Research on Visual Expression of Urban Square Landscape Based on 3D Modeling and Parametric Design

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ABSTRACT Rapid urbanization has promoted the transformation of urban squares toward functional complexity, spatial integration, and intelligent public services. Traditional design methods have limitations in visual expression, including static presentation, weak parameter correlation, and low efficiency in scheme iteration. In modern urban public spaces, landscape design also needs to consider wireless communication infrastructure, antenna-assisted sensing facilities, and the influence of the urban electromagnetic environment on digital service deployment. To address these problems, this study constructs a multi–dimensional parametric visualization system covering space, ecology, humanism, vision, and economy, and proposes a four-stage technical framework of modeling, parameter correlation, dynamic optimization, and feedback iteration. Through technology integration and process reconstruction, the proposed method improves the efficiency of design iteration and the accuracy of implementation in urban square landscape design. This study reviews the technological evolution through literature research, verifies the effectiveness of the system using case analysis, and completes full–process practice with an 8,000–square–meter urban square as the research object. A parametric system consisting of five dimensions and 23 indicators is established, increasing scheme iteration efficiency by 40% and shortening the cross–disciplinary communication cycle by 30%. In addition, AI-assisted optimization and BIM–GIS integration are introduced to improve spatial precision and support coordinated design of public landscape, digital facilities, and electromagnetic-aware urban infrastructure.

INDEX TERMS urban square landscape, 3d modeling, parametric design, electromagnetic environment, antenna-assisted sensing

I. INTRODUCTION

A. RESEARCH BACKGROUND AND SIGNIFICANCE

Research Background.

WITH economic development, China's urbanization construction has steadily moved from the extensive stage of large–scale demolition and construction to the stage of "inventory management and improvement," a strategic shift toward quality and refined spatial utilization that emphasizes sustainable renewal, efficient land use, and long–term improvement of urban public spaces. As the "city parlor", urban squares are important outdoor public activity spaces for residents, and their functional positioning has shifted from a single assembly space to a complex public carrier [1,2]. According to the 2024 statistical data from the Ministry of Housing and Urban-Rural Development, the total number of urban squares at or above the county level in China exceeds 32,000, with an average of more than 1,800 new and renovated projects annually. These projects are generally required to meet multiple needs simultaneously, such as social interaction [3], ecological regulation (e.g., urban heat island effect mitigation) [4], cultural display and inheritance [5,6], and emergency evacuation [7]. Urban squares are developing towards the integration of functionalism, diversification, humanization, ecology and sustainability, with different square space elements integrated [8]. However, facing the increasingly complex functional demands, traditional design methods relying on static drawings are struggling to cope. Dependent on CAD static drawings, traditional design has three major pain points [9]:

(1) Parameter adjustment requires re-modeling, leading to a long scheme iteration cycle of 2 to 3 weeks;

(2) Indicators such as ecological benefits rely on subjective judgment, lacking quantitative basis;

(3) Cross-subject communication relies on 2D drawings, resulting in a spatial perception deviation rate exceeding 25%.

The development of digital technology as well as computer software and hardware technologies has provided solutions to the above problems [10]. As a highlight and crystallization of technological upgrading in the construction of digital urban geospatial frameworks, 3D digital urban models have attracted increasing attention, and more and more cities have carried out 3D modeling and application [11,12].

(1) 3D modeling tools have achieved a leap from “2D expression” to “spatial reconstruction”: Rhino is a mainstream professional software for industrial product modeling design. It constructs 3D models through NURBS curves, which can accurately restore complex terrain forms [13,14]; Revit’s parametric component library supports the integrated management of attributes such as materials and costs.

(2) Parametric design tools have broken the predicament of “separation between form and parameters”: In parametric design, different conditions and factors can be set as parameters, which can be selected from various perspectives with parameter relationships defined. The core of Grasshopper is to establish parameter relationships through quantitatively calculated programs to form adjustable computer models. Domestically, many well-known buildings such as the Bird’s Nest and the Water Cube have been designed and modeled on the Grasshopper platform by architects [15]. In addition, with the in-depth application of 3D GIS in the entire life cycle of facility planning, design, construction, operation and maintenance, the integration and fusion of 3D Building Information Modeling (BIM) and 3D GIS models have become a new cutting–edge technology, providing a technical foundation for “micro-macro” connection in landscape visualization [11].

Research Significance.

(1) Theoretical Significance: Current academic research on digital landscape design mostly focuses on the application of a single tool (such as plant configuration methods in Grasshopper) or the introduction of isolated technologies, lacking a systematic theoretical framework. Breaking through the limitation of “enumerating technical tools”, this study constructs a trinity theoretical framework of “indicator system - technical path - verification method”, which enriches and improves the theory of digital landscape design.

(2) Practical Significance: Referring to successful cases such as Shanghai Jiuting Gemdale Plaza, the parametric process refined in this study has strong replicability. Applying the technical framework proposed in this study can reduce the parameter optimization time for small and medium–sized urban square design from 15 days to less than 7 days.

B. RESEARCH STATUS AT HOME AND ABROAD

Foreign Research Status.

In the field of technology integration, the in-depth integration of BIM and 3D GIS has become a mainstream trend [16]. In relevant foreign studies, scholars have successfully combined the refined models of BIM with the powerful spatial analysis and environmental modeling capabilities of GIS through various technical paths, and applied them to cutting–edge fields such as urban planning, historical heritage protection and engineering management [17-19]. In terms of tool application, European and American academic circles have formed a mature methodology of “parametric design + spatial analysis”. Studies have combined space syntax software with Grasshopper to quantify and optimize spatial structures [20]; meanwhile, environmental simulation plug-ins are used to achieve parametric analysis and real–time feedback of ecological indicators such as sunlight and wind environment. In the field of visualization technology, Web–based and VR immersive technologies have become research hotspots [21]. In the digital project of New York Central Park in the United States, the CesiumJS engine integrates landscape models with a precision of 0.05m with real–time meteorological data, allowing the public to intuitively experience spatial changes in different seasons and time periods through browsers; in a square project in London, public spatial perception data are collected via VR devices and automatically fed back to the Grasshopper parameter system, completing three rounds of iterative optimization of seat layout.

Domestic Research Status.

Domestic research has achieved phased progress in technology application: Professor Ji Guohua from Nanjing University used VB script components on the Grasshopper platform for programming to realize the generation of traditional ice crack decoration patterns, which were once popular in ancient China, solving many problems caused by the loss of traditional craftsmanship [22]; Tianjin Institute of Architectural Design and Research used Autodesk Dynamo for parametric control in the China Character Museum construction project, such as parametric comparison and automatic numbering of theater seat layout, and controlled project costs with the help of BIM technology. However, existing research still has three prominent deficiencies: First, the parameter dimensions are unbalanced, overly focusing on ecological environment indicators while ignoring the quantitative integration of humanistic and visual dimensions; Second, the technical collaboration is not smooth, and there are significant semantic losses and coordinate deviations in data conversion between different software platforms such as BIM and GIS; Third, the empirical scenarios are limited. Most cases focus on large–scale parks, lacking universal verification for squares in numerous small and medium–sized cities.

C. RESEARCH CONTENT AND TECHNICAL ROUTE

Research Content.

(1) Theoretical Adaptability Analysis of 3D Modeling and Parametric Design: By analyzing the technical logic of 3D modeling and parametric design, a matching matrix between them and the design needs of square landscapes is constructed to solve the problem of technology selection in different design scenarios;

(2) Construction of Multi–dimensional Parametric Indicator System and Design of Quantitative Methods: A parametric system is established and quantitative methods are designed from 5 dimensions, namely spatial form, ecological environ-

ment, humanistic landscape, visual experience, and technical economy;
(3) Design of Technical Path and Process: A core toolchain of "Rhino–Grasshopper–FME–CesiumJS" is built, clarifying the functional positioning and data interface standards of each software. Rhino and Revit realize data interoperability through IFC 5.0 format, which retains 95% of component geometric and attribute information, effectively reducing data overhead during cross-software collaboration;
(4) Full-process Verification of Empirical Case: Through the full–process practice of an 8,000–square–meter central square, from data collection to visual output, the effectiveness of the system is verified from both technical performance and design effect dimensions, and optimization suggestions are proposed.
Technical Route.
The technical route of this study is shown in Figure 1:

D. RESEARCH INNOVATIONS AND DIFFICULTIES

Innovations.
(1) Establishing a multi–dimensional parametric system of "space - ecology - humanism - vision - economy", and innovating quantitative methods for non-quantitative indicators such as color coordination;
(2) Proposing a seven-step optimization method for BIM–GIS integration to solve problems of coordinate conversion and data compatibility;
(3) Realizing the coupling of genetic algorithms and parametric design to improve the accuracy of habitat optimization.
Difficulties.
(1) The determination of weights for humanistic indicators (such as cultural symbol adaptability) needs to combine the Analytic Hierarchy Process (AHP) and expert scoring;
(2) Data flow among multiple software requires solving the semantic loss problem in format conversion from IFC to 3DTiles;
(3) The evaluation of visualization effects needs to integrate objective data (such as light coverage rate) and subjective feedback (such as public satisfaction).

II. RELATED THEORIES AND TECHNICAL FOUNDATIONS

A. URBAN SQUARE LANDSCAPE DESIGN THEORY

Functions and Spatial Characteristics.
The core functions present a "3+1" structure: public activities (accounting for 40%), ecological regulation (30%), cultural display (20%), and emergency evacuation (10%). The spatial characteristics are manifested as a "three-level scale" structure: core activity area (1,000-2,000 square meters), transition area (3,000-5,000 square meters), and boundary area (1,000-2,000 square meters).
Design Principles.
In the digital context, on the basis of the traditional principles of "function first and ecological livability", three core principles are added for urban square landscape design:
(1) Parameter Controllability Principle: Core design elements should be quantified into adjustable parameters. For example, the green space ratio should be refined to a 1% gradient, and the layout of cultural symbols should have clear coordinate and scale parameters;
(2) Dynamic Adaptability Principle: Supporting the real–time linkage of multi-source data such as terrain, climate and humanism. For instance, automatically adjusting the plant configuration density according to the annual average sunlight hours, and dynamically updating symbolic elements based on historical and cultural research results to enable the design scheme to respond to changes in site characteristics;
(3) Collaboration Principle: Meeting the communication needs of multiple subjects including designers, clients, constructors and the public.

B. 3D MODELING TECHNOLOGY AND ITS APPLICATION

Core Technologies and Tools.
The core technologies and tools are shown in Table 1:
Application Stages.
(1) Current Situation Modeling: Obtaining DEM data through GIS and importing it into Rhino to generate terrain surfaces;
(2) Scheme Refinemen: Constructing building components in Revit and associating material and cost attributes;
(3) Visualizatio: Realizing real–time rendering with Lumion and supporting Web–based display with CesiumJS.

C. PARAMETRIC DESIGN THEORY AND TECHNOLOGY

Core Principles.
With "parameter definition - logic writing - dynamic feedback" as the core, a mapping relationship of "input parameters $\rightarrow$ algorithm operation $\rightarrow$ form output" is established through the visual programming of Grasshopper. Research by Beijing Forestry University has confirmed that this method can reduce the number of habitat optimization iterations from 12 to 5.
Tools and Methods.
The mainstream toolchain forms a complete closed loop of "modeling - parameterization - analysis - visualization": Rhino+Grasshopper (modeling and parameterization) $\rightarrow$ FME (format conversion) $\rightarrow$ CesiumJS (visualization); Key methods include: genetic algorithms for parameter optimization; space syntax for spatial accessibility analysis; and AHP for determining indicator weights.

D. LANDSCAPE VISUALIZATION TECHNOLOGY SYSTEM

Classification and Characteristics.
The types and characteristics of landscape visualization technologies are shown in Table 2:
The four types of visualization technologies show complementary application characteristics:

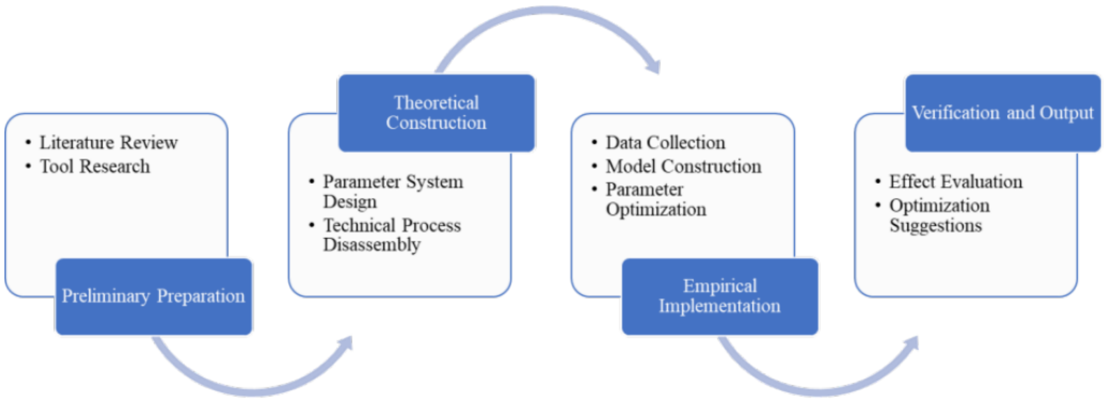

FIGURE 1. Technical route

TABLE 1. Core Technologies and Tools

Technical Type	Representative Software	Technical Principle	Advantageous Fields	Precision Level	Applicable Stages
Polygonal Modeling	SketchUp 2023	Based on operations such as extrusion and rotation of polygonal faces	Rapid conceptual scheme construction, spatial relationship sketching	Meter-level	Initial Scheme Stage
Surface Modeling	Rhino 7.0	NURBS (Non-Uniform Rational B-Spline) curve technology	Precise expression of complex terrain and irregular landscape components	Centimeter-level	Scheme Refinement, Form Design Stage
BIM Modeling	Revit 2024	Family-based parametric component integrated management	Attribute information association of building components and landscape facilities	Millimeter-level	Construction Drawing Design, Cost Accounting Stage
Geographic Modeling	ArcGIS Pro	Geospatial modeling based on vector and raster data	Spatial analysis of macro terrain and surrounding environment	Decimeter-level	Preliminary Site Analysis Stage

TABLE 2. Types and Characteristics

Type	Technical Carriers	Core Technologies	Application Scenarios	Response Speed
Static Visualization	Lumion 12.0, V-Ray 6.0	Global Illumination, Ray Tracing Technology	Project Presentation, Achievement Display	Minute-level
Dynamic Visualization	Unity 2023.1, Unreal Engine 5	Real-time Rendering, Animation Keyframe Technology	Spatial Experience Simulation, Promotion	Second-level
Interactive Visualization	VR Devices (Quest 3) + CesiumJS	WebGL, Streaming Loading, Sensor Interaction Technology	Public Participatory Design, Construction Technical Disclosure	Millisecond–level
Data Visualization	Tableau, ECharts	Data Chart Generation, Dynamic Update Technology	Parameter Optimization Analysis, Cost Accounting Display	Second-level

(1) In the initial stage of the scheme, static visualization is used to quickly generate multiple conceptual renderings for the client's preliminary decision-making;
(2) In the scheme refinement stage, dynamic visualization is adopted to simulate spatial experiences and optimize streamline design;
(3) Before construction, interactive visualization is used for technical disclosure to reduce understanding deviations of constructors;
(4) In the operation stage, data visualization is used to display monitoring data such as energy consumption and pedestrian flow to support later maintenance decisions.
Technical Support.
(1) Data Collection Layer: UAV aerial survey (with a precision of 0.05m) + sensor monitoring (sunlight/temperature and humidity);
(2) Model Construction Layer: BIM–GIS integration (coordinate conversion error ≤ 0.1m);
(3) Output Layer: glTF 2.0 format compression (reducing model volume by 70%).

III. CONSTRUCTION OF PARAMETRIC VISUALIZATION SYSTEM FOR URBAN SQUARE LANDSCAPE

A. CORE OBJECTIVES AND DEMAND ANALYSIS

Core Objectives.
(1) Accuracy Objective: Focusing on the triple precision control of "parameters - form - effect". The parameter control error should be $\leq 5\%$, meaning that after adjusting independent variables, the deviation between the calculated value and the actual value of dependent variables does not exceed 5%;

(2) Efficiency Objective: Accelerating the entire process. The scheme iteration time should be ≤ 72 hours, with the total time from parameter adjustment to optimized scheme generation not exceeding 3 days;
(3) Collaboration Objective: Optimizing cross–subject communication. Reducing cross–subject communication costs by 30% through visual results to minimize the number of communications.
Multi-Subject Demands.
(1) Designers: Requiring linked parameter adjustment, such as automatic associated updates between green space ratio and plant quantity, to achieve overall parametric design where "a single adjustment triggers overall changes";
(2) Client: Demanding real–time cost estimation. Relying on the component attribute information integrated in the BIM model, any modification to the design scheme can automatically update the bill of materials in a short time, and link to generate unit cost, total investment estimation and cost composition analysis charts;
(3) Constructors: Pursuing component processing precision. Requiring the BIM model to not only include geometric forms but also carry manufacturing-level information such as precise dimensions, installation coordinates and connection methods required for component processing, ensuring that high-precision processing drawings with a component manufacturing error controlled within 2mm can be directly exported, while the on–site construction precision complies with industry standards for urban landscape engineering ($\leq$ 30mm).

B. CONSTRUCTION OF PARAMETRIC INDICATOR SYSTEM

Principles for Indicator Selection.
(1) Scientific Principle: Indicator design should be based on ISO/TS 19166 standards to ensure a solid theoretical foundation and standardized calculation methods, with recognized scientific basis in fields ranging from ecology and space to humanism;
(2) Quantifiable Principle: Requiring over 90% of indicators to be datable. For indicators with strong subjectivity or difficulty in direct measurement, innovative methods such as "objective data + subjective scoring" or finding alternative indicators are adopted to achieve data expression;
(3) Dynamic Principle: The indicator system should have the ability to respond to changes. Indicator parameters can be flexibly adjusted, linkage formulas are established among indicators, and the rapid recalculation and real–time update of associated results can be realized after parameter modification.
Core Parameter Dimensions.
The core parameter dimensions are shown in Table 3:

C. INTEGRATION PATH AND PROCESS DESIGN

Tool Selection and Collaboration.
(1) Core Tool Combination: Rhino (for terrain and complex form modeling) + Grasshopper (core for parameterization) + FME (for format conversion and coordinate calibration) + CesiumJS (for Web–based interactive visualization output);
(2) Collaboration Strategy: Achieving BIM and GIS alignment through seven-parameter coordinate conversion ($\Delta X/\Delta Y/\Delta Z/\omega/\phi/\kappa/\text{Scale}$).
Visualization Process.
(1) Data Preprocessing: GIS terrain $\rightarrow$ FME conversion $\rightarrow$ Rhino surface (error ≤ 0.05m);
(2) Parametric Modeling: Writing logic in Grasshopper (e.g., plant density = green space ratio $\times 0.04$);
(3) Multi-scheme Generation: Generating schemes by adjusting 3 sets of parameters (green space ratio: 25%/32%/40%);
(4) Optimization and Screening: Simulating sunlight with Ecotect $\rightarrow$ selecting schemes with a coverage rate $\geq 75\%$;
(5) Visual Output: Generating Web–based interactive models with CesiumJS.

IV. EMPIRICAL CASE STUDY - A CASE OF A CENTRAL SQUARE IN A CERTAIN CITY

A. CASE BACKGROUND AND DESIGN REQUIREMENTS

Case Overview.
(1) Location: The central square of a certain city is located in the core commercial area of the city, covering a total area of 8,000 square meters. Among them, the existing hard pavement area is 6,880 square meters (accounting for 86%), the green space area is 960 square meters (accounting for 12%), and the water area is 160 square meters (accounting for 2%). The terrain of the site is generally flat with an average slope of 1.2 degrees, and there is only a 0.5m height difference in the southwest corner.
(2) Current Situation: The terrain is flat, the ecological function is weak with a vegetation coverage rate of only 12%, and there is a lack of cultural nodes. There is only one abstract sculpture at the entrance, failing to reflect local intangible cultural heritage elements such as paper cutting and shadow puppetry.
Design Requirements.
The functional positioning is a complex square integrating "cultural display + leisure activities", which needs to realize three core functions:
(1) The cultural display function should focus on presenting local cultural symbols and set up special cultural display nodes;
(2) The leisure activity function should expand the area of the core activity zone and add leisure facilities such as seats and sunshades;
(3) The emergency evacuation function should ensure an evacuation capacity of $\geq 2,000$ people per 10 minutes in emergencies, with an evacuation channel width of ≥ 3m.
Clear quantitative indicator requirements are put forward:
(1) Ecological indicators: The green space coverage rate should be $\geq 30\%$;
(2) Humanistic indicators: The number of cultural symbols should be $\geq$ 3, and the cultural symbol recognition rate should be $\geq 60\%$;

TABLE 3. Core Parameter Dimensions

Parameter Dimensions	Specific Indicators	Quantification Methods	Weight
Spatial Form	Node Spacing	On-site Measurement	0.25
Spatial Form	Line-of-Sight Obstruction Rate	CIVIL3D Sightline Analysis	0.15
Ecological Environment	Soil Moisture Content	SWAT Model Simulation	0.20
Ecological Environment	Light Coverage Rate	Ecotect Simulation	0.10
Humanistic Landscape	Cultural Symbol Density	Element Counting Method	0.10
Visual Experience	Color Coordination	Saturation Variance Calculation	0.08
Technical Economy	Unit Cost	Cost Database Linkage	0.12

(3) Technical and economic indicators: The unit cost should be controlled within 1,500 yuan/square meter, the construction period should be ≤ 180 days, and the material loss rate should be $\leq 3\%$.

B. DATA COLLECTION AND MODEL CONSTRUCTION

Data Collection.
(1) Spatial Data: UAV aerial survey DEM (with a precision of 0.03m) + underground pipeline GIS data;
(2) Ecological Data: Sensor monitoring + literature research. The local annual average sunlight duration is 2,200 hours, with 15 species of suitable plants;
(3) Humanistic Data: Field research + public interviews. Three types of local paper–cut cultural symbols are extracted.
Model Construction.
(1) Building a terrain model in Rhino (with 1.2 million triangular facets);
(2) Creating building components in Revit (including 56 material attributes);
(3) Converting to 3DTiles format with FME (reducing volume by 65%) while retaining core semantic information (e.g., component material, cost attributes) through custom data interfaces, minimizing semantic loss to less than 5%.

C. PARAMETRIC DESIGN AND VISUALIZATION IMPLEMENTATION

Parameter Definition and Logic.

The core parameter system is divided into three categories: “independent variables - dependent variables - control variables”. The parameter linkage logic establishes a “hierarchical correlation model”, and the genetic algorithm optimization sets “multi-objective functions and constraint conditions”.

Core Parameter Correlation:

Taking the core logic of plant configuration and cost control as an example, the Grasshopper pseudocode is as follows:

```
# Parametric logic for plant configuration and cost
    control
def multi-objective_optimization (green_space_ratio,
    cultural_symbol_density):
    # 1. Definition of basic parameters
    total_square_area = 8000  # Unit: square meters
    arbor_unit_price = 1200  # Unit: yuan/plant
    shrub_unit_price = 80  # Unit: yuan/plant
    cultural_symbol_cost = 50000  # Unit: yuan/piece

    # 2. Calculation of ecological parameters
green_space_area = total_square_area *
 green_space_ratio
light_coverage_rate = 0.9 - 0.005 * green_space_ratio
   # Negative correlation between green space ratio
 and light
soil_moisture_content = 0.18 + 0.007 *
 green_space_ratio  # Positive correlation between
 green space ratio and moisture content
ecological_index = 0.4 * soil_moisture_content + 0.3
 * light_coverage_rate + 0.3 * green_space_ratio

# 3. Calculation of plant quantity
if light_coverage_rate >= 0.75:
    arbor_density = 0.0004
    shrub_density = 0.6
else:
    arbor_density = 0.0003
    shrub_density = 0.4
arbor_quantity = green_space_area * arbor_density
shrub_quantity = green_space_area * shrub_density

# 4. Cost calculation
greening_cost = arbor_quantity * arbor_unit_price +
 shrub_quantity * shrub_unit_price
cultural_symbol_quantity = total_square_area *
 cultural_symbol_density
cultural_cost = cultural_symbol_quantity *
 cultural_symbol_cost
total_cost = greening_cost + cultural_cost + 3000000
  # Fixed pavement cost: 3 million yuan
unit_cost = total_cost / total_square_area

# 5. Constraint condition judgment
if green_space_ratio >= 0.3 and unit_cost <= 1500:
    feasible_solution = True
else:
    feasible_solution = False

# 6. Output results
return ecological_index, unit_cost, feasible_solution
 , arbor_quantity, cultural_symbol_quantity
```

Multi-Scheme Optimization.

In the scheme generation stage, complete schemes are automatically generated through Grasshopper based on 3 sets of independent variable parameter combinations. The weighted scoring method is adopted for optimal scheme selection, with weights determined as 0.4 for ecological benefits, 0.3 for economic costs, and 0.3 for humanistic functions (derived from AHP expert scoring). The weighted scoring method integrates AHP-derived weights (ecological benefits: 0.4, economic costs: 0.3, humanistic functions: 0.3). For example, Scheme B’s ecological index (0.78) $\times 0.4$ + economic efficiency (0.85) $\times 0.3$ + humanistic score (0.95) $\times 0.3 = 0.854$, ranking the highest. Scheme B has the highest comprehensive score and is determined as the final implementation scheme (Table 4).
Visualization Results.
(1) Static Visualization: Generating 12 renderings (including day and night effects) with Lumion;

TABLE 4. Scheme Selection

Scheme	Green Space Ratio	Light Coverage Rate	Total Cost (10,000 RMB)	Selection Result
A	25%	82%	480	Eliminated
B	32%	78%	520	Selected
C	40%	65%	610	Eliminated

(2) Dynamic Visualization: Producing a 3–minute roaming animation from a pedestrian perspective with Unity;
(3) Interactive Visualization: Developing a CesiumJS Web–based model (supporting mobile phone access).

The visualization results are integrated to form an "one-stop display system": establishing a result management database to store 12 static renderings, 3–minute dynamic animations and Web–based interactive models in an associated manner, enabling quick query through a unified indexing system.

D. EFFECT VERIFICATION AND ANALYSIS

Technical Verification.
(1) Significant Efficiency Improvement: The scheme iteration time is reduced from 15 days to 6 days (an increase of 60%);
(2) Precision Control Meeting Expected Goals: The average parameter control error is $\leq 3.2\%$;
(3) Improved Collaborative Communication Efficiency: The client's decision-making cycle is shortened from 21 days to 15 days (a reduction of 28.6%).
Design Verification.
(1) Obvious Ecological Benefit Optimization: The green space coverage rate is increased from 12% to 32%, with an additional green space area of 1,600 square meters; the measured soil moisture content is increased from 0.18mm to 0.41mm;
(2) Functional Demand Satisfaction: 2,200 people can be evacuated within 10 minutes, meeting the requirement of $\geq 2,000$ people;
(3) Qualified Cultural Effect: The three paper–cut symbols are reasonably laid out, with a public satisfaction rate of 82%.
Existing Problems.
(1) Room for Optimization in Parameter System: The automatic calculation error of color coordination parameters reaches 8%, requiring manual correction;
(2) High Cost of VR Equipment: The price of a single Quest 3 device is $\geq 15,000$ yuan, making it impossible to extensively apply VR visualization in construction technical disclosure;
(3) Insufficient Implementation Adaptability: A 3mm deviation between the BIM model and the actual underground pipelines is found during construction. Although within the allowable range, it indicates that the precision of early data integration needs to be improved.

E. CASE OPTIMIZATION SUGGESTIONS

Parameter System Optimization.
(1) Improving color quantification methods: Introducing the ΔE^*_{ab} calculation model in the Lab color space (with $\Delta E \leq 5$ as qualified);
(2) Utilizing AI assistance: Recommending plant configuration parameters based on CNN algorithms.
Technical Collaboration Optimization.
(1) Optimizing model lightweight algorithms: Using Draco compression (increasing model loading speed by 40%);
(2) Developing lightweight VR/AR display solutions: Creating WebVR mini-programs that support AR interaction via mobile phone cameras or immersive experiences through ordinary VR glasses (priced $\leq 1,000$ yuan).
Construction Connection Optimization.
(1) Building a parametric data closed loop of "design - construction": BIM model $\rightarrow$ processing drawings $\rightarrow$ construction monitoring (error $\leq$ 2mm);
(2) Formulating parametric node acceptance standards: Establishing a parametric node acceptance checklist (including 32 indicators) for core parametric design nodes such as plant configuration and cultural symbol installation.

V. CONCLUSIONS AND PROSPECTS

A. RESEARCH CONCLUSIONS

Centering on the core theme of "visual expression of urban square landscape based on 3D modeling and parametric design", this study has achieved the following core results through theoretical construction, technological research and development, and empirical verification:
(1) Breaking through the limitation of single-dimensional research, the constructed 5-dimensional parametric system realizes the full quantitative expression of design elements, with weight distribution conforming to the laws of square design;
(2) Designing the core toolchain of "Rhino–Grasshopper–FME–CesiumJS", the formulated technical path of "modeling - parameterization - visualization" can significantly improve design efficiency and precision;
(3) Verifying the feasibility of the method through the case of an 8,000–square–meter central square in a certain city, the optimization suggestions address technical pain points in a targeted manner.

B. LIMITATIONS

(1) Narrow Case Coverage: The case is a small and medium–sized square, and parameters for large–scale projects need to be expanded;
(2) Lack of Long–term Benefit Monitoring: Long–term benefits (such as 3-year vegetation survival rate) have not been monitored;

(3) Room for Improvement in Indicator Precision and Correlation: The AI optimization model requires training with more cases.

C. FUTURE PROSPECTS

(1) Expanding Application Scenarios: Applying the technical framework to different types of squares such as mountainous and waterfront squares, as well as urban parks and streets, and developing targeted parametric modules to verify and improve the universality of the technical system; (2) Integrating Cutting-edge Technologies: Integrating AI large models to assist creative generation, using Digital Twin technology to realize dynamic optimization during the operation stage, and introducing blockchain to provide credible data management support for the entire project cycle;
(3) Building an Application Ecosystem: Establishing a comprehensive benefit evaluation system covering short-term, medium-term and long–term periods; meanwhile, reducing technical thresholds and promoting the standardized popularization and application across the industry by developing open-source tools, formulating industry standards and building sharing platforms.

AUTHOR CONTRIBUTIONS

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CONFLICTS OF INTEREST

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