Comparative Research on the Low-Carbon Urban Block Morphological Design

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Abstract: Reducing carbon emissions to mitigate global warming is a major problem facing mankind. Since city is the main region of global carbon emission, it is of great significance to promote low-carbon development and build low-carbon city. The urban block scale is the key aspect of the construction of low-carbon city, thus the scientifically compiled urban design guidelines have a kind of quite essential practical guiding value for the construction of low-carbon cities. For this reason, the shortcomings of the methods are summarized in this paper through combing, comparing and analyzing the relevant literature from four aspects of calculation and evaluation of carbon emission in block scale, carbon emission and block shape, optimization design method of low carbon block shape, scientific guidance and control of low carbon block form. Furthermore, the key issues, main problems to be solved and aims of future study are discussed.

1. Introduction

1.1 Urban carbon emission reduction is a major problem confronted by our country at present.

Greenhouse gases and carbon emissions generated by human activities are the important causes of global climate change [1]. From the source of carbon emissions, cities are the concentration of population, construction, transportation, industry, and logistics, but also the concentration of high-energy consumption and high-carbon emissions. Studies indicate that greenhouse gas emissions from various activities in the city account for about 80% of global emissions [2]. Further, urbanization has been proved to have a strong correlation with the increase of carbon emissions [3]. At present, China is the world's largest emitter of greenhouse gases with CO2 emissions of about 8 billion tons in two years, and will continue to soar in the future [4]. Thus, promoting low-carbon development and building low-carbon cities are not only the inevitable choice under the new normal economic situation, but also related to the well-being of the broad masses of our people and the long-term future of our nation.

1.2 Urban block scale is the key aspect of building low-carbon cities

As a space unit enclosed by the city trunk roads, urban block is the "cell" that constitutes the whole space of the city, which is the basic space unit of the urban system to realize the low carbon goal, and the significant content in designing the low-carbon cities. The low-carbon research on urban block scale is not only the synthesis and promotion of micro-level building low-carbon technology research, but also the concrete implementation of macro-level urban low-carbon strategy, which plays a key role in connecting the preceding and the following.

1.3 The typical hot-summer and cold-winter urban central area is conducive to further research and extension of results.

First of all, as the most densely populated and the fastest growing area in China, the hot-summer and cold-winter regions have high energy consumption and great potential for emission reduction in cities and buildings. At the same time, there are two kinds of extreme climate in this area, which involves the complicated problems, such as high design requirements and great difficulty, so it is very meaningful to take it as a breakthrough point. Secondly, dominated by the public buildings and tertiary industry, the urban center is the most concentrated area of urban activities, with large population and high-intensive buildings, but also the most serious problem of carbon emissions in the region. How to optimize the combination and intensive utilization of the space in the center area to realize the development of low carbon and low energy consumption is a subject worth studying.

2. Comparison of domestic and foreign researches

2.1 Calculation and evaluation of carbon emission in block scale

Low-carbon assessment methods for block scale have been developed in many developed countries, which are mostly extended by single building assessment methods, but there are some differences in assumptions, calculation methods, data sources, statistical boundaries, etc. The US LEED-ND mainly evaluates the land location and traffic connection, the block shape pattern, the green infrastructure and the construction and so on [7]. In addition to providing an evaluation tool for the comprehensive performance of the urban built environment, the Japanese CASBEE-UD also determines the effectiveness of urban energy conservation and emission reduction by continuously monitoring the effectiveness of urban environmental policy [8]. In Germany, DGNB-NS comprehensively quantitatively evaluates the sustainability of newly built urban blocks from five aspects: environmental quality, economic quality, social function quality, construction technology quality and process quality, further, it firstly puts forward the calculation method of the whole life cycle carbon emission in the urban block scale [9].

China has yet to promulgate the low-carbon assessment standards for block levels. The main technological innovation of the researchers concentrates upon how to integrate the carbon emission assessment technology with the existing urban planning and design system. For example, by rearranging the detailed categories of activities and emission factors in the national greenhouse gas emission inventory, Ye Zuda established a preliminary assessment method for controlled detailed planning [10]. Qiu Hong et al proposed a method of carbon emission assessment for meso-micro scale urban design projects, the statistical items include the fixed carbon sources, moving carbon sources, carbon emissions from process carbon sources and carbon removals from natural carbon sinks [11].

In general, the above evaluation and calculation methods employ the same basic procedure, that is, the discharge and removal activity of the block is multiplied by the corresponding emission coefficient, and then the sum of the total amount is obtained. The main value lies in solving the problem of scientific management and decision-making in the process of planning. However, as a kind of post-design evaluation, the statistics of carbon emission data is comprehensive and abstract, which is difficult to integrate into the urban design process grasped by form, therefore, the guiding significance of the urban shape design process is relatively weak. In fact, on the meso-micro scale, even if the function type and scale are the same, there are significant differences in carbon emissions from different blocks [12], but the impact of urban morphology is not taken into account in determining the emission coefficient of each evaluation method.

2.2 Correlation analysis between carbon emission and block form

The correlation research between the geometric attributes of urban space and its environmental performance has been attached great importance to by the western academic circles for a long time [13]. In recent years, many scholars have carried out the research on the carbon emission characteristics of urban spatial morphology. The main adopted methods are to obtain urban carbon emission data through literature cases, questionnaires [14][15] or computer simulation [16]of environmental performance. Further, the mathematical relationship between the two methods is established by GIS technology [17] to quantify urban spatial morphology, and then to establish the mathematical relationship between the two methods by the regression model. In addition, the statistics scope of carbon emission includes several sources of carbon emissions from urban buildings (building materials, building operation, transportation, etc.) and the use of renewable energy sources from the perspective of the whole life cycle [18], and can also focus on only a few important aspects [19]. The form representation can be a measure index of urban form [20][21][22] or a type of spatial structure extracted from it [17][23][24].

The further significance of recognizing the mechanism of the effect of morphology on carbon emissions lies in effectively evaluating and comparing the different forms of design schemes, to improve the precision of urban emission prediction at the meso-micro level. For example, Ratti et al coupled the LT (Lighting and Thermal) model with the DEMs (Digital Elevation Models) to simulate the energy consumption characteristics of urban buildings [25]. Other scholars have transformed the urban geometry into a simple representative grid and kept the key information parameters in order to improve the speed of estimating the energy consumption of complex urban buildings [26]. From the perspective of urban morphology typology and index, domestic researchers have integrated a complete analysis method from the early diagnosis of urban form to the calculation of building energy consumption [27].

The above literatures indicate that urban form has a strong effect on carbon emissions and the degree of this effect is related to the mode, degree, and the regional environment and climate. Therefore, the analysis of the characteristics of carbon emission and energy consumption in regional cities is of great significance to the low-carbon city construction. However, although the carbon emission prediction model, based on this kind of correlation analysis, has the great reference value for design, it is still constrained to the evaluation after design, and is relatively lagging behind, lack of flexibility in response to the ever-changing shape design process.

2.3 Shape optimization design of low-carbon block2.2 Calculation and evaluation of carbon emission in block scale

The design practice of low-carbon city needs to be put forward and optimize the specific design strategies [28]. The low carbon design strategy based on quantitative analysis and qualitative judgment is feasible and scientific in guiding practice. For example, some foreign scholars adopted the performance data to evaluate the advantages and disadvantages of different design strategies, and put forward a combination model of optimal design strategies [29]. Other researchers, such as Golany [30], Scott [31] and Okeil [32], applied the quantitative tools to compare different neighborhood morphology patterns, summarize appropriate low-carbon spatial models, and propose the design solutions for spatial prototypes under different geographical and climatic conditions, thus realizing the shape optimization.

Some researchers employed the computer parameterized modeling techniques, to evaluate the generated form samples one by one by using formulas, algorithms, or performance simulation software [33], and to obtain the optimal shape scheme by constructing an automatic optimization process through the artificial intelligence evolutionary algorithms (such as genetic algorithms, annealing algorithms, etc.). The evaluation contents are mainly the wind and heat environment [34], solar radiation energy utilization [35][36][37], daylighting [38][39] and so on. This technical method is scientific and has the important reference significance for this study.

However, in practice, the formation of urban form is often jointly influenced by many factors (such as society, economy, culture, technology, ecology and so on), which was ignored in the existing research.

The optimal form is a static design result, which can not adapt to the dynamic design process and the possibility of changing design conditions. Therefore, how to make the form design process meet a variety of complex and interwoven constraints in the low carbon-oriented premise is a problem worthy of further study.

2.4 Scientific guide and control of low-carbon block form

Urban design is the management and control of urban three-dimensional space. Low-carbon urban design is to give effective control and guidance to the results of form design with low-carbon guidance. Some studies have focused on linking the low-carbon design goals with existing planning systems, such as hierarchical classification of commonly used low-carbon indicators, screening out the indicators that can be implemented in urban form control, and proposing the specific strategies to achieve the indicators [40]. Further, the added low-carbon indicators can be proposed on the basis of the traditional regulatory through questionnaire survey, factor analysis, cluster analysis and other methods [41]. Besides, some scholars have constructed a carbon balance model with the control elements of the regulatory detailed planning, so that the carbon balance influence factors are directly related to the control elements in the regulatory plan [42]. Wang takes the controlling carbon emissions and expanding carbon sinks as the criteria, uses the analytic hierarchy process (AHP) to empower the low-carbon leading factors, and constructs the index system and evaluation method of low-carbon residential blocks [43].

Another research approach is to analyze and summarize the characteristics of low-carbon form to form the guiding control method or elements. For example, in the passive design aspect, Knowles has proposed that the Solar Envelop can be employed to determine the maximum buildable space of the site to satisfy the need for solar radiation to enter the adjacent site [44]. As for the active design, the New York City Planning Agency's "Zone Green" Ecological Planning tool sets the space guidelines for rooftop solar panels, greenhouses and mini-generators [45]. Some scholars also adopt the performance simulation software to analyze the basic characteristics or patterns of urban morphology, so as to refine the key guiding elements. In addition, Yang Peiru has applied the spatial analysis method to discuss the relationship between urban inner spatial structure and carbon emission, and put forward the policy framework and process of low-carbon city design [46]. Further, with the energy analysis tool, Energy Performa, the MIT team has explored the relationship between energy consumption and urban morphology on a neighborhood scale, and proposed 11 guiding elements for large high-rise community cities aimed at energy efficiency [47].

Although the two research ideas are different in starting point and technology path, the common goal is to establish the relationship between the guiding elements of urban design and the characteristics of urban carbon emission, so as to introduce the results of quantitative analysis into the process of urban form control and improve the scientific nature of low-carbon city design, which is the core of this study.

3. The future research

3.1 The research prospect

Based on the above analysis, future study will focus on the following three key issues that need to be solved urgently:

First, how to refine the basic characteristics and patterns of low-carbon block form and transform it into a design strategy for designers' reference, to optimize the guiding elements of design guidelines under low-carbon guidance.

Second, how to lay stress on the rationality of the setting the controlling guide elements in the compilation of design guidelines for low-carbon cities, so that the combination of quantitative control and qualitative guidance can be realized by the method of low-carbon guide and control, to meet the requirements of scientificity and the characteristics of urban space form.

Third, how to set up a set of systematic, comprehensive and scientific methods and processes of guidance and control for a particular region and climate type, and make it better integrate with planning management and design practice.

Hence the problems to be solved in the future study include:

(1) Considers two important aspects that affect the carbon emission and carbon neutralization of the block, which can be deemed as a more comprehensive and systematic study of the mechanism and effect of morphological design on carbon emissions.

(2) Integrates the abstract scientific analysis results into the design strategy and the guide control method, which effectively improves the effectiveness and scientificity of urban design control.

(3) Realize the internal unity of quantitative control and qualitative guidance in the compilation of design guidelines for low-carbon cities.

3.2 The research steps

To solve the key issues mentioned above, several steps be applied, as explained below (Appendix A):

(1) Urban block form carbon emission database:A large enough carbon emission database of urban block morphology is established by computer morphology generation and performance simulation technology, which includes three corresponding sub-databases: controlling elements collection, urban block form and its carbon emissions. According to the characteristic site and the basic building module, the morphogenesis can be implemented by the computer random algorithm, taking the controlling control element as the constraint condition of the form generation, and selecting the appropriate block shape sample according to the urban building regulations, to establish the third level database of control element collection-block form-carbon emission through calculating the carbon emission of the form samples one by one by the environmental performance simulation software.

(2) Multi-objective optimization and feature description of low-carbon block form: By comparing the similarities and differences between the optimal forms generated by the same group and different controlling elements collections, some morphological characteristics and formation patterns of low-carbon urban blocks have been summarized and summarized. In this process, cognitive experiment and correlation analysis were adopted, comprehensive opinions of expert evaluation were introduced, and the feasibility of form deepening design was combined to select the best, to increase the objectivity and practicability of the conclusion. In addition, the optimized configuration pattern and design strategy were translated into computer programming language, and the automatic process of morphology generation-performance evaluation was used to test the extent of the improvement of low-carbon guiding and control performance after adopting the design strategy, and to sort out.

(3) Performance evaluation and optimization of block form guide and control element collects: The improvement of low-carbon conducting performance of morphological control elements can be considered as an optimal control problem for stochastic distributed systems. Stochastic optimal control is a control method that selects control variables and makes a certain performance index of stochastic system optimal. When the system meets Gaussian input assumption, the objective of the control is the mean and variance of the system output. Based on the preliminary statistics of the three-level database of block morphology carbon emissions, the average and mean square deviation of the block carbon emission data can be obtained according to the samples generated by each collection of controlling elements. After adding the optimal value obtained by evolutionary algorithm, three evaluation indexes of system control performance can be formed, and then the total performance evaluation index can be obtained by artificial weighting.

(4) Practical application and principle popularization: The morphologic change in the design practice is much more than the possibility of computer generation, so it is necessary to verify the effect of the guide control method in practice through the design experiment. According to the two types of residential and office blocks, the research draws up the task book on the basis of the specific district plots, invites the experienced urban designers to complete the design in groups, and then carries out the computer simulation and data analysis according to the designer’s sketches. The experiment verifies three aspects: whether the guidance and control performance assistant system forecast is accurate or not; whether the reasonable assignment of controlling elements plays a role in improving the guiding performance; whether the low-carbon design strategy plays an effective role in guiding.

3.3 The technologies involved

Firstly, the environmental performance simulation technology is needed for the urban block form carbon emission database. Two performance evaluation modules of building energy consumption and renewable energy utilization are implemented by UMI and Geco+Ecotect software (Figure 1 and Figure 2). Ecotect can be employed to analyze and calculate the annual solar radiation on the main surfaces of block buildings, and Geco plug-in is to realize the real-time cooperation of Grasshopper parametric model and Ecotect. The data of building energy consumption and solar radiation are converted to carbon emissions according to the photoelectric conversion rate and the emission factor of the regional power grid, further, the data table is fed back to the Rhino interface and put into the fitness evaluation module of the genetic algorithm plug-in.

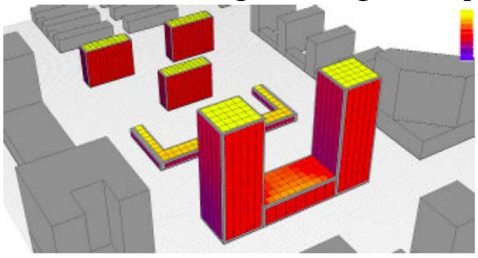

Figure 1. UMI urban building energy consumption analysis diagram

Figure 2. Geco-Ecotect solar radiation energy analysis schematic

The second one is the computer parametric morphology generation technology. The 3D modelling tool Rhino and its program algorithm plug-in Grasshopper platform are applied to establish the parametric model of urban block morphology (Figure 3). Based on the spatial organization logic and the building unit, the whole block form is generated, which is to digitize the key variables into parameters, and adopt the data link to connect the operation modules in Grasshopper to form the flow, so as to describe and control the model.

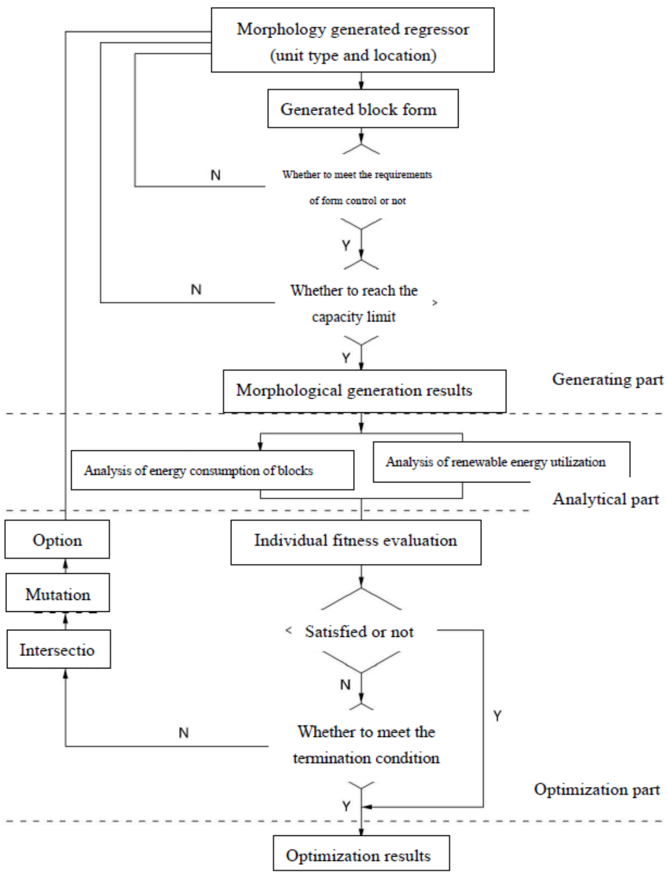

Figure 3. Morphology generation and multi-objective optimization program schematic diagram

Genetic algorithms is a self-adaptive global optimization probabilistic search algorithm based on Darwinian evolutionary theory of survival of the fittest, which introduces the concepts of reproduction, hybridization, mutation, competition and selection into the algorithm, to obtain the optimal solution in the end by recombining the feasible solutions and improving the moving path or trend of the feasible solutions in multidimensional space. The Octopus plug-in of Grasshopper can provide a wealth of selfdefined optimization parameter options, algorithm parameter setting (including SPEA-2 and HypE algorithm) and visual feedback interface.

Thirdly, as it's mentioned above that statistical model of the controlling elements carbon emission guide should be obtained from the basic data of carbon-emission, the statistical analysis of data based on artificial neural network is highly appreciated. The BP (Back Propagation) artificial neural network belongs to the multilayer feedforward neural network, whose self-training process mainly depends on the error back propagation, and adjusts the weight and the threshold value of the whole network continuously, until reaches the expected error range. It has a simple structure, multiple adjustable parameters and wide application. The mapping between morphological control elements and block carbon emission control performance index can be established by using Neutral Network Toolbox module in Matlab (Figure 4).

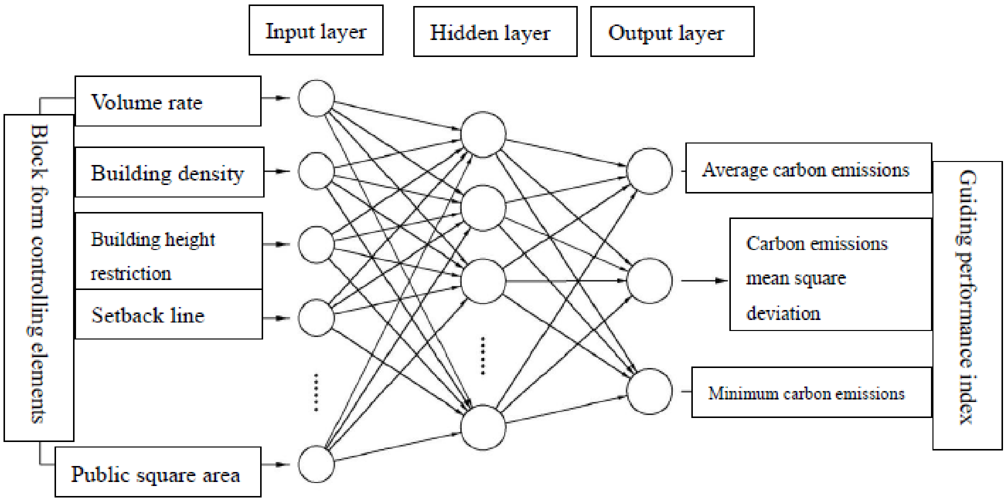

Figure 4. Schematic diagram of artificial neural network structure

Finally, a Python-based assistant evaluation system and user interface should be simply developed. In order to meet the working habits of architects and urban designers, the statistical model obtained by artificial neural network algorithm is introduced into Python platform for software interface development, therefore, the performance prediction of controlling elements and other extended functions can be realized.

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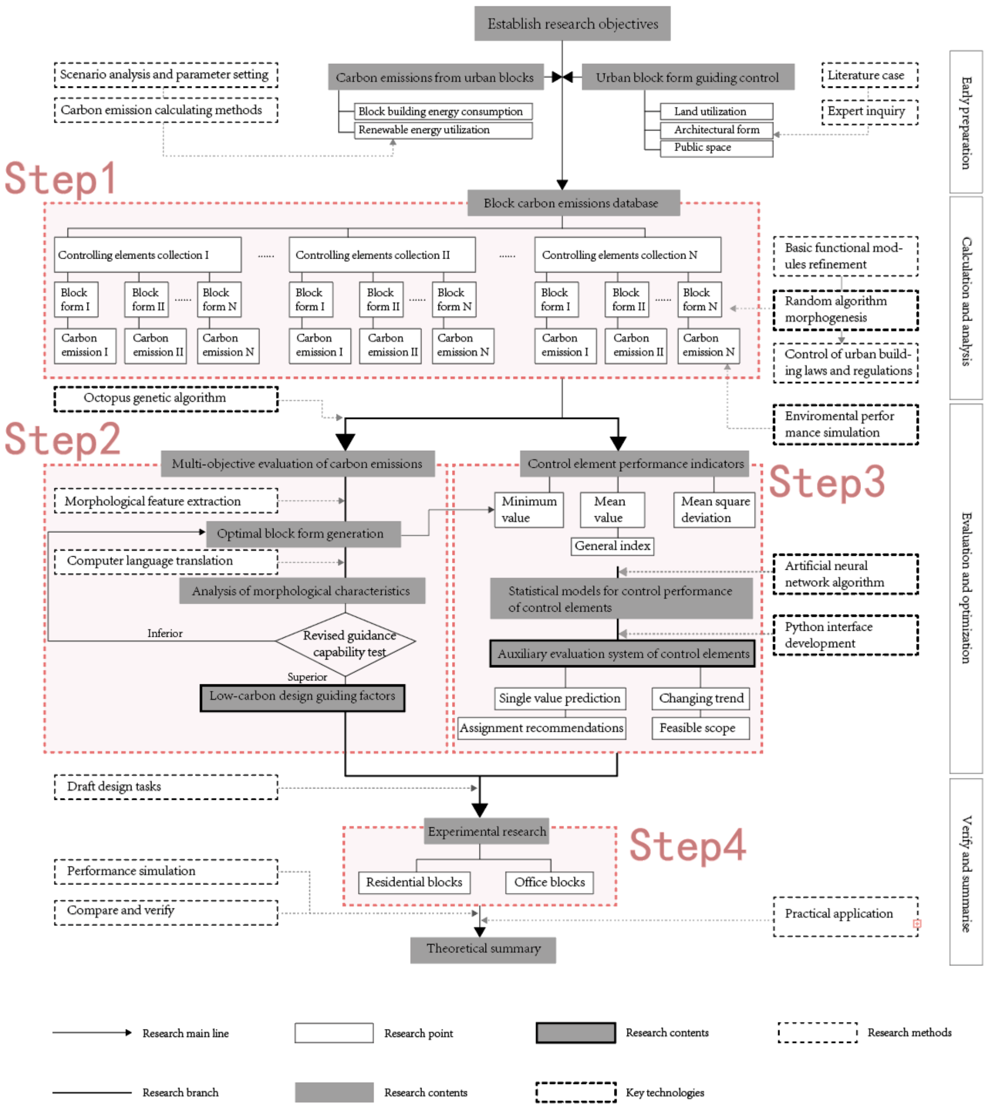

Appendix A. Technology route