lutheran Missions Home and Agency Building is the highest, and the wall damage rate on the sixth floor is the lowest. In the past six years, the damage rate of the first-floor wall has increased the most, and the damage rate of the sixth-floor wall has increased the slowest.

Table 4. Survey map of the enclosure system of the Lutheran Missions Home and Agency Building from 2019 to 2024.

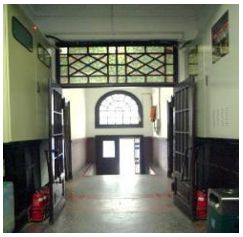
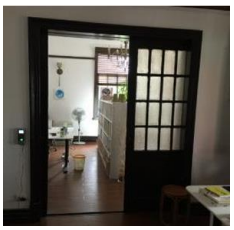
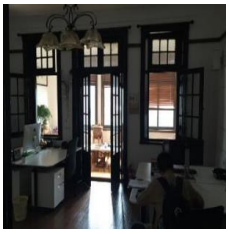
Position	2019	2024	Damage Trend
Roofing			Due to the invasion of disastrous weather such as rain and snow, the overall damage to the roof is not serious, but some load-bearing components have shown bending, deformation, splitting, and decay.
Doors and Windows			Due to their service life, some doors and windows have missing or broken glass, and some door handles are also damaged.
Indoor			The functions of some rooms in the building are changing flexibly, the indoor skirtings are seriously damaged, and most of the walls have peeling paint.

Table 5. Survey map of the Lutheran Missions Home and Agency Building's equipment system from 2019 to 2024.

Position	2019	2024	Damage Trend
Power supply equipment			There is an increasing trend of power supply pipelines hanging and exposed on the exterior walls of buildings. With the occurrence of severe weather and the aging of pipeline equipment themselves, the probability of fire increases.
Drainage equipment			Because the drainage equipment is installed directly on the exterior wall of the building, it not only increases the erosion of the building foundation, but the water stains left behind also continue to damage the beauty of the exterior wall.

Table 6. Beam damage data from 2019 to 2024.

Building Parts	2019	2020	2021	2022	2023	2024
Basement Floor (%)	3.73	3.73	3.94	3.98	3.99	4.13
First floor (%)	3.67	3.68	3.89	3.91	3.95	3.99
Second floor (%)	2.59	2.59	2.86	2.89	2.91	3.25
Third floor (%)	2.44	2.45	2.57	2.58	2.61	2.75
Fourth floor (%)	1.78	1.78	1.96	1.98	2.14	2.47
Fifth floor (%)	2.39	2.39	2.68	2.72	2.83	2.96
Sixth floor (%)	1.56	1.57	1.74	1.96	1.96	2.32
Total (%)	18.16	18.19	19.64	20.02	20.39	21.87

Table 7. Floor damage data from 2019 to 2024.

Building Parts	2019	2020	2021	2022	2023	2024
Basement Floor (%)	2.88	2.89	3.24	3.57	3.68	3.91
First floor (%)	2.74	2.75	3.29	3.46	3.57	3.94
Second floor (%)	2.82	2.82	3.04	3.35	3.46	3.78
Third floor (%)	2.53	2.54	2.78	2.89	2.93	2.95
Fourth floor (%)	1.96	1.96	2.49	2.52	2.56	2.81
Fifth floor (%)	2.45	2.55	2.68	2.79	2.84	2.92
Sixth floor (%)	3.67	3.67	3.81	3.95	4.02	4.64
Total (%)	19.05	19.18	21.33	22.53	23.06	24.95

Table 8. Column damage data from 2019 to 2024.

Building Parts	2019	2020	2021	2022	2023	2024
Basement Floor (%)	1.51	1.61	1.78	1.83	1.89	1.97
First floor (%)	1.73	1.73	1.87	1.97	2.24	2.56
Second floor (%)	1.62	1.65	1.76	1.78	1.81	1.95
Third floor (%)	1.53	1.57	1.68	1.69	1.72	1.98
Fourth floor (%)	1.44	1.53	1.65	1.68	1.69	1.84
Fifth floor (%)	1.43	1.45	1.56	1.59	1.62	1.74
Sixth floor (%)	1.41	1.42	1.46	1.49	1.54	1.58
Total (%)	10.67	10.96	11.76	12.03	12.51	13.62

Table 9. Wall damage data from 2019 to 2024.

Building Parts	2019	2020	2021	2022	2023	2024
Basement Floor (%)	2.85	2.89	3.13	3.34	3.46	3.58
First floor (%)	3.96	4.67	4.97	5.12	5.24	5.69
Second floor (%)	3.68	3.69	3.88	4.03	4.11	4.26
Third floor (%)	3.41	3.45	3.67	3.75	3.78	3.82
Fourth floor (%)	2.88	2.89	3.34	3.36	3.38	3.43
Fifth floor (%)	2.83	2.86	2.98	3.02	3.15	3.21
Sixth floor (%)	2.82	2.84	2.89	2.93	2.98	3.03
Total (%)	22.43	23.29	24.86	25.55	26.10	27.02

The foundation is the core part of the building and plays a vital role in the life cycle of the building. From Table 10, it can be found that the damage rate of the foundation of the Lutheran Missions Home and Agency Building is also increasing with the increase of years, so the reason for the continuous deterioration should be found.

Table 10. Foundation damage data from 2019 to 2024.

Building Parts	2019	2020	2021	2022	2023	2024
Foundation (%)	2.46	2.57	2.68	2.95	3.19	3.31

The carbonization rate (carbonization depth) of concrete can reflect the durability of concrete components on the one hand and also have a great influence on the rebound value of concrete on the other hand. Concrete is a weakly alkaline material, which has a protective effect on the corrosion resistance of steel bars. Affected by the environment, concrete will lose its alkalinity after carbonization and lose its protective effect on steel bars. Generally, when the carbonization depth is close to the thickness of the concrete protective layer, the reinforcement protection performance of the protective layer will be lost, and the steel bars will be prone to rust. We use appropriate tools to form a hole with a diameter of 15 mm on the surface of the measuring point, and its depth is greater than the carbonization depth of the concrete. We remove the powder and debris in the hole and use a 1% phenolphthalein ethanol test solution. After spraying it into the hole, the uncarbonized concrete will be pink, and the carbonized concrete will not change color. When the boundary between carbonized and uncarbonized concrete is clear, we use a vernier caliper to measure the vertical distance from the interface of carbonized and uncarbonized concrete to the concrete surface, which is the carbonization depth value of the concrete. The ratio of the carbonization depth value to the total depth of the measuring part is the carbonization rate of concrete. The specific values are shown in Table 11.

Table 11. Concrete carbonization data from 2019 to 2024.

Building Parts	2019	2020	2021	2022	2023	2024
Beam (%)	2.79	2.80	2.88	2.89	2.94	2.95
Floor (%)	2.97	2.99	3.17	3.19	3.22	3.24
Column (%)	2.76	2.77	2.79	2.80	2.93	2.94
Wall (%)	3.68	3.69	3.86	3.87	3.89	3.91
Foundation (%)	3.19	3.20	3.36	3.37	3.39	3.40
Total (%)	15.39	15.45	16.06	16.12	16.37	16.44

The location of the Lutheran Missions Home and Agency Building was selected, and its inclination rate was measured. From Table 12, it can be found that the inclination rate of the Lutheran Missions Home and Agency Building fluctuates relatively smoothly and is within a safe and controllable range. The specific values are shown in the following table.

Table 12. Tilt rate data from 2019 to 2024.

Years	2019	2020	2021	2022	2023	2024
Building inclination (%)	0.013	0.013	0.014	0.014	0.014	0.015

3.4.2. Analysis of Maintenance System Damage Data

The forms of damage on the floor slabs are mainly analyzed from three aspects: cracks, fissures, and no damage. The damage rate of doors and windows is the highest, followed by indoor damage, and the damage rate of the roof is the lowest. Among them, the damage rate of doors and windows has increased the most, and the damage rate of the roof has increased the least. The specific values are shown in Table 13.

Table 13. Maintenance system damage data from 2019 to 2024.

Building Parts	2019	2020	2021	2022	2023	2024
Roofing (%)	8.33	8.51	9.02	9.42	9.45	9.68
Doors and Windows (%)	21.41	23.07	24.89	25.25	25.60	26.17
Indoor (%)	7.32	8.00	8.20	9.09	9.52	10.76

3.4.3. Equipment System Damage Data Analysis

In the equipment system, the damage rate of power supply equipment is higher than that of drainage equipment. The specific values are shown in Table 14.

Table 14. Equipment system damage data from 2019 to 2024.

Building Parts	2019	2020	2021	2022	2023	2024
Power supply equipment (%)	3.65	3.68	3.72	3.78	3.84	3.86
Drainage equipment (%)	1.32	1.45	1.63	1.79	1.82	1.86

3.4.4. Data Summary

This paper takes the Wuhan Lutheran Missions Home and Agency Building as a specific case study and uses the specific values of the damage rate of each part of the historical building from 2019 to 2024 as the research sample. Through field research, survey detection, and other related channels, detailed detection is carried out, and the on-site detection data are collected and summarized to provide sufficient data support for the analysis of this paper. The specific values are shown in Table 15. The meanings of the symbols X_1–X_{12} in Table 15 correspond to those in Table 1.

Table 15. Index values of factors affecting the residual life of the Lutheran Missions Home and Agency Building.

Indicators	2019	2020	2021	2022	2023	2024
X_1 (%)	18.16	18.19	19.64	20.02	20.39	21.87
X_2 (%)	19.05	19.18	21.33	22.53	23.06	24.95
X_3 (%)	10.67	10.96	11.76	12.03	12.51	13.62
X_4 (%)	22.43	23.29	24.86	25.55	26.10	27.02
X_5 (%)	2.46	2.57	2.68	2.95	3.19	3.31
X_6 (%)	15.39	15.45	16.06	16.12	16.37	16.44
X_7 (%)	0.013	0.013	0.014	0.014	0.014	0.015
X_8 (%)	8.33	8.51	9.02	9.42	9.45	9.68
X_9 (%)	21.41	23.07	24.89	25.25	25.60	26.17
X_{10} (%)	7.32	8.00	8.20	9.09	9.52	10.76
X_{11} (%)	3.65	3.68	3.72	3.78	3.84	3.86
X_{12} (%)	1.32	1.45	1.63	1.79	1.82	1.86

From the survey data in the above table, we can see that the damage rate of each part of the historical building has basically increased year by year, indicating that the current protection of the historical building is still lacking in scientific input, which has a negative impact on the remaining life of the historical building. In the past five years, the floor slabs have the largest increase in damage rate, and the building inclination rate has the smallest increase in damage rate. The damage rate of historical buildings increases from high to low in the order of X_2, X_9, X_4, X_1, X_{10}, X_3, X_8, X_6, X_5, X_{12}, X_{11}, X_7.

3.5. Method Results

3.5.1. Entropy Weight Method Results

The index values of the factors affecting the residual life of the Lutheran Missions Home and Agency Building in Table 15 are used as the basic data for analysis.

(1) Data standardization

Using Formulae (2)–(4), Python (3.0) was employed to perform dimensionless processing on the evaluation indicators. The results of this processing are shown in Table 16.

Table 16. Dimensionless processing values of evaluation indicators.

Indicators	2019	2020	2021	2022	2023	2024
X_1	1.0001	0.992014	0.601178	0.498752	0.399022	0.0001
X_2	1.0001	0.978066	0.613659	0.410269	0.320439	0.0001
X_3	1.0001	0.901795	0630608	0.539083	0.376371	0.0001
X_4	1.0001	0.812736	0.470688	0.320361	0.200536	0.0001
X_5	1.0001	0.870688	0.741276	0.423629	0.141276	0.0001
X_6	1.0001	0.942957	0.362005	0.304862	0.066767	0.0001
X_7	1.0001	1.000100	0.500100	0.500100	0.500100	0.0001
X_8	1.0001	0.866767	0.488989	0.192693	0.170470	0.0001
X_9	1.0001	0.651361	0.269008	0.193377	0.119848	0.0001
X_{10}	1.0001	0.802426	0.744286	0.485565	0.360565	0.0001
X_{11}	1.0001	0.857243	0.666767	0.381052	0.095338	0.0001
X_{12}	1.0001	0.759359	0.426026	0.129730	0.074174	0.0001

(2) Calculate the weight matrix

Using Formula (5) and the data from Table 3, the evaluation index proportions of the factors influencing the Wuhan Lutheran Missions Home and Agency Building were calculated, as shown in Figure 3.



Figure 3. The proportion of evaluation indicators.

(3) Calculate the information entropy, variance coefficient, and weight of the indicator

Based on Figure 3, the proportion of evaluation indicators for the factors affecting the residual life of the Wuhan Lutheran Missions Home and Agency Building was obtained. Using Formulae (6)–(8), the entropy value and difference coefficient of the indicators were calculated, allowing for the determination of the weights of these indicators as shown in Table 17.

Table 17. Evaluation indicators weight calculation results.

Indicators	Entropy	Coefficient of Variation	Weight
X_1	0.862149	0.137851	0.061254
X_2	0.846926	0.153074	0.068018
X_3	0.866564	0.133436	0.059292
X_4	0.816519	0.183481	0.081530
X_5	0.817949	0.182051	0.080894
X_6	0.751122	0.248878	0.110588
X_7	0.865142	0.134858	0.059924
X_8	0.782724	0.217276	0.096546
X_9	0.749689	0.250311	0.111225
X_{10}	0.865402	0.134598	0.059808
X_{11}	0.798298	0.201702	0.089626
X_{12}	0.727030	0.272970	0.121294

In the entropy weight method, a larger entropy value corresponds to a smaller entropy weight, indicating a lower importance of the indicator. However, as the selected evaluation indicators are reverse indicators, a larger entropy value results in a larger entropy weight, signifying greater importance. It can be observed that in the three dimensions—structural system, enclosure system, and equipment system—the entropy weights are ranked from largest to smallest as follows: structural system, enclosure system, and equipment system. This indicates that the structural system has the greatest influence on the residual life of historical buildings, followed by the enclosure system, and finally the equipment system. Furthermore, from analyzing the evaluation indicators it is clear that a lower weight indicates higher importance. Based on the weight coefficients of the individual indicators, the following indicators are identified as highly important for the residual life of historical buildings: column damage ratio, indoor damage ratio, building inclination rate, beam damage ratio, floor damage ratio, foundation damage ratio, wall damage ratio, power supply equipment failure rate, roof damage ratio, concrete carbonization rate, door and window damage rate, and drainage equipment failure rate.

3.5.2. Results of the Grey Relation Method

(1) Determine the reference sequence and comparison sequence

The comparison sequence for the evaluation system of the residual life influencing factors of the Wuhan Lutheran Missions Home and Agency Building consists of the original data X_1–X_{12}, representing the subsequence. The reference sequence Y is the sum of the selected indicators for each year, representing the parent sequence. For further details, please refer to Table 18.

(2) Dimensionless processing

As outlined in the steps of the EWM, it is essential to make the data dimensionless in order to ensure its meaningfulness. In this paper, the averaging method was applied to process both the comparison sequence and the reference sequence. Python (3.0) was used to perform the calculations, as shown in Table 19.

After dimensionless processing, the values of both the reference sequence and the comparison sequence exhibited an overall downward trend. The standardized value graphs for each sequence are presented in Figure 4.

Table 18. Numerical table of evaluation indexes for each sequence.

Indicators	2019	2020	2021	2022	2023	2024
X_1	0.061260	0.060765	0.036825	0.030551	0.024442	0.000006
X_2	0.068025	0.066526	0.041740	0.027906	0.021796	0.000007
X_3	0.059298	0.053469	0.037390	0.031963	0.022316	0.000006
X_4	0.081538	0.066262	0.038375	0.026119	0.016350	0.000008
X_5	0.080902	0.070434	0.059965	0.034269	0.011428	0.000008
X_6	0.110600	0.104280	0.040034	0.033714	0.007384	0.000011
X_7	0.059930	0.059930	0.029968	0.029968	0.029968	0.000006
X_8	0.096556	0.083683	0.047210	0.018604	0.016458	0.000010
X_9	0.111237	0.072448	0.029920	0.021508	0.013330	0.000011
X_{10}	0.059814	0.047992	0.044514	0.029041	0.021565	0.000006
X_{11}	0.089635	0.076831	0.059760	0.034152	0.008545	0.000009
X_{12}	0.121306	0.092105	0.051674	0.015735	0.008997	0.000012
Y	1.000101	0.854725	0.517375	0.333530	0.202579	0.000100

Table 19. Dimensionless processing values of evaluation index sequence.

Indicators	2019	2020	2021	2022	2023	2024
X_1	1.718783	1.704895	1.033206	0.857175	0.685774	0.000168
X_2	1.805973	1.766177	1.108142	0.740867	0.578655	0.000186
X_3	1.740288	1.569218	1.097328	0.938056	0.654934	0.000176
X_4	2.139618	1.738765	1.006989	0.685382	0.429036	0.000210
X_5	1.888719	1.644335	1.399928	0.800036	0.266795	0.000187
X_6	2.241718	2.113620	0.811437	0.683339	0.149664	0.000223
X_7	1.714163	1.714163	0.857167	0.857167	0.857167	0.000172
X_8	2.206818	1.912601	1.078999	0.425200	0.376153	0.000229
X_9	2.686300	1.749571	0.722548	0.519404	0.321911	0.000266
X_{10}	1.768494	1.418958	1.316126	0.858642	0.637603	0.000177
X_{11}	1.999799	1.714136	1.333274	0.761947	0.190643	0.000201
X_{12}	2.511260	1.906745	1.069748	0.325744	0.186255	0.000248
Y	2.063191	1.763283	1.067336	0.688067	0.417917	0.000206

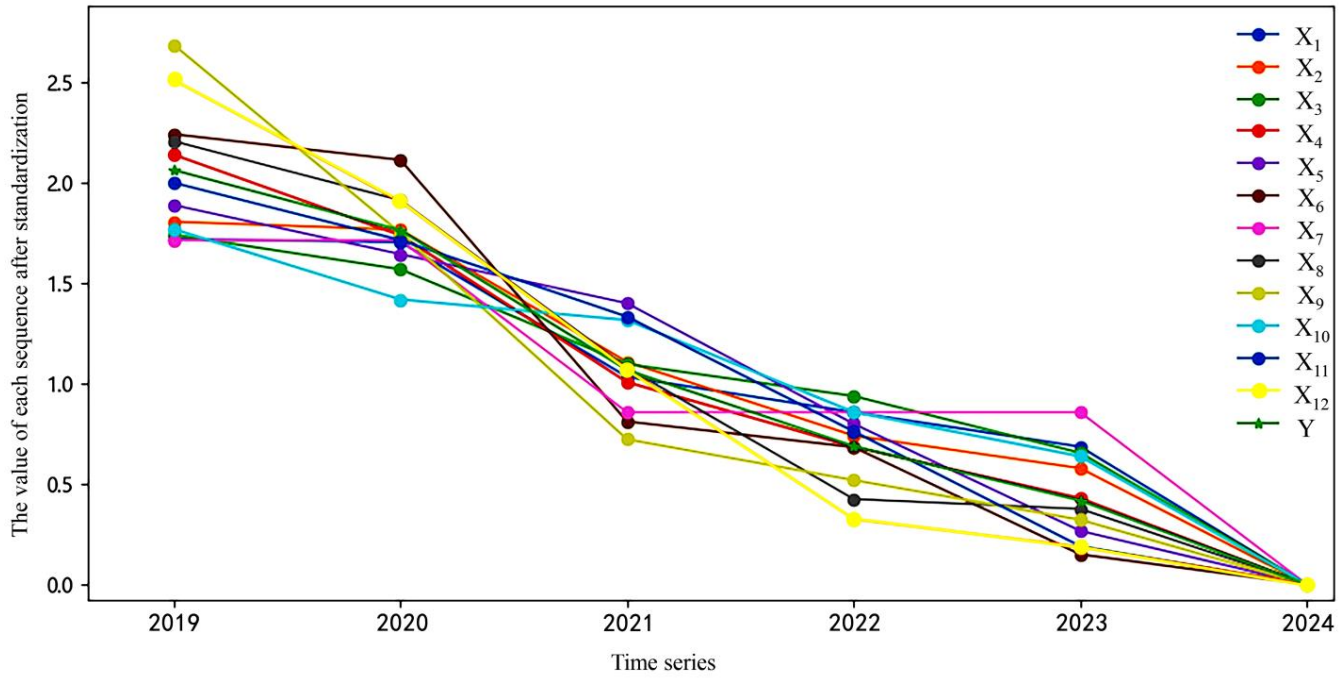


Figure 4. Numerical graphs of each sequence after standardization.

(3) Calculate the deviation matrix

According to Formulae (14)–(20), combined with the data in Table 19, the deviation matrix for the evaluation index of the residual life influencing factors of the Wuhan Lutheran Missions Home and Agency Building was calculated, as shown in Figure 5.



Figure 5. Evaluation index deviation matrix.

(4) Calculate the association matrix

Since the elementary function SSD(ρ) is continuous in the range (0,1], the one-dimensional search method can be applied to determine max SSD. The monotonicity of the function SSD(ρ) in this interval is influenced by the deviation matrix, and the value of ρ directly impacts the ranking of the correlation. By analyzing the data from Figure 5, it was found that when ρ = 0.110, the sum of the square deviations of the correlation reached its maximum value of 0.130, as shown in Figure 6. Therefore, to ensure more accurate ranking of the correlation for the residual life influencing factors of the Wuhan Lutheran Missions Home and Agency Building, ρ is set to 0.110, as shown in Figure 6.

Based on the calculation results in Figure 5 and Table 19 and applying Formulae (21)–(23), the correlation coefficients for each indicator can be derived, and are shown in Table 20.

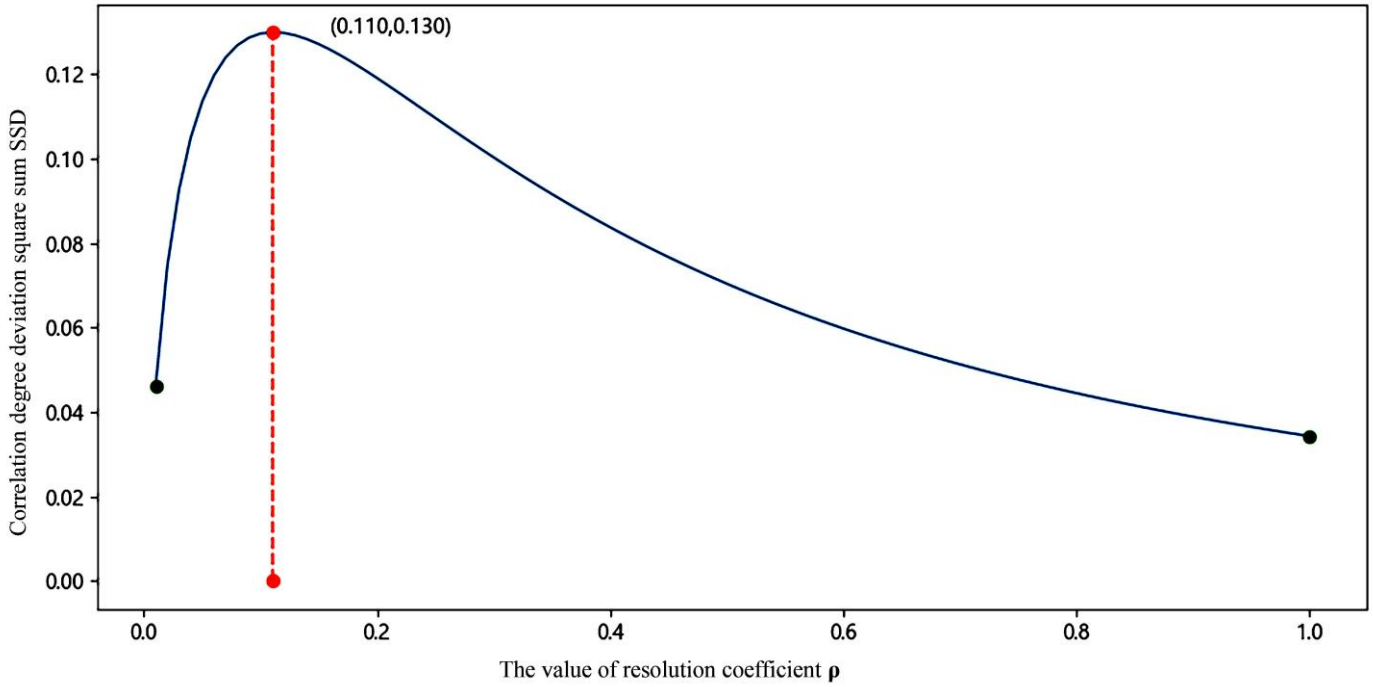


Figure 6. Correlation coefficient of evaluation indicators.

Table 20. Evaluation index correlation coefficient value table.

Indicators	2019	2020	2021	2022	2023	2024
X_1	0.1659899	0.5400250	0.6676169	0.2884306	0.2037631	0.9994995
X_2	0.2104177	0.9595395	0.6268585	0.5648933	0.2989604	0.9997545
X_3	0.1751091	0.2610194	0.6956504	0.2151928	0.2243286	0.9996124
X_4	0.4728293	0.7365710	0.5318191	0.9623610	0.8604637	1.0000000
X_5	0.2820637	0.3655963	0.1708793	0.3797307	0.3120480	0.9997680
X_6	0.2774357	0.1636408	0.2112731	0.9355226	0.2035233	0.9998099
X_7	0.1641535	0.5825643	0.2459385	0.2884398	0.1349875	0.9995472
X_8	0.3230715	0.3146311	0.8546236	0.2068312	0.6214120	0.9997283
X_9	0.0991043	0.8333441	0.1658377	0.2889724	0.4165683	0.9991878
X_{10}	0.1887064	0.1660235	0.2160061	0.2866606	0.2378175	0.9996315
X_{11}	0.5195446	0.5824295	0.2049318	0.4812833	0.2317170	0.9999726
X_{12}	0.1326832	0.3233223	0.9660537	0.1590884	0.2283298	0.9994387

(5) Analysis of correlation differences

Using the indicator weights calculated in Table 20, Python (3.0) was employed to calculate the grey correlation values for the evaluation index of the residual life influencing factors of the Wuhan Lutheran Missions Home and Agency Building. It was found that when $\rho = 0.110$, ρ intersects with R_1–R_{12} at specific points. The value at these intersection points represents the grey correlation value of the evaluation index for the residual life influencing factors of the Wuhan Lutheran Missions Home and Agency Building. The results are presented in Figure 7.

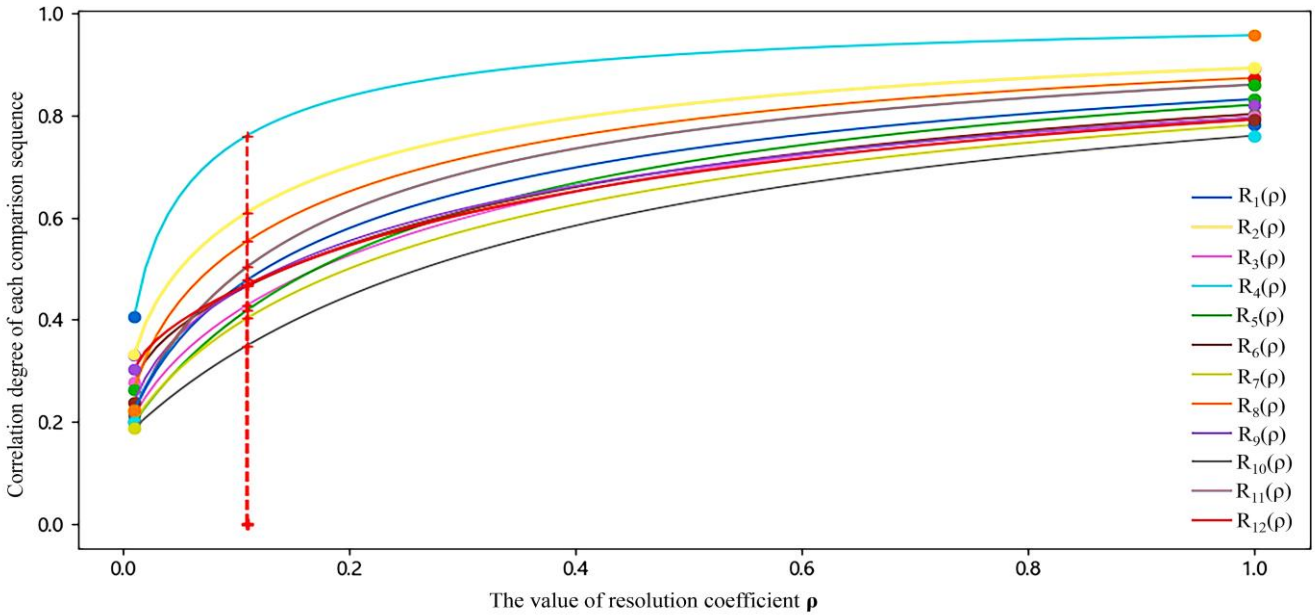


Figure 7. Reference sequence association curve.

The higher the grey correlation value, the greater the impact of that factor on the residual life of the building. Based on the calculations, the most influential factor is the wall damage ratio (R_4), while the least influential is the indoor damage ratio (R_{10}). Consequently, the factors affecting the residual life of the historical building of the Wuhan Lutheran Missions Home and Agency Building, ranked from most to least influential, are as follows: wall damage ratio, floor damage ratio, roof damage ratio, power supply equipment failure rate, beam damage ratio, drainage equipment failure rate, door and window damage ratio, concrete carbonization rate, column damage ratio, foundation damage ratio, building inclination rate, and indoor damage ratio. These results are illustrated in Figure 8.

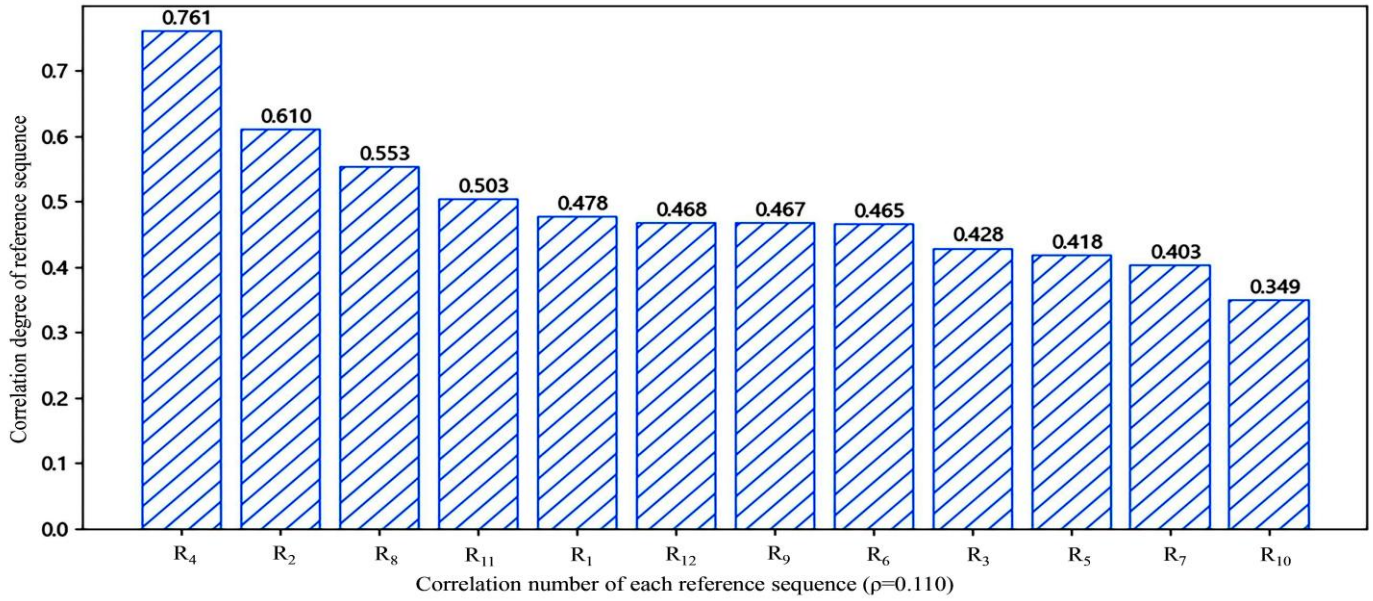


Figure 8. Reference sequence association ranking diagram.

4. Results and Discussion

Grey relation analysis was conducted on 12 factors in three dimensions of historical buildings. The influencing factors of the structural system include the beam damage ratio, the floor damage ratio, the column damage ratio, the wall damage ratio, the foundation damage ratio, the concrete carbonization rate, and the building inclination rate. The influencing factors of the enclosure system include the roof damage ratio, the door and window damage ratio, and the indoor damage ratio. The influencing factors of the equipment system include the power supply equipment failure rate and the drainage equipment failure rate.

From the perspective of dimension, the importance and grey correlation of indicators obtained according to weights are from large to small, namely, the structural system, the enclosure system, and the equipment system. From the perspective of single influencing factors, the larger the entropy value, the lower the weight, and the more important the indicator. In the structural system, the importance of indicators obtained according to weights are from large to small, namely, the column damage ratio, the building inclination rate, the beam damage ratio, the floor damage ratio, the foundation damage ratio, the wall damage ratio, and the concrete carbonization rate; the grey correlation is from high to low, namely, the wall damage ratio, the floor damage ratio, the beam damage ratio, the concrete carbonization rate, the column damage ratio, the foundation damage ratio, and the building inclination rate. In the enclosure system, the importance of indicators obtained according to weights are from large to small, namely, the indoor damage ratio, the roof damage ratio, and the door and window damage ratio; the grey correlation is from high to low, namely, the roof damage ratio, the door and window damage ratio, and the indoor damage ratio. In the equipment system, the importance and grey correlation of indicators obtained according to weights are from large to small, namely, the power supply equipment failure rate and the drainage equipment failure rate.

Historical buildings are similar to the human body. If any organ is damaged, it will affect its life. According to the results of the EWM and the GRA, in the structural system of historical buildings, the column damage ratio and the wall damage ratio have the largest weight and gray correlation, respectively. In the enclosure system of historical buildings, the indoor damage ratio and the roof damage ratio have the largest weight and gray correlation, respectively. In the equipment system of historical buildings, the power supply

equipment failure rate has the largest weight and gray correlation. Therefore, in the future protection of historical buildings, the maintenance of these factors should be given priority.

Rúben Santos [49] used an improved BIM method to evaluate the life cycle and life cycle cost of office buildings, integrating historical data for sustainable predictions. This highlights the growing application of BIM in managing the life cycle of buildings, including historical ones. David Bienvenido-Huertas [50] utilized the J48 algorithm within the H-BIM model to manage historical building information, focusing on its visualization for better scientific management. This method aids in effectively storing and analyzing historical building data. Eduard Hromada [51] applied life cycle cost theory using MONUREV software to maximize the extension of the life of historical buildings, focusing on sustainable management practices. While the aforementioned studies focus on life cycle management, cost analysis, and data management through various advanced modeling techniques (like BIM, H-BIM), none of them explicitly analyze the factors affecting the residual life of historical buildings. This study fills this gap by introducing the EWM-GRA model (entropy weight method and grey relational analysis) to explore the coupling relationship between the factors affecting the residual life of historical buildings.

This paper establishes the EWM-GRA model to study the coupling relationship between the factors affecting the residual life of historical buildings, analyzes the coupling characteristics of each influencing factor in a single factor and in each dimension, quantifies the correlation between the degree of influence of each factor on the remaining life of historical buildings, and also provides a certain reference for the effective protection and extension of the service life of historical buildings. However, this study also has certain limitations. This article selected 12 indicators of factors affecting the residual life of historical buildings, and the selection of indicators needs to be more comprehensive. In the future, when studying the factors affecting the residual life of historical buildings, policy-related indicators can be combined. The article's conclusions on factors affecting the remaining lifespan of historical buildings are based on analysis of only six years of data from one historical building and may not be applicable to all historical buildings. In the future, we can draw comprehensive and scientific conclusions by analyzing the remaining lifespans of different types of historical buildings.

5. Conclusions

Based on the damage rate data of the building structure, enclosure system, and equipment system of the Wuhan Lutheran Missions Home and Agency Building from 2019 to 2024, this paper constructs an evaluation system of factors affecting the residual life of historical buildings from three dimensions: the structural system, the enclosure system, and the equipment system of historical buildings. The EWM is used to calculate the index weights of the factors affecting the residual life of historical buildings. On this basis, the GRA is used to calculate and rank the correlation of the factors affecting the residual life of historical buildings. The EWM-GRA model is constructed to analyze the complex relationship between the factors affecting the residual life of historical buildings, in order to improve the resilience of historical buildings.

(1) This study first justifies the use of the entropy weight method and grey relation analysis to assess the factors affecting the residual life of historical buildings. Next, the evaluation criteria for these factors are established. Finally, the evaluation system is applied to determine the indicators. Based on the data of the relevant factors of the Wuhan Lutheran Missions Home and Agency Building, and after processing the data, the factors affecting the remaining life of historical buildings are divided into three dimensions: building structure, enclosure system, and equipment system. The EWM is used to calculate the indicator weights of the 12 factors in these three dimensions,

and the GRA is used to calculate the correlation coefficient and grey relation closeness to achieve a comprehensive evaluation; finally, according to the results, the most influential factors within each dimension are identified, and the interrelationships between these factors are analyzed to determine their impact on the residual life of historical buildings.

(2) This paper uses the EWM-GRA model to analyze the factors affecting the residual life of historical buildings. It is found that from the perspective of dimensions, the factors affecting the residual life of historical buildings are the structural system, the enclosure system, and the equipment system in descending order of importance. From the perspective of single influencing factors, the correlation of the factors is from large to small, namely, wall damage ratio, floor damage ratio, roof damage ratio, power supply equipment failure rate, beam damage ratio, drainage equipment failure rate, door and window damage rate, concrete carbonization rate, column damage ratio, foundation damage ratio, and building tilt rate.

(3) Based on the analysis of the relevant influencing factors of the residual life of the Wuhan Lutheran Missions Home and Agency Building, it can be found that the core factor is their structural system. Therefore, in the future protection of historical buildings, periodic health monitoring of their structures should be strengthened to promptly identify problems and take corresponding measures. At the same time, the management personnel of historical buildings should promptly repair the damaged parts of the enclosure system. It is also very important to promptly check the equipment system failures of historical buildings in service and to regularly check the equipment system failures of historical buildings that are not in service.

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References

1. Ribera, F.; Nesticò, A.; Cucco, P.; Maselli, G. A multicriteria approach to identify the Highest and Best Use for historical buildings. *J. Cult. Herit.* **2020**, *41*, 166–177. [CrossRef]
2. Bai, Y.; Ma, Y.; Yang, Q.; Florez-Lopez, J.; Li, X.; Biondini, F. Earthquake-induced damage updating for remaining-life assessment of steel frame substructure systems. *Mech. Syst. Signal Process.* **2021**, *159*, 107782. [CrossRef]
3. Mishra, M. Machine learning techniques for structural health monitoring of heritage buildings: A state-of-the-art review and case studies. *J. Cult. Herit.* **2021**, *47*, 227–245. [CrossRef]

4. Munarim, U.; Ghisi, E. Environmental feasibility of heritage buildings rehabilitation. *Renew. Sustain. Energy Rev.* **2016**, *58*, 235–249. [CrossRef]
5. Pagella, G.; Mirra, M.; Ravenshorst, G.; Gard, W.; van de Kuilen, J.-W. Characterization of the remaining material and mechanical properties of historic wooden foundation piles in Amsterdam. *Constr. Build. Mater.* **2024**, *450*, 138616. [CrossRef]
6. Yung, E.H.K.; Langston, C.; Chan, E.H.W. Adaptive reuse of traditional Chinese shophouses in government-led urban renewal projects in Hong Kong. *Cities* **2014**, *39*, 87–98. [CrossRef]
7. Zhang, M.; Zhao, H.; Fan, L.; Yi, J. Dynamic modulus prediction model and analysis of factors influencing asphalt mixtures using gray relational analysis methods. *J. Mater. Res. Technol.* **2022**, *19*, 1312–1321. [CrossRef]
8. Schwartz, S.; Jiménez, J.J.M.; Vingerhoeds, R.; Salaün, M. An unsupervised approach for health index building and for similarity-based remaining useful life estimation. *Comput. Ind.* **2022**, *141*, 103716. [CrossRef]
9. Park, J.H. Seismic hazard level reduction for existing buildings considering remaining building lifespans. *Earthq. Eng. Eng. Vib.* **2019**, *18*, 649–661. [CrossRef]
10. Angjeliu, G.; Coronelli, D.; Cardani, G. Development of the simulation model for Digital Twin applications in historical masonry buildings: The integration between numerical and experimental reality. *Comput. Struct.* **2020**, *238*, 106282. [CrossRef]
11. Franco, G.; Magrini, A.; Cartesegna, M.; Guerrini, M. Towards a systematic approach for energy refurbishment of historical buildings. The case study of Albergo dei Poveri in Genoa, Italy. *Energy Build.* **2015**, *95*, 153–159. [CrossRef]
12. Elam, J.; Björdal, C.G. Long-term study on wood degradation in urban soil-water systems-implications for service life of historic foundation piles. *Int. Biodeterior. Biodegrad.* **2022**, *167*, 105356. [CrossRef]
13. He, J.; Wang, H.; Wang, J.; Zuo, C.; Wang, Z.; Zhao, X. Decision-Making Method for Multi-Objective Demagnetization Strategies of Underwater Vehicles Based on Improved Grey Relation Analysis. *IEEE Trans. Instrum. Meas.* **2023**, *73*, 2505313. [CrossRef]
14. Mishra, M.; Lourenço, P.B.; Ramana, G.V. Structural health monitoring of civil engineering structures by using the internet of things: A review. *J. Build. Eng.* **2022**, *48*, 103954. [CrossRef]
15. Eskew, E.L.; Jang, S. Remaining stiffness estimation of buildings using incomplete measurements. *Struct. Control Health Monit.* **2017**, *24*, e1899. [CrossRef]
16. Vilches, A.; Garcia-Martinez, A.; Sanchez-Montanes, B. Life cycle assessment (LCA) of building refurbishment: A literature review. *Energy Build.* **2017**, *135*, 286–301. [CrossRef]
17. Xia, J.; Shi, Q.; Li, H.; Zhou, M.; Wang, W.; Wang, K.; Jiang, K. Historical data-independent remaining useful life prediction method based on dual-input deep learning neural network. *J. Energy Storage* **2023**, *72*, 108427. [CrossRef]
18. Vásquez, F.; Løvik, A.N.; Sandberg, N.H.; Müller, D.B. Dynamic type-cohort-time approach for the analysis of energy reductions strategies in the building stock. *Energy Build.* **2016**, *111*, 37–55. [CrossRef]
19. Nielsen, A.N.; Jensen, R.L.; Larsen, T.S.; Nissen, S.B. Early stage decision support for sustainable building renovation—A review. *Build. Environ.* **2016**, *103*, 165–181. [CrossRef]
20. Assefa, G.; Ambler, C. To demolish or not to demolish: Life cycle consideration of repurposing buildings. *Sustain. Cities Soc.* **2017**, *28*, 146–153. [CrossRef]
21. Nadkarni, R.R.; Puthuvayi, B. A comprehensive literature review of Multi-Criteria Decision Making methods in heritage buildings. *J. Build. Eng.* **2020**, *32*, 101814. [CrossRef]
22. Hasik, V.; Escott, E.; Bates, R.; Carlisle, S.; Faircloth, B.; Bilec, M.M. Comparative whole-building life cycle assessment of renovation and new construction. *Build. Environ.* **2019**, *161*, 106218. [CrossRef]
23. Sobotka, A.; Linczowski, K.; Radziejowska, A. Substitution of building components in historic buildings. *Sustainability* **2021**, *13*, 9211. [CrossRef]
24. Angrisano, M.; Fabbrocino, F.; Iodice, P.; Girard, L.F. The evaluation of historic building energy retrofit projects through the life cycle assessment. *Appl. Sci.* **2021**, *11*, 7145. [CrossRef]
25. Xie, L.; Wu, C.; Duan, M.; Lyu, N. Analysis of freeway safety influencing factors on driving workload and performance based on the gray correlation method. *J. Adv. Transp.* **2021**, *2021*, 6566207. [CrossRef]
26. Letzter, J.; Neuman, E. Addition to historic building: A hermeneutic interpretation. *Cogent Arts Humanit.* **2022**, *9*, 2079587. [CrossRef]
27. Redden, R.; Crawford, R.H. Valuing the environmental performance of historic buildings. *Australas. J. Environ. Manag.* **2021**, *28*, 59–71. [CrossRef]
28. Charlton, J.; Kelly, K.; Greenwood, D.; Moreton, L. The complexities of managing historic buildings with BIM. *Eng. Constr. Archit. Manag.* **2021**, *28*, 570–583. [CrossRef]
29. Perhavec, D.D.; Kamnik, R. The use of artificial intelligence in building engineering for historic buildings build in the Austro-Hungarian monarchy. *ACM J. Comput. Cult. Herit.* 2024, *just accepted*. [CrossRef]
30. Karic, A.; Atalić, J.; Kolbitsch, A. Seismic vulnerability of historic brick masonry buildings in Vienna. *Bull. Earthq. Eng.* **2022**, *20*, 4117–4145. [CrossRef]

31. Strojecki, M. Modelling particle deposition onto surfaces in historic buildings. *Sci. Total Environ.* **2023**, *896*, 165205. [CrossRef] [PubMed]
32. Pinheiro, V.R.; Fontenele, R.; Magalhães, A.; Frota, N.; Mesquita, E. Evaluation of the influence of climatic changes on the degradation of the historic buildings. *Energy Build.* **2024**, *323*, 114813. [CrossRef]
33. Bertolin, C.; Loli, A. Sustainable interventions in historic buildings: A developing decision making tool. *J. Cult. Herit.* **2018**, *34*, 291–302. [CrossRef]
34. Kincaid, S. Practical challenges in mitigating the aftermath of fire in historic buildings. *Hist. Environ. Policy Pract.* **2021**, *12*, 77–96. [CrossRef]
35. Chen, C.S.; Chiu, Y.H.; Tsai, L. Evaluating the adaptive reuse of historic buildings through multicriteria decision-making. *Habitat Int.* **2018**, *81*, 12–23. [CrossRef]
36. Fauzi, R.T.; Lavoie, P.; Tanguy, A.; Amor, B. Life cycle assessment and life cycle costing of multistorey building: Attributional and consequential perspectives. *Build. Environ.* **2021**, *197*, 107836. [CrossRef]
37. Gachkar, D.; Gachkar, S.; Martínez, A.G.; Angulo, C.; Aghlmand, S.; Ahmadi, J. Artificial intelligence in building life cycle assessment. *Archit. Sci. Rev.* **2024**, *67*, 484–502. [CrossRef]
38. Lee, P.-C.; Xie, W.; Lo, T.-P.; Long, D.; Tang, X. A cloud model-based knowledge mapping method for historic building maintenance based on building information modelling and ontology. *KSCE J. Civ. Eng.* **2019**, *23*, 3285–3296. [CrossRef]
39. Agrawal, S.; Sarkar, S.; Srivastava, G.; Maddikunta, P.K.R.; Gadekallu, T.R. Genetically optimized prediction of remaining useful life. *Sustain. Comput. Inform. Syst.* **2021**, *31*, 100565. [CrossRef]
40. Younus, I.; Al-Hinkawi, W.; Lafta, S. The role of historic building information modeling in the cultural resistance of liberated city. *Ain Shams Eng. J.* **2023**, *14*, 102191. [CrossRef]
41. Akai, A.; Kojima, Y.; Sato, Y. Assessment of remaining fatigue life based on temperature-evolution measurements. *Nondestruct. Test. Eval.* **2022**, *37*, 258–276. [CrossRef]
42. Zou, J.; Li, P. Modelling of litchi shelf life based on the entropy weight method. *Food Packag. Shelf Life* **2020**, *25*, 100509. [CrossRef]
43. Jin, Y.; Shou, Y.; Lei, Q.; Du, C.; Xu, L.; Chen, N.; Ma, W.; Zhu, X.; Zhou, S.; Zheng, Y.; et al. An entropy weight method to integrate big omics and mechanistically evaluate DILI. *Hepatology* **2024**, *79*, 1264–1278. [CrossRef]
44. Cao, Z.; Zhang, T.; Tong, X.K. Quality evaluation of chicken soup based on entropy weight method and grey correlation degree method. *Sci. Rep.* **2024**, *14*, 13038. [CrossRef]
45. Na, W.; Zhao, Z.C. The comprehensive evaluation method of low-carbon campus based on analytic hierarchy process and weights of entropy. *Environ. Dev. Sustain.* **2021**, *23*, 9308–9319. [CrossRef]
46. Cunha-Zeri, G.; Guidolini, J.F.; Branco, E.A.; Ometto, J.P. How sustainable is the nitrogen management in Brazil? A sustainability assessment using the Entropy Weight Method. *J. Environ. Manag.* **2022**, *316*, 115330. [CrossRef]
47. Deng, Z.; Xie, Z.; Jiang, F.; Xu, J.; Yang, S.; Xu, T.; Zhao, L.; Chen, Y.; He, J.; Hou, Z. Research on the coupling coordination of land use and eco-resilience based on entropy weight method: A case study on Dianchi Lake Basin. *Landsc. Ecol. Eng.* **2024**, *20*, 129–145. [CrossRef]
48. Song, H.; Chen, X.; Zhang, S.; Xu, L. Multi-objective optimization design of 6-UPS parallel mechanism based on Taguchi method and entropy-weighted gray relational analysis. *Appl. Sci.* **2022**, *12*, 5836. [CrossRef]
49. Santos, R.; Costa, A.A.; Silvestre, J.D.; Vandenbergh, T.; Pyl, L. BIM-based life cycle assessment and life cycle costing of an office building in Western Europe. *Build. Environ.* **2020**, *169*, 106568. [CrossRef]
50. Bienvenido-Huertas, D.; Nieto-Julián, J.E.; Moyano, J.J.; Macías-Bernal, J.M.; Castro, J. Implementing artificial intelligence in H-BIM using the J48 algorithm to manage historic buildings. *Int. J. Archit. Herit.* **2020**, *14*, 1148–1160. [CrossRef]
51. Hromada, E.; Macek, D.; Heralova, R.S.; Brožová, L.; Střelcová, I. Integrating Life Cycle Cost Analysis for Sustainable Maintenance of Historic Buildings. *Buildings* **2024**, *14*, 1479. [CrossRef]

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