www.cadanda.com
Computer-Aided Design AND APPLICATIONS

Application of 3D CAD in Landscape Architecture Design and Optimization of Hierarchical Details

Xiao Zhao

School of Fine Arts, Xinxiang University, Xinxiang, Henan 453000, China, mina1979@126.com

Corresponding author: Xiao Zhao, mina1979@126.com

Abstract. The landscape garden landscape has multiple functions such as ecology, culture, society and aesthetics. The scientific and reasonable garden landscape organization is an important part of urban construction. Traditional three-dimensional garden landscape construction and virtual display have problems such as inflexible landscape space organization, the limitation of the application of virtual garden simulation to reality, and the heavy workload of garden vegetation and building model construction. This paper comprehensive utilization of three-dimensional CAD (3D CAD), virtual reality and geographic information system technology, integrated parametric modeling plant, immersion technologies such as virtual reality, virtual landscape study parameter-driven integrated build, organize and display the overall process, build a garden The three-dimensional digital terrain model and the real-time fluctuation of the garden water body model realize the Fresnel dynamic optical reflection effect of the water body based on the light direction. Through the techniques of scene cropping and hierarchical detail model, the drawing efficiency and real-time rendering of the garden landscape have been improved.

Key words: Landscape Architect; 3D CAD; virtual reality; landscape modeling
DOI: https://doi.org/10.14733/cadaps.2021.S1.120-132

1 INTRODUCTION

Garden design is based on garden planning, applying landscape garden design theory, and comprehensively utilizing scientific, technical, and artistic means to protect and create outdoor environments. The entire scene and environment need to be represented. The design performance of a garden designer must not only express the design plan through a two-dimensional plan, but also express the actual scene visually and intuitively through a three-dimensional model [1]. Based on 3D solids and 3D parametric solid modeling CAD technology, a feature model can achieve 2D/3D correlation. The 3D CAD model generated by parametric solid modeling is used to accurately and vividly represent the spatial position relationship between solids [2]. Photorealistic rendering and animation, while generating static effects, set the animation path to generate dynamic animation effects, more fully reflect the environmental characteristics of the entire scene, more accurately represent the design ideas of garden designers, and truly achieve the purpose [3]. Vries et. al [4] said that the garden designer can get rid of a lot of simple and repetitive work and concentrate on the creative professional design. Therefore, it is particularly important to use 3D CAD technology to complete the garden design.

The biggest difference between garden design and other engineering design is that both scientific and analytical methods should be used to solve practical problems, and the artistic essence of the garden designer should be displayed, which is accompanied by more individual cultural connotations. Clayton et. al [5] pointed that the design history of the garden has a long history and contains rich cultural connotations. It has both a magnificent royal garden and an exquisitely designed and unique private garden. The design is accompanied by the uniqueness of the cultural foundation. Boshche et. al [6] pointed that the garden design tends to earth planning and landscape garden design, professional design system, complete, and pay more attention to scientific strict performance. With the accelerated development of urbanization and the economic benefits brought by the pursuit of development, the gradual westerly wind has brought a definite impact on the concept of garden design, but it still cannot change the huge difference from western garden design, that is, the garden design Reflected cultural connotation [7].

For general garden design, the two-dimensional graphic use 3DSMax software to build a three-dimensional model and image processing [8]. It has also become the model for most domestic garden design units production methods and expressions, but the fundamental problem is that the two-dimensional design and the three-dimensional performance are poorly correlated, the generated three-dimensional renderings are patterned, and they differ greatly from the real scene, making people have a strong sense of reality. Ghadai et. al [9] said that the application of multiple software on multiple platforms requires high levels of user use. It is impossible for a garden designer who has completed a professional design to be versatile in the use of general software. 3D CAD applications in the construction and machinery industries were earlier. The application in garden design is lagging behind, basically staying in the drawing stage, and lacking the application software that integrates parametric solid modeling, realistic rendering and animation based on 3D CAD technology.

3D CAD mainly solves key technologies such as precise positioning of 3D models, dynamic display of large-capacity 3D graphics, and real-time browsing of realistic graphics, so that 3D CAD can meet application requirements in garden design. Apply 3D CAD technology to establish parametric 3D solid models, record 3D solid data, and provide editing methods for parametric models. Chen et. al [10] showed that 3D CAD technology is more focused on the processing and editing of professional solid data. Difficulties in the application of 3D CAD is the problem of real-time. Ding et. al [11] pointed that 3D browsing of large-capacity is using the hardware acceleration of the graphics card. Its interface language such as OpenGL can quickly triangulate complex 3D entities. Park et. al [12], the smooth processing of specific three-dimensional mesh patches also greatly reduces the data processing, which plays a significant effect in practical applications. By reading 32 transparent channel bit color bitmap information, OpenGL achieves the floor space textures display technology in the performance. The ring in the past can be achieved with king environmental aspects.

The construction method of virtual garden vegetation landscape is universal. As showing in Figure 1, there are large differences in gardens in different regions and climates, such as the incompatibility of vegetation species composition and garden configuration styles. The 3D modeling of garden vegetation landscape, as the process with the greatest workload in landscape visualization, can be specifically constructed by relying on various mature 3D modeling tools, but a limited number of 3D vegetation models are used in the construction of quite rich garden landscapes. González-Lluch et. al [13] showed that a garden landscape is a special kind of landscape in a three-dimensional scene. In order to ensure the authenticity of the garden vegetation model, its complex three-dimensional geometric structure is often saved in the scene, which greatly increases the amount of scene data [14]. Because vegetation models have complex structures and a wide variety of features, realistic 3D vegetation models are constructed and loaded in large quantity in 3D scenes, which increase the rendering pressure of the overall landscape of the 3D garden. In a virtual reality display device, this contradiction is magnified more clearly due to the dual-channel nature of virtual reality rendering. In order to improve scenic realism and rendering efficiency, optimization solution is also a key issue for the construction and virtual display of 3D garden landscapes. The three-dimensional garden landscape design is based on planning, design, and evaluation. The main problem is the changeability and organization of the scenic landscape [15]. In response to the above-mentioned needs and problems, this paper uses virtual reality technology, virtual plants, geographic information systems, and parametric modeling technologies to design and implement a three-dimensional garden landscape construction system that supports multi-platform virtual display. It also optimized the rendering of tree vegetation models with large amounts of data and integrated various modules to achieve the overall construction, organization, and virtual display of 3D garden landscapes.

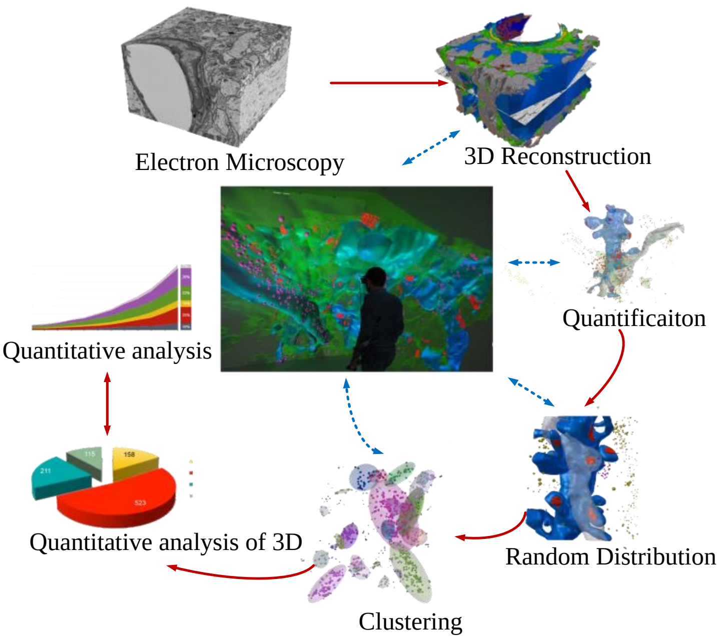

Figure 1: The 3D CAD applications of the principles of the design in the landscape.

2 METHODS

2.1 Principles of Three-dimensional Image Analysis for the Distribution of Landscape Gardens

In the process of analyzing the rationality of the distribution of landscape gardens, we first obtain matching images of the newly added local landscape garden images in the original image set to form the landscape garden image set and reconstruct a local point cloud model of the landscape garden. By matching different landscape gardens, the projected points of the local point cloud model in the same image are used to obtain a consistent corresponding point set between the point cloud models of the landscape garden. As shown in Figure 2, the optimal alignment transformation of the point cloud set is solved to achieve the integration of the entire landscape garden and the local point cloud model.

$$x_i = PX_i \tag{1}$$

In the formula, X_i represents the coordinates of the three-dimensional image points of the landscape scene image, P represents the camera matrix corresponding to the landscape scene image K, and x_i represents the two-dimensional coordinates projected onto the landscape picture K.

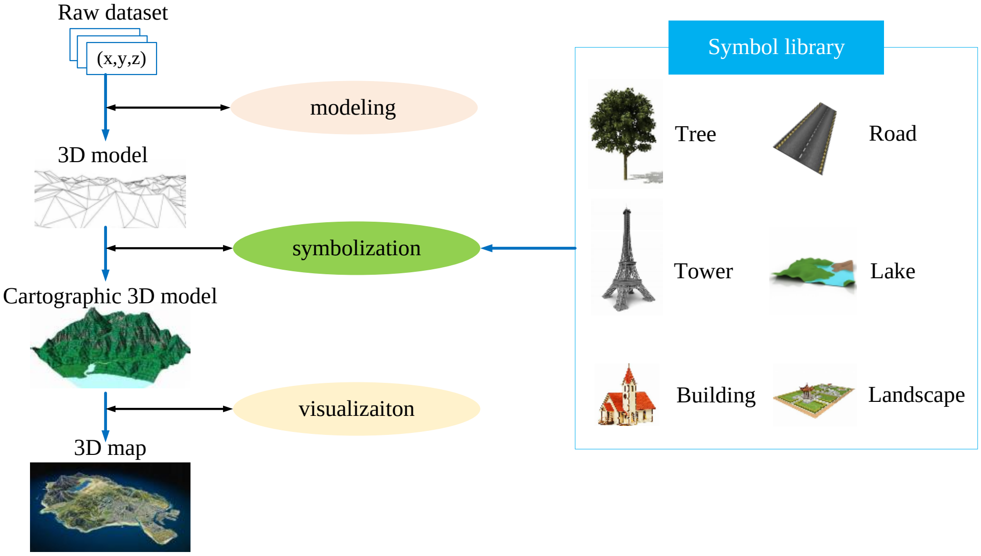

Figure 2: Schematic diagram of 3D map reconstruction.

Assume that the consensus point pairs P_{k1} and P_{k2} in the three-dimensional point cloud models P_1 and P_2 of the landscape scene image have been obtained. By finding an approximate transformation T, the coordinate alignment of all corresponding sets in P_{k1} and P_{k2} is completed. The transformation T is translated by the translation vector L, the rotation matrix R, and the scaling factor s are formed, and then the transformation problem is solved by the objective function problem given by the transformation minimization formula (2).

$$E(P_{k1}, P_{k2}) = \left\| P_{k1} - (s \cdot P_{k2} \cdot R + L) \right\| \tag{2}$$

According to the analysis formula (2), the function optimization problem is a Procrustes problem. The following steps are used to solve the corresponding transformation step by step, and the geometric centers of P_{k1} and P_{k2} are calculated by using formula (3).

$$O = \sum_{i=1}^{N} X_i / N \tag{3}$$

The digital three-dimensional model is the foundation of the entire virtual garden environment. In the virtual garden environment, the model environment includes 3D visual modeling and 3D auditory modeling. Since the construction of the main purpose of the virtual garden environment for landscape design provides a visual garden environment division. The visual construction is the focus of construction. And auditory modeling only needs to add sound files to the activities of users and objects. Visual modeling is mainly based on graphics and image-based modeling. For buildings, the first method is mainly used. For sky, trees, flowers and other scenery, the second method is used.

The requirements for the model are basically the same. When a VR model is made, the basic content contains scene ruler, such as units, model classification collapse, naming, node editing, texture, coordinates, texture size, texture format, etc. A model file with clear classification is very necessary for program control management. When making a single body in the scene, you must strictly follow the CAD modeling. When there is no CAD drawing, you should refer to photos, videos, and other influencing data to sketch the model proportions. The model built at this stage can be simplified without considering the number of faces. Model simplification and texture production are performed synchronously after the preliminary model is completed. This has the advantage of making the model being made more intuitive and further grasping the proportion of the model. At this time, it is not necessary to adjust the coordinates very accurately, and only the coordinates of the patch or object can be given.

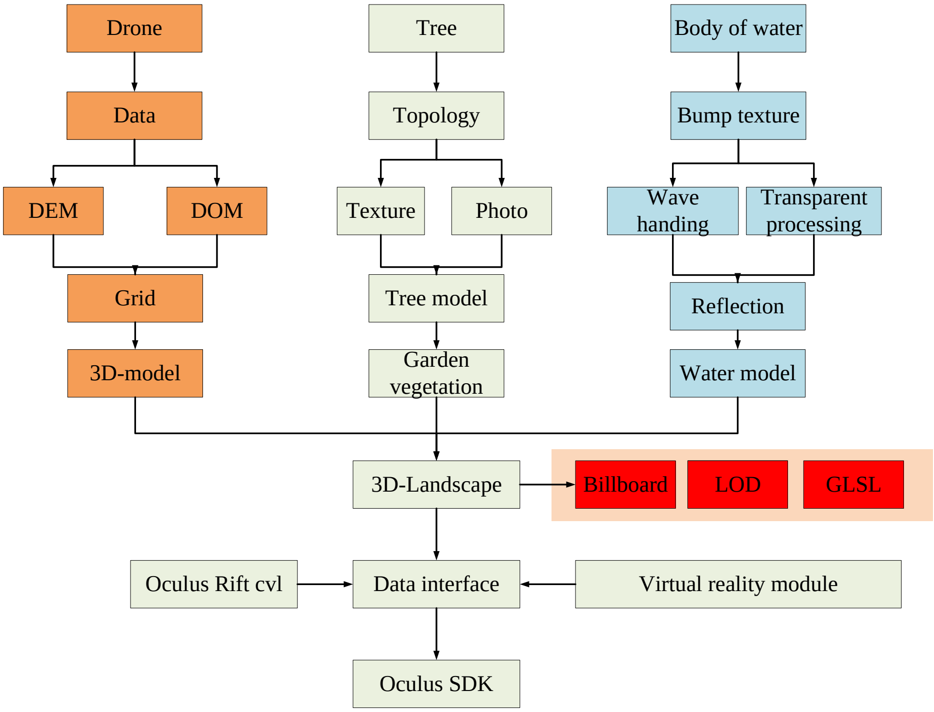

Figure 3: Research roadmap of the three-dimensional model of the rational distribution of landscape gardens.

As shown in Figure 3, the basic method of texture production is to adjust the related pictures by stretching and rotating to obtain the desired texture. Remove the shadow and strong light effects in the texture. Use the stamp tool to remove the impurities contained in the texture. If the texture is repeated texture, you need to deal with it easily and repair the obvious repeating effect. Every map you make should pay attention to the aspect ratio, so as not to stretch the picture when the picture will be realized in the future. When the model needs to be processed through channels, textures with channels need to be made. When making the channel texture of the tree, it is best to change the opaque part to the main color of the tree, so that the color of the effective edge part can be correct when rendering. Channel textures use more resources when rendering programs than ordinary textures of the same size.

Under the premise of ensuring that the effect is clear, the size of the texture should be minimized, or some objects do not need a clear texture. The amount of texture is the basis for ensuring the speed of large scenes. When it is necessary to use large textures to represent, you can split the model into multiple small objects and express them with small textures respectively. This increases the number of textures and reduces the amount of texture data, which is a better way to optimize resources.

2.2 The Application Flow of 3D CAD in Landscape Design

Modeling of the entire virtual environment VR foundation system is built is one of the important areas of research virtual environment, but also virtual reality software heavy part wanted. Precision is a measure of how accurately the model represents the entity. The ideal expectation is that all models are accurate, but from a technical and systematic perspective, it is sometimes impossible or unnecessary. In general, the accuracy of the model depends on the application itself. For example, most CAD applications require accurate mathematical models of objects rather than polygonal representations. The polygon representation is often used in situations where display speed is more important than accuracy, such as the virtual reality modeling software applied in a virtual city environment. Many applications have large restrictions on the display time. If a large number of objects need to be drawn, the drawing time of each object cannot be too longs. It will greatly affect the usability of the system. Modelers should represent geometric and behavioral models of entities as accurately as possible, while constructing and using a good model as simple as possible, rather than making it more and more complicated. The modeling technology should be able to quickly and effectively describe a complex solid object. At the same time, it is easy to control every detail. Controlling the details of a solid object often requires the ability to control each vertex of the solid object. Good modeling techniques can provide a wide range of solid modeling.

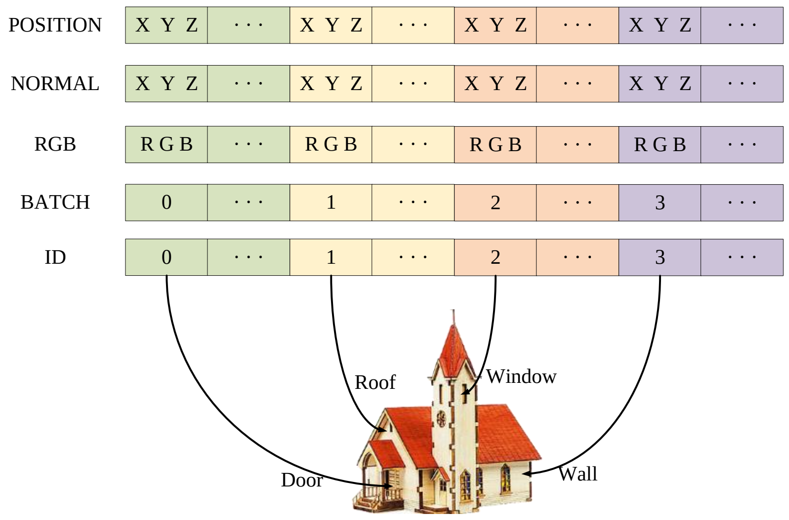

Figure 4: Virtual real data collected in the building CAD reconstruction in principle.

Different VR project types will involve different production processes and production methods. There are very few models and textures in small scenes, but the accuracy and realistic degree of texture of the model may be higher. As shown in Figure 4, this type of VR model is easy to make, production specifications are relatively loose, and the production method is relatively simple. The number of faces in a medium-sized scene is less than 500,000, and the amount of texture does not exceed 100m. This type of project will focus on one or more areas, which require a high degree of precision and richness. It will be an urban planning simulation, large-scale restoration of ancient cities, or large-scale urban area planning simulation. The number of faces is more than 500,000, and the texture exceeds room. Two sets of simple models may be required in the key performance area, and more references and scene editing skills will be used. According to the style of project performance, including virtual simulation of modern architecture, ancient architecture, industrial processes, and geomorphology.

The scenic design that is mainly involved in functional performance is set to the highest level, and the scenic area level is divided according to the degree of emphasis to determine different levels of standard models and effective performance methods. The collection of picture data is a very important part in model making. Rich, detailed, clear and complete picture data can not only improve the production speed, but also avoid the trouble of secondary data collection in the middle of project production.

3 3D CAD FOR LANDSCAPE CONSTRUCTION AND LANDSCAPE RENDERING

3.1 Spatial Organization of Garden Scene Parameters

In geographic information system, geographic data is regarded as a kind of special information and geographic information. Geographic information expresses the spatial location information, properties, and characteristics of geographic entities on the surface of geospatial space. As a kind of geographic scene, the garden scene also has the characteristics of many elements and artificial random space organization. To build an overall three-dimensional garden landscape, the reasonable spatial organization of the various elements is three-dimensional. The key problems to be solved in the construction of the garden landscape.

The overall layout control of the spatial layout of the overall garden vegetation landscape and other landscapes is specifically constrained by parametric vector layers in the geographic information system. In the geographic information system, the geographic information data of the features are organized into two different internal data structures, namely raster data and vector data. Among them, raster data divide the geographical space evenly into grids of equal size. Each grid has specific attributes, and its attribute value determines the physical properties of the features. The vector data use points according to the real-world characteristics of the features. Each spatial position has a unique spatial coordinate value, which accurately describes the spatial topological relationship and position of various types of features. The two types of spatial data structures describe geographic information as a logical data structure that can be understood, stored, and managed by computers. Based on the OSG graphics rendering engine, the scene organization features in the form of tree nodes and the requirements for the construction of three-dimensional garden landscapes need to be accurately described. The vector type geographic information data structure is more suitable for the landscape distribution in this paper.

According to the spatial distribution relationship of real scenes, digital editing is performed on the basis of two-dimensional image maps by means of computer digitization, transforming the spatial layout of scenes into vector parametric expressions, and forming parametric vector layers. As shown in Figure 5, the rule-based spatial data parametric is layout management organization. The factorized layers visualized through the OSG graphics rendering engine can not only constrain the planting area of the vegetation landscape, but also express the main ground position relationships in the garden, such as rivers, lakes and other water bodies, roads, buildings and other artificial garden elements. It can also include attribute parameter data of corresponding features, such as water depth, floor height, and vegetation density.

3.2 Landscape Architecture Construction

There are many methods for virtual plant modeling, but the contradiction between accuracy and data volume is common in models constructed by different modeling methods. In many virtual geographic scene construction applications, the trees in the scene only use a simple cross-structure three-dimensional plant model built based on billboard technology. Although this method reduces the amount of model data, but Poor realism. In the three-dimensional garden landscape, the vegetation landscape is the main display part, which needs to reflect the reality. A simple vegetation model based solely on the bulletin board technology is not applicable. Under the premise of ensuring the accuracy of the model, the number of patches and related data constituting the tree model has increased exponentially, which is a challenge to be solved for the real-time requirements of virtual reality rendering.

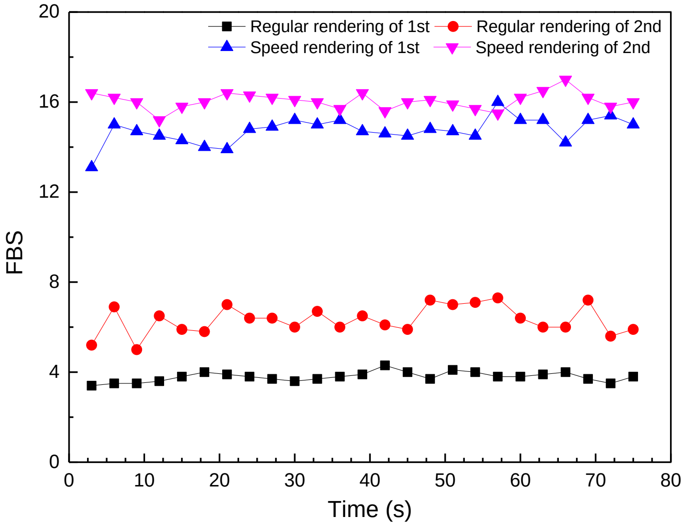

Figure 5: Frame rate comparison between viewpoint 1 and viewpoint 2.

Therefore, in this paper, a parametric modeling method is used to construct a three-dimensional tree model with high realism. Through the hierarchical structure model, the trees are divided into different hierarchical structures and rendered hierarchically. Figure 6 shows the level of realistic landscape architecture

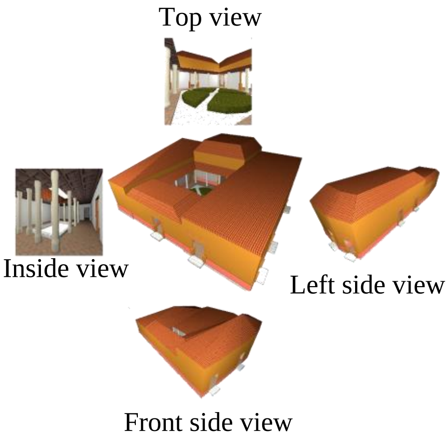

Figure 6: The level of realistic landscape architecture.

According to the spatial distribution relationship of real scenes, digital editing is performed on the basis of two-dimensional image maps by means of computer digitization, transforming the spatial layout of scenes into vector parametric expressions, and forming parametric vector layers. Through cross-platform components, import accurate digitalized factorized layers into the scene, and implement the rule-based spatial data parametric layout management organization. The factorized layers visualized through the OSG graphics rendering engine can not only constrain the planting area of the vegetation landscape, but also express the main ground position relationships in the garden, such as rivers, lakes and other water bodies, roads, buildings and other artificial garden elements. It can also include attribute parameter data of corresponding features, such as water depth, floor height, and vegetation density.

Because of its irregular distribution characteristics, the garden vegetation landscape is difficult to be scientifically and reasonably constrained. The overall spatial configuration of the garden landscape is directly related to the artistic effect of the overall garden and the rationality of the planning. Vegetation spatial organization based on parametric vector layer management can quickly define and arrange the spatial position of various types of vegetation in a three-dimensional garden landscape according to the composition characteristics of the vegetation in the field. Because the parametric vector layer can not only contain spatial position relationship data, the scene organization of the vegetation landscape can be greatly accelerated through automatic acquisition. In artificial garden scenes, the distribution of trees is generally more regular and usually needs to be constrained according to certain rules. Therefore, based on the visualization of garden vegetation, Parametric layout management, planning and organization of the spatial location of tree vegetation. Garden vegetation includes regional green vegetation, linear sidewalk tree vegetation, etc. This study conducts constrained planting of vegetation based on parametric data such as green vegetation or linear road vectors in planar areas.

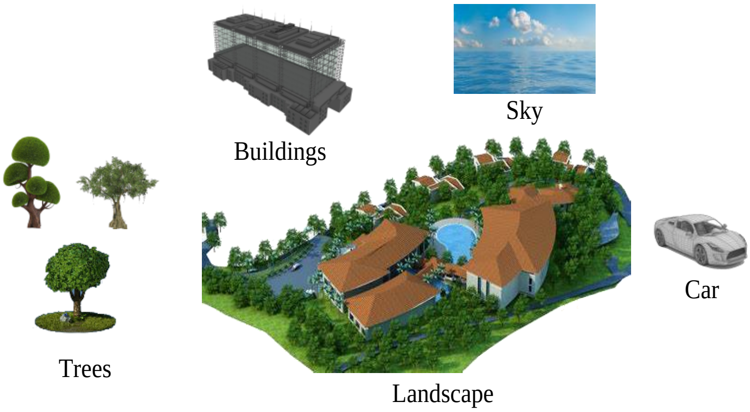

Figure 7: Envelope levels of three-dimensional landscape architecture.

When the parametric vector layer is constructed, the vegetation spatial distribution constraint mode can be specifically divided into planting along the line, regional row and column planting, and regional random planting. As shown in Figure 7, the planting mode along the line considers two types of organizational modes, namely, pure linear vegetation landscape and street tree landscape. It mainly focuses on street trees in garden landscapes and edge-modified vegetation of various landscapes. Constraints are based on road or other linear boundary vector parameters in the scene. When the 3D tree model is imported into the scene, the length of the parametric linear vector is obtained, the vegetation planting range is determined, and the space is calculated according to the user-preset attributes such as tree interval, tree offset, plant size, plant orientation, etc.

The terrain point cloud of the relevant research area obtained by the fixed-wing UAV has obvious data noise, that is, various unrelated features such as building, tree, and water body point cloud errors, etc. To accurately describe the topographic characteristics of specific garden landscapes, it is necessary to remove the point cloud of noise by removing the point cloud of error. Point cloud processing software removes the error point cloud. The point clouds data without noise points can more accurately describe the topographic characteristics of the corresponding landscape. However, the voids caused by it will also generate large terrain fluctuations during the 3D network construction of the point cloud, which will affect the overall performance of the terrain. We hope that the terrain after removing the holes is relatively smooth. We can add the corresponding three-dimensional model of the landscape after the digital terrain model is generated. As mentioned earlier, the IDV interpolation method can generate relatively smooth approximate junction data based on the surrounding neighborhood points.

3.3 The Proof of Three-dimensional CAD

In order to prove the effectiveness of the proposed three-dimensional image analysis method based on the rationality of the distribution of landscape architecture, a simulation is needed. In Windows7 reasonable distribution of three-dimensional image analysis simulation platform to build landscape architecture environment. The camera used was Point Grey Flea2 with a resolution of 640pi 520pi. 50 frames of images provided by Guangdong Landscape Architecture Association were selected as the experimental data set. Three-dimensional image analysis experiments of the rationality of the distribution of landscape gardens were performed using three-dimensional vision method and depth estimation method, respectively. The number of feature points extracted from landscape garden images can measure the performance of 3D image reconstruction accuracy of landscape garden images, but the key factor is the corresponding feature point pairs of the same name that accurately matches two landscape garden images. The two methods are used to match the feature points of landscape garden images. The comparison of the number and the matching rate is shown in Table 1.

Um.	Frequency	Matching rate (%)	Time (ms)
A	572	26.81%	578
B	356	24.67%	245
C	267	23.92%	338
D	356	26.67%	709
E	235	28.93%	589

Table 1: Matching number and matching rate of image feature points in 3D vision method.

Um.	Frequency	Matching rate (%)	Time (ms)
A	502	30.21%	601
B	567	35.27%	364
C	492	32.21%	309
D	342	42.55%	423
E	335	27.46%	562

Table 2: Depth estimation method image feature point matching number and matching rate.

Analysis of Tables 1 and 2 shows that in different landscape scenes, the number of matching pairs and matching ratios of landscape feature points obtained by the three-dimensional visual method is better than the depth estimation method, and the time-consuming process of image feature point matching is relatively Short, combined with prior knowledge, it can be seen that the higher the matching rate of image feature points in the 3D image reconstruction process, the higher the accuracy of the 3D image reconstruction of the landscape scene image, and at the same time fully prove that the 3D vision method is used for landscape gardening in the high precision landscape scene. Reliability of distribution rationality analysis.

3.4 Three-dimensional Garden Landscape Construction and Virtual Display System Design

Paper constructs and virtual display to landscape a specific area, the design and implementation of a multi-platform display, flexible organization dimensional landscape scene model building and virtual display system, using Oculus Rift as a virtual experience of the equipment, and the three-dimensional garden scene is displayed, and the garden area of the university library is taken as a case to construct a corresponding garden landscape, and a multi-directional virtual display is performed. For three-dimensional garden landscape scenes, it is necessary to consider various characteristics such as the ornamental characteristics, ecological functions, and aesthetic art of garden vegetation landscapes. A complete three-dimensional garden landscape system needs to achieve the scientific and technical unity of the landscape. The basic geographic data and thematic factor data are used as Support, to form a three-dimensional simulation of the overall artistic effect of the garden landscape diagnosis and interpretation platform. Aiming at the new requirements of 3D garden landscape construction and virtual display system, a conceptual model of a garden landscape system based on OSG graphic rendering engine and parametric modeling was proposed through data organization, 3D modeling and scene rendering, and virtual display.

As shown in Figure 8, the effect of immersion scenes in virtual reality can be improved to a certain extent by presetting appropriate FOV parameters and scene pixel density values. According to the initial parameters, the required texture sizes of the left and right eye sights are calculated. The function obtains the textures to be rendered and submits them to the texture swap chain mixer. In the layered texture mixer, the left and right eye texture merges processing is implemented to ensure the overlapping transition of the left and right eye sights. In this process, the Oculus SDK performs frame-by-frame processing for graphic distortion correction, frame rate delay, etc. Clayton et. al [5] pointed that the GPU is synchronized and sRGB color correction is performed to ensure the final effect of the rendered texture and the vividness of the scene. In addition, it supports the calculation of device poses to predict the texture rendering delay, thereby improving the stability of the overall scene in the helmet display device, obtaining helmet poses and frame drawing time through specific functions, and passing this information to the texture eyes [7]. In the post array, the texture prediction processing of the next frame is performed. After the texture rendering is finished, the module will call functions to destroy the mirrored textures constructed during the rendering process, exchange texture buffers and corresponding process objects to prevent errors such as memory overflow.

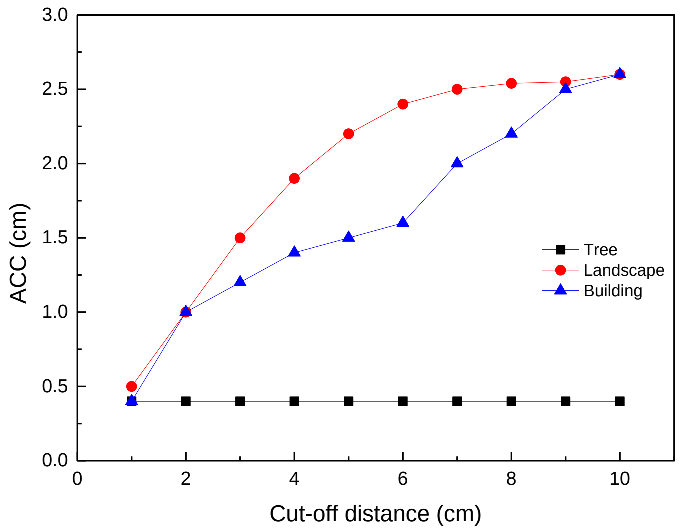

Figure 8: Completeness evaluation of the final model.

4 CONCLUSIONS

This study takes three-dimensional garden landscape as the research object, and studies the aspects of garden landscape element modeling, landscape element spatial organization, and multi-platform virtual display. The main research contents include the construction of three-dimensional garden vegetation, terrain, and water bodies. Data volume Optimization of 3D scene data rendering and development and integration of immersion display components for virtual reality.

This research has carried out research on rendering acceleration for issues such as the large amount of data in garden landscape vegetation models. The program rendering expenses has been reduced to a certain extent. In order to ensure the real-time rendering of three-dimensional garden scenes, the GPU- accelerated rendering method of the GLSL programmable rendering pipeline method is used. Based on this method, a more complex water body wave model in the garden landscape is realized, and the reality of the garden water body is improved. The feasibility of drawing a large number of garden vegetation leaf data based on GPU rendering was studied. Compared with the original vegetation leaf billboard method based on the OSG graphics rendering engine, the feasibility of controlling shaded drawing and rendering based on the GLSL method was tested. It provides a certain ideal for large-scale, high-precision, real-time rendering of vegetation landscape in virtual reality.

Xiao Zhao, https://orcid.org/0000-0002-6527-0824

REFERENCES

[1] Jiang, W.; Zhang, Y.: Application of 3D Visualization in Landscape Design Teaching, International Journal of Emerging Technologies, 14(06), 2019, 53-62. https://doi.org/10.3991/ijet.v14i06.10156

[2] Rajurkar, K.-P.; Yu, Z.-Y.: 3D Micro-EDM Using CAD/CAM, CIRP Annals, 49(1), 2000, 127–130. https://doi.org/10.1016/S0007-8506(07)62911-4

[3] Centenero, S.-A.-H.; Hernández-Alfaro, F.: 3D planning in orthognathic surgery: CAD/CAM surgical splints and prediction of the soft and hard tissues results–Our experience in 16 cases, Journal of Cranio-Maxillofacial Surgery, 40(2), 2012, 162 – 168. https://doi.org/10.1016/j.jcms.2011.03.014

[4] Vries, B.-B.; Harink, J.-J.: Generation of a construction planning from a 3D CAD model, Automation in Construction, 16(1), 2007, 13 – 18. https://doi.org/10.1016/j.autcon.2005.10.010

[5] Clayton, M.-J.; Warden, R.-B.; Parker, T.-W.: Virtual construction of architecture using 3D CAD and simulation, Automation in Construction, 11(2), 2002, 227 – 235. https://doi.org/10.1016/S0926-5805(00)00100-X

[6] Bosche, F.; Haas, C.-T.: Automated Retrieval of 3D CAD Model Objects in Construction Range Images, Automation in Construction, 17(4), 2008, 499 – 512. https://doi.org/10.1016/j.autcon.2007.09.001

[7] Roh, M.-I.; Lee, K.-Y.: Generation of the 3D CAD model of the hull structure at the initial ship design stage and its application, Computers in Industry, 58(6), 2007, 539 – 557. https://doi.org/10.1016/j.compind.2006.12.003

[8] Nahm, Y.-E.; Ishikawa, H.: A new 3D-CAD system for set-based parametric design, The International Journal of Advanced Manufacturing Technology, 29(1), 2006, 137 – 150. https://doi.org/10.1007/s00170-004-2213-5

[9] Ghadai, S.; Balu, A.; Sarkar, S.: Learning localized features in 3D CAD models for manufacturability analysis of drilled holes, Computer Aided Geometric Design, 62(1), 2018, 263–275. https://doi.org/10.1016/j.cagd.2018.03.024

[10] Chen, Z.; Xu, B.; Devereux, B.: Urban landscape pattern analysis based on 3D landscape models, Applied Geography, 55, 2014, 82–91. https://doi.org/10.1016/j.apgeog.2014.09.006

[11] Ding, B.: 3D CAD Model Representation and Retrieval based on Hierarchical Graph, Journal of Software, 9(10), 2014, 2499–2506. https://doi.org/10.4304/jsw.9.10.2499-2506

[12] Park, J.; Kim, B.; Kim, C.: 3D/4D CAD applicability for life-cycle facility management, Journal of Computing in Civil Engineering, 25(2), 2011, 129 – 138. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000067

[13] González-Lluch, C.; Contero, M.; Camba, J.-D.: A survey on 3D cad model quality assurance and testing tools, Computer-Aided Design, 83(5), 2017, 64 – 79. https://doi.org/10.1016/j.cad.2016.10.003

[14] Anadioti, E.; Aquilino, S.-A.; Gratton, D.-G.: 3D and 2D Marginal Fit of Pressed and CAD/CAM Lithium Disilicate Crowns Made from Digital and Conventional Impressions, Journal of Prosthodontics, 23(8), 2014, 610–617. https://doi.org/10.1111/jopr.12180

[15] Zhang, C.; Zhou, G.: A view-based 3D CAD model reuse framework enabling product lifecycle reuse, Advances in Engineering Software, 127(2), 2019, 82 – 89. https://doi.org/10.1016/j.advengsoft.2018.09.001