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The Application of Generative Artificial Intelligence in the Conceptual Design Phase of Green Buildings: A Bridge Between Theory and Practice

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Abstract: In the development of green buildings, the conceptual design phase determines the whole-life-cycle environmental performance and comprehensive benefits. However, traditional conceptual design methods face bottlenecks such as low efficiency and strong dependence. As a new type of digital tool, generative artificial intelligence (Generative AI) can promote the optimization of green building conceptual design and effectively improve building effects through its capabilities in data learning and goal-seeking. Starting from the conceptual design phase of green buildings, this paper analyzes the application value of generative artificial intelligence and proposes specific application and practice strategies, aiming to promote the in-depth development of green buildings and provide reference for the subsequent optimization of the green building conceptual design phase.

Keywords: Generative artificial intelligence; Green buildings; Conceptual design

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1. Introduction

Against the background of global climate change, green buildings have gradually become one of the main directions for the transformation of the construction industry. The core of green buildings is to achieve goals such as resource conservation and environmental protection throughout their life cycle, and to create a healthy and comfortable space for people. The conceptual design phase is the starting point, which usually determines the building form, technical route, etc., and the decisions made at this phase play a crucial role. Traditional green building conceptual design relies too much on designers' experience and intuition. Although it can be assisted by green building evaluation standards and performance simulation software, the process is relatively linear, making it difficult to achieve in-depth integration of concepts and practices. The development of generative artificial intelligence enables it to learn the aesthetics, functions, etc., contained in design data, combine relevant constraints, and generate design solutions that meet requirements, providing a new paradigm for green building conceptual design.

2. Application value of generative artificial intelligence in the conceptual design phase of green buildings

2.1. Exponentially expand design space and stimulate innovation potential

Designers in the construction industry are usually limited by existing experience and their own cognitive abilities, and the number of schemes they can produce within a limited time is relatively limited [1]. The application of generative artificial intelligence can quickly generate schemes with diverse spatial organizations and forms based on the learned design vocabulary on the premise of meeting basic functions and specifications. Quantitative changes may lead to qualitative changes, freeing designers from tedious labor to focus more on reviewing, evaluating, and guiding the generation direction of artificial intelligence, resulting in logically valid innovative forms. For example, combined with special climatic conditions such as sunshade and lighting, complex organic forms can be generated, and artificial intelligence can be used to learn the relationship between natural biological forms and physical properties [2].

2.2. Realize pre-driving and integrated optimization of performance goals

The application value of generative artificial intelligence in the field of green buildings lies in promoting the achievement of performance goals. From the perspective of the traditional model, it follows the principle of "design first, simulation later", and performance goals are mainly used for screening. In contrast, the application of generative artificial intelligence can take performance goals as input conditions and optimization objectives in the generation process [3]. At the same time, it integrates physical simulation models with AI generation models to form a closed loop of "generation-simulation-evaluation-regeneration". Artificial intelligence can find parameter combinations that meet multi-objective designs in each iteration. Its essence lies in performance optimization and extraction at the end of the design process, promoting the achievement of performance-driven design goals. Designers can intuitively understand the impact of various forms and orientations on various performance indicators during concept definition, facilitating scientific decision-making [4].

2.3. Integrate and activate multi-source heterogeneous knowledge to assist complex decision-making

Green design is complex and requires decision-making in accordance with multiple criteria, involving diverse disciplinary knowledge such as architecture, landscape architecture, materials, and environmental psychology. Generative artificial intelligence technology can be combined with knowledge graph technology to promote the integration of various heterogeneous knowledge [5]. The application of this technology can learn from a large number of excellent green building cases, transform unstructured design experience into an associable knowledge network. For new design tasks, generative artificial intelligence can not only generate relevant forms but also propose associated material suggestions and localized ecological technology selections, and objectively explain the underlying logic. It is equivalent to equipping designers with a super knowledge base, facilitating them to access global green building wisdom and integrate localized specifications, effectively reducing the threshold for cross-disciplinary cooperation [6].

2.4. Promote a new human-machine collaborative design paradigm and improve design quality and efficiency

Generative artificial intelligence cannot replace designers; it mainly plays a collaborative role. In the context of the new paradigm, the designer's role has transformed from the sole creator to the goal setter, process guide, and result evaluator. Designers are mainly responsible for inputting design intentions, value orientations, and aesthetic preferences [7]. Generative artificial intelligence can efficiently explore the solution space and provide multiple possibilities. Designers can make selections and adjustments based on professional judgment, humanistic care, and the schemes generated by AI. The collaboration between human thinking and AI execution helps significantly shorten the design cycle, concentrate more resources on creative and strategic links, and effectively improve the quality and performance of design outcomes.

3. Application strategies of generative AI in the conceptual design phase of green buildings

3.1. Precisely define multi-objective generation tasks and constraints

In any intelligent generation process, clear goal definition and boundary setting are the foundation. The core of this initial phase is to systematically transform abstract sustainable development concepts and project requirements into a form that generative artificial intelligence models can accurately identify and understand [8]. In this process, designers need to give full play to their leading role and formulate multi-level input conditions through communication with structural, landscape, and other teams.

First, core performance goals. As the specific manifestations of green buildings, they need to be converted into indicators with clear numerical boundaries, such as an annual total energy consumption per unit area not exceeding 80 kWh/m^2. Clarifying relevant performance indicators can provide a reference for the optimization objectives of subsequent AI-generated schemes and set mandatory constraints that must be followed [9].

Second, basic functional and specification constraints. These specifically include various rigid requirements formulated by the project task, such as the area ratio of different functional zones and the logical sequence of spaces. The proposal of relevant rigid requirements can ensure that the generated schemes comply with basic specifications and have good feasibility, laying the foundation for subsequent green building conceptual design.

Third, semantic and aesthetic intention guidance. Through natural language descriptions (e.g., “closely integrate with the natural terrain to construct an earth-sheltered building form”) or by providing representative visual image sets, guide AI to generate content that meets design expectations in terms of building form and spatial atmosphere.

Through the above practices, a complete set of design condition parameters with a clear structure can be formulated [10]. Such parameters not only provide computable and controllable input basis for subsequent intelligent generation but also ensure that the generation process is on the correct track, connecting human creative intentions with machine generation logic, and laying a solid foundation for the development of subsequent green buildings.

3.2. Construct the learning foundation and generation engine of the model

After clarifying the task, it is necessary to equip generative AI with “fuel” and “engine”. High-quality, multi-dimensional, and structured data and knowledge are the fundamental guarantee for AI to conduct valuable creation rather than random output.

(1) Construct a multi-modal domain dataset

Systematically collect and annotate drawings (CAD/BIM), 3D models, real-life photos, corresponding physical environment simulation data (energy consumption, lighting, wind environment, etc.), material composition, and design description texts of successful green building cases. This dataset, which aligns “drawings-performance-semantics”, enables AI to learn the complex mapping relationships between form, technology, and performance behind green design [11].

(2) Develop and integrate a domain knowledge graph

To make up for the difficulty in capturing implicit knowledge in data, it is necessary to construct a green building domain knowledge graph. It materializes knowledge such as design specifications, material properties, construction methods, climate strategies, and ecological technologies, and establishes logical relationships between them (e.g., "external wall insulation material X 'is applicable to' cold regions", "vertical greening 'can improve' microclimate and 'reduce' building energy consumption"). The introduction of the knowledge graph enables AI's generation process to not only be based on statistical laws of data but also follow engineering logic and professional common sense, improving the rationality and interpretability of generated schemes.

(3) Match and train adaptive generation models

Select and train appropriate generation models according to the specific dimensions of design generation (e.g., 2D plans, 3D volumes, facade details) [12]. For example, conditional generative adversarial networks or diffusion models can be used for master planning and plane function generation; for multi-objective synchronous optimization of complex 3D volumes, generative design methods deeply integrated with parametric platforms are often adopted, where AI agents (e.g., based on evolutionary algorithms or reinforcement learning) are responsible for efficient search in the parameter space.

3.3. Integrate real-time feedback and iterative optimization of performance simulation

The core value of generative artificial intelligence in promoting revolutionary breakthroughs in the field of green design is to completely transform the performance evaluation link originally located at the end of the process from the traditional "backend inspection" model to a "frontend driving" mechanism. This transformation means that the design process is deeply integrated with sustainability and environmental protection requirements from the very beginning, and the key technical foundation for achieving this lies in building a highly intelligent and continuously iterative automated closed-loop system [13].

(1) Technology coupling path

Seamlessly connect parametric generation platforms, generative AI models, and professional performance simulation engines through application programming interfaces (APIs). Every time AI proposes a set of design parameters, the system automatically generates a geometric model and calls the simulation engine to calculate its various performance indicators.

(2) Multi-objective optimization process

Based on the performance data fed back by the simulation (e.g., energy consumption value, illuminance distribution, wind speed coefficient), combined with a preset multi-objective optimization function, AI automatically evaluates the pros and cons of the current scheme and intelligently adjusts the design parameters to evolve towards the direction of simultaneously improving multiple performance goals. After thousands of rapid iterations, a Pareto optimal solution set is finally output, a set of schemes that achieve the best balance among multiple performance indicators, where the improvement of any one indicator will lead to the decline of other indicators. This provides designers with a clear and quantitative performance trade-off map.

3.4. Human-machine collaborative interaction and decision-making interface

Generative artificial intelligence represents a set of possibilities, and the final decision usually requires designers to make judgments based on comprehensive values to draw relevant conclusions. In this regard, in practice, it is necessary to attach importance to the construction of intuitive and efficient human-machine collaborative scenarios to promote the integration of machine computing power and human insight.

First, visualization and interpretability. The human-machine collaborative interface can intuitively visualize complex multi-dimensional results. For example, parallel coordinate graphs can show the performance of different schemes in various performance indicators, facilitating designers to better understand the trade-off relationships [14]. At the same time, artificial intelligence can provide corresponding explanations based on key design features, helping designers better understand its generation logic.

Second, interactive exploration and semantic editing. Designers should not passively select schemes but need to take the initiative to guide. The collaborative interface can support designers to make slight adjustments to preferred schemes through direct operations and natural language instructions [15]. Artificial intelligence can better understand their intentions and conduct local generation and collaborative activities under the adjusted constraints, promoting the construction of a hybrid intelligent creation model, truly realizing that designers' creativity serves as guidance while AI refines and executes.

Third, intelligent clustering and scheme management. For a large number of design schemes, the human-machine collaborative system can automatically cluster and sort them according to form and performance characteristics, helping designers quickly identify representative directions, avoid information overload, and truly focus valuable energy on high-level concept comparison.

4. Conclusion

In summary, the development of generative artificial intelligence has promoted the transformation of green building conceptual design. Like a solid bridge, it can connect advanced theoretical systems such as sustainable development and low-carbon cycles with creative design practices that incorporate inspiration, intuition, and humanistic care. At the same time, the core contribution of generative artificial intelligence is to transform design from a closed reasoning process relying on personal experience into a data and knowledge-driven exploration system.

Disclosure statement

The author declares no conflict of interest.

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