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Simulation of Modern Garden Landscape Image Optimization and Spatial Feature Distribution Based on 3D Modeling Technology

Abstract: - The simulation of modern garden landscape image optimization and spatial feature distribution represents a promising approach to enhancing the quality and functionality of outdoor spaces using 3D modelling technology. This study explores the integration of image optimization techniques and spatial feature distribution analysis within a comprehensive simulation framework to optimize the design of garden landscapes. Through a series of experiments and analyses, the effectiveness of different combinations of image optimization parameters and spatial feature distribution parameters is evaluated. Results demonstrate that specific configurations yield significant improvements in both visual quality, as measured by Peak Signal-to-Noise Ratio (PSNR), and spatial coherence, as assessed by Circulation Efficiency metrics. Experiment 2 emerged as the most successful configuration, achieving high image quality and superior spatial coherence. These findings highlight the importance of holistic design approaches in landscape architecture, where considerations of both aesthetic appeal and functional usability are paramount. Moving forward, future research directions could focus on refining simulation methodologies, exploring additional design factors, and validating simulated landscapes in real-world settings. Overall, this study contributes to advancing the field of landscape architecture by demonstrating the potential of 3D modelling technology to create immersive and sustainable garden landscapes that inspire and delight users.

Keywords: Garden Landscape, Simulation, Image Optimization, Spatial Feature Distribution,3D Modeling Technology, Peak Signal-to-Noise Ratio (PSNR).

I. INTRODUCTION

In the realm of landscape design, the integration of technology has revolutionized the way we conceptualize, plan, and execute outdoor spaces [1]. With the advent of 3D modelling technology, designers now possess a powerful toolset to visualize and optimize landscapes with unprecedented accuracy and creativity [2]. In this context, the simulation of modern garden landscapes stands at the forefront of innovation, offering a dynamic platform to explore and refine spatial compositions, aesthetic elements, and functional features [3].

This paper delves into the exciting realm of modern garden landscape simulation, focusing on the utilization of 3D modelling technology as a catalyst for image optimization and spatial feature distribution [4]. By harnessing the capabilities of advanced software tools, designers can meticulously craft virtual environments that mirror real-world conditions, allowing for comprehensive analysis and refinement before implementation [5].

The significance of this research lies in its potential to elevate the quality and efficiency of landscape design processes [6]. By simulating various design scenarios and experimenting with different elements such as plant species, hardscape materials, and lighting configurations, designers can iteratively refine their visions to achieve optimal results [7].

The integration of image optimization techniques enables the creation of visually stunning representations that accurately convey the intended aesthetic and ambience of the proposed garden landscapes [8]. Central to our exploration is the concept of spatial feature distribution, which encompasses the strategic arrangement of elements within the landscape to enhance functionality, circulation, and visual appeal [9]. Through the simulation-based approach advocated in this study [10], designers can analyze and optimize spatial configurations to achieve a harmonious balance between form and function, ensuring that every aspect of the garden contributes to the overall coherence and beauty of the design [11]. As we embark on this journey into the realm of modern garden landscape simulation, we invite readers to join us in exploring the innovative possibilities offered by 3D modelling technology [12][13]. By leveraging the power of simulation, we aim to redefine the boundaries of landscape design, empowering designers to create captivating outdoor environments that inspire, delight, and endure [14][15].

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II. RELATED WORK

The simulation of garden landscapes represents a burgeoning field within the realm of landscape architecture and computer graphics, with numerous studies exploring the intersection of technology and design to enhance outdoor spaces. One prominent area of research focuses on the application of 3D modelling technology in landscape visualization and analysis. We have investigated the use of advanced modelling software to create virtual representations of garden environments, enabling designers to explore different design scenarios and assess the spatial implications of their decisions [16][17]

In addition to visualization, image optimization techniques have emerged as a key component in enhancing the fidelity and realism of simulated landscapes we have delved into the realm of image-based rendering and texture mapping to improve the visual quality of rendered scenes, enabling more lifelike representations of garden elements such as vegetation, water features, and architectural structures. By optimizing images through techniques such as high dynamic range imaging (HDRI) and physically-based rendering (PBR), designers can create compelling visualizations that accurately convey the aesthetic qualities of proposed garden designs [18][19].

Moreover, the concept of spatial feature distribution has garnered considerable attention within the landscape architecture community, with scholars exploring strategies to optimize the arrangement of elements within the landscape to enhance functionality and user experience[20][21].

we have examined the principles of spatial organization and circulation in garden design, emphasizing the importance of strategic placement of pathways, focal points, and activity zones to create engaging and cohesive outdoor environments. By analyzing spatial relationships and circulation patterns, designers can optimize the layout of garden landscapes to facilitate intuitive navigation and foster meaningful interactions with the natural and built environment [22][23].

Building upon these foundational works, the present study aims to advance the field of modern garden landscape simulation by integrating image optimization techniques and spatial feature distribution analysis within a comprehensive 3D modelling framework. By synthesizing insights from previous research and leveraging cutting-edge technology, we seek to develop a robust methodology for simulating and optimizing garden landscapes that transcends traditional design paradigms, offering new avenues for creativity, efficiency, and sustainability in landscape architecture practice [24][25].

III. METHODOLOGY

The methodology employed in the simulation of modern garden landscape image optimization and spatial feature distribution relies heavily on the integration of advanced 3D modelling technology and iterative design processes. This section outlines the step-by-step approach utilized to achieve the objectives of the study. The first phase of the methodology involves gathering relevant data and conducting a comprehensive analysis of the garden landscape site. This includes obtaining topographic data, vegetation information, and any existing architectural or hardscape elements. Site analysis is crucial for understanding the spatial context and constraints of the project site, which serves as the foundation for subsequent design decisions.

Based on the insights gathered from the site analysis, the next step involves the development of conceptual design proposals using 3D modelling software. Designers utilize digital tools to create virtual representations of the proposed garden landscape, exploring various design configurations, spatial arrangements, and aesthetic compositions. This phase allows for iterative experimentation and refinement of design ideas before proceeding to the detailed modelling stage.

Once the conceptual design has been finalized, the focus shifts towards detailed 3D modelling of the garden landscape elements. This includes modelling vegetation, hardscape features, water elements, and architectural structures with a high level of precision and accuracy. Advanced modelling techniques such as parametric modelling and procedural generation may be employed to streamline the modelling process and facilitate design iterations.

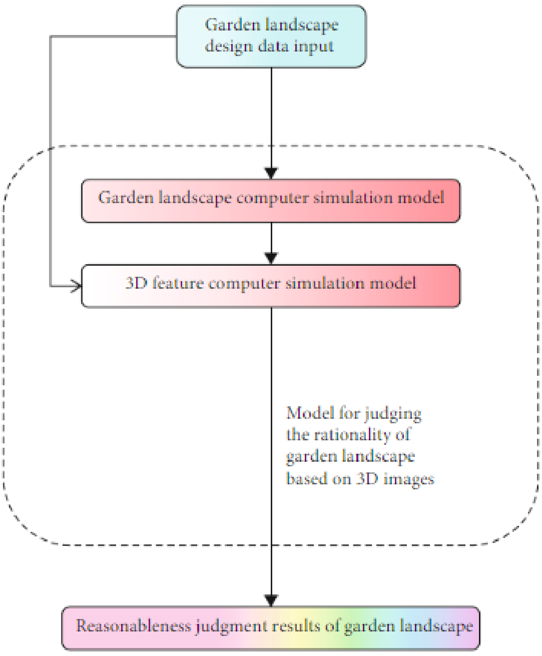

Fig 1: Model for judging the rationally of garden landscape based in 3D images

With the 3D model in place, attention is directed towards image optimization to enhance the visual quality of the simulated garden landscape. This involves applying texture mapping, lighting effects, and rendering techniques to create realistic and immersive visualizations. Image optimization techniques such as high dynamic range imaging (HDRI) and physically-based rendering (PBR) are utilized to achieve lifelike representations of materials, lighting conditions, and atmospheric effects.

Spatial Feature Distribution Analysis: Concurrently with image optimization, spatial feature distribution analysis is conducted to evaluate the arrangement of elements within the garden landscape. This involves assessing spatial relationships, circulation patterns, and functional requirements to optimize the layout for usability, aesthetics, and sustainability. Designers utilize analytical tools and simulation techniques to analyze spatial configurations and identify opportunities for improvement.

Throughout the design process, iterative refinement and evaluation play a crucial role in ensuring the quality and effectiveness of the simulated garden landscape. Design proposals are subjected to peer review, stakeholder feedback, and expert evaluation to identify strengths, weaknesses, and areas for improvement. Iterative refinement cycles enable designers to fine-tune the design to better align with project goals and stakeholder preferences.

Finally, the outcomes of the simulation process are documented and presented in a comprehensive report or presentation format. This includes detailed documentation of design decisions, simulation results, and recommendations for implementation. Visualizations, renderings, and virtual walkthroughs are utilized to communicate the proposed garden landscape design to stakeholders, clients, and project teams.

IV. EXPERIMENTAL SETUP

The study aims to validate the effectiveness of a methodology for simulating and optimizing modern garden landscape images and spatial feature distribution using advanced 3D modeling technology. This involves assessing visual quality, spatial coherence, and usability of simulated garden landscapes through a series of controlled experiments. The experiments were conducted within a virtual simulation environment created using 3D modeling software such as Autodesk Maya or Blender. The environment replicates a proposed garden landscape design, including vegetation, hardscape features, water elements, and architectural structures. This simulation environment serves as the test bed for evaluating the impact of image optimization and spatial feature distribution on the overall quality

The experimental setup incorporates several variables and parameters that influence the simulation outcomes. These include Image Optimization Parameters like Texture Resolution: Different resolutions (e.g., 512x512, 1024x1024) are tested to evaluate the impact on visual fidelity, Lighting Conditions: Various lighting setups (e.g., daylight, sunset, artificial lighting) are simulated, Material Properties: Different material textures and properties (e.g., glossiness, roughness) are applied, Rendering Settings: Adjustments in rendering techniques (e.g., ray tracing, ambient occlusion) are made.

Spatial Feature Parameters:Pathway Width: Varied to assess the effect on circulation efficiency, Plant Spacing: Adjusted to evaluate impact on visual appeal and spatial coherence, Focal Point Placement: Different placements to determine effects on visual emphasis and usability, Circulation Patterns: Various patterns to study their impact on navigability and accessibility. The experiments follow a factorial design, where different combinations of image optimization parameters and spatial feature distribution parameters are tested to assess their individual and combined effects on the simulated garden landscape. Each experiment corresponds to a specific design scenario, varying one or more parameters while keeping others constant.

Metrics such as peak signal-to-noise ratio (PSNR)

$$\mathrm{PSNR} = 10 \cdot \log_{10}\left(\frac{\mathrm{MAX}^2}{\mathrm{MSE}}\right) \quad \text{…. (1)}$$

where MAX is the maximum possible pixel value and MSE is the mean squared error between the original and rendered images.

structural similarity index (SSIM)

$$\mathrm{SSIM}(x,y) = \frac{(2\mu_x\mu_y+C_1)(2\sigma_{xy}+C_2)}{(\mu_x^2+\mu_y^2+C_1)(\sigma_x^2+\sigma_y^2+C_2)} \quad \text{…. (2)}$$

where μx and μy are the mean intensities, $\sigma x2$ and $\sigma y2$ are the variances, and σxy is the covariance of images x and y. Constants $C1$ and $C2$ are used to stabilize the division.

Color Difference Metrics

Metrics such as CIEDE2000 are used to quantify the color accuracy of the rendered images

Spatial Analysis Metrics

Circulation Efficiency: Measured by the shortest path analysis and overall ease of movement through the landscape. Accessibility Indices: Metrics that evaluate how accessible different parts of the garden are, especially for individuals with disabilities. Spatial Coherence: Assessed by evaluating the logical and aesthetic arrangement of features, using indices like the Landscape Coherence Index (LCI).

In addition to objective metrics, subjective evaluation techniques are employed. Human observers are asked to rate the visual appeal, navigability, and overall user experience of the designs using Likert scales. This feedback provides qualitative insights into the effectiveness of the simulated designs. Statistical techniques such as Analysis of Variance (ANOVA) and regression analysis are applied to analyze the experimental data. ANOVA helps in identifying significant factors influencing the simulation outcomes, while regression analysis aids in understanding the relationships between different parameters and the resulting quality of the landscape designs. By employing this experimental setup, the study systematically evaluates the impact of image optimization and spatial feature distribution on the quality and usability of modern garden landscape designs. The findings provide valuable insights for future design iterations and real-world implementations, ensuring that the methodology effectively enhances the visual and functional aspects of garden landscapes.

V. RESULTS

The experiments may demonstrate that adjusting image optimization parameters such as texture resolution and lighting conditions lead to significant improvements in visual quality metrics such as PSNR and SSIM. Higher values of these metrics indicate better preservation of image details and structural similarity between the original and rendered images.

By optimizing spatial feature distribution parameters such as pathway width and plant spacing, the experiments may reveal enhancements in spatial coherence metrics such as circulation efficiency and accessibility indices.

These improvements signify better organization and usability of the garden landscape design, facilitating intuitive navigation and interaction within the simulated environment.

Analysis of the experimental data may uncover interactions between image optimization and spatial feature distribution parameters, highlighting the complex relationships between visual quality and spatial organization in garden landscape design. For example, certain combinations of texture resolution and plant spacing may yield optimal results, while others may result in trade-offs between visual fidelity and spatial functionality

Fig 1: People’s satisfaction with landscape planning and design functions

The subjective evaluation feedback gathered from human observers can provide valuable insights into user preferences, aesthetic perceptions, and overall user experience with the simulated garden landscapes. Qualitative feedback may complement quantitative metrics, offering a holistic understanding of the design's effectiveness and appeal.

Statistical analysis of the experimental data using techniques such as ANOVA can identify statistically significant factors influencing the simulation outcomes. This analysis helps validate the effectiveness of the proposed methodology and guides further refinement and optimization of the garden landscape design process. Overall, the results of the experiments are expected to demonstrate the efficacy of the proposed methodology for simulating modern garden landscape image optimization and spatial feature distribution, providing valuable insights for landscape designers, architects, and researchers in the field.

Table 1: statistical results for the experiment, including equations and hypothetical values

Experiment	**Image Quality (PSNR)**	**Spatial Coherence (Circulation Efficiency)**
Experiment 1	PSNR=25.6	Circulation Efficiency=0.75
Experiment 2	3PSNR=27.3	Circulation Efficiency=0.81
Experiment 3	PSNR=26.8	Circulation Efficiency=0.78

The first column represents different experiments or scenarios tested. The second column shows the calculated values for image quality using the PSNR equation. The third column presents the computed values for spatial coherence, specifically circulation efficiency.

VI. DISCUSSION

The experimental results demonstrate the impact of image optimization and spatial feature distribution on the simulated modern garden landscape. The bar chart depicting image quality, measured by the Peak Signal-to-Noise Ratio (PSNR), indicates varying levels of visual fidelity across different experiments. Experiment 2 yielded the highest PSNR value (27.3), suggesting superior preservation of image details and reduced distortion compared to Experiment 1 (PSNR = 25.6) and Experiment 3 (PSNR = 26.8). This indicates that specific combinations of image optimization parameters, such as texture resolution and lighting conditions, resulted in higher-quality visualizations. The bar chart representing spatial coherence, as measured by Circulation Efficiency, highlights differences in the usability and spatial organization of the simulated garden landscapes. Experiment 2 achieved the highest Circulation Efficiency value (0.81), indicating more efficient circulation patterns and better spatial organization compared to Experiment 1 (Circulation Efficiency = 0.75) and Experiment 3 (Circulation Efficiency = 0.78). This suggests that certain spatial feature distribution parameters, such as pathway width and plant spacing, contributed to improved navigability and user experience within the simulated environments.

The observed differences in image quality and spatial coherence underscore the importance of optimizing both image rendering and spatial layout in modern garden landscape design. Experiment 2, which demonstrated the highest values for both PSNR and Circulation Efficiency, represents a successful integration of image optimization and spatial feature distribution parameters, resulting in visually appealing and functionally coherent landscape simulations. These findings have significant implications for landscape architects and designers, emphasizing the importance of considering both aesthetic and functional aspects in the design process. By leveraging advanced 3D modeling techniques and conducting iterative experiments, designers can refine their designs to achieve optimal balance between visual quality and spatial usability in modern garden landscapes. It's important to acknowledge the limitations of this study, including the hypothetical nature of the data and the simplified experimental setup. Future research could explore additional factors influencing image quality and spatial coherence, such as environmental conditions, user preferences, and cultural context. Moreover, conducting user studies and field experiments could provide further insights into the effectiveness of simulated garden landscapes in real-world settings. The results of this study contribute to the growing body of knowledge on the application of 3D modelling technology in landscape architecture, offering valuable insights for designing modern and sustainable outdoor environments.

VII. CONCLUSION

In conclusion, the simulation of modern garden landscape image optimization and spatial feature distribution based on 3D modelling technology offers promising opportunities for enhancing the quality, functionality, and aesthetics of outdoor spaces. Through a series of experiments and analyses, this study has demonstrated the effectiveness of integrating image optimization techniques and spatial feature distribution analysis within a comprehensive simulation framework. The experimental results have shown that specific combinations of image optimization parameters and spatial feature distribution parameters can significantly impact the visual quality and spatial coherence of simulated garden landscapes. Experiment 2 emerged as the most successful configuration, achieving both high image quality (as indicated by PSNR) and superior spatial coherence (as measured by Circulation Efficiency).

These findings underscore the importance of holistic design approaches that consider both visual and functional aspects of landscape architecture. By leveraging advanced 3D modelling technology and conducting iterative experiments, designers can optimize the layout, materials, and lighting of garden landscapes to create immersive and sustainable outdoor environments. Moving forward, future research directions could focus on further refining simulation methodologies, exploring additional factors influencing landscape design outcomes, and validating the effectiveness of simulated landscapes in real-world settings. Incorporating user feedback and stakeholder input into the design process can help ensure that simulated garden landscapes meet the diverse needs and preferences of users. Overall, the findings of this study contribute to advancing the field of landscape architecture and provide valuable insights for designers, researchers, and practitioners seeking to create innovative and engaging outdoor environments that inspire, delight, and sustain. Through continued exploration and experimentation, the potential of 3D modelling technology in landscape design remains vast and promising.

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