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Intelligent design and dynamic adaptation model of building facade based on artificial intelligence

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Abstract: An intelligent design and dynamic adaptation model of building facade based on artificial intelligence (AI) is proposed. The model adopts hierarchical architecture, including data acquisition layer, intelligent design layer and dynamic adaptation layer. The data acquisition layer collects environmental parameters and user preference information through sensor networks and user surveys; Intelligent design layer uses deep learning and genetic algorithm to generate a variety of innovative and practical design schemes; The dynamic adaptation layer combines reinforcement learning and fuzzy control algorithm to optimize and adjust the design scheme according to real-time environmental changes and user feedback. The experimental results show that the model is superior to the traditional method in terms of design innovation, practicability and user satisfaction. The building energy efficiency is improved by 18.27%, the residential comfort score is improved by 22.39%, and the user satisfaction score is improved by 20%. This study provides an intelligent and dynamic solution for building facade design, which has important theoretical and practical significance.

1. Introduction

In the field of architectural design, the application of artificial intelligence (AI) is gradually showing its great potential. As an important interface between the building and the external environment, the facade of the building not only bears the aesthetic value of the building, but also directly affects the energy consumption efficiency, living comfort and integration with the urban environment.

The design process of traditional building facades often depends on the designer's experience and intuition, which not only limits the possibility of design innovation, but also makes it difficult to fully consider all kinds of environmental changes that buildings may encounter during use [1]. For example, with the change of seasons, environmental factors such as light, temperature and humidity will change, and the traditional building facade design is often difficult to adapt to these changes dynamically, which leads to the increase of building energy consumption and the decrease of living comfort [2]. Therefore, it is particularly important to explore an intelligent design and dynamic adaptation model of building facade based on AI. This model can make full use of the powerful computing power of AI to intelligently design the building facade, so that it can not only meet the aesthetic requirements, but also dynamically adjust according to environmental changes, so as to achieve the goals of energy saving and consumption reduction and improving living comfort.

In this study, an intelligent design and dynamic adaptation model of building facade based on AI is developed. By introducing advanced AI algorithm and data processing technology, the problems of low efficiency and poor adaptability in traditional building facade design are solved.

2. Model construction

2.1. Model design

In order to meet the needs of intelligent design and dynamic adaptation of building facades, a layered architecture model is constructed, as shown in Figure 1. The architecture consists of data acquisition layer, intelligent design layer and dynamic adaptation layer. The data acquisition layer focuses on collecting environmental parameters (including illumination, temperature, humidity and wind direction, etc.) and user preferences (such as style, color selection and materials), which are passed to the intelligent design layer, and multiple design schemes are formulated by applying AI algorithm [3]. The dynamic adaptation layer adjusts and optimizes the selected design scheme according to the real-time updated environmental conditions and users' feedback, so as to ensure that the building facade can achieve the most ideal visual and functional effects.

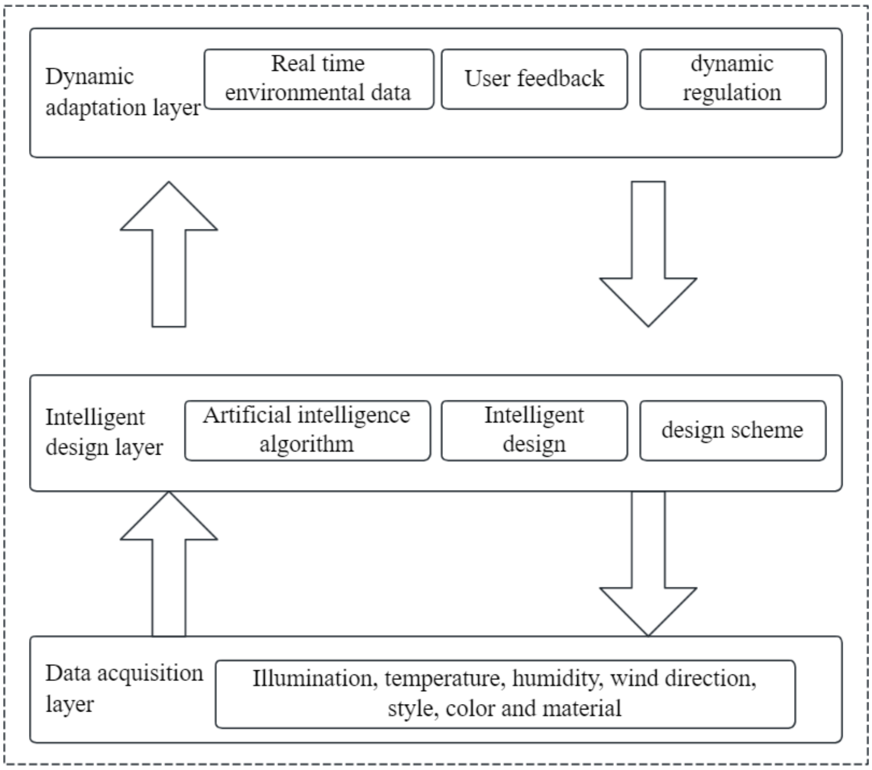

Figure 1 Hierarchical architecture model

The key modules include data acquisition, feature extraction, intelligent design algorithm and dynamic adaptation algorithm. The data acquisition module collects environment and user preference data through sensor networks and user surveys or online platforms; The feature extraction module then preprocesses these data and extracts key features to provide a basis for design. The intelligent design algorithm module adopts technologies such as deep learning or genetic algorithm, and generates several innovative and practical façade design schemes based on the extracted features [4-5]. The dynamic adaptive algorithm module uses reinforcement learning or fuzzy control to adjust and optimize the design scheme according to the real-time environmental changes and user feedback, so as to ensure that the building facade can continuously adapt to the changes of external conditions and user needs.

2.2. Algorithm realization

The data acquisition module obtains the environmental data (such as illumination, temperature, humidity, wind direction, etc.) of the building facade in real time by deploying sensor networks, and collects and preprocesses the user's preference information about style, color and material through user surveys or online platforms. The feature extraction module then preprocesses these environment and preference data, such as cleaning, denoising and normalization, and then analyzes the data by using machine learning algorithm to extract key features, such as the variation pattern of illumination intensity and the distribution characteristics of user preferences, so as to provide accurate data support for subsequent design.

A deep learning network is constructed, with the output of the feature extraction module as input, and the design law of the building facade is learned through training to generate multiple design schemes. The design problem of building facade is transformed into an optimization problem, which is solved by genetic algorithm, and an innovative and practical design scheme is generated through operations such as selection, crossover and mutation [6].

The dynamic adaptive algorithm module realizes the optimization and adjustment of the design scheme by constructing reinforcement learning model and applying fuzzy control theory [7]. Reinforcement learning algorithm is based on real-time environmental data and user feedback, and determines the optimal design adjustment strategy through trial and error learning. The fuzzy control algorithm, based on the same input, makes fuzzy rules to fine-tune the parameters of the design scheme to ensure that the design can flexibly adapt to environmental changes and update the user's needs.

3. Experimental verification

3.1. Data set construction

Construct a comprehensive data set including environmental data and user preference data. Environmental data are obtained in real time through the sensor network deployed on the facade of the building, including light intensity, temperature, humidity, wind direction, etc. User preference data is collected through user surveys or online platforms, covering users' preference information on the style, color and material of the building facade.

Several buildings located in different climatic regions were selected as monitoring objects, and multiple sets of sensors were deployed in each building, and environmental data were continuously collected for one year, with the total amount of data reaching millions. Through online questionnaire survey and social media data mining, the preference information of thousands of users from all over the world is collected, covering user groups of various ages, genders, occupations and cultural backgrounds. Environmental data is time series, that is, it shows certain regularity with time change. User preference data are diverse, and different users have significant differences in their preferences for building facades. The dataset also contains some outliers and noises, which need to be preprocessed before feature extraction and model training.

3.2. Experimental setup

Convolutional neural network (CNN) is selected as the basic network structure of intelligent design algorithm, and multi-layer convolution layer, pooling layer and full connection layer are set up. Set three convolution layers, the filter size of each layer is 3x3, 5x5 and 7x7, the step size is 1, and the filling method is "same". The pool layer adopts maximum pool, with a window size of 2x2 and a step size of 2. The number of neurons in the fully connected layer is set to 1024. The model performance is optimized by adjusting the parameters such as the number of network layers, the number of neurons and the learning rate. The initial learning rate is set to 0.001, and the dynamic adjustment strategy is adopted. When the accuracy of the verification set is no longer improved, the learning rate is halved.

The genetic algorithm is configured with population size of 100, crossover probability of 0.8 and mutation probability of 0.05 to ensure that the optimal solution can be found quickly. In Q-learning algorithm, the state space consists of environment and user preference data, the action space covers the adjustment of design parameters, the reward function is based on the user satisfaction score, and a discount factor of 0.95 is set to guide the model to learn the best strategy. Fuzzy control makes several sets of rules through real-time environmental data and user feedback, such as selecting materials with low reflectivity according to light intensity, or giving priority to materials with good heat dissipation performance when the temperature is high, so as to fine-tune the design scheme to adapt to changes.

The traditional design method of building facade and the dynamic adaptation method based on rules are selected as the comparison methods. The traditional method mainly depends on the designer's experience and intuition, while the rule-based method adjusts the design scheme through preset rules.

3.3. Result analysis

The design scheme generated by intelligent design algorithm is superior to the traditional method in innovation, practicability and user satisfaction. Through the learning of deep learning network, the model can automatically generate a variety of design schemes with novel styles and unique elements, which meets the diverse needs of users for the building facade.

Table 1 Design innovation contrast score

Evaluation index	Intelligent design algorithm score	Traditional method score
Innovation-application of unique elements	8.75	6.23
Innovation-style diversity	9.12	5.89
Innovation-the integration of materials and technology	8.93	6.57
Innovative-environmental adaptive design	9.05	6.18
Innovation-user demand response	8.87	5.92
Overall innovation score	8.94	6.15

Table 1 shows that the intelligent design algorithm significantly surpasses the traditional methods in many aspects of design innovation, such as unique element application (8.75 vs 6.23), style diversity (9.12 vs 5.89), material and technology integration (8.93 vs 6.57), environmental adaptive design (9.05 vs 6.18) and user demand response (8.87 vs 5.92). These results reflect that intelligent design can not only better integrate novel design elements, provide richer style choices, but also be more advanced in the combination of materials and technologies, and pay more attention to environmental harmony and accurate satisfaction of user needs. The score of intelligent design algorithm in innovation is 8.94, which is much higher than the traditional method's 6.15, which shows its obvious advantages in design innovation.

Most users are satisfied or very satisfied with the design scheme generated by intelligent design algorithm, accounting for 80.4% of the total users. However, the proportion of users who are generally dissatisfied or very dissatisfied is relatively small, accounting for 12.3%, 4.2% and 3.1% respectively. It reflects the effectiveness of intelligent design algorithm in meeting user needs and improving user satisfaction. The proportion of user satisfaction is shown in Figure 2.

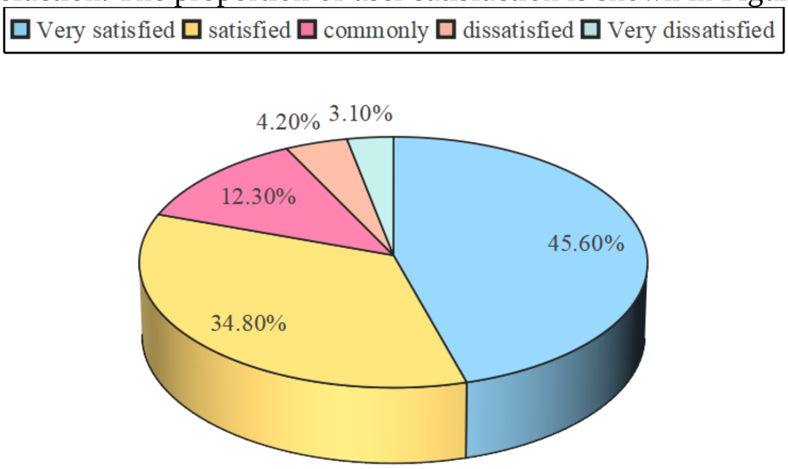

Figure 2 Proportion of user satisfaction

The dynamic adaptation algorithm can dynamically adjust the design scheme according to real-time environmental data and user feedback, ensuring the continuous adaptability and optimization of the building facade. Through the combination of reinforcement learning and fuzzy control, the model can flexibly respond to environmental changes and the update of user needs, and realize the intelligent adjustment of design scheme.

Compared with when the algorithm is not used, the building energy efficiency is improved by 18.27%, which shows that the algorithm effectively reduces energy consumption. The residential comfort score increased by 22.39%, the indoor temperature fluctuation decreased by 40%, the natural lighting rate increased by 12.73%, and the indoor air quality index improved by 19.95%, all of which indicated that the algorithm significantly enhanced the residential comfort and health. In addition, the user satisfaction score has increased by 20%, which directly reflects the user's high recognition of the improvement brought by the dynamic adaptive algorithm. Dynamic adaptive algorithm is excellent in improving building performance and user experience. See Table 2 for the effect comparison of dynamic adaptive algorithm.

Table 2 Effect comparison of dynamic adaptation algorithm

index	Before using the dynamic adaptive algorithm	After using the dynamic adaptive algorithm
Building energy efficiency (kWh/m ² ·year)	125.3	102.4
Residential Comfort Rating (1-10)	6.7	8.2
Indoor temperature fluctuation (℃)	3.5	2.1
Natural lighting rate (%)	65.2	73.5
Indoor Air Quality Index (AQI)	75.4	60.2
User satisfaction rating (1-10)	7.1	8.5

The advantage of intelligent design algorithm is that it can automatically learn and extract the design rules of building facades and generate a variety of innovative and practical design schemes. This greatly improves the efficiency and accuracy of design and reduces the workload of designers. The advantage of dynamic adaptation algorithm is that it can perceive the changes of environment and users' needs in real time and adjust the design scheme dynamically. This ensures the continuous adaptability and optimization of the building facade, and improves the energy efficiency and living comfort of the building. Compared with traditional methods and rule-based methods, this model has obvious advantages in innovation, practicability and user satisfaction. This verifies the effectiveness and feasibility of this model, and provides new ideas and methods for intelligent design and dynamic adaptation of building facades.

4. Conclusion

Advanced AI algorithm and data processing technology are introduced to solve the problems of low efficiency and poor adaptability in traditional building facade design. The experimental results show that the model is significantly superior to the traditional methods in innovation, practicability and user satisfaction. Intelligent design algorithm automatically generates a variety of innovative and practical design schemes through deep learning network, which improves the design efficiency and accuracy and reduces the workload of designers. The dynamic adaptation algorithm can perceive the changes of environment and users' needs in real time, dynamically adjust the design scheme, ensure the continuous adaptability and optimization of the building facade, and improve the energy efficiency and living comfort of the building. Compared with traditional methods and rule-based methods, this model has obvious advantages in many evaluation indexes, which verifies its effectiveness and feasibility, and provides new ideas and methods for intelligent design and dynamic adaptation of building facades.

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