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A Life-Cycle Carbon Emissions Model for Traditional Residential Houses: Applying to Traditional Dong Dwellings in Qandongnan, Guizhou Province, China

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Abstract: In recent years, due to the low energy utilization of the whole life-cycle of buildings and the diminished indoor and outdoor comfort of buildings and the impact on the surrounding environment caused by the carbon emissions of the building life-cycle, the establishment of a whole life- cycle carbon emission model for buildings to improve their energy utilization at all stages of their life-cycle has received unprecedented attention. In China, the construction industry has become a major carbon emitter, and traditional houses, as a green development building type, are an effective way to achieve carbon neutrality in buildings, but the existing green building evaluation system lacks quantitative indicators of carbon emissions in the building life-cycle. The exclusive evaluation indexes for regional and characteristic buildings, such as traditional houses, are neglected; This study explored the formula for calculating the life-cycle carbon emissions model of traditional residential houses under a carbon emission intervention and used real measurements of the physical environment and comparative analysis of the limitations of existing local standards; The results showed that the carbon emission calculation formulas for each stage of the life-cycle of traditional residential houses must be established by combining the selection of local building materials, and the materials for sustainable energy and carbon sinks of green systems. Based on the results of indoor and outdoor heat and humidity environmental tests of residential houses and an analysis of the limitations of existing evaluation indexes due to locality, four important factors affecting locality green buildings in terms of energy utilization, site ecology and landscape, land saving and material saving were extracted; on this basis, the whole life-cycle carbon emission model of traditional residential houses is constructed by combining the existing green building evaluation standards with the carbon emission indexes of the life-cycle of traditional residential houses.

Keywords: dong dwellings; comfortable residence; green building; building physical environment; life-cycle carbon emissions

1. Introduction

At the *75th UN General Assembly*, China proposed an initiative to strive to reach its carbon peak by 2030 and achieve carbon neutrality by 2060 [1]. With current global warming, the *IPCC* special report on a global warming value of *1.5°C* clearly states that the global temperature has increased by *1.0°C* since preindustrial levels [2], where the main influence on climate change is the emission of carbon dioxide [3]. In the context of global warming, extreme heat events have been frequently observed [4]. Some studies demonstrate that extreme heat events pose a serious threat to human health, and that they are even life-threatening and fatal in severe cases [5,6]. The total global CO_2 emissions from the construction sector were *5.7 billion tons* in 2009, accounting for *23%* of the total CO_2 emissions from global economic activities [7], and among the various strategies developed to meet energy demand and reduce CO_2 emissions, improving the energy efficiency of buildings has proven to be the best option [8,9]. According to the data from the China Building Energy Consumption Research Report (2020), the total energy consumption of the whole life cycle of buildings in China was *2.147 billion ton* of standard coal equivalent in 2018, accounting for *46.5%* of

the total national energy consumption. The total carbon emissions of the whole building process in China were *4. 93 billion tce* in 2018, accounting for *51.2%* of the national carbon emissions, and the energy consumption of building materials accounted for more than *20%*. The energy consumption and carbon emissions of the construction industry were much higher than those of other industries. A study showed that with the development of urbanization and the investment in rural revitalization, the total carbon emissions in rural areas of China increased from *408.53 Mt* in 1997 to *619.57 Mt* in 2015 [10], rural residential buildings and household appliances such as air conditioners and hot water supply in daily life and their time of use have increased significantly, and rural areas are becoming the second largest source of greenhouse gas emissions [11], of which residential living systems have become the main source of Greenhouse Gas emissions [12]. Therefore, the country started to promote the low-carbon transition of rural residential buildings more thoroughly to reduce CO_2 emissions [13], Therefore, this is essential to deal with reduce energy consumption, and safeguard residents' health [14,15]. There is a certain internal logical relationship between green building and achieving the carbon peak carbon neutrality goal, and green building development(*GBD*) has an important role in improving the carbon emission reduction efficiency(*CEEOCI*) of the construction industry and accelerating the achievement of the carbon neutrality goal in the construction industry [16].

At the onset of the 21st century, to keep up with the pace of the world, China sought to reduce the pollution of building environments and improve the efficiency of energy consumption by the Chinese construction industry as well as develop and improve the Chinese green building evaluation system, which can better promote the development of green buildings. The early studies focused mainly on comparing the international mainstream green building evaluation system in terms of factors such as evaluation scope, evaluation indexes, and control items to analyze the advantages, disadvantages and development status [17,18] and to identify the problems encountered in its implementation in each phase of the whole building life cycle [19] to propose improvement measures to continuously improve the Chinese green building evaluation standards. Using the definition of green buildings, some scholars have developed a multi-objective evaluation model for green buildings under the three dimensions of objective, professional and time (*OPT*) [20]; these theories have been validated with actual projects to propose new ideas for the construction of green building evaluation indexes. The limitations of the existing national and provincial green building evaluation standards, combined with the unique topography, ecological environment, architectural culture and building type of each region, to propose important regional green building factors, upon which an evaluation model was established to build a green building evaluation system that met the local regional characteristics [21,22]. At this stage, under the guidance of Chinese policies and relevant standards, China's green building evaluation standards have developed to the relatively mature third generation of green building evaluation standards after two revisions. With the introduction of China's *GB/T50378-2019* Green Building Evaluation Standard, research on the differences in the framework structure, scoring criteria, evaluation objects, evaluation process and methods of the latest domestic and foreign standards in the horizontal aspect has been carried out [23]. The aim is to reveal the differences of different green building evaluation standards at home and abroad through the comparison of the same index and weight, combining the current conditions such as the complex climate environment and the lack of professional talent in China, to refine the transparent evaluation process; the new standard is more concerned with the life specific green technology to the people to improve the living environment. Green buildings pay more attention to the deep-seated demand for the human living environment and healthy buildings and pay more attention to the health of personnel [24].

In the past, the most used questionnaire for constructing evaluation system indicators was the Delphi expert questionnaire method, through which experts' opinions on indicators were repeatedly solicited, summarized and modified and finally used formed the basic unanimous opinion of experts. The fuzzy Delphi method is a good way to predict the results. In contrast, the fuzzy Delphi method can overcome the ambiguity and uncertainty problems of the Delphi method in the investigation when constructing green building evaluation indexes [25], and the constructed building evaluation indexes are more objective and scientific. In terms of practical application, the hierarchical analysis

method has been used by many experts and scholars over many years of research. The use of hierarchical analysis can be used to simplify and draw conclusions that are scientific and accurate. Second, the solution process of using hierarchical analysis is clear and makes it easy to organize ideas, which can ensure the accuracy of the results [26]and build a green building evaluation system that is optimized for the country, province and city as well as the region [27].

However, a green building is an extremely complex system that requires different evaluation systems to support it from the national to the traditional residential building levels within a specific geographical area [28]. Currently, green buildings, as sustainable buildings, are an effective way to achieve the dual carbon goal. However, the latest version of *GB/T50378-2019* "Green Building Evaluation Standard" lacks a calculation model and quantification method for the evaluation index of carbon emissions in each stage of the building life cycle. Compared with international research, research on the calculation of building carbon emissions in China is still immature, and the establishment of a database on building carbon emissions needs to be improved. Although China promulgated the national standard "Building Carbon Emission Calculation Standard" in 2019 to make up for the deficiency in this regard, the new version of the "Green Building Evaluation Criteria" does not have the relevant hard requirements of the "Building Carbon Emission Calculation Standard" and lacks targeted calculation data, and thus, it cannot meet the existing requirements for constructing green building evaluation indexes. With the low-carbon and dual-carbon policies, domestic scholars began to establish carbon calculation models for typical green civil buildings based on life cycle theory for different regions [29]; therefore, it is of great practical significance to incorporate building life cycle carbon emission indexes and calculation models into green building evaluation.

The objectives of this study under carbon emissions intervention were as follows:(1) establish a life-cycle carbon emission accounting model for traditional residential houses; (2) compare and analyze *DBJ52/T065-2017* "Green Building Evaluation Standards of Guizhou Province" and the indoor and outdoor heat and humidity environments of the actual measured residential houses and refine the important factors about regional green buildings; The purpose of this study was to explore the construction of a building life cycle carbon emission model for traditional residential buildings in the context of carbon emissions. The research results can improve the building life cycle carbon emission system in China and provide a scientific evaluation method for quantitative research on zero-carbon and low-carbon buildings.

2. Research areas and information

2.1. Research areas

The energy saving of rural residential buildings is a key field and an important link for China to achieve the goal of "2030 carbon emission reduction". China's "Carbon Peak in Urban and Rural Construction Implementation Plan" proposes to promote the construction of green and low-carbon rural housing, promote the large-scale development of low-carbon buildings, and encourage the construction of zero-carbon buildings in rural areas. There are many minority characteristic villages in Guizhou Province, and from the distribution of national and provincial minority characteristic villages, Qiandongnan Prefecture occupies the first position of minority villages in the province; the Dong ethnic group is an important part of the minority in Qiandongnan, and the number of characteristic villages ranks among the top three in the state. Most are distributed in nine counties, such as Congjiang, Rongjiang, and Liping, as marked in the green block of Figure 1. To ensure that the residential physical environment was measured with sufficient sample size, the sample was selected from five representative Dong traditional villages: Biapa Village, Xiage Village, Tangan Village, Gaozeng Village, Zhaoxing Village (*from the official website of Chinese Traditional Villages, http://www.chuantongcunluo.com/*).
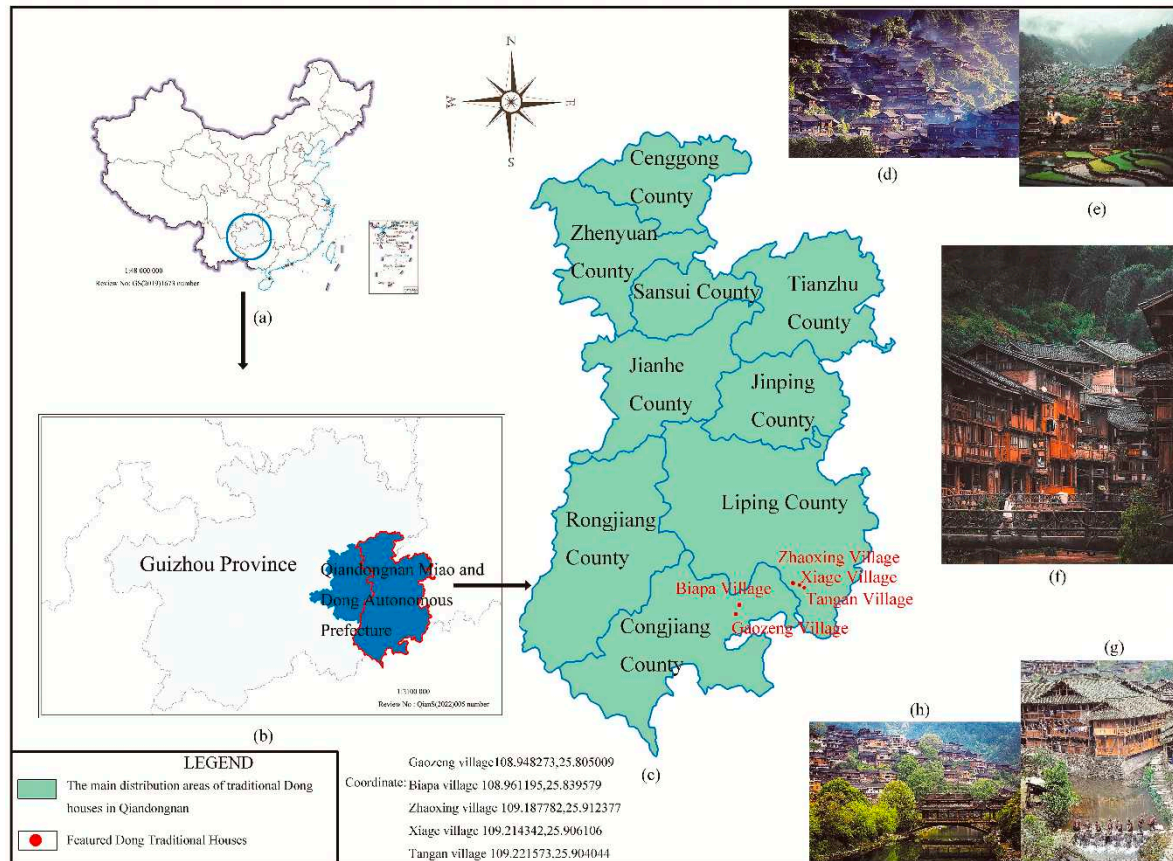
Figure 1. (a) Location of Guizhou Province in China; (b) The geographical location of Qiandongnan Prefecture; (c)The main distribution areas of Dong traditional dwellings in Qiandongnan; (d),(e),(f),(g),(h)The current situation of Dong traditional dwellings in Qiandongnan.

2.2. Physical environment measurements of civil houses

Over time, there have been many studies on the physical environment of buildings, and the thermal environment of buildings is the most important part of the physical category of buildings; thus, the thermal environment received the earliest human research and attention. Domestic and foreign scholars of the physical environment have also focused more on the thermal environment of buildings. The main factors affecting the thermal environment of buildings are determined by the indoor and outdoor thermal environments of buildings, namely, the indoor air temperature, humidity, heat emitted from production and life, outdoor air temperature, humidity and wind, and rain and snow. Using relevant instruments to take actual measurements, the indoor and outdoor air temperatures (Ta), the relevant humidity (RH), and the black bulb temperature (Tg) were selected for actual measurement in this study.

Actual measurement time: When conducting the actual measurement, the local winter and summer representative extreme weather times were selected as follows: winter: January 15, 2022, continuous temperature testing time of 24:00 h; summer: July 24, 2022, continuous temperature testing time of 24:00 h; method: indoor and outdoor halls, bedroom layer measurement point location temperature and humidity for 24 hours of continuous testing, outdoor air temperature and humidity measurement points 1 arranged 1 m from the wall; indoor air temperature and humidity measurement points 2 hall, bedroom, the instrument is arranged in the center of the room, 1 m from the ground; every hour the instrument automatically collects a set of data, the measured meteorological parameters include the air temperature (Ta), relative humidity (RH) and black ball temperature (Tg). Table 1 shows the basic information such as the accuracy and range of the measurement instruments. Therefore, the instruments were in compliance with the *ASHRAE*

Standard 55-2017 [30], as shown in Table 1. *ASHRAE* stands for the American Society of Heating, Refrigerating and Air-Conditioning Engineers.

Table 1. Experimental equipment information.

Parameters	Unit	Instrument Model	Instrument parameters	Parameter Value	Function	Time
Temperature	°C	JT2011 Black Ball Thermometer	Temperature range	0~50°C (32~122°F)	Air temperature	1h
			Accuracy	±0.8°C		
			Black ball size	Diameter 75mm	Wet bulb temperature	
		AT-380 infrared thermometer	Temperature range	-50~380°C	Ground temperature	1h
			Precision	±2%	Wall temperature	
		JTR08 Temperature and Humidity Meter	Precision	±0.3°C ±1.5%	Indoor and outdoor air temperature	1h
Humidity	%	JT2011 Black Ball Thermometer	Measurement Range	0~100%RH	Air Relative Humidity	1h
			Accuracy	±3%		

2.3. Scope of carbon emissions accounting for traditional residential buildings

From a large number of studies in the literature, it was found that the scope of carbon emissions accounting for buildings still differed to some extent. The current research on carbon emissions accounting in the field of construction is mainly divided into two levels: one is the micro level, i.e., the longitudinal life-cycle carbon emissions accounting of single building units, and the other is the macro level, i.e., the accounting of global, national, provincial and municipal regional building carbon emissions. The measurement of microscopic single building carbon emissions is mainly used for the determination of single building carbon emission levels when carrying out green building evaluation and building carbon emissions trading. This paper focused on the carbon emissions of the life cycle of traditional residential buildings, combining China *GB/T50378-2019* "Building Carbon Emission Calculation Standard" and *CECS 374:2014* "Building Carbon Emission Measurement Standard", from a microscopic single building life cycle carbon emission perspective. It is proposed that the life cycle carbon emissions of traditional residential buildings should include the sum of the carbon emissions from four aspects: the production and transportation stage of building materials, the construction stage, the operation stage and the demolition and disposal stage.

2.4. Carbon emission calculation methods for each stage of the life cycle of traditional residential buildings

At present, the commonly used methods in carbon emissions accounting research are the actual measurement method, carbon emissions factor method and mass balance method. After comparing and analyzing the three methods in terms of their characteristics, advantages, limitations, applicable scales and application statuses, the carbon emissions factor method was found to be most suitable for carbon emissions accounting in the construction field. The carbon emissions factor method is the most dominant method used for calculating carbon emissions and is also the method used in the Standard for Carbon Emission Calculation in Buildings (from *GB/T50378-2019* Standard for Carbon Emission Calculation in Buildings). Therefore, the carbon emissions factor method was used in the study for carbon emissions accounting of traditional residential buildings. The functional unit for carbon emissions accounting of the life cycle of traditional residential buildings is the carbon emissions per

square meter of a building per year, and the unit of measurement is $kgCO_2eq/(a \cdot m^2)$, which is calculated using the carbon emissions factor method in the 2006 *IPCC* Guidelines for National Greenhouse Gas Inventories. It is calculated by multiplying the materials, energy and machinery used in each stage of the building life cycle with their corresponding carbon emissions factors to find the sum.

That is, total carbon emissions = total building life cycle (TW) × emission factor (EF)

where the total building life cycle (TW) is the amount of building materials consumed and the total amount of energy consumed in each activity, and the emission factor (EF) is the amount of carbon dioxide equivalent produced per unit of building activity data, also known as the carbon emissions factor.

According to the definition of the scope of carbon emissions accounting for the life cycle of traditional residential buildings, the whole life cycle of residential buildings has four stages: production and transportation of building materials, construction, operation and demolition and disposal. Combined with the evaluation requirements of the national standard *GB/T50378-2019* "Green Building Evaluation Standard" and factors such as the geographic location and natural environment of Qiandongnan, the total carbon emissions of the building life cycle are the sum of the carbon emissions of each stage, and the calculation formula is as follows.

$$E_q = E_{sy} + E_{sg} + E_{yy} + E_{cc} \tag{1}$$

Type: E_q - indicates the total carbon emissions over the lifetime of the traditional dwelling ($kgCO_2eq$).

E_{sy} - indicates the carbon emissions during the production and transportation phase of the building materials ($kgCO_2eq$).

E_{sg} - indicates the carbon emissions during the construction phase of the building ($kgCO_2eq$).

E_{yy} - indicates the carbon emissions during the operational phase ($kgCO_2eq$).

E_{cc} -indicates the carbon emissions from the dismantling and disposal phase ($kgCO_2eq$).

2.5. Selection of carbon emissions impact factors for traditional residential buildings

The Dong traditional dwellings in Qiandongnan still retain wood as the main building support and maintenance structure from ancient times to the present. In this study, the building types involved refer only to traditional residential dwellings, while the energy used in the operation of residential dwellings mainly refers to the energy consumed by rural households for cooking and heating. The main types of energy used in operation are electricity and biomass (straw and fuel wood). Among them, biomass energy consumption is an important part of rural residential energy use. Building construction activities involve many energy-use aspects, and this study considered mainly the energy consumption involved in the production of building materials and the transportation and construction of building materials. The production of building materials refers to the process from the entry of raw materials into the factory to the delivery of finished building materials. The transportation of building materials refers to the process from the delivery of building materials to the arrival of building materials at the construction site. The energy consumption of the construction stage mainly includes the energy consumption of construction personnel and on-site construction equipment, and the demolition and disposal stage is the energy consumption of on-site construction personnel carbon emissions caused by the energy consumption of the demolition of buildings and that of various machinery, the carbon emissions from the transportation and disposal of construction waste, and the carbon emissions from the recycling of construction materials. In this study, the carbon emissions factors were selected from four aspects: energy and fuel, building materials, transportation and human and mechanical equipment.

3. Methods

The technical framework of this study is shown in Figure 2, which outlines the research structure, data sources and methods of this study.
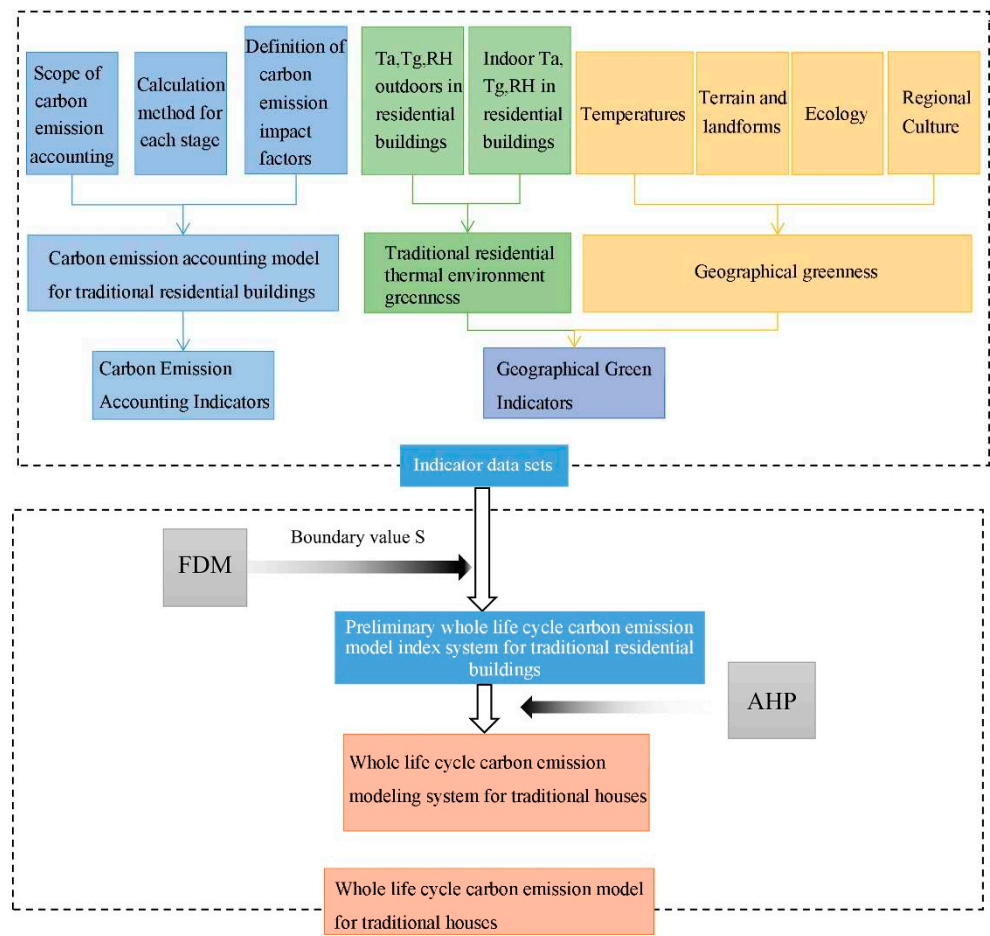

Figure 2. The technical framework of this study.

3.1. Fuzzy Delphi method (FDM)

Combining fuzzy mathematical theory (*FT*) with the Delphi method (*Delphi*), statistical analysis and fuzzy calculations were used to transform the uncertainty and vagueness of subjective expert opinions into quasi-objective data to achieve the desired research objectives [25]. The fuzzy Delphi method starts by asking experts' opinions in the form of an expert questionnaire based on qualitative and quantitative methodological indicators, each of which contains two important components, namely, the importance level indicator and the acceptable range indicator. Importance degree: is to assess the importance of this indicator to the previous level of evaluation, and fill in a single value representing the importance of this indicator. Acceptable range: The acceptable range for evaluating the importance of this indicator to the previous level of evaluation，expressed as the maximum value O^i and the minimum value C^i . Each indicator has three key values: "most conservative perception", "most optimistic perception" and "single value" [31]. After removing any extreme values that are greater than two times the standard deviation value for each indicator, the minimum, maximum, and geometric mean values of the remaining three key values were calculated, i.e., the minimum value C_L^i , the geometric mean C_M^i , and the maximum value C_U^i for the "most conservative perception value" and the "most optimistic perception value" O_L^i , geometric mean O_M^i , maximum O_U^i , and minimum, maximum, and geometric mean in "single value". The fuzzy triangular number method and the gray correlation analysis method were used to integrate the expert opinions and judge whether the expert opinions reached convergence, and only after the opinions converged could we

calculate the expert opinion leveling degree and whether it was rigorous and reasonable. The fuzzy triangular numbers of the "most conservative perception value" and "most optimistic perception value" of each index i were established as follows:

$$C^i = (C_L^i, C_M^i, C_U^i), O^i = (O_L^i, O_M^i, O_U^i) \tag{2}$$

$$M^i - Z^i = M^i \left(O_M^i - C_M^i\right) - Z^i \left(C_U^i - O_L^i\right) \tag{3}$$

Using Formula 3 to calculate the gray area, if the result of $M^i - Z^i$ is positive, it means that the experts' opinions are converging and the evaluation index has reached convergence; the opposite indicates the experts' opinions are not convergent and have not reached convergence, and a second questionnaire survey is needed. The higher the value is, the higher the degree of consensus among experts and the higher the importance of the index, as shown in Figure 3.
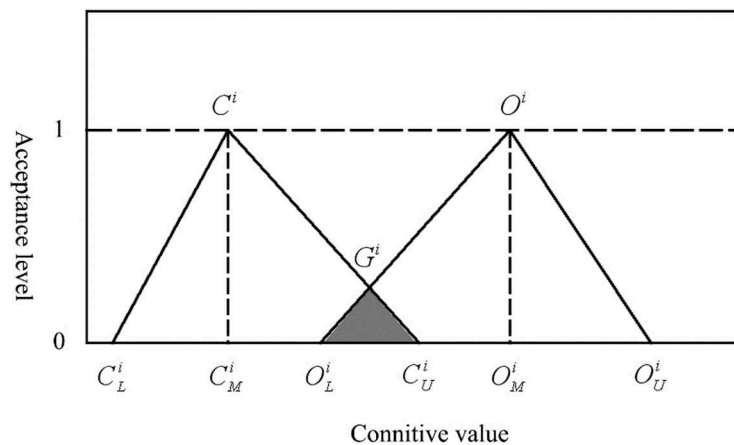

Figure 3. Schematic diagram of double triangular fuzzy number.

By setting the threshold value *s*, the indicators with insufficient importance are excluded. The threshold value *s* can be set according to expert opinion or related literature, or the geometric mean of the three key values of all the indicators to be screened can be calculated by taking the geometric mean of the three key values of all the indicators to be screened and screening out the appropriate number of indicators that are considered important by experts. In this study, the threshold s was set by using the geometric mean of the three key values of all the assessment indicators to be screened and then calculating the geometric mean of *s*.

3.2. Analytical hierarchy process (AHP) analysis

Hierarchical analysis combines qualitative and quantitative approaches to decompose complex problems into different structural levels of simplicity [26] and uses a two-by-two comparison of indicators to derive the ratio of relative importance among the levels and thus the weights among the levels. The basic steps are as follows.

3.2.1. Construct a hierarchical model based on the structure of indicators

First, based on life cycle carbon emissions modeling indexes of green buildings of traditional residential houses discussed in this study, for the purpose of relying on each evaluation index of traditional residential houses, the evaluation indexes involved the whole information of the evaluated target, and the indexes involved different levels and were divided into several levels to construct a hierarchical model.

3.2.2. Construction of the judgment matrix

According to the constructed hierarchical model, the indicators at the same level were compared with each other to determine the weight that an indicator received at the same level, and based on this quantification of importance, a judgment matrix was constructed. $u = \{u_1, u_2, u_i, \ldots\ldots, u_n\}$ equation, $u_i \in U, (i = 1, 2, \ldots\ldots, n)$. To determine the degree of weight that a certain indicator occupies in the whole criterion layer, the weight of the indicator in the whole criterion layer was determined by comparing the indicator with each indicator under the criterion layer in turn. u_{ij} denotes the importance of element i and j element, and the constructed judgment matrix is denoted by $A = \left(u_{ij}\right)_{m \times n}$. That is:

$$A = \left(u_{ij}\right)_{m \times n} = \begin{bmatrix} u_{11}u_{12}\ldots u_{1n} \\ u_{21}u_{22}\ldots u_{2n} \\ \ldots\ldots\ldots \\ u_{m1}u_{n2}\ldots u_{mn} \end{bmatrix} \tag{4}$$

Use saaty nine scale method，the results obtained by comparing the indicators within the criterion layer of the same hierarchy were quantified to obtain nine scales, and the importance of a single indicator relative to another was obtained by describing these scales in detail, as shown in Table 2.

Table 2. Importance differentiation scale.

Scale value	Definition
1	Same importance
3	The former is slightly more important than the latter
5	The former is clearly important compared to the latter
7	The former is strongly important compared to the latter
9	The former is absolutely important compared to the latter
2, 4, 6, 8	denotes the middle value of the above two adjacent scales

Construct the judgment matrix $A = \left(u_{ij}\right)_{m \times n}$, satisfying the conditions that (1) $u_{ij} > 0$, (2) $u_{ij} = \dfrac{1}{u_{ij}}$, and (3) when $u_{ij} = 1$, then the matrix $A = \left(u_{ij}\right)_{m \times n}$ becomes a positive mutual inverse matrix.

3.2.3. Weight calculation method

After constructing the judgment matrix $A = \left(u_{ij}\right)_{m \times n}$, the weight value of each individual index was calculated by the sum and product method or the square root method.

For the judgment matrix:

$$A = \left(u_{ij}\right)_{m \times n} = \begin{bmatrix} u_{11}u_{12}\ldots u_{1n} \\ u_{21}u_{22}\ldots u_{2n} \\ \ldots\ldots\ldots \\ u_{m1}u_{n2}\ldots u_{mn} \end{bmatrix} \tag{5}$$

Normalizing each column of the vector of A yields:

$$w_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}}; \tag{6}$$

w_{ij} Will be summed by row to obtain:

$$w_{ij} = \frac{a_{ij}}{\sum_{j=1}^{n} w_{ij}} ; \qquad (7)$$

Finally, it was normalized, that is, the exact value of the weight value vector for the one-criterion layer of

$$w_i = w_i / \sum_{i=1}^{n} w_i, w = (w_1, w_2, ..., w_n) \qquad (8)$$

3.2.4. Calculate the approximate value of the maximum characteristic root w_i

The approximate value of the maximum characteristic root is obtained by calculating:

$$\lambda = \frac{1}{n} \sum_{i=1}^{n} \frac{(Aw)_i}{w_i} \qquad (9)$$

$$Aw = \begin{bmatrix} u_{11}u_{12}...u_{1n} \\ u_{21}u_{22}...u_{2n} \\ .... \\ u_{m1}u_{n2}...u_{mn} \end{bmatrix} \begin{bmatrix} w_1 \\ w_2 \\ ... \\ w_n \end{bmatrix} = a_{i1}w_1 + a_{i2}w_2 + ... + a_{in}w_n \qquad (10)$$

3.2.5. Consistency test

The established model was tested to see if it passed the consistency test by judging a specific value. The test formula is as follows: $CR = \dfrac{CI}{RT}$. When $CR<0.1$, the model achieves the required consistency; Conversely, when $CR \geq 0.1$, the model does not meet the consistency test, and the model needs to be adjusted to meet the required values.

3.2.6. Calculation of weights for each level of indicators of traditional residential buildings

The detailed calculation of each index was carried out by *yaahp* software, and according to the model that was established in this paper, the respective weight values of each index was calculated so that different weight tables for different index layers were derived.

4. Results

4.1. Building material production and transportation stage

Qiandongnan prefecture of Guizhou, has special topography and geography, and the forest area of the whole region occupies more than *67%* of the national forest area (*from Qiandongnan Forestry Bureau, http://ly.qdn.gov.cn/*), but the state has strict requirements for the cutting of forest trees to protect the Dong architecture with ethnic characteristics. Thus, the Qiandongnan state according to the Forest Law of the People's Republic of China and the State Council Management Measures for the Renewal of Forest Harvesting Sites" and related regulations the "Measures for the Renewal of Harvesting Sites in Qiandongnan Prefecture" were formulated, and after residents cut down the needed timber according to their requirements, the harvesting sites should be completed for reforestation in the current year or the following spring. The production and transportation of materials was divided into two parts: production of building materials and transportation of building materials:

$$E_{sy} = C_s + C_y \qquad (11)$$

Type: E_{sy} - carbon emissions from the production and transportation phase of building materials ($kgCO_2eq$).

C_s - indicates the carbon emissions from the production of construction materials ($kgCO_2eq$).

C_y - indicates the carbon emissions from the transportation of construction materials ($kgCO_2eq$).

Carbon emissions are calculated for each phase as follows:

Carbon emissions from the production of construction materials C_s, the carbon emissions from the production of construction materials refer to the carbon emissions from the development of raw construction materials, the transportation to processing plants and the energy consumed in the production of materials, which can be obtained from the product of the consumption of construction materials and the carbon emissions factor per unit of construction materials, calculated as follows:

$$C_s = \sum_{i=1}^{n} m_i \times EF_i \tag{12}$$

Type: n - the type of building materials.

m_i - the amount of building materials used in category i.

EF_i - the carbon emissions factor for the building materials of category i.

Carbon emissions from transportation of construction materials C_y, the carbon emissions from material transportation are mainly related to factors such as the mode of transportation, transportation distance and transportation volume of materials. The road traffic situation is complicated by high mountains, narrow roads, sharp curves, and the poor resistance of road foundations in the territories of Qiandongnan Miao and Dong Autonomous Prefecture. According to relevant studies, generally for roads with large slopes and poor road surfaces, transporting the same weight of goods by the same transport mode consumes more energy than when transportation occurs roads with small slopes and good levelness; therefore, when calculating the amount of energy consumed by the road conditions for transportation into villages in the state, statistics can be made according to the actual situation and fuel consumption, and the calculation formula is as follows:

$$C_y = \sum_{i=1}^{n} M_i \times D_i \times EF_i + \sum_{j=1}^{m} M_j \times EF_j \tag{13}$$

Type: n n- the number of types of building materials.

M_i - the consumption of building materials from category i.

D_i - the average transport distance of the transport of building materials from category i.

EF_i - the carbon emissions factor per unit weight of transportation distance for the i type of building material.

m - the number of transport mode categories.

M_j - the actual amount of energy consumed by each mode of transport.

EF_j - the carbon emissions factor per unit mass per unit transport distance for transport mode j.

4.2. Construction phase

The construction of rural houses is self-built, and a construction team basically builds each house. The team mainly relies on manpower, and the workers start the construction with their years of accumulated experience. This construction method can start quickly to improve the project's progress and shorten the construction period; therefore, there are few opportunities to use machinery and equipment during the construction process, and the carbon emissions at this stage come from the CO_2 emitted by the construction personnel on site due to concentration and the carbon emissions generated during the use of machinery and equipment. The carbon emissions released from the process of construction machinery are mainly generated by the energy consumption of diesel,

gasoline and electricity consumed by the operation of machinery. The calculation formula is as follows:

$$E_{sg} = \sum_{i=1}^{n} TB_i \times EF_i + \sum_{j=1}^{m} P_j \times EF_j + \sum_{k=1}^{d} B_k \times EF_k \qquad (14)$$

Type: n - the number of mechanical types.

TB_i - the number of machinery units used for machinery of category i during the construction phase of the building.

EF_i - the carbon emissions factors released by construction machinery of category i.

m - the number of types of construction methods in the construction process.

P_j - the amount of construction for each construction method.

EF_j - the carbon emissions factor for each construction method.

d - the number of construction workers.

B_k - the number of working days.

EF_k - the artificial carbon emissions factor, taken as *7.30 kgCO₂/(man-working day)*.

4.3. Operation phase

The carbon emissions in the building operation phase mainly involve the comprehensive calculation of carbon emissions from energy consumed by air conditioning, heating, domestic hot water, lighting, and ventilation, as well as carbon reductions from renewable energy systems and building carbon sinks. However, the operational energy consumption of rural buildings is influenced not only by local climatic conditions and economic factors but also by many uncertain factors, such as the ethnic background, cultural quality, and behavior of indoor occupants. Furthermore, a hot summer and cold winter building climate is typical in Qiandongnan, Guizhou. However, the rural areas in the state seldom use air conditioning for cooling in summer and still retain the habit of burning charcoal for heating in winter; therefore, burning charcoal for heating in winter is the main energy consumed by residential dwellings. With the development of society, although household appliances have become popular, only televisions are used every day with the exception of lamps and lanterns for lighting, which are necessary for daily life. In addition, high-grade household appliances such as refrigerators, air conditioners and computers have not yet become popular.

With the deepening of China's awareness of the ecological environment, rural dwellings are added to green building technology or renewable energy systems when new and existing dwellings are reconstructed to improve the living environment of residents and the protection of the natural environment. In Qiandongnan, as a forest resource with more than *67%* of the national forest area, the local dwelling buildings are still mainly made of wood, which is a renewable green material and has the function of long-term carbon storage. In summary, the carbon emissions of the building operation stage are calculated as follows:

$$E_{yy} = \left(\sum_{i=1}^{n} m_i \times EF_i + M \times EF_m - \sum_{i=1}^{n} R_i \times EF_i - LH \right) \times Y \qquad (15)$$

Type: n - the number of energy types.

m_i - the annual consumption of energy in i.

EF_i - the carbon emissions factor of the i-*th* energy source.

M - the annual consumption of charcoal.

EF_m - the carbon emissions factor for charcoal.

R_i - the annual savings of the i-*th* energy source.

LH - the annual carbon reduction of the green system.

Y - the life of the building.

4.3.1. Calculation of energy consumption and carbon emissions

Energy consumption data in the operation phase of buildings can be obtained through actual surveys and statistics, and when specific values are not available, they can be calculated using relevant energy consumption simulation software. Statistical data for domestic surveys were mainly obtained from the China Energy Statistical Yearbook, the China Rural Statistical Yearbook and statistics from government authorities at all levels from 2001-2019. Among the more mature energy consumption simulation software both at home and abroad, *DeST* has a strong geographic presence, and this energy consumption software can be used to simulate the building operation phase and calculate the carbon emissions in this phase.

4.3.2. Carbon reductions from renewable energy, plants, and building wood carbon sinks

At present, renewable energy systems include solar domestic hot water systems, photovoltaic systems, ground source heat pump systems and wind power generation systems, combined with the current national standard "Green Building Evaluation Standard" *GB/T 50378* for renewable energy in three forms: renewable energy to provide domestic hot water, air conditioning with cold and heat, and electricity. These three forms correspond to the solar photo thermal system, ground source heat pump system (including the buried pipe type and water source type), solar photovoltaic power generation system, etc. (from *GB/T51366-2019* "Carbon Emission Calculation Standard for Buildings"). The pristine green mountains and water and farming crops in Qiandongnan have provided abundant biomass for many years. The development of rural renewable energy in Qiandongnan over time has been based mainly on the utilization of biomass energy supplemented by micro-hydropower and solar energy. The utilization of biomass energy is also based mainly on the burning and utilization of fuel wood (called fuel wood in rural areas) and on crop straw, which comes from forestry biomass and agricultural biomass. Fuel wood does not contain harmful elements such as sulfur and does not pollute the atmosphere when burned, making it a clean fuel; in contrast, the direct burning of straw will produce many harmful gases such as carbon dioxide, which cause atmospheric pollution. Thus, there must be a method of turning straw into clean energy, e.g., a special boiler inside the combustion, so that the waste can be converted to clean fuel or straw processing called clean energy fuel. However, in the territory of Qiandongnan, due to various factors such as transportation and economics, the region does not currently have the ability to turn straw into clean energy. Therefore, this study in the residential area focused on the following: apply the energy system of renewable energy directly deducted from the consumption of fuel wood; give the solar thermal system energy and photovoltaic power generation system an energy calculation formula and install the method in rural areas using these systems, and calculate the annual energy provided according to the local climate, the amount of sunshine and the relevant design information and product parameters using the calculation formula reference *GB/T51366-2019* "Building carbon emissions calculation standards".

The annual carbon reduction (*LH*) of the greening system is the amount of CO_2 in the atmosphere that is reduced by the vegetation at the building site through photosynthesis, which absorbs CO_2 from the atmosphere and fixes it in the vegetation and soil. There are abundant plant species in Qian southeast China; thus, the intensity of photosynthesis varies among different plant types, and the amount of carbon reduction varies. The amount of carbon reduction of vegetation is affected by the climate, growth environment, species and other factors. Currently, the agriculture and forestry industries have developed relevant calculation methods, such as the Methodology of Carbon Sink Measurement and Monitoring for Bamboo Forestry Projects issued by the State Forestry Administration. However, no official methodology has been issued for the carbon sink methodology of green vegetation in residential buildings. In this paper, we refer to the relevant algorithm in the Technical Assessment Manual for Green Low-carbon Settlements in China for calculation, and the calculation formula is as follows:

$$LH = \frac{\sum_{i=1}^{n} G_{e,i} \times A_{e,i} - 600 \times R \times A_s}{40} \tag{16}$$

Type: n - the different planting methods in the greening system.

$G_{e,i}$ - the carbon sequestration per unit area of 40 years for the i-th planting method.

$A_{e,i}$ - the green area of the i-th planting method.

R - the green space ratio, %.

A_s - the total land area of the building.

4.4. Dismantling and disposal stage

The stage of building demolition is equivalent to the reverse process of building construction. After the demolition of residential houses in Qiandongnan, the building materials were divided into two methods of treatment, namely, recycling and disposal. Metal materials such as steel and aluminum alloy used in residential buildings are recycled, and building materials such as wood and glass, which have been exposed for a long time and are no longer suitable for the recycling of building materials, are processed with certain technologies and used for household items or other objects. For abandoned building materials such as bricks that have lost their load-bearing capacity, a general simple treatment is use as roadbed filling. The calculation formulas are as follows:

$$E_{cc} = Q_{CC} + Q_{fy} + Q_{cl} \tag{17}$$

$$Q_{cc} = \sum_{i=1}^{n} TB_i \times EF_i + \sum_{j=1}^{m} P_j \times EF_j \tag{18}$$

Type: n = the number of types of machinery

Q_{cc} - the carbon emissions from building demolition.

TB_i - the amount of machinery shifts used for machinery of category i in the construction demolition phase.

EF_i - the carbon emissions factors released by the construction machinery of category i.

m - the number of types of demolition methods in the demolition process.

P_j - the amount of construction for each demolition method.

EF_j - the carbon emissions factors for each demolition method.

$$Q_{fy} = \left(\sum_{i=1}^{n} M_i \times D_i \times EF_i + \sum_{j=1}^{m} M_j \times EF_j \right) \times \left[\left(1 - R_{rec,i} \right) \times D_w + R_{rec,i} \times D_r \right] \tag{19}$$

Type: Q_{fy} - the carbon emissions from construction waste transportation.

n - the number of types of building materials.

M_i - the consumption of building materials of category i.

D_i - the average transport distance of the transport of building materials category i.

EF_i - the carbon emissions factor per unit weight of transport distance for the i-th type of building material.

m - the number of transport mode categories.

M_j - the actual amount of energy consumed by each mode of transport.

EF_j - the carbon emissions factor per unit mass per unit transport distance for transport mode j.

D_w - the average transport distance of no recyclable waste from the demolition site to the waste treatment plant.

D_r - the average transport distance of recyclable waste from the demolition site to the recycling station.

$$Q_{cl} = \sum_{i=1}^{n} W_i \times \left(EF_{la,i} \times R_{la,i} + EF_{inc,i} \times R_{inc,i} \right) \qquad (20)$$

Type: Q_{cl} - the carbon emissions from construction waste disposal (including landfill and incineration).

W_i - the total mass of waste of category i.

$R_{la,i}$, $R_{inc,i}$, $R_{rec,i}$ - the proportion of category i waste that is landfilled, incinerated, and recycled, respectively.

$EF_{la,i}$, $EF_{inc,i}$ - the carbon emissions factors for landfill and incineration of category i waste, respectively.

4.5. Selection of carbon emissions factors

4.5.1. Selection of the energy fuel factor

Energy carbon emissions factors can be subdivided into fossil energy carbon emissions factors corresponding to direct carbon emissions and electricity and heat carbon emissions factors corresponding to indirect carbon emissions. According to the energy balance sheet data of Guizhou Province in previous years, heat accounts for a relatively small proportion of domestic consumption, mostly concentrated in industrial consumption, and heat data were missing from 2009-2014. Therefore, in the calculation of carbon emissions from secondary energy consumption in residential life, only carbon emissions from electricity were calculated.

CO$_2$ emissions from fossil fuel combustion are the most important source of greenhouse gases, and accurate accounting of CO$_2$ emissions from fossil fuel combustion is the basis for emission reduction policy formulation and implementation. The accuracy of building carbon emissions accounting comes from the selection of carbon emissions factors. Though the analysis of the current domestic and foreign selection of building carbon emissions factors vary, there are some differences. This paper mainly selected China in 2019 to develop the "building carbon emission calculation standards" in carbon emission factors.

Electricity carbon emissions factor, different regions of China have different grid structures. At present, there is no unified standard for calculating electricity carbon emissions in China, and there are two main electricity carbon emissions factors in the process of accounting for electricity carbon emissions: one is the baseline emissions factor of the regional grid, and the other is the average carbon emissions factor of the regional grid. China has vigorously developed clean energy generation in recent years, and the energy structure in the building operation phase has changed significantly, which has reduced the electricity carbon emissions factor. Therefore, the latest published weighted average of *OM* and *BM* in 2019, was chosen in this study to calculate the electricity carbon emissions of southern residential buildings，The baseline emission factors of regional power grid include power marginal emission factor (OM) and capacity marginal emission factor (BM). The electricity marginal emission factor is used to calculate the carbon reduction of Clean Development Mechanism (CDM) projects in China's key emission reduction areas when the grid is saturated. The capacity margin emission factor is used to calculate the carbon emission reduction under the condition of grid saturation.

4.5.2. Carbon emissions factor of building materials

The acquisition of carbon emissions factors for building materials requires the analysis of the whole process of building material production, which is difficult to calculate because of the wide variety of building materials and the different production and processing processes of different building materials. Currently, there are mature building material databases for building material

carbon emissions factors at home and abroad, but the authoritative database in China is preferred in consideration of the study site. At present, the main Chinese building foundation databases are the China Material Environment Database (*Sino center*), the China Life Cycle Foundation Database (*CLCD*) and the *CTC*-Green Building Materials Evaluation System. The carbon emissions factors of building materials in China's Standard for Calculating Building Carbon Emissions (*GB/T 51366-2019*) were all from the China Life Cycle Foundation Database, and considering the accessibility of data, the relevant data from the China Life Cycle Foundation Database were also selected for the carbon emissions factors of building materials in this study.

4.5.3. Transportation carbon emissions factor

Since there are many types of transportation vehicles and the types and amounts of energy consumed when transporting construction materials vary from one vehicle to another, the carbon emissions generated are also different, and the data are difficult to obtain. Thus, this study used the carbon emissions factors for the transportation of building materials given in the Standard for Calculating Carbon Emissions from Buildings (*GB/T 51366-2019*).

4.5.4. Carbon emissions factors for machinery and equipment

The machinery and equipment involved in this study were mainly construction machinery and equipment used in the building construction and demolition stages, such as cranes, bulldozers, and excavators. Considering the availability and accuracy of data, the carbon emissions factors of machinery and equipment given in the Standard for Calculation of Carbon Emission of Construction (*GB/T 51366-2019*) were used.

4.6. Implementation analysis of Dong traditional houses in Guizhou southeast based on current standards

4.6.1. Limitations of the current standard in terms of temperature

Because of the complex and varied environment and landscape and climate in Guizhou, many indicators and clauses in the Guizhou Green Building Evaluation Standard *DBJ52/T066-2017* are not relevant when evaluating the Dong traditional dwellings in Qiandongnan .
Tier 1 indicators: Energy saving and energy use.
Not enough: For the traditional residents of the Dong ethnic group in Qiandongnan, the winter is damp and cold with a temperature close to 0 degrees due to various factors such as temperature and humidity, and the summer is hot and humid, when the envelope structure of residential buildings will cause a large waste of resources if it cannot play a good role in heat insulation and thermal insulation, which will cause the local residents to cool down in winter and summer by using air conditioners and heat preservation by electric ovens. Therefore, the shape design, orientation arrangement, Window-to-Wall ratio and thermal performance of the building itself are more important in the Qiandongnan region and should not be given a lower rating score. The Qiandongnan Dong villages are mostly combined with mountain contour areas or river valleys in a narrow strip of site selection and construction; due to the low surrounding air pressure, there are often valley winds formed by the local thermal environment, the reasonable use of valley wind resources; therefore, the use of natural ventilation to improve the indoor environment is one of the effective methods and should improve the value of this score.

4.6.2. Limitations of the current standard in terms of terrain

The current Guizhou Green Building Evaluation Standard *DBJ52/T065-2017* is mainly reflected in the land saving and outdoor environment.
Tier 1 indicators: Land saving and outdoor environment.
Not enough: The weight of this indicator is too low for the mostly mountainous region of Qiandongnan.

4.6.3. Limitations of the current standard in the ecological environment

Some indicators in the existing Guizhou green building evaluation system in the first-level indicators of land saving and outdoor environment, material saving and material resource utilization were closely related to the ecological environment.

Tier 1 indicators: Material saving and material resource utilization.

Not enough: The topography of the Qiandongnan region is complex and varied, and the region is rich in forest ring resources to produce wood and stone for local construction. To adapt to this situation, the green building standards should give a higher score to "the use of locally produced wood, stone and other building materials" to better achieve material conservation. The current Guizhou Province "Standard" gives too low a score to this aspect and is not applicable to the unique forest environment of Qiandongnan.

4.6.4. Limitations of the current standard in terms of the regional cultural characteristics

Each nationality has its own unique culture and tradition, and if it does not do a good job in greening the national culture, it will not be recognized by local residents. The regional technical characteristics of the Dong traditional dwellings in Qiandongnan form dry appendage buildings in the mountainous terrain; under the condition of abundant tree resources, the Dong people make use of the materials and make the best use of them in building construction. Second, the natural economy of self-sufficiency has led the Dong people to form a value system based on nature, which is reflected in the spatial form of the villages and single buildings, which can be constructed only as small villages with mainly residential functions and a clear spatial form of functional division within the dwellings. Finally, the Dong people of Qiandongnan China have made use of their unique natural conditions to build a low-carbon and energy-saving water circulation system, and they have a harmonious coexistence of rice, fish and duck production, as well as other national ideals of pursuing a sustainable life cycles.

4.7. Empirical analysis of the physical environment of the Dong traditional dwellings in Qiandongnan

4.7.1. Regional ambient (alleyway) air temperature and wet and black bulb temperature analysis

As shown in Table 3, the average air temperature (*Ta* 35.5°C in summer and *Ta* 6.9°C in winter) and the average black-bulb temperature (*Tg* 38.6°C in summer and *Tg* 7.0°C in winter) of Gaozeng Village were the highest compared to the other four villages in winter and summer because Biapa, Xiage and Tangan Village are mountainous villages built on sunny slopes near water sources. The forest vegetation around the villages can regulate the physical environment of the villages and the external environment of the dwellings, and the microclimate of the areas with a large amount of vegetation can be effectively improved. Although Gaozeng Village and Zhaoxing Village are both flat dam-type villages formed by the impact of rivers causing flat dams, Zhaoxing Village is 180*m* higher in elevation than Gaozeng Village, making the maximum *Ta* and *Tg* in summer lower than those in Gaozeng Village.

Table 3 shows that the average *Ta*, the highest *Ta* and the lowest *Ta* of Lane 1 are higher than those of Lane 2 in winter, and the average *Ta*, the highest *Ta* and the lowest *Ta* of Lane 1 *Ta* are lower than those of Lane 2 *Ta* in summer because although Lane 1 and Lane 2 are parallel east–west, Lane 1 is wider than Lane 2, and Lane 1 (*D/H > 1*) and Lane 2 (*D/H < 1*). In winter, as Lane 2 is narrow, the cold wind passes through and makes *Ta* fluctuate greatly compared with Lane 1. Therefore, under the condition that the wind direction is certain and the road is built downwind, a suitable lane size can change the *Ta* value of the environment at the building site to a certain extent.

Table 3. Ambient (alleyway) air temperature wet and black bulb temperature data in the region.

Season	Site		Ta (℃)			Tg (℃)			RH (%)		
			Mean	Max	Min	Mean	Max	Min	Mean	Max	Min
Winter	Gaozeng Village, Gaozeng Township		6.9	9.9	3.9	7.0	10.6	3.3	74.5	80.2	66.7
	Zhaoxing Village, Zhaoxing Town		6.3	7.3	5.2	6.7	7.9	5.5	75.4	83.9	66.9
	Biapa Village, Gaozeng Township	Lane 1	4.4	5.8	3.0	4.8	5.5	4.1	83.3	87.6	78.9
		Lane 2	4.1	5.6	2.6	—	—	—	—	—	—
	Xiage Village, Zhaoxing Town		3.2	4.5	1.9	3.8	4.9	2.6	84.0	89.9	78.1
	Tangan Village, Zhaoxing Town		3.8	6.2	1.4	4.4	6.9	1.8	77.8	87.2	68.4
Summer	Gaozeng Village, Gaozeng Township		35.5	44.5	26.4	38.6	48.9	28.3	57.8	72.3	43.3
	Zhaoxing Village, Zhaoxing Town		32.4	36.7	28.1	32.7	37.9	27.5	71.1	82.1	60.1
	Biapa Village, Gaozeng Township	Lane 1	30.5	33.9	27.1	31.7	36.3	27.1	70.1	83.5	56.7
		Lane 2	32.8	34.9	27.7	—	—	—	—	—	—
	Xiage Village, Zhaoxing Town		29.9	34.8	25.0	30.7	35.1	26.2	67.0	80.3	53.6
	Tangan Village, Zhaoxing Town		29.2	33.5	24.8	29.7	34.3	25.1	73.0	82.3	63.7

4.7.2. Analysis of the internal environment of traditional houses

As shown in Table 4 shows that the summer village dwelling *Ta* is as follows: Gaozeng Village (*35.5℃*) > Biapa Village (*34.6℃*) > Xiage Village (*34.5℃*) > Zhaoxing Village (*34.3℃*) > Tangan Village (*32.9℃*), the bedroom *Ta* of Xiage Village (*34.5℃*) > Gaozeng Village (*34.1℃*) > Biapa Village (*34.0℃*) > Zhaoxing Village (*33.2℃*) > Tangan Village(*32.3℃*) ,this is because many factors determine the indoor *Ta*, mainly because these two dwellings have a common feature: the opening ratio of doors and windows in the building is small and some walls do not have windows. The maximum, minimum and average *RH* values of the dormitory and bedroom of Gaozeng Village were the lowest among the five residential measurement points of *RH* in winter and summer because the vegetation cover of the Gaozeng Village residential site is small compared with the other four measurement points, and plants have the function of moisture retention. The shielding effect of plants reduces the transpiration of water, making the indoor *RH* of the other four residential houses higher than that of Gaozeng Village at the five points.

In winter, excluding the influence of the altitude factor, the average indoor *Ta* of the selected village residential buildings, except for Xiage Village, was as follows: bedroom *Ta* > hall *Ta* > outdoor *Ta*, mainly because the outdoor open space is directly affected by the external climate, while the building envelope of residential buildings can delay the rapid change of indoor temperature with the change of outdoor temperature. Thus, the indoor temperature is higher than the outdoor temperature, and the bedroom is a relatively small space; as a result, the bedroom loses the least amount of heat during the day. The average indoor/outdoor *Ta* of Xiage Village in winter follows the order of living room > bedroom > outdoor because the Dong people have implemented the habit of "fire ward" in winter since ancient times, and fire pits are usually placed in the hall, making the average temperature of the hall higher than that of the bedroom during the day.

Table 4. Indoor air temperature and humidity and related humidity data of traditional residential houses.

Season	Site	Space	Ta (℃)			Tg (℃)			RH (%)		
			Mean	Max	Min	Mean	Max	Min	Mean	Max	Min
Winter	Gaozeng Village, Gaozeng Township	Hall	7.5	10.4	4.5	7.9	10.9	4.8	71.8	80.4	63.1
	Zhaoxing Village, Zhaoxing Town	Hall	6.8	7.6	6.0	7.3	8.1	6.5	77.4	85.9	68.9
	Biapa Village, Gaozeng Township	Hall	4.9	6.0	3.8	5.1	6.2	4.0	84.3	90.8	77.8
	Xiage Village, Zhaoxing Town	Hall	4.7	6.8	2.5	4.6	6.8	2.4	84.6	90.8	78.3
	Tangan Village, Zhaoxing Town	Hall	5.0	7.2	2.8	5.6	7.9	3.2	77.7	87.0	68.4
	Gaozeng Village, Gaozeng Township	Bedroom	8.7	11.6	5.7	9.1	12.2	5.9	73.5	82.7	64.2

	Zhao Xing Village, Zhaoxing Town	Bedroom	6.8	7.8	5.8	7.0	7.8	6.1	75.5	85.2	65.7
	Biapa Village, Gaozeng Township	Bedroom	5.1	6.2	3.9	5.1	6.3	3.9	85.3	87.2	83.4
	Xiage Village, Zhaoxing Town	Bedroom	4.0	5.6	2.3	4.4	5.8	3.0	85.5	89.9	81.1
	Tangan Village, Zhaoxing Town	Bedroom	5.3	7.3	3.2	5.5	7.6	3.4	83.4	88.9	77.8
Summer	Gaozeng Village, Gaozeng Township	Hall	30.5	35.5	25.5	31.8	36.6	27.0	67.3	76.7	57.8
	Zhao Xing Village, Zhaoxing Town	Hall	30.8	34.3	27.3	31.2	34.7	27.7	74.9	84.3	65.4
	Biapa Village, Gaozeng Township	Hall	29.9	34.6	25.1	30.1	34.3	25.8	72.2	85.2	59.2
	Xiage Village, Zhaoxing Town	Hall	30.4	34.5	26.3	30.7	34.5	26.8	73.4	81.4	65.3
	Tangan Village, Zhaoxing Town	Hall	29.0	32.9	25.0	29.2	32.7	25.6	72.8	82.4	63.2
	Gaozeng Village, Gaozeng Township	Bedroom	30.1	34.1	26.1	31.0	35.7	26.3	67.0	77.8	56.1
	Zhao Xing Village, Zhaoxing Town	Bedroom	30.1	33.2	27.0	31.9	35.9	27.9	73.3	85.4	61.2
	Biapa Village, Gaozeng Township	Bedroom	30.0	34.0	26.0	30.2	34.3	26.1	70.3	81.3	59.3
	Xiage Village, Zhaoxing Town	Bedroom	30.0	34.5	25.4	30.3	34.9.6	25.6	71.0	80.4	61.5
	Tangan Village, Zhaoxing Town	Bedroom	28.7	32.3	25.1	29.1	33.1	25.0	73.7	82.3	65.0

4.8. Constructing locality model evaluation indicators provides important indicator choices

Based on the limitations of green building evaluation indexes in Guizhou Province in terms of temperature, topography, ecological environment and regional culture for the application evaluation of Dong traditional dwellings in Qiandongnan, combined with the field research of Dong traditional dwellings in Qiandongnan and the quantitative analysis of the thermal environment inside and outside the dwellings and villages using relevant instruments, we provide important index choices for the construction of a regional traditional dwelling whole life cycle carbon emission model evaluation index system.

4.8.1. Energy use

Village street building *D/H* (width to height ratio): When the village street building *D/H* (width to height ratio) ≥ *1*, the outdoor environment of residential houses uses the street ratio to form artificial wind ducts in summer to remove the excess heat brought by solar radiation in the street; in winter, it reduces the air circulation of cold outdoor air in the street.

Indoor air circulation: Use the dominant summer wind direction to remove excess heat from the room and increase the comfort of the indoor thermal environment. The further reduces the input of related energy and saves energy.

4.8.2. Site ecology and landscape

Application of plants in the landscape: Using the characteristics of plants themselves, the natural landscape of the village building is shaped by plants, and the visual, physical and psychological comforts of the site around the building are enhanced by the planting techniques with horizontal and vertical layers.

Use of plants in the physical environment: The rational use of plants' own ability to sequester carbon, maintain the humidity of the surrounding air and block solar radiation from affecting the physical environment of residential buildings optimizes the overall quality of the building's indoor and outdoor environments.

4.8.3. Land saving

Building site selection and safety: The all-round use of the local geographical environment for building site selection and safety considerations can reduce economic losses due to natural disasters, save resources and reduce the investment of human and material resources.

Building orientation: A reasonable building orientation can reduce the comfort because of cold air entering the room in winter and can form a wind tunnel with doors and windows in summer to remove excess heat from the room and improve the overall thermal stability and comfort of the room.

Building window and door hole ratio: The proportion of the window and door openings in the envelope directly affects the thermal stability of the building's interior, and a reasonable window and door hole ratio largely affects the natural ventilation of the building's interior in summer and the intake of indoor light in winter.

4.8.4. Material saving

Envelope materials: Choosing the right building envelope can improve the indoor thermal environment and enhance the comfort of residents indoors.

4.9. Life-cycle carbon emission model of traditional Dong houses in Qiandongnan

4.9.1. Composition of the indicator system

Combining qualitative analysis and quantitative physical environment measurements, we initially constructed 4 primary indicators, 7 secondary indicators and 17 tertiary indicators, as shown in Table 5, following the four principles of scientific selection of indicators, combining qualitative and quantitative factors, highlighting regional characteristics and providing foresight.

Table 5. Preliminary whole life cycle carbon emission model index system for traditional residential buildings.

Target layer	Tier 1 indicators	Secondary indicators	Tertiary indicators
Life-cycle carbon emission model of traditional Dong houses in Qiandongnan	Resource Conservation	Land saving and land use	Village building site selection
			Site safety performance
		Energy saving and energy use	Building orientation
			Building window and door opening ratio
			Village street building D/H
			Internal air circulation of residential houses
	Livable Environment	Site ecology and landscape	Use of plants in the physical environment of buildings
		Outdoor physical environment	Outdoor ventilation conditions
			Regional heat island intensity
	Ethnic Culture	Ethnic architectural features	Building form design
			Building interior space design
			Building layout design
		Ethnic beliefs	Architectural decoration
	Ecological Quality	Whole life cycle carbon emissions of buildings	Building materials production and transportation
			Construction
			Operation and maintenance
			Dismantling and disposal

4.9.2. Determination of model indicators for the whole life cycle carbon emissions of traditional houses

Using the fuzzy Delphi expert questionnaire method, a detailed survey was completed with relevant personnel in three fields: construction experts, architectural designers, and building constructors. The preliminary whole life cycle carbon emission model index system for traditional residential buildings was established by determining the weight scores of each index through the *AHP* method.

A hierarchical analysis method was used to construct a recursive hierarchical structure model of multilevel indicators, and the importance of each indicator was quantified using the hierarchical structure model. Its importance was divided into nine scales, and the importance of the indicators was judged based on the size of the numbers derived from each indicator. After that, a judgment matrix was constructed to compare the weights of two indicators, and then a consistency test was conducted by calculating the maximum eigenvalue and related parameters. Under the condition of passing the consistency test, the weight coefficient of each indicator was calculated, upon which a complete evaluation system was finally constructed. The multilevel structure model was established, the hierarchical structure model used in this paper referred to the typical *AHP* method, and the model was divided into four levels in total, as shown in Table 6.

Table 6. Index weights of the whole life cycle carbon emission model of traditional houses.

Target layer	Tier 1 indicators	Secondary indicators	Tertiary indicators
Life-cycle carbon emission model of traditional Dong houses in Qiandongnan	Resource Conservation	Land saving and land use	Village building site selection
			Site safety performance
		Energy saving and energy use	Building orientation
			Building window and door opening ratio
			Village street building D/H
			Internal air circulation of residential houses
	Livable Environment	Site ecology and landscape	Use of plants in the physical environment of buildings
		Outdoor physical environment	Outdoor ventilation conditions
	Ethnic Culture	Ethnic architectural features	Building form design
			Building interior space design
		Ethnic beliefs	Architectural decoration
	Ecological Quality	Whole life cycle carbon emissions of buildings	Building materials production and transportation
			Construction
			Operation and maintenance
			Dismantling and disposal

Since there were 4 primary indicators, 7 secondary indicators and 15 tertiary indicators in this study, using the professional calculation software of *AHP*, *yaahp*, reduced both the workload and the errors of software calculation. A complete model was created using *yaahp* software, and the software was used to calculate all the indicators of the study by itself, i.e., as shown in Table 7.

Table 7. Weighting score of whole life cycle carbon emission index of traditional houses.

Target layer	Tier 1 indicators	Secondary indicators	Tertiary indicators
Life-cycle carbon emission model of traditional Dong houses in Qiandongnan	Resource Conservation 0.2008	Land saving and land use0.0829	Village building site selection0.0308
			Site safety performance0.0521
		Energy saving and energy use0.1179	Building orientation0.0345
			Building window and door opening ratio0.0363
			Village street building D/H0.0289
			Internal air circulation of residential houses0.0182
	Livable Environment 0.2081	Site ecology and landscape0.0769	Use of plants in the physical environment of buildings0.0769
		Outdoor physical environment0.1312	Outdoor ventilation conditions0.1312
	Ethnic Culture 0.0702	Ethnic architectural features0.0583	Building form design0.0311
			Building interior space design0.0272
		Ethnic beliefs0.0119	Architectural decoration0.0119
	Ecological Quality 0.5209	Whole life cycle carbon emissions of buildings0.5209	Building materials production and transportation0.2489
			Construction0.0450
			Operation and maintenance 0.1605

Dismantling and disposal 0.0665

5. Discussion

5.1. The influence of multidimensional indexes on the construction of different degrees of carbon emission model indexes for the whole life cycle of residential buildings

From Table 7, the weight of the ecological quality index was 0.5209, occupying the first position, and its first-level index was the life-cycle carbon emissions of residential buildings, which was the trend of gradually increasing energy consumption by rural buildings in China since rural revitalization began and the improvement of the economic level and the living standard of residents, and the government has increased the importance of carbon emissions of rural buildings. According to the analysis of the Qiandongnan Statistical Yearbook, the per capita disposable income of rural permanent residents in 2020 was 11,082 *yuan*, a nominal increase of 8.3% over 2019. The per capita living consumption expenditure of rural permanent residents grew from *RMB* 6963 in 2016 to *RMB* 10639 in 2020, with an average annual growth rate of 13.2% (*data from Qiandongnan Statistical Yearbook*). With the improvement of the economic level and living standards, farmers' requirements for their own living environments have increased, the use and renewal of living equipment has accelerated, and farmers have improved the indoor comfort of residential buildings by adding air conditioning and heating equipment, which has increased the carbon emissions of the building life cycle and further increased the energy-saving requirements for rural buildings. As seen in Table 7, the production and transportation phase of building materials and the operation phase of traditional residential buildings each occupied weight scores of 0.2489 and 0.1605, which were higher than the carbon emissions scores of the building construction and demolition and disposal phases because the building materials of traditional residential buildings are mainly wood-based, and wood, the main building material of wood-frame buildings, as well as engineered wood materials have carbon sequestration properties. The carbon emissions flow of wood-frame residential buildings is minimal compared to other structural residential buildings, and the carbon emissions flow in the abandonment and recycling phase is mainly negative, which occupies an important position in the stage of enhancing the carbon emission of optimized residential buildings. Further investment in a range of green building technologies, such as local building materials, solar hot water, and greening systems, in the building operation phase has carbon reduction potential. From Table 7, it was found that the weight of the demolition and disposal stage was higher than that of the building construction stage, mainly because the demolition and disposal stage had more carbon emissions consumed by waste removal, transportation, and recycling than did the construction stage, so more attention should be given to the carbon emissions of this stage and we should invest in optimizing and upgrading more green technologies in this stage.

From the Table 7, it was found that the index weights of healthy livability occupied the second position, mainly because the health and livability indexes were related to both the feeling and the health of people's outdoor activities and ecological protection and affected the indoor environmental quality of buildings and energy savings. Green plants, as an important factor affecting the microclimate of outdoor activity space, can regulate the microclimate of courtyard space to a certain extent and play a role in improving the outdoor thermal comfort of residents. The plant landscape influences the built environment at the level of spatial construction, experiential perception, and cultural cues. The unavoidable effects of environmental changes caused by development activities can be compensated for by outdoor site greening and the three-dimensional greening of buildings. The outdoor microclimate, air circulation, and humidity all affect the outdoor physical environment, and the physical environment can enhance the livability and comfort of traditional villages and improve the outdoor thermal environment of residential areas. According to the Qiandongnan Statistical Yearbook, the Dong population in Qiandongnan increased by 48,000 people from 2016 to 2020, an increase of 3.4%, and the increase in the Dong population requires more attention in terms of planning the environment of rural settlements to create a livable and comfortable outdoor working

environment. It is difficult to have good climate adaptability if the regulation of the building monolith itself is detached from the overall environment of the village.

As seen in Table 7, the weight of 0.2008 was given to resource saving indicators in the first level, and the reason for this phenomenon was related to the fact that rural areas have started to pay attention to building energy efficiency. With the resident demand to improve their habitat and the country's energy shortage in the context of continuing the traditional style and improving building energy efficiency for the sustainable development of traditional villages, rural buildings designed using energy-efficient building methods consume less energy than ordinary Energy-Efficient buildings. Among the factors considered for energy-efficient building design, the high energy consumption and crude energy utilization methods of rural houses have become important constraints on their environmental protection, so it is important to focus on rural ecological environmental protection and building energy conservation. We can see that among the indicators of resource conservation, energy conservation and energy use indicators were weighted close to twice that of the other indicator and occupied a very important position. This result is because in the "energy conservation and energy use" section of the 2019 edition of the standard, compared with the basic content of the 2014 edition, and the further optimization of building energy consumption was encouraged in the improvement and innovation items. At the courtyard level, the choice of south-north orientation layout, a reasonable enclosure method and the layout form indicators could regulate the natural climate and reduce the use of energy. Under the condition that the building orientation prioritized topography, the indoor thermal environment of new residential buildings and the thermal insulation of buildings could be effectively improved by optimizing the construction practices of residential facades.

The culture of ethnic characteristics is also an important part of the construction of Building carbon emission model indexes, and at the level of monolithic construction, the adaptability of building monoliths to the terrain, the building components in response to solar radiation, the building envelope and the building roof slope in response to the climate environment affect the adaptation to the climate natural geographical environment. The construction materials and building shapes of the southwestern dwellings have the characteristics of the low technical, regional and ecological construction techniques of the southwestern traditional dwellings. In addition to the airtightness of the envelope structure and the law of indoor temperature fluctuation, the preservation of the style and architectural decoration details are important objects of attention for the renewal and renovation of traditional houses.

5.2. Limitations and applicability

There are still some shortcomings in this study. First, the service life of residential buildings is long, and the technical skills of residential construction, the characteristics of building energy equipment, and the behavior of occupants will change over time. Thus, the environmental impact of greenhouse gas emissions has a time lag. To achieve a closer assessment of the long-term environmental performance of residential buildings, a dynamic life-cycle assessment method should be considered. However, the research on dynamic life cycle theory is still immature, and the calculation itself is complicated; therefore, the life cycle carbon emissions accounting model of traditional residential buildings established in this paper did not consider the time dimension, which should be studied in subsequent work. Second, for the extraction of local evaluation indexes using physical environment measurements, the measurement time is only one day of the local extreme climate, and the thermal and humid environment is only the measured indoor and outdoor temperature and humidity, so future research should not only increase the measurement time of the local extreme climate but also increase the thermal environment influencing factors to construct more comprehensive green evaluation indexes for traditional houses.

Despite these shortcomings, this study has strong use and application value. The building carbon emissions can be applied to residential houses in regions other than Southwest China to further account for the carbon emissions of residential houses, which has practical significance for the conservation and development of traditional residential houses.

6. Conclusions

To implement the concept of green development, promote the green development of construction and better achieve the goals of energy saving and carbon reductions in the construction industry, building carbon emission evaluation index and green building evaluation system can not only ensure the authenticity of green building energy saving and carbon reduction but also help promote energy saving and carbon reductions in the construction industry. Combined with the regional characteristics of the Dong traditional dwellings in Qiandongnan, the "Whole Life Cycle Carbon Emission Model of Traditional Houses in Qiandongnan", was constructed. (1) The life cycle carbon emission calculation model of residential buildings was divided into four stages: production and transportation of building materials, construction, operation and demolition and disposal. (2) Analyzing the limitations of the existing local standards in China and the actual measurement of the physical environment of the Dong traditional dwellings in Qiandongnan, the 2019 national version of the Green Building Evaluation Criteria was combined with the reorganization and construction of an index system suitable for the Dong traditional dwellings in Qiandongnan, with the following primary indicators: resource conservation, environmental livability, culture of ethnic characteristics and ecological quality, and the following special features: increasing the primary indicators. Under the people-oriented main theme, the new indicators could better reflect the construction of the local environment and the regional characteristics. (3) The carbon emissions generated by construction workers during the construction phase were an important part of the total carbon emissions in this phase, so carbon emissions generated by construction workers cannot be ignored. In this paper, carbon emissions from construction personnel activities were considered in the calculation of the life-cycle carbon emissions of residential buildings, and a corresponding calculation method was proposed. In addition, due to the difference in building types and regions, the carbon sink capacity of wood in the operation stage of the building was not emphasized in previous studies, which will result in errors in the carbon emissions calculation of traditional residential buildings with wood as the main building material; thus, this paper included the carbon sink capacity of wood in the operation stage of the building. In this paper, the carbon emissions reduction from the production stage of building materials was underestimated. To address this issue, this paper considered the carbon emissions of building material recycling in the demolition and disposal stage, which was more in line with the actual situation.

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