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AI-Assisted Design: Generative Architectural Design

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Abstract. By applying computer algorithms, architectural generative design can achieve efficient and precise architectural planning and design. With the development of artificial intelligence technology, architects and industry experts are actively exploring deep learning algorithms, particularly neural network learning, in order to optimize the architectural design workflow and alleviate the workload of designers. Through thorough comparison and research, the author has discovered that Convolutional Neural Networks (CNN), in particular, have the widest range of applications. They can extract various features of buildings and classify these features, thereby assisting us in evaluating and optimizing design systems. By training on existing image data or 3D model data, Generative Adversarial Networks (GANs) can effectively learn from the datasets provided by people. Through the adversarial interplay between the generator and discriminator, GANs continually refine their learning accuracy and subsequently generate new image data.

Keywords. Artificial intelligence technology, deep learning, generative design, human-computer collaboration.

1. Introduction

With the arrival of the 21st century, the field of architecture has undergone a significant shift from traditional hand-drawn sketches to digitalization, relieving architects from heavy physical labor. However, along with the widespread adoption of digital design, new challenges have emerged. Many individuals still find themselves trapped in repetitive and inefficient workflows. As technology continues to advance, the application of artificial intelligence (AI) in architectural design has matured, greatly improving the efficiency of architects and facilitating the complexity, diversity, and scalability of modern architecture, thereby enhancing their creativity.

The concept of using computer algorithms for architectural design, known as generative design, has been around for a long time. By leveraging advanced computer technologies, architects can not only envision exquisite forms but also unlock boundless realms of imagination, leading to unprecedented advancements in the field of design. Extensive practice has demonstrated that by combining relevant design elements in a specific sequence, innovative inspiration and creative thinking beyond traditional design methods can be sparked. By integrating deep learning algorithms with generative design, we can bring more innovation and surprises to architectural design.

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2. Generative Design

2.1. In the Past Computer-Aided Architectural Design Had Limitations in Terms of Design Creation

Since ancient times, the pattern of architectural design has been constantly changing. Architects have been exploring the principles of architectural design. In the early days, there was no connection between computer science and architecture. However, with their deep intersection, computers have become an essential support for architectural design, ushering in a new era of Computer-Aided Architectural Design (CAAD). In recent years, the widespread application of CAD technology has profoundly influenced the architecture industry, leading to in-depth exploration in various theoretical and practical aspects, encompassing various fields of architectural design [1]. The development of intelligent design assistance systems has become an important research topic in this field. In the 1990s, Ashok K. Goel, an outstanding artist, proposed that cognitive abilities, collaborative capabilities, and creativity are key features of the next generation of design assistance systems [2]. Among these, the most challenging and significant aspect is utilizing artificial intelligence technology to address design innovation problems [3]. Although existing design assistance tools can help architects break free from traditional thinking frameworks [4], they are often too abstract and complex, requiring advanced programming skills for implementation. As a result, they are difficult to widely apply or directly use in practical design [5].

2.2. AI Aided Design System Based on Deep Learning Algorithm

AI-aided design systems based on deep learning algorithms can help architects design more efficiently. The emergence of artificial intelligence (AI) has generated significant interest among experts in the architecture industry, driven by three key factors:

First, the significant improvements in computer hardware, such as faster processing speeds and increased memory capacity, have made design automation more accessible.

Second, in the era of big data, machine learning can leverage vast amounts of data to build superior models, benefiting from the increased scale and diversity of available data.

Third, the optimization of deep learning algorithms allows for the extraction of useful information from complex datasets, enabling effective learning from simple images to intricate data. Over time, machine learning techniques, particularly deep learning, have achieved remarkable success in various fields such as art, music, and graphic design [6].

Many researchers are leveraging machine learning techniques to delve into automated generation in architecture, aiming to achieve better results. Deep learning possesses the unique advantage of “biological similarity” as it helps architects conceive and develop practical solutions while providing more accurate outcomes. Its powerful capabilities make it the preferred choice for tackling various design challenges, particularly in the realms of art and aesthetics. It assists in better direction-setting and offers innovative design approaches [7]. The application of deep learning and generative systems can greatly improve the design process, enhancing its automation and intelligence, thus paving a new path for future research. While deep learning has been widely applied in computer vision, its connection to architectural design and design innovation is still not fully explored, and relevant research remains limited.

3. Human-Machine Collaborative

In the early stages of architectural design, being able to effectively translate architects' inspiration into tangible solutions or provide them with a multitude of comparable and selectable options can significantly enhance their creativity and greatly improve the efficiency and quality of the design. This survey proposes a design pattern called "AI-assisted Collaborative Design" that employs intelligent design systems to explore specific design tasks. These systems can simulate human thinking and behavior, and provide personalized, comparable, and actionable design solutions according to different needs, thereby assisting architects in their work. Through the collaboration between intelligent design systems and architects, we can achieve more efficient design solution creation, leading to more effective architectural outcomes.

By analyzing the architectural form during the conceptual design phase, we have explored the design pattern of human-computer collaborative solutions. Through the use of intelligent design systems, architects can more easily explore architectural forms, extract design intentions more effectively, and incorporate this information into the actual design process, resulting in architectural form solutions that better meet practical requirements. This process encompasses various domains, including design innovation, shape linguistics, and artificial intelligence. This article will delve into our intelligent design system and discuss how it assists architects in conducting architectural intelligent design more effectively.

4. AI Intelligent Assistant System for Architecture Design

Building an AI Intelligent Design System that can intelligently generate preliminary conceptual references based on architects' initial sketches, providing designers with divergent thinking and further design development, is the core of achieving collaborative design between artificial intelligence and architects. This is also the key to the collaboration between AI and architects. Many architects often rely on visual reasoning to complete design proposals, but this approach is not always effective. Therefore, this paper proposes a deep learning-based human-AI collaborative design system (Figure 1) that combines visual reasoning with human-AI collaboration, thus enabling more efficient design proposals. In the second part, various techniques such as shapes, texts, and other elements will be utilized for data transformation and model development. Initially, this system will assist architects in collaboration in two directions: 1. conducting in-depth research on the initial architectural volumes to propose relevant solutions, and 2. presenting multiple architectural forms as extensions based on intentions. This paper mainly focuses on the second aspect.

5. AI Generative Design Assistant System

The AI Generative Design Assistant System (AIGC) is created using convolutional neural networks, and it possesses highly intelligent features. The design process of this system is illustrated in figure 2. Initially, the architect conducts a thorough analysis of the design task, determines the final dimensions of the building, and selects the design intention. Through the AIGC system, in-depth exploration of the design intent can be achieved, effectively extracting valuable information and integrating it into the design of the architectural solution. The design system can quickly respond to the architect's ideas, propose effective solutions, and provide feedback to the architect. This enables them to compare and analyze different options effectively, stimulating creativity, inspiring innovation, and advancing the design process.

5.1 The Core Features Implemented by the AIGC System

Through the AIGC system, the process of intelligent architectural design is achieved, consisting of three main steps: data processing, model generation, and analysis and prediction of the final architectural outcome (figure 1).

1. Model Training: Utilizing the preliminary sketches of the design, the AIGC system is employed to expand the design intentions. The large-scale and low-resolution (LORA) models are trained based on the desired intention images specified by the design concept.

2. Dimensionality Reduction: The two-dimensional sketches of the original design and the three-dimensional models of the design intentions are preprocessed to transform them into a unified standard of two-dimensional data files. These files are then imported into the Convolutional Neural Network (CNN) of the AIGC system, referred to as AIGC-CNN, to achieve more efficient data processing.

3. Form Design: Through the AIGC-CNN program, we can extract the design intention files imported from the large model and LORA model, and combine them with the initial massing scheme to generate two-dimensional architectural data files with unique design styles and morphological features.

4. By adopting the same data processing techniques as in 1, we can convert the original two-dimensional data files into three-dimensional architectural massing models, enabling more accurate modeling.

These four steps of data processing mainly involve deep learning algorithms, image preprocessing, and architectural and environmental feature design using AIGC-CNN.

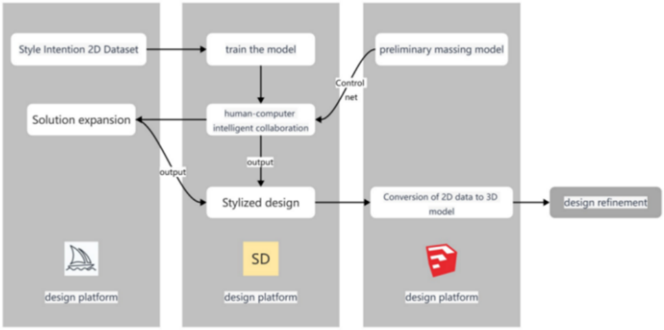

Figure 1. AIGC system and its design process.

5.2. The Main Influential Parameters of the AIGC System

The AIGC system can generate significant variations in the final appearance of the buildings based on the changes in parameters. By adjusting these parameters, architects can easily modify the building's exterior and internal structure to achieve the desired performance. The key factors that influence these changes include the number of iterations for style transformation, weight parameters for initial designs, weight distribution for design intentions, and their underlying relationships (as shown in table 1). Among these factors, the selection of the initial file may have a significant impact on architectural form design compared to other factors.

Table 1. RCNN structure and parameter design

Parameter name	Illustrate	Affects the effect
The number of iterations for style transfer (steps)	Steps ≥ 0， steps $\in Z$	As the number of steps increases, the expression strength of the design intention's style in the initial massing increases.
Weight parameters of the initial design proposal (weight)	Steps ≥ 0， weight $\in R$	As the weight decreases, the degree of retention of design elements in the initial design proposal decreases.
Weight distribution of design intent (cfg scale)	cfg scale = [a1, a2, a3, a4, a5], ai ≥ 0， ai $\in R$	As the ratios of a1, a2, a3, a4, a5 change, the expressed design intent style features vary.
Deep-level influencing parameters	Representative parameters include： Content loss function Style loss function Fusion loss function	In design practice, default settings are often used for the corresponding parameters, so they are not elaborately discussed in this paper.

6. The Practical Applications of the Human-Machine Collaborative Solution Creation Mode

Through the adoption of the human-machine collaborative approach to design, we have delved into the methods and processes of this design paradigm and drawn robust conclusions, proving its feasibility. In practical application, we will design a small-scale building with the primary function of a tea house to meet the local residents' tea culture demands. By leveraging AIGC technology, our architects are empowered to employ artificial intelligence methods for the overall architectural aesthetics and the design of the surrounding environment. Please refer to the following steps for further details.

6.1. Preliminary Architectural Design Task

In Sketch Up, the architect has constructed a preliminary 3D model of the site to better illustrate the design task and the surrounding environment. Additionally, based on the initial concept, an initial architectural massing model has been created (figure 2). Embracing the design philosophy of "New Chinese Style", the architect has integrated the characteristics of the site and its surroundings to establish the design direction for this project. By combining the architectural features of New Chinese Style with the autumnal landscape of layered trees, the architect aims to harmoniously blend the design with the existing site environment, achieving a preliminary design of the architectural form and the surrounding context.

Figure 2. Sketch of the intended building.

6.2 Exploring the Feasibility of Human-Machine Collaborative Design

This study investigates the feasibility of human-machine collaborative design and aims to achieve optimal design outcomes through the collaboration between architects and an intelligent design system. By conducting in-depth research on the original building dimensions and design concepts, architects and the intelligent design system engage in collaborative design to enhance efficiency. The architects utilize a retrieval system to gather relevant two-dimensional data of buildings and autumn scenes that align with their initial visions. This data is then transformed into training sets for the AI large-scale model and Lora model for further model training. Through the utilization of the AIGC system, the architects effectively integrate the initial volumetric data with the design intent, enabling a thorough exploration of design feasibility. The specific workflow is as follows:

1. The designers input the initial data and design intent into the webui AI, which generates tag files corresponding to the data information through a preprocessing program (figure 3). Finally, the trained model is inputted into the deep learning process through the AIGC-CNN algorithm. In the stable diffusion environment, the AIGC-CNN program is activated, and during the learning of the morphological features (style features) of the design intent, the model may experience underfitting and overfitting. The graph shows that as the number of sampling steps increases, the loss value decreases, and the learning effect becomes closer to the training set. However, to avoid overfitting, it is necessary to set a reasonable number of sampling steps and choose the minimum value within the region during the model training process (figure 4).

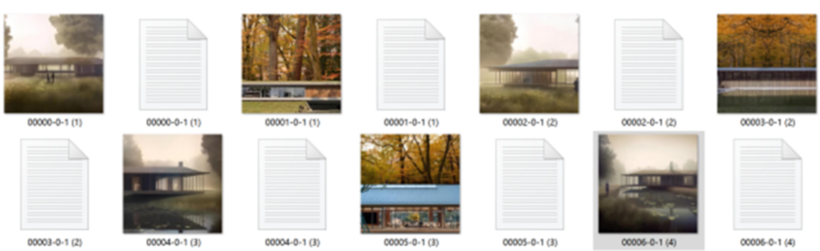

Figure 3. LORA training set.

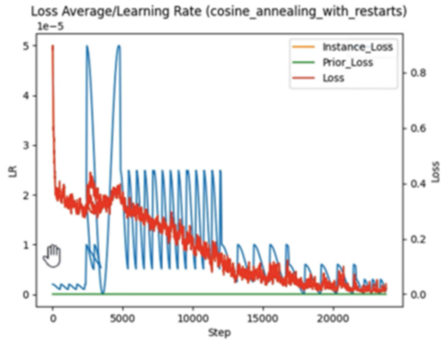

Figure 4. Learning rate curve.

2. In the stable diffusion phase, the system activates and runs the large model and lora model. By controlling the network, the architecture's morphology is manipulated to generate two-dimensional data that aligns with the initial building volume of the design. This results in the generation of two-dimensional data with distinct characteristics of the New Chinese style(figure 5).

3. By reediting and processing the two-dimensional data files, the system can create three-dimensional architectural models and showcase them on the Sketch Up platform.

The AIGC system can automatically recognize the design intent features within the architectural volume and integrate them with the initial architectural volume to create a unique design style. In this process, the AIGC design system, based on an "assistant architect" approach, combines the architect's creativity to achieve diversified, intelligent, and in-depth exploration of the design. Through in-depth analysis of the design results, it provides architects with strong references to help them better evaluate the feasibility of design concepts. AIGC technology played an important role in this design, as the generated architectural solutions exceeded the original design expectations, demonstrating the feasibility of this design system.

Figure 5. The building generated by the AIGC system.

The design system showcased in this project goes beyond simple imitation of "extraction, combination, and re-creation" in the design process. Instead, it involves deep-level intelligent iterative expansion based on the original materials. Through "silent interaction and communication", architects and the intelligent system can collaborate effectively in the design process, enhancing design efficiency.

7. Conclusion

The application of artificial intelligence technology has transformed the traditional "individual" design mode into a "collective" design approach, significantly reducing the workload of architects and improving their efficiency. By harnessing the power of artificial intelligence, architects can better accomplish design tasks and establish productive collaborations to foster design depth and innovation. Unlike previous design tools that were limited to simple drafting, the integration of artificial intelligence offers new possibilities. While this study focused on the design of an architectural collaboration system and has certain limitations, it provides valuable insights into the potential of efficient design communication and innovative solutions through the collaboration between artificial intelligence and architects.

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