sustainability

Article

Rural Environmental Landscape Construction Based on Virtual Reality Technology

Bowen Sun [1,†], Yanan Jiang [1,†], Yanyan Liu [1], Xue Wu [2] and Qiang Liu [1,*]

1 Academy of Arts & Design, Tsinghua University, Beijing 100084, China; sbw19@mails.tsinghua.edu.cn (B.S.); jiangyn22@mails.tsinghua.edu.cn (Y.J.); liuyy22@mails.tsinghua.edu.cn (Y.L.)
2 School of Humanities and Social Sciences, Xi'an Jiaotong University, Xi'an 710049, China; wuxuejs@xjtu.edu.cn
* Correspondence: liu-qiang@mail.tsinghua.edu.cn
† These authors contributed equally to this work.

Abstract: With the recent shift in public aesthetics, tourism agriculture, which combines tourism with modern agriculture, has become a new and popular form of tourism, exhibiting great potential. Internationally, tourism is known as a sunrise industry that will never decline because the benefits and impact introduced by tourism are not only limited to the industry itself but also the development of other fields. It stimulates the labor force by creating job vacancies, consumption, economic benefits, and opportunities for the surrounding areas. Therefore, paying attention to the development of tourism and focusing on the trending frontier issues of the industry are of practical value to the development of social economy and culture. Traditional forms of tourism develop economic value by focusing on people's direct experiences at specific times and places. However, this approach is somewhat limited by time and space constraints, preventing the full exploitation of the economic and cultural value of tourism landscapes. In contrast, modern rural tourism models based on virtual environment modeling and virtual reality technology can address this issue, enhancing the development of rural tourism industries. Virtual environment modeling designs specific spatial environments and simulates internal elements, providing authenticity to environments and a sense of reality using textures. Virtual reality technology goes further in creating highly realistic virtual environments that are generated by computers, encompassing visual, auditory, linguistic, force, tactile, motion, and olfactory elements, and enabling natural interactions between various sensory devices of the operator and the landscape model. The combination of these two approaches offers a broader scope and more nuanced physical and mental experiences for the rural tourism industry. This paper explores the optimization role of virtual environment and environmental landscape modeling based on virtual reality technology in designing rural tourism landscapes. It examines the specific elements of optimization within this type of technology and, using algorithms, demonstrates that these methods provide a 15.73% optimization rate in the sightseeing process compared to traditional tourism models, making them widely applicable in the design of rural tourism landscape environments.

Keywords: virtual reality technology; the country; agricultural sightseeing; environmental landscape construction

check for updates

Citation: Sun, B.; Jiang, Y.; Liu, Y.; Wu, X.; Liu, Q. Rural Environmental Landscape Construction Based on Virtual Reality Technology. *Sustainability* **2023**, *15*, 16377. https://doi.org/10.3390/su152316377

Academic Editors: Tsung Hung Lee and Fen-Hauh Jan

Received: 25 October 2023
Revised: 17 November 2023
Accepted: 24 November 2023
Published: 28 November 2023

1. Introduction

The rapid development of science and technology is the main theme of social civilization in the 21st century, which means that the boundaries between the concepts of science and technology and daily life are no longer clearly divided but extend into all aspects of life. The developing path of science and technology is expanding from precision and efficiency toward life and emotion [1]. Today, science and technology not only provide convenience in people's lives but also improvements in the pursuit of environmental quality and aesthetic realization. Currently, efficient and convenient landscape design and development software plays a key role in the planning, design, and construction of urban landscapes and architecture, and virtual reality technology gives these designs a sense of reality, interaction, and immersion. In recent years, the value of rural landscapes has been gradually highlighted, and the practical value of the design and development of rural agricultural landscapes has been demonstrated [2]. With improvements in life quality, modern people appear to pay more attention to sensory experience, which not only puts forward higher requirements for urban construction to balance life function and aesthetic value but also focuses attention on rural tourism. As a compound area that integrates natural scenery, folk architecture, and traditional culture, rural areas have the emotional support of Chinese people and exhibit the historical spirit of national culture. Currently, with the development of modern civilization, rural areas can be used to trace the simple emotions and aesthetics of the Chinese people. Accordingly, government management departments and related architectural design units invest more funds and manpower in this regard, and they have begun to pay attention to the development and application of relevant technologies [3]. Therefore, methods for using VR, combined with the characteristics of agricultural sightseeing, in the development of three-dimensional scenic spots have played a significant role in the research into virtual tourism. Virtual environments are interactive visual simulations created by computers, affecting users through sight, sound, and touch and providing them with an immersive experience. Virtual environments are one of the most important research areas in virtual reality technology and are an essential component of virtual reality software. Virtual environments have three main prominent features: interaction, immersion, and imagination. Virtual environment modeling can be used in a variety of applications, such as architectural walkthroughs, furniture displays, creating movie scenes, simulating work environments, like large hydroelectric power stations, production workshops, operating rooms, and municipal planning, such as road construction simulations, etc. [4]. By applying virtual environment modeling, it is possible to construct virtual environments with a sense of realism, which means creating virtual environments that are graphically or visually similar to real environments. The specific implementation methods are divided into two categories: image-based virtual modeling methods and geometry-based virtual environment modeling methods. With respect to generating models, the application of texture mapping and lighting models further enhances their realism [5].

The countryside is an organic system that comprises multi-nature architecture, such as practical architecture, cultural architecture, and overlapping natural landscapes. The old practice of understanding the rural agricultural landscape via a single view has become impracticable. Due to the public's aesthetic requirements with respect to tracing their roots and returning to nature, the establishment of a five-dimensional (including coordinates and time and object attributes) model of the rural agricultural landscape may further develop and realize its ornamental value. Therefore, virtual reality technology and "digital Earth" system technology can be regarded as new perspectives in the development of the rural agricultural tourism industry in China [6]. The countryside is a complex system that is interwoven between humans and nature. It involves the intensification of resources, environment, economy, culture, population, etc. Its structure, appearance, and planning not only affect the development space and practical benefits of rural agricultural tourism but also affect the lifestyle of residents. Therefore, reasonable rural agricultural landscape design not only requires designers to create beautiful scenery via artistic design—which is pleasing to the eye and satisfies tourists' sightseeing needs—but also ensures that the local ecological environment and the life and culture of residents in the area are not deformed, which provides a huge opportunity and creates challenges for landscape planners [7]. Landscape planning and design no longer comprise simple artistic expression, and their engineering application has proceeded far beyond its inception. As the technical foundation and pillar of virtual reality technology and "digital Earth" technology, the application of computer technology in landscape construction can render landscape construction more standardized, scientific, and accurate from the initial stages of geological exploration and program research to the later stages of simulation environment design [8].

The application of computer technology in the field of landscape design and construction is also more suitable for the requirements of rural landscape systems. The rural landscape system contains a variety of elements: for instance, the human landscape, the natural environment, and the social structure. It is an ecological complex based on the interaction between humans and the environment. The rich ecological, social, economic, and cultural aesthetic values in rural landscapes interact with each other, reflecting strong humanistic values. Therefore, the rural landscape design process needs to consider multiple factors and interactions in order to construct comprehensive design combinations to enhance the visual presentation effect of rural landscapes. Under this context, the value and necessity of computer technology can be observed [9]. With the humanistic value of the landscape becoming increasingly prominent, people have begun to search for tourism resources that integrate ornamental and emotional values with naturalness and modernity. Agricultural sightseeing parks that are based on the rural environment have adopted economic, aesthetic, social, and cultural values, and they have developed rapidly [10]. VR, as one of the major achievements of digital technology in the 21st century, is affecting and changing our lives. Thus, we utilize a concept of the "real world" (virtual world) that is constantly intertwined with reality, reflecting human intelligence and creativity [11]. VR is a smart tool for understanding and analyzing the digital Earth, connecting global resources and information, building a visual, tactile, and auditory VR environment for everyone, and helping people understand and explore our planet. From the above analysis, it can be observed that the value space currently displayed via virtual reality technology is ushering in opportunities. In recent years, the research and application of virtual reality technology have become a focus of attention [12]. For rural landscapes relative to the context of the rural tourism industry, VR technology has many application scenarios and much potential. Taking current practical problems as an example, the information characteristics of VR technology can provide solutions for inconvenient transportation and immersion experiences, and could be used as substitutes when factors such as unreasonable development, low-level services, and inconvenient seasons and epidemics are present. In addition, the novel characteristics of VR technology can aid in the avoidance of serious homogenization and weak commercial promotion. Therefore, the application of VR technology in the design and construction of the rural environmental landscape plays a substantial role at the technical level in solving practical problems and promoting the development of rural tourism industries [13].

1.1. The Innovation of This Paper Lies within the Following

1. This article introduces virtual environment modeling and explores methods for constructing and optimizing a realistic virtual environment that is similar in shape to an actual environment (which can be graphical or image-based).
2. The article discusses the application of VR technology in environmental landscape modeling. After understanding environmental modeling and its contents, it is also crucial to comprehend the relationship between VR technology and environmental landscape models, as well as the interaction between the environment and people. The characteristics and advantages of VR technology have significant value in the field of landscape design as they can promote improvements and developments in landscape design and enhance the experience of people in landscape environments.
3. The research methods and the results are introduced and discussed in order to inform readers. In this manner, the contents of the article can also be more comprehensive.

1.2. The Significance of This Research Lies in the Following

1. Academic Significance The use of VR technology has optimized the efficiency of traditional architectural models by 15.73%. This result not only proves the effectiveness of VR technology in practical applications but also demonstrates the innovative potential of the integration of technology in theory and practice. It reflects the theoretical value of technological crossovers and integration in innovative research, further explor-

ing the application of virtual reality (VR) technology in landscape design and rural tourism planning. Technological integration under this interdisciplinary approach provides a new perspective and methodology for related fields. The study's data confirm that the application of VR technology in environmental landscape construction offers a more realistic and interactive experience. This finding expands the theoretical framework of traditional landscape design and rural tourism planning, as well as our understanding of environmental landscape design theories. The findings deepen our comprehension and analytical depth of complex issues while proving the importance of applying new technologies to traditional areas. The research methods and results of the paper provide a new perspective on the fields of landscape design and rural tourism planning. This VR-based simulation method offers new tools and approaches for research in these areas, especially in precise prediction and planning.

2. Practical Significance Using VR technology, an accurate simulation of traditional buildings and environments was carried out, which helps in better assessing and managing the impact of human activities on the environment, further optimizing these processes. Moreover, simulating and predicting the impact of human activities on the environment with VR technology can help planners and decision makers more effectively assess and manage environmental projects. For example, VR simulations can be used to predict the impact of urban expansion or tourism activities on natural landscapes. Our research demonstrates how modern technology can optimize environmental planning in rural tourism and landscape design, reducing negative environmental impacts by implementing more precise planning, which is significant for promoting sustainable development. From an economic perspective, the application of VR technology in rural tourism and landscape design mentioned in the paper not only enhances user experience but may also provide new business opportunities and economic growth to related industries. Considering the aspect of environmental education, our study also has practical significance: research shows that VR technology can provide the public with a more intuitive display of environmental issues and planning schemes. This not only increases the public's awareness of the environment but also promotes their participation in environmental protection. The public can understand and experience environmental issues and planning schemes intuitively via the environments simulated by VR technology, raising awareness and participation with respect to environmental protection.

1.3. This Paper Is Divided into Five Sections

The Section 1 provides a background and overview. The Section 2 discusses related research and provides a brief introduction. The Section 3 comprises virtual environment and environmental landscape modeling. The Section 4 discusses the methods and results. The Section 5 provides conclusions.

2. Literature Review

We collected, studied, and integrated various types of studies that were necessary for this research, focusing mainly on the concepts, mechanisms, and key issues or problems in the application of virtual reality technology and virtual environment modeling. This enabled us to raise meaningful questions and provide valuable references for the study.

The term "virtual reality" was coined by Jaron Lanier in 1987 as part of his in-depth research into immersive technologies (Virtual Reality Society 2017). Virtual reality is an environment that is digitally simulated by computers, which mimics the real world, but presents content that is immersive and captivating. In addition to simulating real environments and constructing virtual ones, virtual reality technology also allows for interactive experiences where participants can fully immerse themselves in the environment. Using relevant equipment, they can feel and touch simulated objects in specific environments, giving the impression that these objects truly exist. Participants can interact with the virtual environment, either by using standard input devices, such as keyboards and mice, or multimodal devices, like wired gloves, Polhemus's armatures, or omnidirectional treadmills. As a result, users can interact with real-time virtual objects via an intuitive interface, experiencing genuine perception, understanding, and communication [14]. Lanier has been leading the way in 3D graphics and immersive interactions; the first commercial virtual reality devices, such as virtual reality glasses and data gloves, were produced by this company [15]. Narcis Pares came up with the idea of "artificial reality" and showed the public a virtual environment called Videoplace [16]. Shi proposed a 3D vectorized data structure (3D FDS), which consists of four components: the node, arc, edge, and surface elements [17]. Fumagalli suggested a more in-depth study of data models within 3D space that examines different spatial modeling methods for spatial phenomena, and proposed many 3D spatial data models [18]. Rong suggested several research and development activities relative to VR techniques and finally developed many useful products. These advanced VR products have attracted substantial attention from many industries [19]. Ayah Hamad suggested some research and development activities regarding VR technology and eventually developed many useful products. These advanced VR products have attracted strong interest in VR technology in many industries [20]. Elif Hilal Korkut proposed the components of VR technology, including 3D image-rendering technology, sensory interaction technology, and high-definition display technology, and also determined the research and development direction of VR technology [21]. Anna proposed a variety of hierarchical representation modes, and their algorithm generates a simplified surface by reducing the resolution of the grid [22]. Guo Yuanyuan believes that people have continuously high demands relative to their living environment, and designers can organically combine VR technology with related spatial designs to create an ideal environment more vividly for the public, which could further result in new and trending creative designs [23]. As a rapidly developing form of integrated information technology, virtual reality plays a significant role in the innovation of landscape design due to its powerful capabilities. It can be used to construct spatial layouts and shorten the design cycle of landscape design. By fully integrating necessary elements into designs, it accurately positions the design within a virtual space. Consequently, this can solve issues such as long project cycles, large and complex workloads, and high human and material costs [24].

Therefore, when using virtual reality technology for virtual environment and landscape modeling, the fidelity of scene reproductions and the ability to save time are important considerations. These are currently highly focused issues in the field of virtual reality technology research, particularly in studies related to modeling quality and efficiency optimization. Ensuring the realism of the "texture," high-resolution CAD drawing processes, color fidelity during rendering, and the use of image pre-rendering and caching to improve modeling efficiency are significant factors that affect the congruence between the environments constructed by virtual reality technology and the real world. Thus, these are also important aspects in our research relative to optimizing environmental landscape design using virtual reality technology.

3. Virtual Environment Modeling and Environmental Landscape Modeling

3.1. Virtual Environment Modeling

Virtual environment modeling, a convergence of technology and landscape design, has emerged as an indispensable tool in our current design paradigm. It offers a method for digitally replicating physical environments, enabling professionals to visualize and refine designs before their real-world implementation. While its origins trace back to applications in video games and entertainment, its value in urban planning, landscaping, and architectural design has become increasingly apparent.

The process of 3D landscape design, delineated in Figure 1, commences with a preliminary concept. This is similar to envisioning a spatial layout or planning an architectural construct. This initial vision is then translated into a detailed scheme using computer-aided design (CAD), serving as a foundational blueprint for the intended space.

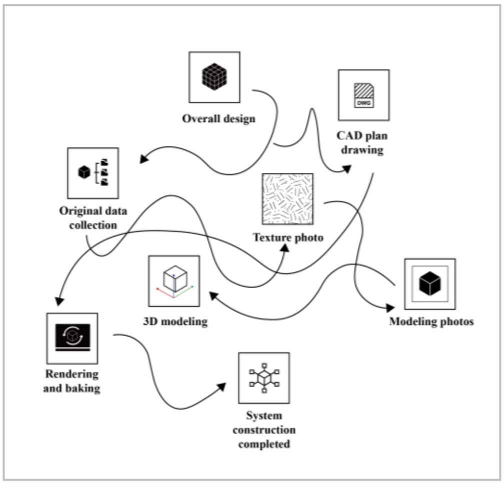

Figure 1. Design process of 3D Landscapes.

To enhance the quality of these designs, a thorough data collection phase is necessary. This involves gathering information related to the terrain, climate conditions, local vegetation, and other relevant environmental variables. A complete data collection process should include the following stages: (1) identifying the design subject and its environmental type, as well as specific modeling elements within the environment; (2) selecting and digitally representing the terrain, natural elements, and cultural elements of the environment in which the design subject is located in order to construct a virtual environment; and (3) collecting texture, color, light, and shadow characteristics and other detailed feature data of the landscape's content for a more precise and delicate portrayal of the environmental model, continually shaping the realism of the environment and landscape. For example, if the design involves a mountainous area, the virtual model should first collect and integrate information about the orientation, natural topography, environmental elements, and even cultural content of the area. Then, the area's slopes, valleys, plateaus, water systems, and possible cultural landscapes are systematically modeled to form a virtual environment model with sufficient elements. Finally, a more precise, detailed, and realistic depiction of each element is achieved, for instance, by capturing reflections, ripples, and other interactive elements of water bodies in order to portray the realism and fluidity of this element, refining the environmental model.

Textures play an integral role in lending realism to these models. Drawing a parallel to real-world scenarios, we consider the diversity of tree barks in a forest. To replicate this in a virtual space, high-resolution photographs of various trees and their barks are captured. These images are then seamlessly integrated into virtual designs, ensuring that the 3D models resonate with a tangible sense of realism.

The post-design phase involves rendering, a process that infuses life into these models. By simulating natural elements, such as sunlight, shadows, and precipitation, rendering enhances immersive experiences, making the digital environment almost indistinguishable from its physical counterpart.

However, there are many challenges during the modeling process. One of the pivotal considerations revolves around the trade-off between details and computational efficiency. Overloading a model with excessive details can strain computational resources, necessitating a balanced approach. Additionally, simulating natural interactions, such as the rustling of leaves or the flow of water, mandates the use of sophisticated algorithms to capture these nuances accurately.

The realism in virtual environments is of great significance, especially in landscape design. Such authenticity not only enhances visual engagement but deepens the emotional and cognitive connections that users form within the space. The use of high-resolution image-based techniques enriches this realism, capturing real-world textures and nuances. Coupled with digital deformation technology, these elements come alive, replicating dynamic interactions, like the sway of trees or the ripples of water. By bolstering this verisimilitude, stakeholders can gain a truer sense of the proposed designs, fostering confidence and facilitating more informed decision making.

Consider the implications of virtual environment modeling in a practical context. Let us say that there is an initiative to design a recreational park in a rural setting. By utilizing virtual modeling, planners can construct the entire park within the digital realm. This virtual representation can then be explored, evaluated, and modified based on feedback from various stakeholders, including the local community. Then, a final design that aligns closely with communal needs and preferences is obtained, ensuring the park's longevity and relevance.

Virtual environment modeling acts as a bridge, connecting visionary designs with tangible real-world implementations. As technological advancements continue to reshape the landscape of design methodologies, this tool will remain pivotal in ensuring that our built environment aligns with both human aspirations and environmental sustainability.

3.2. VR Technique and Environmental Landscape Model

Virtual reality (VR) is not a novelty in the technological world, but its pervasive influence across various sectors, particularly landscape design, marks a paradigm shift with respect to how professionals visualize and execute projects. While the fundamental premise of VR is to immerse users in a simulated digital environment, its integration into landscape modeling has been refined and optimized in terms of the way designs are conceptualized, reviewed, and implemented.

According to Figure 2, the workflow of a VR system can be dissected into sequential yet interrelated stages. The system's foundation lies in establishing various perception models that serve as digital replicas of real-world elements. Once formed, these models are displayed, giving users a tangible sense of space and perspective. However, merely visualizing these models is not sufficient. To amplify the immersive experience, a natural interaction between the human and the machine is fostered. This interaction, underpinned by high-performance graphics computing, ensures that users navigate and engage with the environment seamlessly.

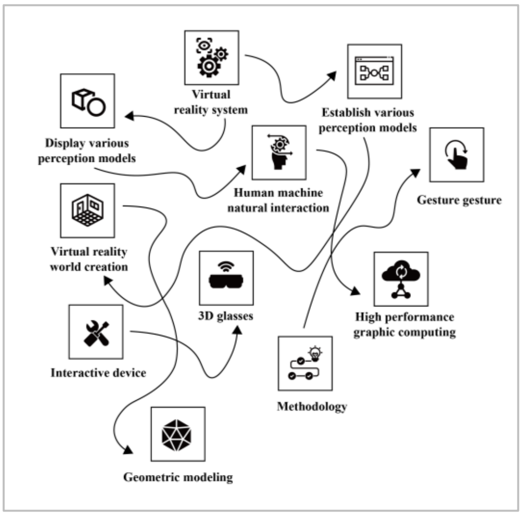

Figure 2. VR system.

From the establishment of perception models, the journey moves toward creating the virtual world. It is during this step that the essence of the landscape comes alive, with every tree, water body, and architectural structure precisely placed as per the design. This virtual world subsequently undergoes geometric modeling, refining shapes, dimensions, and spatial relations. One can also note the significance of interactive devices, like 3D glasses, that serve as a bridge between the user and the digital realm, enhancing depth perception and spatial awareness.

In the landscape design arena, VR's value is monumental. Beyond the allure of sophisticated technology, VR offers a tangible tool for designers to test, alter, and perfect their designs in real time. This dynamic approach not only saves time and resources but also ensures that the final output is a well-optimized solution that resonates with the stakeholders' vision and the community's needs.

Over the years, agritourism or agricultural sightseeing has witnessed significant growth, marrying the realms of agriculture and tourism. By intertwining VR technology with agritourism, a fresh wave of innovation in modern agriculture is observed. VR allows tourists to experience farms, orchards, or vineyards digitally before visiting, transforming them into more informed and engaged visitors. For farmers, VR can be a tool used to showcase their processes, crops, and innovations to a global audience, opening avenues for education, investment, and collaboration.

The prowess of VR, however, is often encapsulated in its three hallmark features termed the "3Is": integration, interaction, and imaging.

- **Integration** revolves around the harmonization of various elements within the virtual space, ensuring that each component aligns with the overarching design vision.
- **Interaction** denotes the user's engagement level with the virtual environment, dictating how they navigate, manipulate, or even alter elements within the space.
- **Imaging** underscores the visual fidelity of the environment. It is not merely about high-resolution graphics but captures the nuances—shadows, reflections, and textures—that lend authenticity to the virtual realm.

Moving beyond landscape design, VR's reach extends across various disciplines. Whether it is medical training—where surgeons practice complicated procedures in a risk-free environment—or education—where students take virtual field trips to historical sites—the applications are manifold. Within landscape design, VR enables designers to visualize environmental changes, assess the impact of architectural additions on the local ecosystem, and even simulate different weather conditions to test the resilience of their designs.

Another intriguing intersection is the integration of VR with the geographic information system (GIS). GIS, as a powerful tool, has long been providing professionals with detailed spatial data and invaluable analytical tools. When combined with the immersive nature of VR, the potential benefits multiply. By merging these two tools, geographical data are not only visualized, but they are also experienced. Users can delve deep into a 3D representation of the spatial data, navigating through terrains, understanding topographies, and appreciating land uses in their natural context.

For urban planners, this synergy means the ability to virtually walk in cityscapes, assessing the feasibility of the proposed infrastructure or visualizing the potential impacts of urban expansion. Environmentalists can simulate scenarios, like the effects of deforestation or urban runoff, in a controlled, virtual space, providing them with a holistic perspective of potential ecological impacts. Landscape designers benefit by overlaying their design concepts onto real-world terrains, ensuring compatibility and sustainability.

This integration also fosters collaborative work. Teams can simultaneously immerse themselves in these virtual geographical realms, discussing, altering, or optimizing designs in real time. Stakeholders can be virtually transported to the proposed development sites, bridging the gap between technical jargon and tangible experience. Moreover, the educational implications are vast. Students and researchers can be virtually placed in distant geographies, enhancing their learning experience beyond textbooks and 2D maps.

VR is not only a technological marvel but also a transformative tool for a myriad of sectors, especially those related to landscape design. Its seamless integration with systems like GIS showcases the depth of its potential. As we advance, VR promises not only innovation but also a foundation for more holistic, sustainable, and inclusive design strategies.

4. Methods and Results

4.1. Research Questions and Approaches

Within the realm of virtual reality (VR), several challenges consistently emerge as technology progresses. Three prominent issues—optimizing rendering speeds, the quantification of landscape quality improvements, and ensuring color fidelity—stand out as particularly influential in shaping the user's experience. In this section, we will elucidate these challenges, exploring their context and the complexities they introduce. Moreover, we will propose strategies and solutions for addressing these challenges effectively.

4.1.1. Optimizing Rendering Speed

Virtual reality (VR) applications' demands are intensifying with respect to the need for faster, real-time rendering in order to offer a seamless experience for users. Two major techniques are critically needed in order to meet this demand: image pre-rendering with caching and efficient algorithms tailored for VR.

1. Image pre-rendering and caching: This technique pre-renders static elements in the scene to avoid real-time computations during user interactions.

Let S be the rendered static portion of the scene, cached into the memory, and let $D(t)$ be the dynamic portion at any given time t. The time taken to render static portion S at the outset can be represented as T_S. The time it takes to render the dynamic part of the scene without utilizing the cache is T_D. Therefore, the total time saved, $T_{saved}(t)$, by using cached content can be represented by the difference:

$$T_{saved}(t) = T_S + T_D - T_{dynamic}(D(t))$$

where $T_{dynamic}(D(t))$ is the time used to render only the dynamic portion after retrieving the static portion from the cache.

2. Employing efficient algorithms: Modern algorithms optimally render scenes by rendering areas within a user's direct gaze at a higher resolution and peripheral areas at a lower resolution. This method, called foveated rendering, capitalizes on the human visual system's characteristics.

Let us denote the high-resolution area's pixel density by P_H and the peripheral or low-resolution area by P_L. The computational load, $R(t)$, at any time t can be represented as a weighted sum of pixel densities:

$$R(t) = \alpha \times P_H + \beta \times P_L$$

Here, α and β are the weights representing the computational requirements per pixel for high- and low-resolution areas, respectively.

By integrating these techniques, VR systems can substantially reduce rendering time, paving the way for smooth, immersive experiences even in complex and detailed virtual environments.

4.1.2. Ensuring Color Fidelity

Ensuring accurate color representation in VR landscapes is paramount for achieving a high degree of realism. As we venture into the intricacies of color fidelity, let us delve into the technicalities with respect to achieving true-to-life colors.

1. Color space conversion: Every color can be represented in different color spaces, with RGB (red, green, and blue) and CIELAB being among the most prominent. The transformation from RGB to CIELAB is non-linear and based on the human perception of colors. For example, let us consider the red component in RGB. Its transformation into the L^* component in CIELAB can be obtained via the following:

$$L^* = 116 \times f\left(\frac{R}{255}\right) - 16$$

where $f(t)$ is defined as follows:

$$f(t) = \begin{cases} t^{1/3} & \text{if } t > \left(\frac{6}{29}\right)^3 \\ \frac{1}{3} \times \left(\frac{29}{6}\right)^2 \times t + \frac{4}{29} & \text{otherwise} \end{cases}$$

2. Color correction: For an immersive and lifelike VR landscape experience, the accuracy of color rendering is paramount. Color discrepancies between what is intended and what is rendered can potentially disrupt a user's sense of realism within the virtual space.

One fundamental approach to maintaining color fidelity is to calculate the color deviation and subsequently correct it. The primary objective is to ensure that C_{rendered} closely approximates C_{intended}. This color deviation can be articulated as follows:

$$\Delta C = C_{\text{intended}} - C_{\text{rendered}}$$

This deviation can then be utilized to adjust the settings of the rendering engine or device. A correction factor, denoted by k, can be applied to this deviation to yield a color output that is closer to the target:

$$C_{\text{corrected}} = C_{\text{rendered}} + k \times \Delta C$$

Here, k is a value that is less than 1, representing the intensity of the correction. Its value can be determined based on prior experience, device characteristics, or user feedback. Moreover, each dimension in the color space (for instance, R, G, and B in the RGB space) can be individually corrected, facilitating a more accurate color match.

By employing such techniques, the fine-tuning of colors in the virtual environment is achieved, ensuring that they align closely with the anticipated colors and enhancing the realism of the VR landscape.

4.1.3. Quantification of Landscape Quality Improvements

Virtual reality (VR) has revamped landscape design presentations, turning static designs into immersive experiences. The qualitative benefits of VR in visualizing landscapes are evident. However, determining the precise value of these enhancements poses a challenge. While experiencing a design in VR is more engaging, how can this perceived improvement in quality be transformed into quantifiable data?

In landscape architecture, certain evaluation metrics, such as spatial coherence, textural accuracy, and ambient lighting representation, become vital. Each metric is assigned a weighted factor w_i. Aggregate quality score Q can be defined using matrix multiplication and considering the weight and score matrix $\boldsymbol{M}$**,** which contains scores for each metric across various landscapes:

$$Q = \boldsymbol{W} \times \boldsymbol{M}$$

where $\boldsymbol{W}$ is a row matrix of weights, and $\boldsymbol{M}$ contains scores for each metric.

User feedback offers invaluable insights. By comparing feedback from VR and traditional renderings, we can compute the enhancement factor. Let us denote the feedback matrix for VR as $\boldsymbol{F_{VR}}$ and the traditional method as $\boldsymbol{F_T}$. Enhancement E is given by the eigenvalue decomposition of the difference between feedback matrices:

$$E = \lambda(\boldsymbol{F_{VR}} - \boldsymbol{F_T})$$

where λ represents the eigenvalues of the difference matrix.

Furthermore, using statistical learning, a regression model predicts quality improvements based on VR features. Given features $\boldsymbol{X}$ and the corresponding coefficient β, our predictive model can be formalized as follows:

$$Q' = \beta_0 + \boldsymbol{X}\beta + \epsilon$$

where Q' represents the predicted improvement in landscape quality, β_0 is the intercept (baseline improvement), $\boldsymbol{X}$ is the vector of VR features, β the vector of coefficients, and ϵ is the error term; this provides a structured approach for quantifying the impact. Higher coefficients indicate a greater positive influence of a VR feature on landscape quality, while lower or negative values suggest minimal or negative impact.

This approach thus seeks to translate the visceral appreciation of VR into quantifiable metrics, offering a structured evaluation tool for VR's influence in landscape design.

We summarize the above content briefly; the specific research questions, methods, and results are shown in Table 1.

Table 1. Research questions, research methods, and results.

Research Questions	Research Methods	Results
Optimize rendering Speed	Image pre-rendering and caching	Significantly reduces rendering time, enabling users to experience a smooth and immersive environment, even in complex and detailed virtual settings
	Employing efficient algorithms	
Ensure color fidelity	Color space conversion	Achieved the fine-tuning of colors in virtual environments, ensuring a close match with expected colors and enhancing the realism of VR landscapes
	Color correction	
Quantification of landscape quality improvement	Allocate weighting factors to evaluation indicators and obtain a scoring matrix via matrix multiplication	Transforms the intuitive appreciation of VR into quantifiable indicators, providing a structured tool for assessing the impact of VR in landscape design
	Utilize regression models to predict quality improvements and formalize the prediction model	

4.2. Results and Discussion

4.2.1. Optimization of Rendering Speed

From Figures 3 and 4, we obtain a clearer picture of the changes that our optimization techniques have introduced. Specifically, Figure 3, which charts the algorithm's convergence over time, indicates a trend of steady efficiency gains. While these improvements are not ground breaking, they are noteworthy. Moreover, Figure 4's time curve complements this observation by showing the reduction in the overall rendering time. This curve illustrates the practical impact of our optimization techniques on VR rendering speeds. The observed decrease in rendering times is a tangible manifestation of the theoretical improvements proposed above. This highlights the effectiveness of our methods in real-world scenarios, emphasizing the importance of rendering speeds in enhancing the user experience in VR.

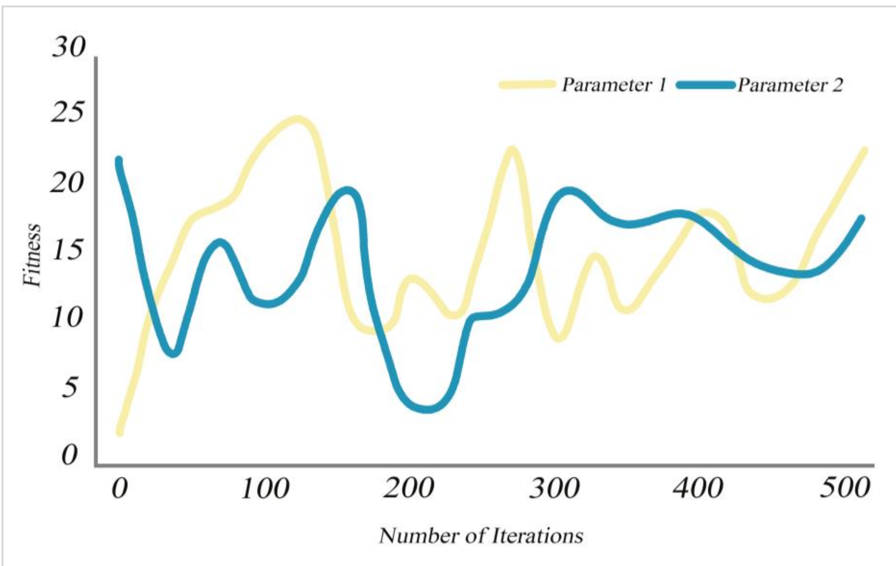

Figure 3. Algorithm convergence curve.

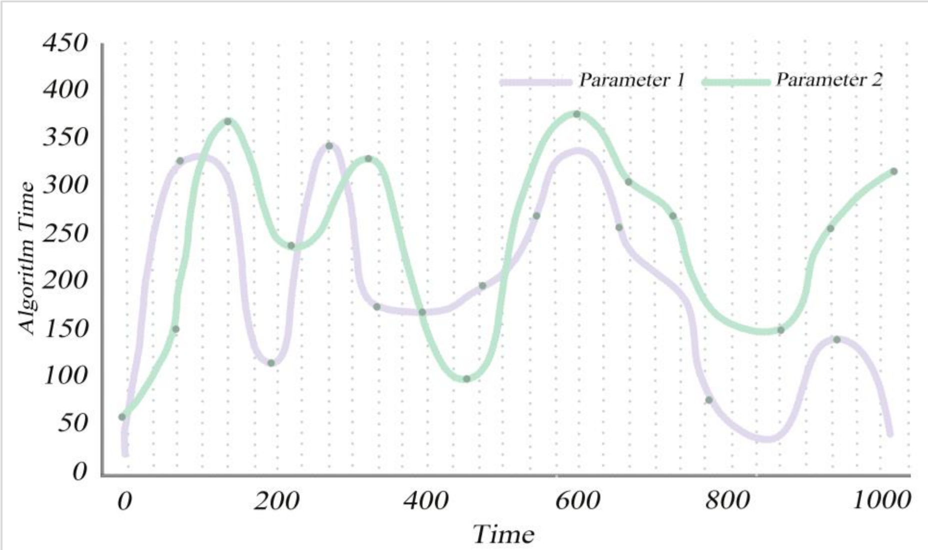

Figure 4. Algorithm time curve.

Diving deeper into the parameters from our earlier formulas, particularly α and β, it is evident that they have significant roles in influencing the results. Their values can fine-tune the balance between rendering different regions of the visual scene. As we move forward, continual adjustment and experimentation with these parameters might be the key to unlocking even greater efficiencies.

4.2.2. Color Fidelity

Turning our attention to color fidelity, Figures 5 and 6 shed light on the nuances of our techniques within the realm of VR color rendering. Figure 5, which displays reflectance curves across various saturations, suggests that the colors in the VR landscape seem to be more vibrant and varied.

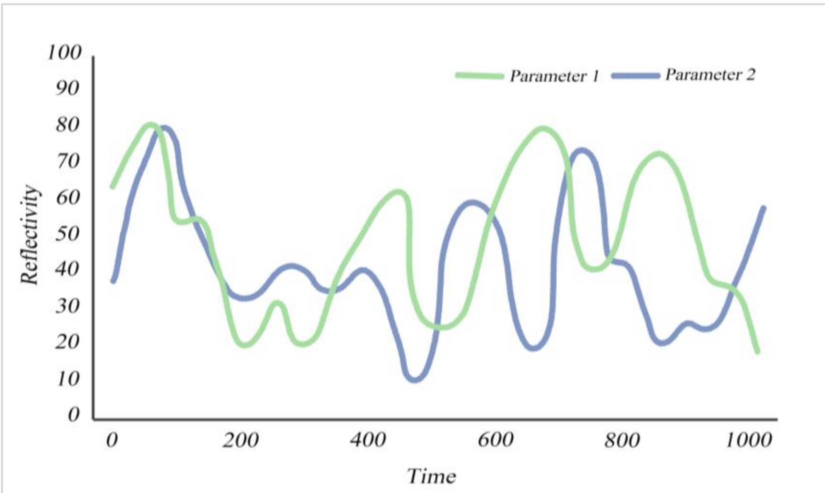

Figure 5. Reflectance curves of different saturations.

Similarly, the spectral power distribution curve in Figure 6 provides insights into how light interacts with these colors. We can observe the ranges within which our techniques excel and where further fine-tuning could be beneficial.

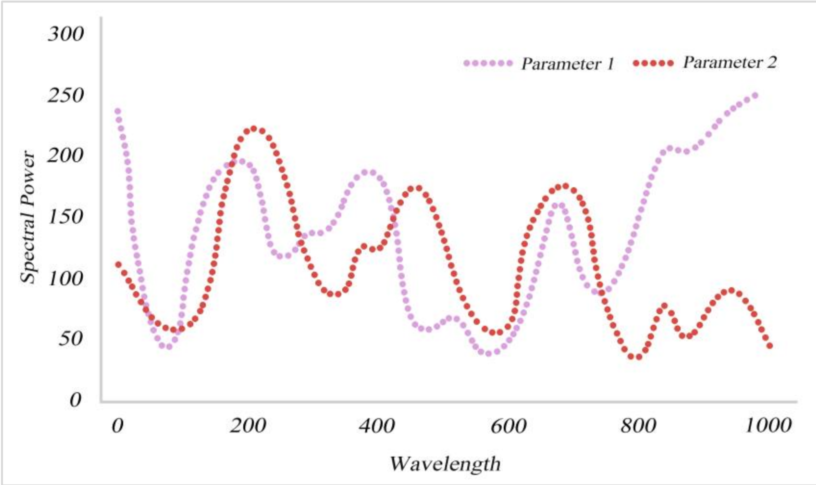

Figure 6. Spectral power distribution curve.

Now, considering our earlier discussions on color correction factor k, it is clear that it is a linchpin in this process. The precise value of k can greatly influence the end color product in VR. Future research should, therefore, prioritize understanding how different k values affect different types of scenes and environments.

4.2.3. Quantifying VR's Impact on Landscape Quality

Figure 7 and Table 2, taken together, underscore the transformative potential of VR in elevating landscape quality. The quantified data show that, for traditional buildings, the integration of our VR techniques leads to an increase in quality by as much as 15.73%.

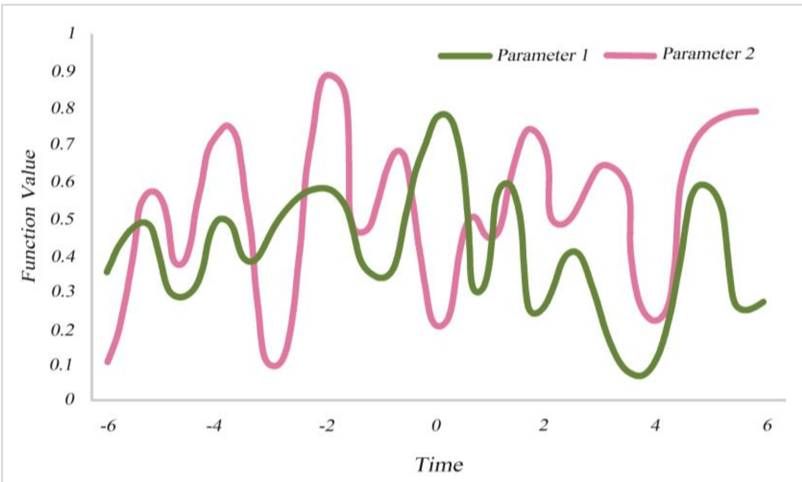

Figure 7. Functions under different enhancement factors.

Table 2. Functions under different enhancement factors.

	−6	**−4**	**−2**	**0**	**2**	**4**	**6**
Parameter 1	0.35	0.38	0.61	0.89	0.25	0.06	0.27
Parameter 2	0.11	0.93	0.71	0.19	0.87	0.64	0.85

However, the following question remains: how do we effectively transform the abstract notion of "quality" into concrete, quantifiable metrics? Our approach, as elucidated in the previous section, provides a roadmap.

Recall that landscape architecture prizes certain evaluation metrics—spatial coherence, textural accuracy, and ambient lighting representation. We assigned each of these a weighted factor w_i. By integrating these weights with the score matrix, we derive an aggregate quality score Q, which is a representation of the landscape's overall quality.

More importantly, we have also anchored our quantification with respect to the invaluable feedback provided by end users. Contrasting feedback scores from VR with those from traditional renderings, we computed enhancement factor E, leveraging eigenvalue decomposition. This ensures that our metrics are not merely theoretical constructs but are grounded in real-world perceptions and experiences.

Our regression model ties all these together. Given a set of VR features X and their corresponding coefficient β, the model predicts the anticipated improvement in landscape quality. This connection of data-driven analytics with VR nuances helps us understand the synergy between various features and their potential impact.

5. Conclusions

In this study, we have delved into the dynamic intersection between virtual reality (VR) technology and landscape design, addressing several key challenges and quantifying the impact of VR on landscape quality. Our research has yielded insightful results and promising solutions.

The optimization of rendering speeds: our optimization techniques have demonstrated notable efficiency gains over time. Figure 3 illustrates the algorithm's steady convergence trend, showcasing improvements in rendering speed. Figure 4 further highlights a substantial reduction in overall rendering times. The parameters play pivotal roles in influencing these results, offering potential for further fine-tuning.

Color fidelity: Our efforts in ensuring color fidelity have resulted in more vibrant and varied colors in the VR landscape, as evidenced in Figure 5. The spectral power distribution curve in Figure 6 provides guidance with respect to the areas in which our techniques excel and where refinement is beneficial. The color correction factor remains a crucial element, requiring in-depth exploration to optimize its value for different scenes and environments.

Quantifying VR's impact on landscape quality: Figure 7 and Table 2 reveal the transformative potential of VR in elevating landscape quality. For traditional buildings, the integration of our VR techniques leads to an increase in quality by up to 15.73%. Our approach, rooted in specific evaluation metrics and user feedback, provides a concrete roadmap for quantifying landscape quality improvements.

In summarizing the implications of integrating virtual reality (VR) techniques in landscape planning and design, our research presents significant statistical findings. The optimization rate of 15.73% for traditional buildings via the application of VR technology marks a substantial advancement in this field. This figure not only quantifies the efficiency gains but also highlights the effectiveness of VR in enhancing the design process.

In conclusion, the synergy between VR technology and landscape design is reshaping the way we envision and create our environments. These findings highlight the tangible benefits of VR in optimizing rendering speeds, enhancing color fidelity, and quantifying landscape quality improvements. As we continue to explore this dynamic field, further research and experimentation will unlock new horizons for immersive and sustainable landscape design.

Our research has some limitations with respect to the research process and specific research content; there are also future directions we can take with respect to these limitations. Firstly, in the research process, our preliminary research mainly focused on the construction of a theoretical framework and algorithm verification, which confirmed the positive role of VR technology in environmental landscape design and its practical significance in rural tourism planning. However, there is still substantial room for more practical and in-depth research based on the obtained results, and we will pursue this avenue. In terms of specific research content, virtual reality technology is still in the process of development, and it has always had certain limitations. The current main challenge is the demand for high-quality data while facing the difficulties of accurately simulating complex ecological interactions. Therefore, this is also a topic that we will continue to explore in depth. We also aim to explore methods for optimizing the effect of VR technology in environmental landscape design, improving efficiency, and meeting growing demands. In summary, the integration of VR technology and other technologies has great potential in environmental science, and our research space is very broad.

Author Contributions: Investigation, Y.L. and X.W.; Writing-original draft, B.S. and Y.J.; Writing-review & editing, Q.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Artificial Intelligence Design-Driven Smart Rural Knowledge Graph grant number 20222910003. And The APC was funded by Tsinghua University-Tsingshang Joint Institute for Smart Scene Innovation Design.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Xin, F. Application of virtual reality technology in landscape design. *Environ. Eng.* **2021**, *39*, 268.
2. Li, Y.; Li, F.; Zhu, S.; Xu, D. 3D Reconstruction from Multiple Images in Rural Landscape Design. *J. Northeast For. Univ.* **2019**, *47*, 84–89.
3. Wang, R.; Chen, K.; Huang, Y. Summary of Rural Cultural Landscape Design Research. *Packag. Eng.* **2022**, *43*, 80–94.
4. Li, L.; Zhang, Z.; He, Y. Modeling Method and Application of Virtual Environment. *J. Chongqing Univ.* **2002**, *6*, 32–34.
5. Tang, Q.; Chen, D.; Kong, J. Virtual environment modeling method and application. *World Build. Mater.* **2002**, *3*, 37–39.
6. Jing, L.; Tao, H. Application of Virtual Reality Technology in Analysis of the Three-Dimensional Evaluation System of Rural Landscape Planning. *Math. Probl. Eng.* **2021**, *16*, 6693143. [CrossRef]
7. Li, G. Rural tourism planning and landscape design from the perspective of ecological development. *Ju She* **2023**, *12*, 130–133.
8. Wang, H.; Wang, Y.; Wang, Y. Application of virtual reality technology in landscape design. *Urban Archit. Space* **2020**, *27*, 145–146.
9. Bian, Q. The application of VR technology in rural landscape design. *Contemp. Hortic.* **2023**, *46*, 160–162.
10. Yuan, Y. The development status, existing problems and countermeasures of sightseeing agriculture in China. *Shanxi Agric. Econ.* **2022**, *10*, 137–140.
11. Zhang, X.; Pang, Z. The application prospect of virtual reality interactive technology in field reconstruction. *Digit. Technol. Appl.* **2018**, *36*, 233–234.
12. Zhao, Q. The development trend of VR after the first year. *Sci. Technol. Rev.* **2017**, *35*, 1.
13. Zhao, G.; Wang, Z.; Liu, D.; Shang, Z.; Xu, M. The application of VR technology in the development of rural tourism industry under the strategy of rural revitalization. *Rural Sci. Technol.* **2022**, *13*, 62–66.
14. Pallavi, H.; Sahil, S.; Harsh, S.; Hardik, S.; Anuj, S. A Review on Virtual Reality. *Int. J. Comput. Sci. Issues* **2012**, *9*, 325–330.
15. Berkman, M.I. History of Virtual Reality. In *Encyclopedia of Computer Graphics and Games*; Springer: Berlin/Heidelberg, Germany, 2018; pp. 1–9.
16. Narcis, P.; David, A. Analyzing the Adequacy of Interaction Paradigmsin Artificial Reality Experiences. *Hum. Comput. Interact.* **2012**, *28*, 688469.
17. Shi, W.; Yang, B.; Li, Q. An object-oriented data model for complex objects in three-dimensional geographical information systems. *Int. J. Geogr. Inf. Sci.* **2003**, *17*, 411–430. [CrossRef]
18. Donna, P. A conceptual framework and comparison of spatial data models. *Cartogr. Int. J. Geogr. Inf. Geovisual.* **1984**, *21*, 66–113.
19. Rong, Y.; Zhang, T.; Zheng, Y. Three-dimensional urban flood inundation simulation based on digital aerial photogrammetry. *J. Hydrol.* **2019**, *37*, 124308. [CrossRef]
20. Ayah, H.; Bochen, J. How Virtual Reality Technology Has Changed Our Lives: An Overview of the Current and Potential Applications and Limitations. *Int. J. Environ. Res. Public Health* **2022**, *19*, 11278. [CrossRef]
21. Korkut, E.H.; Surer, E. Visualization in virtual reality: A systematic review. *Virtual Real.* **2023**, *27*, 1447–1480. [CrossRef]
22. Anna, D.; Marco, T.; Manuel, V.M. Modern Conceptions of Cities as Smart and Sustainable and Their Commonalities. *Sustainability* **2018**, *10*, 2642.

23. Guo, Y.; Liu, Y. Application of VR Technology in Residential Space Design. *Peak Data Sci.* **2017**, *6*, 166–167.
24. Sun, S.; Meng, Q.; Ma, Y.; Ren, Z. Application of Virtual Reality Technology in Landscape Design. In Proceedings of the 2021 International Symposium on Artificial Intelligence and its Application on Media (ISAIAM), Xi'an, China, 21–23 May 2021. [CrossRef]