The Design and Implementation of the Procedural Generation Design System

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Abstract: Environmental art design integrates disciplines such as space, form, function, and aesthetics. The process of design is highly complex. Traditional design methods have certain limitations in meeting diverse and efficient design requirements. Process-based generative design introduces algorithmic rules and parametric logic, providing new possibilities for artistic environmental design creation. In particular, it has significant value in generating complex forms, optimizing spatial layouts, and enhancing design consistency. Therefore, this study analyzes the requirements of the process-based generative design system, designs and implements the process-based generative design system. The system is designed with a B/S architecture, with software modules such as the input and parameter configuration module, rule definition and knowledge base module, process-based generation engine module, output, evaluation and optimization module as the core.

Keywords: Process-Based Generative Design; Parameter Configuration; Environmental Art Design

1. Introduction

With the rapid development of artificial intelligence technology, it profoundly influences the form of environmental art design. Process-based generative design is a key content of the digital transformation of environmental art design. Through the process-based generative design system, programmatic logical codes can be converted into perceptible and executable rule parameters, thereby ensuring the iterative optimization of design schemes under preset constraints. In the field of environmental art design, traditional design methods have difficulty in efficiently handling multi-objective balance, form innovation, and site response issues. Introducing process-based generative methods not only inherits the accuracy of parametric design but also enables process-based design innovation through intelligent algorithms, thereby ensuring the sustainable development of environmental art design.

2. The Importance of Process-Based Generation Design System in Designing Environmental Art

The process-based generation design system is of great significance for the innovation of environmental art design. It can transform the elements of environmental art design into a rule-driven exploration process through intelligent algorithms. Traditional environmental art design mainly relies on the personal experience of designers, which often encounters efficiency bottlenecks when adapting to large-scale scenarios. The process-based generation design system design can integrate site conditions, functional requirements, aesthetic principles, and normative constraints through parametric models, making artistic environmental design more dynamic. The system can automatically generate a large number of logical alternative solutions, thereby expanding the boundaries of process-based design, especially in areas where traditional methods are difficult to precisely control, such as handling complex terrain adaptation, ecological flow simulation, and cultural imagery translation. The system can free designers from basic administrative tasks and enable them to focus more on rule formulation, strategy selection, and aesthetic judgment, thereby enhancing the scientificity and consistency of artistic environmental design.

3. Requirements Analysis of Process-Based Generation Design System

The requirements analysis of the process-based generation design system mainly includes the following aspects: First, the system needs to support flexible input of multi-dimensional parameters and resource allocation, so as to efficiently cope with constraints such as site, function, and culture; second, the system should provide an intuitive visual interface, allowing artistic environmental designers to convert design logic and professional knowledge into generation rules; third, the system needs to have the ability to generate schemes and output in multiple formats, capable of inputting various formats of drawings and reports according to different design requirements of designers; fourth, the non-functional requirements of the system focus on system response performance, operational ease of use, and algorithm interpretability, ensuring that the system can seamlessly integrate into the environmental art design process.

4. Process-oriented Design and Implementation of the Design System

4.1 Overall System Architecture Design

The system adopts a layered architecture design, mainly consisting of the data layer, service layer, application logic layer, and presentation layer. The data layer is responsible for designing the knowledge base, rule base, case base, and project data storage management; the service layer mainly functions to encapsulate the process-oriented generation engine algorithm, rule interpreter, and geometric calculation core. The application logic layer mainly functions to carry out parameter configuration, rule definition, scheme evaluation, and optimization, etc. [1]. The presentation layer mainly functions to provide a visual user interaction interface for users, and the various layers collaborate through standardized communication to realize the application of system functions.

4.2 System Function Module Design

4.2.1 Input and Parameter Configuration Module

The input and parameter configuration module serves as a bridge for communication between the system and the designer. Its main purpose is to establish parameters that can accurately capture the elements of environmental art design. This module enables users to input various parameters in a hierarchical and categorized manner, covering the following aspects: Firstly, objective parameters, which mainly include environmental information such as site boundaries, elevation data, and sunlight climate; Secondly, design parameters, which mainly consist of spatial functional indicators, flow line organization preferences, form aesthetic tendencies, and cultural imagery symbols; Thirdly, rule control parameters, which are used to adjust the number of iterations in the generation process, random seeds, and algorithm weights. Parameters are managed in a structured format to ensure the rationality of data input.

4.2.2 Rule Definition and Knowledge Base Module

The main function of the rule definition and knowledge base module is to convert the professional theories and creative logic of environmental art design into system-understandable and executable rules. The rule definition and knowledge base module can provide designers with a visual node programming interface, allowing them to drag and drop logical units or write conditional statements to establish design rules such as form generation, spatial relationships, and flow organization. The knowledge base subsystem integrates structured design knowledge, mainly including industry norms and standards, construction databases, spatial type patterns, and historical classic case analyses, to form the basis for rule formulation and scheme evaluation. The module realizes the digital transformation of design experience by associating rules and knowledge [2].

4.2.3 Process-oriented Generation Engine Module

The procedural generation engine module, as the core functional module of the system and the central hub for system algorithm application, mainly serves to convert the parameter configuration module's definition into the generation logic of the rule knowledge base and then into a design scheme [3]. The procedural generation engine module receives a structured parameter set, invokes design rules, and performs recursive operations through geometric algorithms. The recursive generation process can be represented by formula (1)

$$S_{n+1} = f(S_n, P, R) \quad (1)$$

In the formula: S_n Expressed as then n step formation process； P It is represented as an input parameter set obtained from the parameter configuration module, mainly covering information such as environment, functions, and spatial layout; R These are expressed as design rules in the rule knowledge base and define the evolution rules of the form. $f(\cdot)$ Expressed as a geometric transformation function, it will change according to the previous generation's form. S_n 、Input parameters P 、Design rules R To generate new forms S_{n+1}

This formula can generate three-dimensional forms that meet the input conditions and logical constraints. The engine design places emphasis on real-time performance, enabling efficient generation of solutions during parameter adjustments and achieving immediate feedback and dynamic optimization in artistic environment design[3].

4.2.4 Output, Evaluation and Optimization Module

The main functions of the output, evaluation and optimization module are to generate multi-dimensional schemes based on the parameters input by the designer. In terms of specific application functions, there are two aspects: First, the output function. This module has strong multi-format output capabilities and can innovatively generate contents such as two-dimensional drawings, three-dimensional models, virtual reality scenes, and structured data reports [4]. Second, the evaluation function. It embeds a multi-level evaluation index system and can rely on intelligent algorithms to conduct dynamic analysis of environmental art design works, such as quantitative scoring of spatial efficiency, aesthetic composition, compliance with norms, and environmental performance, and can also provide dynamic analysis charts [5]. Third, the optimization function. This module has strong optimization capabilities, allowing designers to dynamically adjust key parameters and relying on the built-in intelligent algorithms of the system, dynamically search for better solutions, thereby achieving intelligent iteration from "generation - evaluation" to "re-generation", and the optimization algorithm can be expressed as formula (2):

$$E_{total} = \sum_{i=1}^{n} w_i \cdot E_i \qquad (2)$$

In the formula: E_i Expressed as the i The scores of each evaluation indicator (such as spatial efficiency, aesthetics, compliance, etc.); w_i This is the weight of the i evaluation indicator, representing the significance of the indicator in the overall evaluation. n Expressed as the total number of evaluation indicators.

The entire module transforms subjective design evaluation into objective data support, thereby enhancing the scientificity and accuracy of environmental art design decisions.

4.3 System Testing

4.3.1 Test Process Design

To verify the effectiveness of the system's functions, this study adopted a comparative test. The system was compared with the common commercial parametric design software solutions. The test scenario selected was the generation of ecological park landscape with complex terrain and integrated functions.

The experimental group used the system, while the control group employed a general parametric design platform based on visual node programming. Both groups completed the entire process from rule logic construction to scheme output under the same site data, basic function list, and four-hour time limit conditions. The entire testing process covered indicators such as the efficiency of the parametric design process, the richness of design intent expression, and the professional matching degree of the output results.

4.3.2 Analysis of Test Results

As shown in Table 2, in terms of the generation efficiency indicators, this system produces 3.2 effective solutions per unit time (4 hours), far exceeding the 0.8 solutions produced by the traditional scheme. The steps of parameter adjustment and rule definition have been reduced by approximately 40%. In terms of the comparison of professional expression richness indicators, this system achieves a proportion of up to 87% for professional rules such as the continuity of ecological corridors and visual corridors control. The traditional scheme can only achieve about 15% of its preset general rules. In terms of the comparison of output quality indicators, the average score of expert blind review by this system is 4.3 points (on a 5-point scale), while that of the traditional scheme is 3.1 points. These test results fully demonstrate the advantages of this system in improving design efficiency, deepening professional logic integration, and ensuring the quality of design outcomes.

Table 2 Test Results

Test dimension	Specific indicators	Experimental group (This system)	Control group (General Parametric Platform)
Generation efficiency	The number of effective solutions produced within a unit time (4 hours)	3. 2 units	0.8 unit
	Degree of step simplification	Reduce by approximately 40%	(Basis)
Professional expression richness	The proportion of achieving professional design rules	87%	15%
Output quality	Average score of blind review by experts (on a 5-point scale)	4.3 points	3.1 points
	The automatic compliance rate of key design specifications	92%	65%

5. Conclusion

The process-based generation design system design and application is not only the inevitable path for the digital transformation of environmental art design, but also a key measure for environmental art design to respond to changes in the external environment. This research adopts a hierarchical architecture, designs and implements the process-based generation design system. The system realizes the improvement of the efficiency and professionalism of environmental art design through software functional modules such as the input and parameter configuration module, the rule definition and knowledge base module, the process-based generation engine module, the output, evaluation and optimization module.

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