Received July 23, 2020, accepted August 8, 2020, date of publication August 14, 2020, date of current version August 25, 2020.
Digital Object Identifier 10.1109/ACCESS.2020.3016722

Three-Dimensional Visualized Urban Landscape Planning and Design Based on Virtual Reality Technology

XING LIU
College of Art and Design, Wuchang University of Technology, Wuhan 430223, China
e-mail: starliu11@163.com

ABSTRACT The traditional methods of urban landscape planning and design cannot integrate designs into the entire planning scenes planning processes, and cannot efficiently, intuitively and coordinately express planning effects of multiple schemes and large scenes. With the development of computer science and technology, virtual reality (VR) technology, which is based on similar theory, mathematical theory, control theory, and graphics processing theory, is playing an important role in many aspects of urban landscape planning and design. On the basis of summarizing and analyzing previous research works, this article expounded the research status and significances of three-dimensional (3D) visualized urban landscape planning and design, elaborated the development background, current status and future challenges of VR technology, introduced the methods and principles of spatial roaming sorting algorithm and evaluation indicator screening and system construction, established 3D database and virtual scene model of urban landscapes, performed 3D visualized urban landscape modeling, realized 3D presentation of virtual scene landscape, discussed the integration and optimization of landscape design schemes, analyzed the 3D modeling and interactive adjustment of the landscape planning and design schemes, and finally conducted simulation experiment and its result analysis. The results show that the VR technology provides designer with realistic information processing effects through intelligent drawing, full display and timely information, which greatly improves design efficiency and effectively promotes design quality; the 3D visualized technology can transmit a large number of information through graphics in a short time, enabling professionals to intuitively and quickly observe test results or interactively process these results.

INDEX TERMS Urban landscape, planning and design, virtual reality technology, 3D visualization.

I. INTRODUCTION

Urban landscape refers to the sceneries or scenes of urban geographical spaces, which is a product of the interaction between natural landscape and artificial landscape. Landscape planning is often based on existing environment, and landscape design and its realization are to closely integrate design content with surrounding environment [1]. Traditional sand table, model and computer-aided design technology all cannot integrate planning and design into entire planning scenes and design processes, and cannot efficiently, intuitively and coordinately express planning and design effects of multiple schemes and large scenes [2]. With the comprehensive application of computer technology, network communication technology and graphics technology, urban information construction combines multimedia networks, geographic information systems (GIS) and other infrastructure platforms to combine urban information resources and realize urban digitization. As a new attempt, the use of three-dimensional (3D) visualized technology to assist landscape planning and design has become an important development direction in the planning field [3]. With the continuous development of computer science and technology, virtual reality (VR) technology, which is based on similar theories, mathematical theories, control theory, information processing technology, and computer technology, is playing an important role in many aspects of urban landscape planning and design [4].

The VR technology is an advanced computer user interface that provides users with intuitive and natural real-time perception and interaction methods, and is convenient for users to perform system operations and improve system work

The associate editor coordinating the review of this manuscript and approving it for publication was Zhihan Lv.

efficiency [5]. The emergence and application of this technology has changed the traditional design mode, providing design staff with realistic information processing effects through intelligent drawing, greatly improving the design efficiency, and also promoting the effective improvement of design quality [6]. The 3D visualized technology is to use visualized images to represent data and calculation results, and transmit a large amount of information through graphics in a short time, so that professionals can intuitively and quickly observe the test results or perform interactive processing on the results. The 3D visualized urban landscape planning is based on advanced computer technology, geographic information system, virtual reality, remote sensing and other technologies [7]. On the basis of the establishment of a basic information database of 3D models, it closely combines the business processes of planning and management. The urban landform virtual simulation realizes the scientific and automated dynamic planning, guarantees the timely update of planning information, effectively performs spatial analysis of regional information, supports regional planning deepening, and brings obvious economic, social and ecological benefits to urban construction and management [8].

On the basis of summarizing and analyzing previous research works, this article expounds the research status and significances of 3D visualized urban landscape planning and design, elaborates the development background, current status and future challenges of VR technology, introduces the methods and principles of spatial roaming sorting algorithm and evaluation indicator screening and system construction, establishes 3D database and virtual scene model of urban landscapes, performs 3D visualized urban landscape modeling, realizes 3D presentation of virtual scene landscape, discusses the integration and optimization of landscape design schemes, analyzes the 3D modeling and interactive adjustment of the landscape planning and design schemes, and finally conducts simulation experiment and its result analysis. The detailed chapters of this article are arranged as follows: Section 2 introduces the methods and principles of spatial roaming sorting algorithm and evaluation indicator screening and system construction; Section 3 establishes 3D database and virtual scene model of urban landscapes and realizes 3D presentation of virtual scene landscape; Section 4 analyzes the 3D modeling and interactive adjustment of the landscape planning and design schemes; Section 5 conducts simulation experiment and its result analysis; Section 6 is conclusion.

II. PRINCIPLES AND METHODS

A. SPATIAL ROAMING SORTING ALGORITHM

For a large and complex scene, there are both visible polygons that contribute to human visualized perception and those invisible polygons that do not contribute to visualized perception. In the display and internal calculation of 3D graphics, it is assumed that all vertices are represented by four-dimensional homogeneous coordinates [9]. In the form of (X, Y, Z), which is equivalent to $(X/F, Y/F, Z/F, P/F)$ $(F \neq 0)$. The 3D coordinates (x, y, z) used in the model are equivalent to the four-dimensional homogeneous coordinates (X, Y, Z, P). Then model transformation on 3D model is performed to be displayed and transformed result is:

$$\begin{bmatrix} X & Y & Z & P \end{bmatrix} = \frac{\begin{bmatrix} x & y & z \end{bmatrix} \cdot F_p(x, y, z)}{\begin{bmatrix} x^P & y^P & z^P \end{bmatrix}} \tag{1}$$

where F is a 4×4 transformation matrix, which is the result of various transformations such as translation, rotation, reflection of model coordinates; F_p is the value assigned by expert group to these elements. The gray statistical method is based on the generation of gray-like whitening functions, and the expert group's assignment of elements is counted and analyzed, so the content of the transformation matrix for rotation transformation of the assigned elements is as follows:

$$\begin{bmatrix} X_\alpha^h & Y_\alpha^h & Z_\alpha^h & P_\alpha^h \end{bmatrix} = \begin{bmatrix} X & Y & Z & P \end{bmatrix} \begin{bmatrix} 0 & n0 & 0 & F_p \\ 0 & 0 & F_p & 0 \\ 0 & F_p & 0 & 0 \\ F_p & 0 & 0 & 0 \end{bmatrix} \tag{2}$$

When the current position of an object is $(x, y, z, 1)$, the object can be rotated through operation; the process includes rotation axis h and rotation angle α; the rotation matrix obtained at this time is:

$$F_p(x, y, z, 1) = \begin{bmatrix} -sin\alpha & 0 & cos\alpha & 0 \\ 0 & h & 0 & 0 \\ -cos\alpha & 0 & sin\alpha & 0 \\ 0 & 0 & 0 & h \end{bmatrix} \tag{3}$$

The satisfactory compatibility between h_1 and h_2 is assumed as $I(h_1, h_2)$; the arithmetic mean S_α of the fuzzy judgment weight set given by two experts is used as weight distribution vector of evaluation index factor set as follow:

$$S_\alpha = \begin{cases} I_{\alpha 1} - \dfrac{(F_{p1} - F_{p2})(P_\alpha - W_{avg})}{W_{max} - W_{avg}}, & P_\alpha \geq W_{avg} \\ I_{\alpha 2} - \dfrac{(F_{p2} - F_{p3})(P_\alpha - W_{min})}{W_{avg} - W_{min}}, & P_\alpha < W_{avg} \end{cases} \tag{4}$$

where W_{max}, W_{min} and W_{avg} are the maximum, minimum and average fitness values of population, respectively; P_α is the larger fitness value among individuals performing roaming and sorting operations. For a fixed total number of degrees of freedom $N = N_\alpha$, the determination of optimal roaming grid n and the order t can be transformed into the following optimization problem:

$$S_\alpha(x, y, z, n) = I_\alpha(\mathrm{n}, t) - \lambda \sum_{n=1}^{N_\alpha} P_\alpha \cdot F_p(x, y, z, n) \tag{5}$$

where λ is the estimation error under the total number of freedom degrees, which is a constant. In practical applications, the reduction of errors caused by new degrees of freedom is required to be as large as possible in order to achieve efficient grid improvement. For the above algorithm, it is necessary to find a set of relatively stable correct matching points as the initial point pair for calculation. Therefore, the key step of the algorithm is to find a set of such points, because only one set of initial matching points needs to be found.

B. EVALUATION INDICATOR SYSTEM CONSTRUCTION

According to the landscape function of urban landscape, combined with research results of related fields, the evaluation indicators are analyzed and sorted out, and finally a criterion layer based on the plant landscape, artificial landscape and spatial scale is formed [10]. Suppose judgment matrix $H = (k_{ij})_{m\times n}$; for any $i, j = 1, 2, 3, \ldots$ n, if $0 \leq k_{ij} \leq 1$, then H is called a fuzzy matrix; a general mathematical formula that calculates the weights of fuzzy complementary judgment matrices can organize the data of expert scoring judgment weight calculation:

$$T_i = \frac{\int_{i=1}^{n} k_{ij}dx + \frac{n}{2}\sum_{i=1}^{n} H_{ij}}{n\,(n-1)} \tag{6}$$

In the formula, n is the order of the fuzzy complementary judgment matrix; according to the characteristics and basic structure of the evaluation index system, the urban landscape system based on VR technology is designed, and the construction of a smart landscape model can be expressed as:

$$H_{ij}T_i = \frac{(a_1 - a_2)\cdot r \pm H_a\,(x, y, z)}{S_m^a \cdot S_n^a} \tag{7}$$

where a_1 and a_2 respectively represent the factors of the evaluation index system; r is the intelligence factor of characteristic space S of urban landscape system; S_m^a and S_n^a represent the corresponding inter-landscape divergence matrix and within-class divergence matrix, respectively.

Suppose M to be the attraction set of evaluation system. In order to clarify its geometric structure, the local selection of evaluation indicators at nearby points is first denoted as:

$$f\,(M_a) = \begin{bmatrix} -ak + T_a & -n & -\lambda k - T_a \\ \lambda m - ak & -a^2 + \lambda k & 0 \\ -m & 0 & n \end{bmatrix} \tag{8}$$

Interactive modification enables the evaluation parameters of landscape monomers, such as floors, heights, materials to be adjusted in real time to the landscape environment. For the above algorithm, it is necessary to find a set of relatively stable correct matching points as the initial point pairs for calculation. If the minimum eigenvalue of positive matrix M is set as $k_0 = a[\lambda k^2(a - r^2) + 2\,ka + b]$, then the following formulation is obtained:

$$M_{ab}^{\lambda} = \begin{bmatrix} \left(ka + \lambda b^2\right) & 0 & 0 \\ 0 & \left(kb - \lambda a^2\right) & 0 \\ 0 & 0 & \left(kab - \lambda a^2 b^2\right) \end{bmatrix} \tag{9}$$

where M_{ab}^{λ} is the b-th index with importance degree of a with the estimation error of λ. Function $f_k(a, b)$ is defined as the whitening function value of b-th index with importance degree of a, then k ($k = 1, 2, 3, \ldots n$) is the number of gray classes, and normalizes and calculates the variance of each component as following:

$$f_k\,(a, b) = \sum_{k=1}^{m} var\left[\frac{\left(ka + \lambda b^2\right)}{\left(kb - \lambda a^2\right)}\right] \tag{10}$$

where $var(a, b)$ is the variance of each component; in order to quantitatively describe the relative importance of each evaluation factor with respect to the upper-level factors, the evaluation indicators are often scaled by the fuzzy scale method of 0.1-0.9 between the schemes and gives a quantitative scale.

III. 3D VISUALIZED URBAN LANDSCAPE MODELING

A. DATABASE ESTABLISHMENTS OF 3D URBAN LANDSCAPE

The data foundation of the city visualized 3D display application system includes 3D model data, basic geographic information data, and thematic data. The 3D model data is mainly the 3D real scene model data of the county and key areas, and the basic geographic information data is mainly the digital city geographic space framework platform. They provide overview map, urban topographic data, electronic map data and place name address data, etc., in which the thematic data is mainly the existing urban planning thematic data. GIS is an efficient technology for managing and processing spatial data; urban landscape planning is one of its important applications [11]. The data layer receives requests from the driver layer, performs data read and save operations, and provides a unified data access interface for the driver layer to call. The operation of the application, the browser, and the rendering of the 3D scene are all real-time dynamic calls and accesses to the 3D database. In order to realize virtual reality in a more economical way, an image-based virtual reality technology was developed. When observing the surrounding scene by rotating in the non-traveling state, the relative position of the stationary objects in the scene relative to the observation point is unchanged, and the perspective relationship between the objects in the visually generated picture is also unchanged. Therefore, in order to ensure that the data called by the application and the browser through the driver layer is easy to maintain and has data commonality, a unified data description format must be adopted. The 3D models called by the application terminal and the browser are all described in a specific file format, and the file is finally stored in the database (Figure 1).

From the perspective of form and function, the 3D visualized urban landscape planning and design system needs to have real-time interactive functions in a 3D space environment, such as planning model replacement in a 3D space environment, landscape model replacement, landscape texture replacement, landscape height adjustment, etc. It can generate landscape maps of specific viewpoints for collision detection, query positioning, spatial coordinate query, distance measurement, etc. In addition, there are attribute data management and index statistics functions to query landscape attribute data, such as the location, structure, owner, purpose, number of floors, height, floor space, building area,

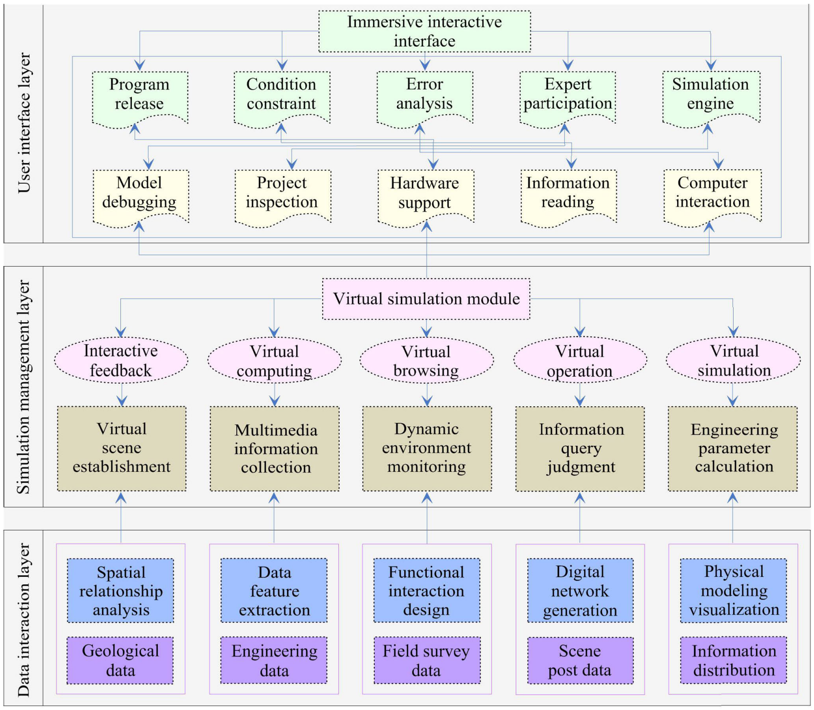

FIGURE 1. Systematic framework of virtual reality platform for 3D visualized urban landscape planning and design.

building age, building unit, total price, etc. In addition to the establishment of a real-time 3D simulation environment and interactive roaming, the system is also equipped with many powerful modules to adapt to different application requirements (Figure 2). The automatic navigation function allows users to set relevant paths and observation angles in advance and automatically roam according to users' preferences without repeated operations, which is convenient for users to query, display and project approval. The editing function allows users to interactively modify the design parameters of each building unit such as floors, heights, materials, etc., and can also make real-time adjustments to the landscape environment. What designers see are what they get, making the modification and evaluation of the project plan very convenient [12].

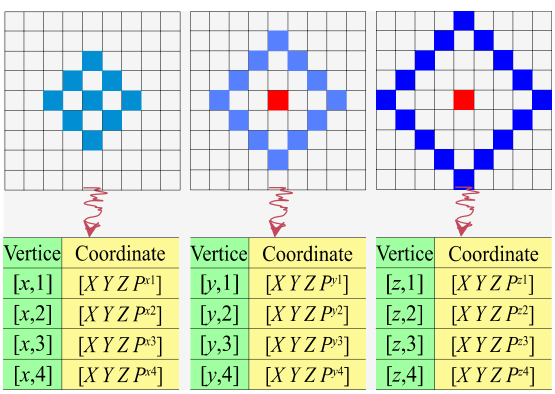

FIGURE 2. Spatial roaming sorting algorithm Database establishments of 3D urban landscape.

The 3D urban landscape structure refers to various 3D entities, and there are two main methods to obtain the frame data of these 3D targets. One is to use digital photography to collect the frame coordinates of the building on a 3D model, and then use modeling software to construct them into solid objects. Another method is to use 3D design software to import and position the designed 3D entities in the terrain and landscape model. No matter which method, the data must be checked to make their connections correct to facilitate the pasting of side textures. For these special features that must be expressed in the urban 3D landscape model, although the real texture and appearance of the digital images can be obtained by using digital photography, the performance of the urban 3D landscape model should not only pay attention to reality, but also express the beauty out of the city. For example, on the ground of a city street, if the real texture of the digital photography is used, the stolen and damaged ground will be captured [13]. The ground shown in the model is very unsightly, and even too many cars on the road will affect the urban landscape model. In order to eliminate these effects, it is generally necessary to modify the ground texture; under the premise of controlling its spatial scale and other characteristics and grasping its authenticity, artificially paste the beautiful ground texture.

B. MODEL REALIZATION OF 3D VIRTUALIZED SCENE

The open source third-party modeling tool is always used, which comes with basic graphics, such as cubes, cylinders, cones, spheres and other geometric graphics needed in the modeling process, through a series of zoom, translation,

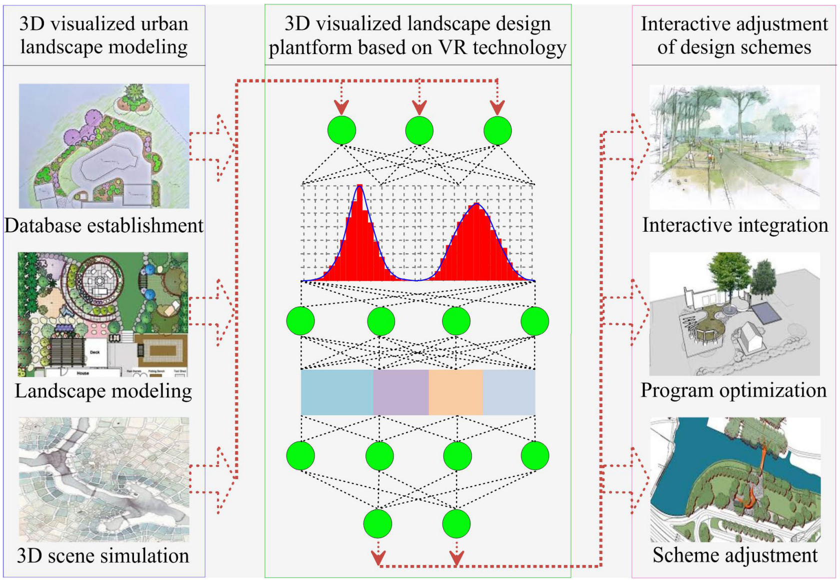

FIGURE 3. Modeling realization of 3D virtualized urban landscape scene.

rotation, and pull operations such as extension and operations can accurately construct a 3D model of the urban landscape and render it to produce a good visualized effect. In the process of modeling, it is necessary to follow the principle of truthfulness and rationality, the principle of removing redundant polygons of the model, and the principle of primary and secondary [14]. They avoid the principle of incompatibility and the principle of excessive emphasis on details, and try to solve the problem of large model data by texture mapping. The 3D visualized of urban landscape planning and design has the characteristics of high complexity and strong practicality. Regular knowledge cannot fully express the planning scheme, and interactive 3D visualized tools can combine two kinds of knowledge to assist in expressing the design scheme (Figure 3). When selecting landscape planning goals, designer can search from the database, combine with city planning goals, and use geographic knowledge to establish rules to form planning and design plans according to site conditions. Geographical knowledge collections are described through geographic objects, relationships, structures, ontology, gazetteers, rules, and mathematical models, and then a knowledge reasoning machine can be established that can be applied to urban landscape planning and design.

Using VR technology, the final effect of urban landscape design is displayed through computer 3D models. Compared with the designer's hand-drawn drawings or 3D sand table display, its intuitiveness is more realistic, real-time discussion is stronger, and it is more feasible through 3D animation technology. They carry out a motion simulation exhibition of the design results, and at the same time achieve an all-round and 3D display of time and space changes (Figure 4). The existing buildings can be divided into two types: regular shape and irregular shape. For regular-shaped buildings, as long as the bottom contours and building heights of these buildings are given, batch modeling can be used. The beauty and

FIGURE 4. Example of landscape model replacement in 3D virtualized urban landscape design.

fidelity of architectural models are mainly reflected by the collection of actual architectural textures [15]. Using aerial photos and high-resolution satellite photos to collect textures on the top of buildings can reduce a considerable amount of fieldwork. In order to ensure the spatial seamlessness of the model after the terrain surface is superimposed with the building model and other ground object models, special treatment must be done on the part that intersects the bottom surface of the building or other ground object surfaces with the terrain surface. Otherwise, it will not only cause the gap in the space of the overall model also affects the visualized effect. There may be many problems in the integrated scene, which requires repeated modifications and adjustments until a satisfactory final scene is formed.

In this system, the realization of the 3D virtual scene model is mainly to improve the fidelity and fluency of the virtual scene. In order to ensure this effect, the degree of conformity between the virtual environment and the real environment must be improved. The key is to satisfy the visualized needs of this system are guaranteed by improving the realism and fluency of the virtual picture in the visualized scene generation of the system. In the realization of system operation, users can perform autonomous mode switching and control of the main display interface based on the original interface. It can be operated either through the touch screen of the interface, or click control through an external connection system. At the same time, the relevant interface is mainly the content in the above interface design, and the user can also switch according to the relevant control keys after the system starts running. In the operation of the system, the interface mainly includes two modes, namely the above-mentioned single window mode and multi-window mode. The user can operate and control the display of the window. In addition, the position of the command panel during some operation can be changed by the user according to their own needs. Under the background of initialization, the command panel is located in the middle of the display interface, so that the user can combine visualized display, information display based on the relevant instructions for landscape design [16].

FIGURE 5. Example of landscape environment replacement in 3D virtualized urban landscape design.

IV. 3D SIMULATION AND INTERACTIVE ADJUSTMENT OF PLANNING AND DESIGN SCHEMES

A. 3D SIMULATION OF VR LANDSCAPE SCENE

From overall planning to urban design, at all stages of planning, through the description of the status quo and the future, urban construction requires immersive urban experience, real-time landscape analysis, building height control, and multi-plan urban space comparison. It provides strong support for improving the living environment and the formation of distinctive urban styles. Planning decision makers, plan designers, urban construction managers and the public play different roles in urban planning [17]. Effective cooperation is the guarantee the prerequisite for the ultimate success of urban planning and management (Figure 5). In the virtual planning scenario, the planned buildings and landscapes are moved, compared from multiple angles, and after comprehensively considering the relationship between the environment and surrounding buildings, building design and other factors, the optimal plan is determined, which can improve the taste of urban construction to promote the sustainable development of the city. It provides the display of general planning, control planning and other planning thematic data in two-dimensional and 3D maps, and can view planning index information, which is convenient for planning departments to make site selection decisions. Through the planning topic list, the structure list of planning data, the contents of planning data and the data name are uniformly displayed, and the planning data is displayed in a 3D scene by selecting planning data in the planning topic list.

According to the collected data, make a 3D architectural model. When modeling, pay attention to the premise that the design requirements are met and the details are not required to be engraved. The number of points and segments required for the model should be reduced as much as possible, and there is no need for visualized design. Have too high precision, so as to avoid excessive pursuit of less important procedures and reduce work efficiency. After that, an appropriate light scene and background can be created, and the virtual landscape 3D model can be displayed in a real state, in which the effect of performance makes the virtual light more realistic. The role of light in the 3D virtual environment is very important. If there is no light, then the transparency and shape of the landscape cannot be reflected. This requires designers to grasp the difference between real light and virtual light, and understand the effect of light changes on the scene. Since the material design directly affects the authenticity of the visualized effect, various factors affecting the visualized effect must be considered when the material design is carried out [18]. The color, texture, roughness, and intensity of the reflected light of the visualized effect must be simulated to make the virtual scene has the unique visualized effects and characteristics of a certain real material, and it also makes the space, components and overall structure of the landscape model present a real characteristic (Figure 6).

The VR technology can help designers from the side to complete the conceptual design and conceptual design, which allows designers to deeply feel their own inspiration and ideas, and transform them from concepts into concrete solutions. Combining the content of the previous analysis, designers can get a deepening plan, and compare the differences between the plans and their respective advantages and disadvantages, and get the concept and plan of the planning and design. Through the immersive experience method, the landscape architect enters the corresponding virtual environment generated by the aforementioned VR system, and analyzes and explores after multi-directional and multi-angle observation and experience [19]. In the VR landscape space, designer can switch between different scenarios in real time, and can also experience the spatial sense and scope of different scenarios from the same viewpoint, and can switch, modify, and reconstruct in real time. According to the steps of the landscape architect planning and designing urban green space, after the plan design is completed, detailed element

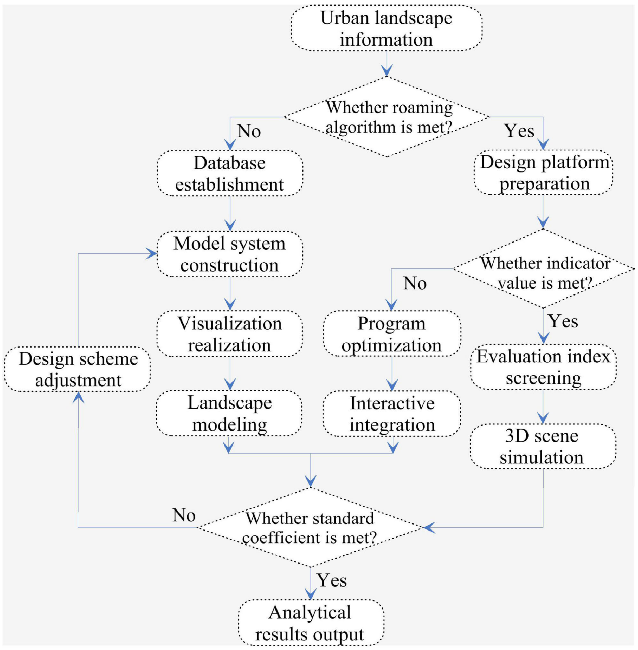

FIGURE 6. Flow chart of 3D visualized urban landscape planning and design based on VR technology.

design of the plan should be carried out (Figure 7). The application of VR technology in this stage is more flexible and rich. The landscape elements set in the VR environment can be changed in size and pasted, moved, deleted, etc., and the entire operation process will be backed up and stored. This immediate feedback function of instant switching and settings ensures the rationality of the designer in the process of designing the inspection plan.

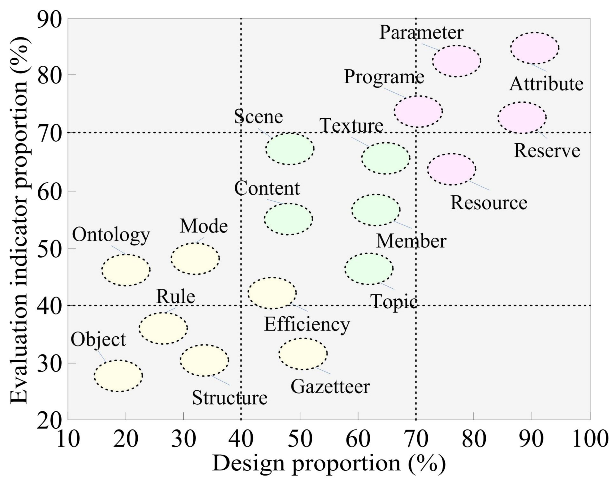

FIGURE 7. Relationship between evaluation indicators and design proportion with different 3D visualized design factors.

The VR technology has three basic characteristics: immersion, interactivity, and conception. The sense of immersion means that the VR system is no longer like a traditional computer. The user's interaction with the computer is already natural, just like the interaction between humans and nature in reality, completely immersed in the virtual environment created by the computer. Interaction refers to the characteristics that distinguish VR systems from traditional three-dimensional animations. Users no longer passively accept information given by computers or are bystanders, but can use interactive devices to manipulate virtual objects to change the virtual world. Conceptuality refers to Users can use the VR system to gain perceptual and rational knowledge from the integrated qualitative and quantitative environment, thereby deepening concepts and sprouting new ideas. In the process of conventional VR technology for landscape design, computer software systems, computer graphics input and processing, equipment demonstrations are generally involved, and landscape design is realized by referring to the characteristics of the VR system. In the process of applying the VR system, it generally presents the characteristics of the concept, and constitutes a quantitative integration link and a qualitative integration link in the system and prompt the experience personnel to deeply feel the exquisiteness of landscape design and expand their own thinking conceives and associates results.

B. INTEGRATION AND OPTIMIZATION OF PLANNING AND DESIGN SCHEMES

The scale setting is the basic and necessary link in the initial stage of virtual scene model making and the production of the scene model is part of the foundation and also a crucial part. The main body of the outdoor building of the whole work is the production of ancient building models. The indoor model part is mainly the production of various ancient small objects, such as vases, tables, chairs, bed lanterns, cabinets, calligraphy and painting, etc. Terrain construction mainly includes model making of mountains, artificial hills and rocks, the production of plant model flowers and trees (Figure 8). The other is the production of various embellishment objects in outdoor scenes. The production method of architectural models is mainly built in the form of stacked wood, some of which use two-dimensional situation to make 3D models, in which the production of virtual scene models is a very important part. Based on the limitations of the post-interaction engine, there are three points to pay attention to in model production: The first is to streamline the number of models to achieve the best effect designer want with as few surfaces as possible; the second is to reduce the output of the model and attach multiple secondary objects into a whole; and the third is that the model texture is not too fine, rather small than large. On the premise of ensuring the effect, the number of models should be as small as possible, and there is no need to make separate places where the texture can be shared. On the premise of ensuring that the texture is sufficiently clear, the texture pixels can be as small as possible to save resources and not waste [20].

The planning and design results are made into a VR system, which breaks through the limitations of traditional renderings, can fully display the effects of the planning plan after completion, and communicate with decision makers

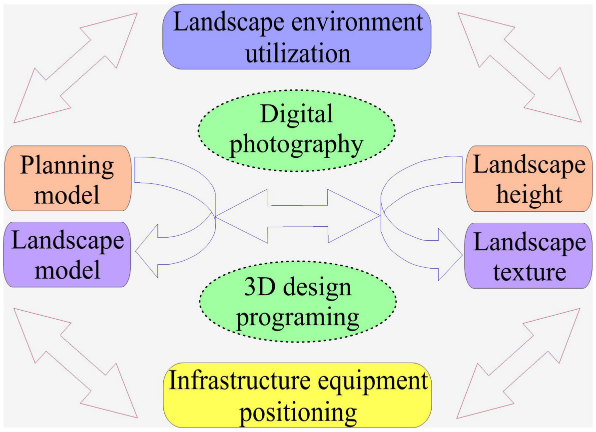

FIGURE 8. Integration and optimization of planning and design schemes.

and visitors intuitively in the form of roaming on any path. At the same time, when bidding for the design project, the design results are required to provide the electronic model of the design scheme and the texture map material of the facade. Before reporting, a 3D model of the design plan can be established through 3D modeling technology, and then loaded into the system's 3D environment, and different design plans can be quickly switched [21]. Experts can observe the effects of different schemes in a 3D environment from different angles and directions through the system. This kind of virtual system is composed of a 3D model established by real data, strictly following the standards and requirements of the project design, and belongs to a scientific virtual system (Figure 9). The traditional way of displaying design results has certain limitations and is flat and static, in which this kind of virtual system is different, dynamic, multi-directional, and multi-angle. The design results can be displayed in three dimensions, which can be presented to the public and the plan can be shown to the owner, so that valuable suggestions can be revised in time to enhance the competitiveness of the plan.

In addition to 3D dynamic simulation and virtual graphics generation, VR technology also includes two-dimensional GIS data processing technology, sensor and display technology, and development of digital analysis technology for VR systems. Therefore, the application of VR technology in urban planning and design can better manage the 3D model of the city. Through the connection of the VR display module and the sensing hardware, visual system observation and system operation can be realized. By using the display module in VR technology, users can reproduce the geographic relationship of the building complex in real time, display the building information, and present the details of the building in a 3D virtual space. This can provide convenience for urban planning and design personnel, compare different planning and design plans, and finally choose the plan for urban planning and design. At the same time, the urban 3D model can also allow the decision makers of urban planning and design to determine the details of the design more accurately, so as to better improve the level of urban planning and design decisions and management (Figure 10). When planning and

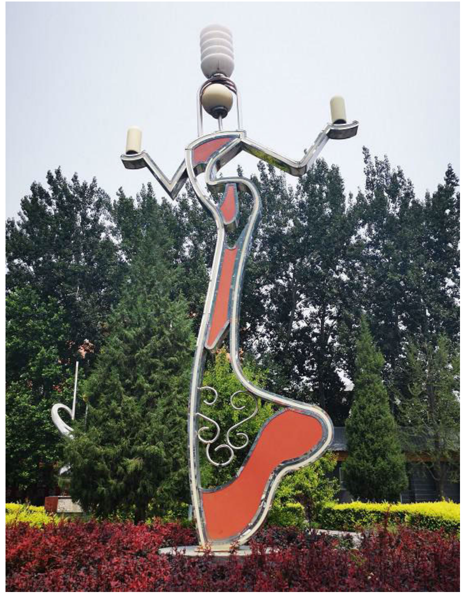

FIGURE 9. Example of landscape height adjustment in 3D virtualized urban landscape design.

designing each module in the city, it must not only construct a visualization of the simulation environment that conforms to the real space, but also conform to the existing urban planning and design schemes.

FIGURE 10. Example of landscape background fusion in 3D virtualized urban landscape design.

Urban landscape design and plan planning can basically be divided into intuitiveness, indirectness and intermediateness. Intuitiveness is mainly to combine all existing objects to reflect the pattern and final effect of the entire urban landscape, including the landscape environment, the use of natural resources, the location of infrastructure equipment, the style environment that each area should have, and the

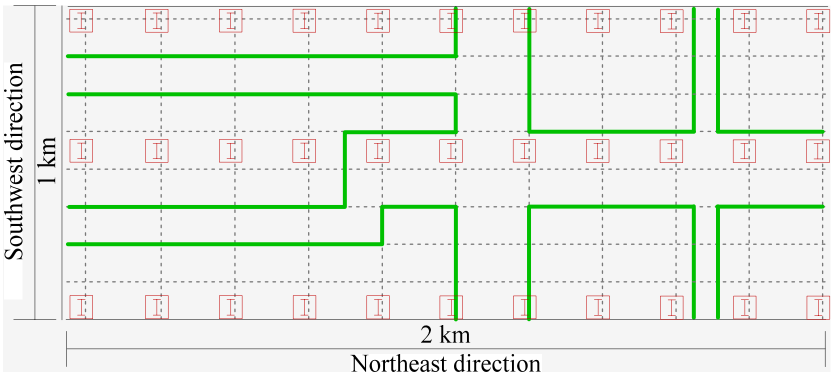

FIGURE 11. Floor plan of simulated area in this study; solid green lines represent road or street; red square represents grid pints.

TABLE 1. Parameter setting of simulation system.

Parameter		Value
Hardware platform	Central processing unit	Intel Core i7-7700HQ
	Graphics card	NVIDIA GTX 980 M
	Random access memory	DDR4 32 GB
	Hard disk	SSD 1T
Software platform	Operating system	Windows 10 Home 64-bit
	Development language	Visualized C++
	Database system	Microsoft Access 2007
	2D drawing software	AUtoCAD
	3D modeling software	Sketch Up
	Simulation drive software	Lumion3D

later provision. In the actual design and planning scheme, VR technology is used to directly draw lines and image conversions for each demand section through 3D software. Through planning, design, verification and calculation of the actual terrain, population planning numbers, traffic planning, natural environment and required materials, all needs are intuitively reflected through VR technology [22]. Indirect urban design planning does not have to have architectural and environmental factors, which also requires a good combination of the landscape and people in each area. The material and sensory of the street are evaluated and determined by the human visualized sense in urban design when conducting indirect evaluation, the most important thing is the suitability and usability of each hardware facility. This immediate feedback function of instant switching and settings ensures the rationality of the designer in the process of designing the inspection plan. For places with large crowds such as commercial streets and pedestrian streets, it is necessary to consider the current situation of use in the later period, and reserve enough space for creation to create a good environment for the later period.

V. SIMULATION AND RESULT ANALYSIS

A. SIMULATION SYSTEM SCHEME

The planned area selected for the simulation of this study is an economic and technological development zone in a first-tier city, located 45 km east of this city, with a total planned area of about 37 km2. The simulation range is the northern part of the central city of the development zone, with an area of about 2 km^2. The floor plan of simulated area in this study; solid green lines represent road or street; red square represents grid pints is shown in Figure 11. The simulation system runs a visualized workstation on a high-configuration computer, and the human-machine interface device takes into account the current application range and only uses the basic computer configuration. This simulation experiment was conducted on a Windows 10 Home 64-bit platform; its central processing unit is Intel Core i7-7700HQ; graphics card is NVIDIA GTX 980 M; random access memory is DDR4 32 GB; hard disk is SSD 1T. The system development software environment adopts Windows 10 operating system and Microsoft Access 2007 database system; the 3D modeling software is Sketch Up, the simulation drive software is Lumion 3D, and the software programming tool uses Visualized C++ (Table 1).

The main expression method of Sketch Up is to imitate the hand-painted effect, which makes the landscape design process more efficient and easy, which is mainly used to model the virtual scene in the garden design. First of all, Sketch Up can use contour lines, grids, geographic data and other methods to generate terrain to form a virtual scene for garden creation. Sketch Up uses the contour lines drawn in the computer-aided design software, and after simple processing, it is imported to generate accurate terrain. If designers only need to simulate the rough terrain space, the grid method is mainly used. For the demanding 3D terrain, they can use geographic data and key point elevation data. Secondly, landscape buildings and structures are also an important part of the design, which basically occupies most of the quantity and volume of the entire scene modeling, especially the creation of some ancient architectural models has become a difficult point for designers to express quickly. Thirdly, Sketch Up also provides an effective way to express plant modeling when drawing garden renderings. Plant modeling is one of the difficulties of 3D modeling in landscape design, because each scene has hundreds of plants of different sizes, and each tree has thousands of leaves. The number after forming a 3D model reaches hundreds and tens of thousands or even tens of millions of levels are a great load for computers.

The simulation system scheme is as follows: First, it is based on visualized simulation, focusing on expressing the urban landscape; the urban landscape is mainly expressed through elements such as buildings, landscapes, and urban furniture; and a large number of landmark buildings and landscapes are concentrated in the central city. The system mainly uses visualized simulation methods to fully display the appearance of each element and the space experience in it, so as to highlight the status of the central city in the future city. The second is the combination of virtual and real; it refers to the organic integration of the current situation of the city and the future of the city, and the virtual environment not only reproduces the city in reality but also virtualizes the future city [23]. The third is that users can simulate a variety of sports for interactive roaming in the virtual city; different from the 3D animation technology that obtains a picture moving along a fixed path after a large number of calculations in advance. This system provides an interactive roaming method, that is, the user can use the human-machine interface device to simulate a variety of motion modes to roam in the virtual environment, making the user has an immersive feeling.

B. RESULT ANALYSIS

Urban landscape planning and design is a complete process from the collection of relevant basic information required for preparation, to the preparation of specific design plans, to the implementation of the design and the feedback to the planning content during the implementation process. Where the process of preparing urban planning is the core of planning and design work of urban landscape is the process of transforming planning goals and planning indicators into tangible spaces [24]. Security and reliability are the biggest characteristics of the system, which are mainly reflected in the functions of user name and password verification, user authority setting, adding and deleting user information, so as to effectively ensure the integrity and security of the system data, and provide information on the planning scheme [25]. The adjustment and replacement function of the landscape models select the building in the planning interface and select the house automatic generation function. In the 3D scene, a series of models will be automatically generated according to the landscape attributes of the selected area in the urban landscape design (Figure 12). This not only provides a simple and fast model generation method, but also can also be compared with the model manually designed by other designers [26]. The planner can adjust the size, orientation, coordinates and other attributes of the selected model, and can also replace the selected model. This provides planners with a platform for vertical and horizontal comparison, so that they can choose their ideal plan.

FIGURE 12. Planning model replacement in 3D virtualized urban landscape design based on VR technology.

FIGURE 13. Human-computer interaction design of 3D visualized urban landscape planning and design based on VR technology [27].

In the software system, the VR technology is mainly divided into the establishment of geometric models, the construction of 3D scenes, and the realization of the basis of user experience; the construction of physical models, the determination of the structural materials of the geometric models, the adjustment of color, lighting and other influencing factors, the establishment of behavior models to describe objects movement and behavior [28]. When making a virtual design, the designer must first digitally process the map of the city, create a basic model, and then combine the location of each landscape in reality to make a 3D arrangement for better, which displays the aesthetic characteristics of the city and brings more accurate and intuitive technical support to the overall design (Figure 13). In terms of real-time driving of the scene, the use of certain technical means for effect

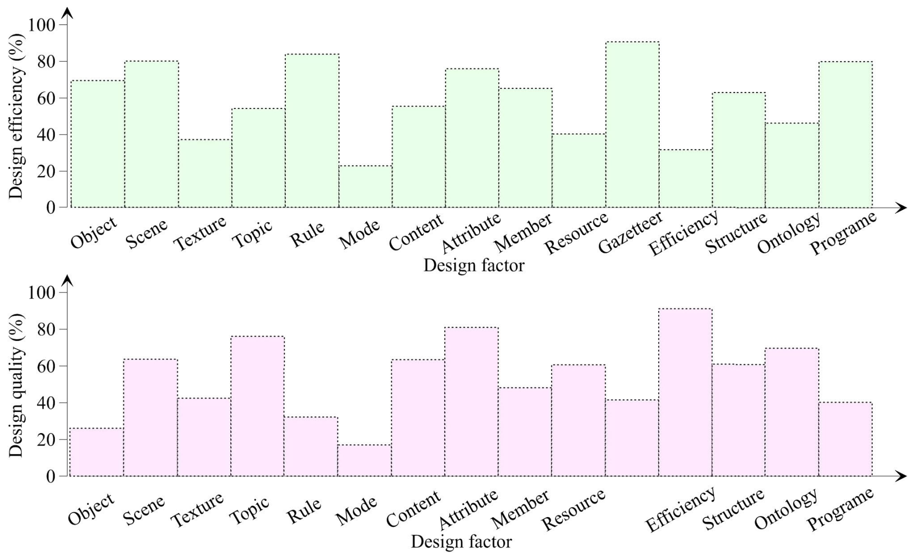

FIGURE 14. Design efficiency and quality of design factors in the 3D visualized urban landscape design platform.

rendering can enhance the realism of the picture, and it is convenient for designers to observe the effect of the urban landscape from various angles and directions, and adjust the design deficiencies in time [29]. In terms of interaction, some VR technologies can be used to improve and control the garden's animals and plants, halo effects, background music and other sensual and color elements, and present a variety of special effects and animation performances, so as to realize the designer's zero distance to the landscape design plan, so as to modify the design plan timely and accurately during the viewing and browsing process, and optimize the landscape design [30].

In order to realize virtual reality in a more economical way, an image-based virtual reality technology was developed. Through research, it is found that in most cases, people often stop motionless when observing things carefully, and look around, rotate, or observe around the object. For specific landscapes and urban spaces, the way of looking around is frequent. When observing the surrounding scene by rotating in the non-traveling state, the relative position of the stationary objects in the scene relative to the observation point is unchanged, and the perspective relationship between the objects in the visually generated picture is also unchanged. In this way, the visual image generated by the observation point can be used in the computer to generate the scene, instead of the full three-dimensional concrete model (Figure 14). Since the surround view images are still connected on the basis of two-dimensional images, they are much simpler in data structure than true three-dimensional graphics and images. Therefore, ordinary computers can realize the roaming of the virtual scene and the image content is very delicate. Utilizing the computer's ability to quickly process images, one or more inner and outer surround views can be combined to provide switching functions between various viewing angles to achieve a roaming effect to a certain extent.

The theme conception of urban landscape design is rich in content and diverse in forms, showing the relationship and integration of cultural history, resource conditions, space environment, seasons and time, and social factors. The most important means of urban landscape design is the landscape expression technique, which fully expresses the multidimensional space of the landscape through the performance of virtual environment, virtual graphics and real-time images [31]. In the design process, the designer usually proposes several design schemes, and conceives the performance of the urban landscape in various ways. Through VR technology, several different types can be treated in real time at the same angle and at the same time as needed and switch between the design schemes and feel different images. Therefore, it often appears that some designers' modifications in the later conception and creation will affect the foundation of the early stage. According to the traditional method, the overall conception must be modified [32]. After the modification, new problems will be discovered and appear in the creative process and then went to solve new problems, so repeated, greatly increased the workload. With the realization of VR technology, technical evaluation can be carried out in the later design, so as to show the relationship between the system and the details in the process of communication and exchange, and achieve synchronous modification.

VI. CONCLUSION

This article established 3D database and virtual scene model of urban landscapes, performed 3D visualized urban landscape modeling, realized 3D presentation of virtual scene landscape, discussed the integration and optimization of landscape design schemes, analyzed the 3D modeling and interactive adjustment of the landscape planning and design schemes, and finally conducted simulation experiment and its result analysis. The realization of the 3D virtual scene model is mainly to improve the fidelity and fluency of the virtual scene; in order to ensure this effect, the degree of conformity between the virtual environment and the real environment must be improved. The key is to meet the visualized needs of users, which is guaranteed by improving the realism and fluency of the virtual picture in the visualized scene generation of the system. The planning and design results are made into a VR system, which breaks through the limitations of traditional renderings, can fully display the effects of the planning plan after completion, and communicate with decision makers and visitors intuitively in the form of roaming on any path. When making a virtual design, the designer must first digitally process the map of the city, create a basic model, and then combine the location of each landscape in reality to make a 3D arrangement to display the aesthetic characteristics of the city and brings more accurate and intuitive technical support to the overall design. In short, the VR technology provides design staff with realistic information processing effects through intelligent drawing, which greatly improves design efficiency and promotes the effective improvement of design quality. The 3D visualized technology can transmit a large amount of information through graphics in a short time so that professionals can intuitively and quickly observe the test results or interactively process the results.

REFERENCES

[1] X. Ma, P. Guo, J. Zhu, and J. Zhao, "An optimization method for urban landscape design and artistic value analysis by using VR technology," *Tech. Bull.*, vol. 55, no. 11, pp. 533–539, Nov. 2017.

[2] Z. Lei, S. Shimizu, N. Ota, Y. Ito, and Y. Zhang, "Construction of urban design support system using cloud computing type virtual reality and case study," *Int. Rev. Spatial Planning Sustain. Develop.*, vol. 5, no. 1, pp. 15–28, 2017.

[3] L. Sun, T. Fukuda, and B. Resch, "A synchronous distributed cloud-based virtual reality meeting system for architectural and urban design," *Frontiers Architectural Res.*, vol. 3, no. 4, pp. 348–357, Dec. 2014.

[4] M. E. Portman, A. Natapov, and D. Fisher-Gewirtzman, "To go where no man has gone before: Virtual reality in architecture, landscape architecture and environmental planning," *Comput., Environ. Urban Syst.*, vol. 54, pp. 376–384, Nov. 2015.

[5] J. Diao, C. Xu, A. Jia, and Y. Liu, "Virtual reality and simulation technology application in 3D urban landscape environment design," *Tech. Bull.*, vol. 25, no. 4, pp. 72–79, Jul. 2017.

[6] J. Novotny, W. R. Miller, F. I. Luks, D. Merck, S. Collins, and D. H. Laidlaw, "Towards placental surface vasculature exploration in virtual reality," *IEEE Comput. Graph. Appl.*, vol. 40, no. 1, pp. 28–39, Jan. 2020.

[7] Y. Nugraha Bahar, J. Landrieu, C. Pére, and C. Nicolle, "CAD data workflow toward the thermal simulation and visualization in virtual reality," *Int. J. Interact. Des. Manuf.*, vol. 8, no. 4, pp. 283–292, Nov. 2014.

[8] T. Miyao, K. Funatsu, and J. Bajorath, "Three-dimensional activity landscape models of different design and their application to compound mapping and potency prediction," *J. Chem. Inf. Model.*, vol. 59, no. 3, pp. 993–1004, Nov. 2018.

[9] L. Chen and H. Wang, "Research on dynamic simulation of landscape design based on Quest3D technology," *Revista De La Facultad De Ingenieria*, vol. 32, no. 5, pp. 677–685, Jan. 2017.

[10] L. Hou and J. Li, "Landscape design system based on virtual reality," *Metall. Mining Ind.*, vol. 7, no. 6, pp. 504–512, Jan. 2015.

[11] Z. Zhou, "Construction simulation analysis of landscape design based on virtual reality technology," *Revista de la Facultad de Ingenieria*, vol. 32, no. 14, pp. 526–531, Jan. 2017.

[12] H. Chen, "Research of virtools virtual reality technology to landscape designing," *Open Construct. Building Technol. J.*, vol. 9, no. 1, pp. 164–169, Aug. 2015.

[13] E. Kim and S. Park, "Three-dimensional visualized space and asset management system for large-scale airports: The case of Incheon International Airport," *Int. J. Architectural Comput.*, vol. 14, no. 3, pp. 233–246, Sep. 2016.

[14] M. Hernández-de-Menéndez, A. Vallejo Guevara, and R. Morales-Menendez, "Virtual reality laboratories: A review of experiences," *Int. J. Interact. Design Manuf.*, vol. 13, no. 3, pp. 947–966, Feb. 2019.

[15] C.-L. Wu and Y.-C. Chiang, "A geodesign framework procedure for developing flood resilient city," *Habitat Int.*, vol. 75, pp. 78–89, May 2018.

[16] K. Puren, V. Roos, and H. Coetzee, "Sense of place: Using people's experiences in relation to a rural landscape to inform spatial planning guidelines," *Int. Planning Stud.*, vol. 23, no. 1, pp. 16–36, Jun. 2017.

[17] M. K. Ak and S. Ozdede, "Urban landscape design and planning related to wind effects," *Oxidation Commun.*, vol. 39, no. 1, pp. 699–710, Jan. 2016.

[18] S. Toy and N. Demircan, "Possible ways of mitigating the effects of climate change using efficient urban planning and landscape design principles in turkey," *Fresenius Environ. Bull.*, vol. 28, no. 2, pp. 710–717, Feb. 2019.

[19] I. D. Bishop, "Location based information to support understanding of landscape futures," *Landscape Urban Planning*, vol. 142, pp. 120–131, Oct. 2015.

[20] H. Moyes and S. Montgomery, "Mapping ritual landscapes using Lidar: Cave detection through local relief modeling," *Adv. Archaeological Pract.*, vol. 4, no. 3, pp. 249–267, Aug. 2016.

[21] E. Beyne, "The 3-D interconnect technology landscape," *IEEE Des. Test. Comput.*, vol. 33, no. 3, pp. 8–20, Jun. 2016.

[22] A. H. Mahmoud and R. H. Omar, "Planting design for urban parks: Space syntax as a landscape design assessment tool," *Frontiers Architectural Res.*, vol. 4, no. 1, pp. 35–45, Mar. 2015.

[23] C. Yufu, "Application and value analysis optimization of multimedia virtual reality technology in urban gardens landscape design," *Tech. Bull.*, vol. 55, no. 13, pp. 219–226, Jan. 2017.

[24] Y. Liu and X. Pan, "Ecotope-based urban post-industrial landscape design," *IERI Procedia*, vol. 9, pp. 185–189, Dec. 2014.

[25] W. Aiqing, W. Xitong, and H. Fengwu, "Research on the digital multimedia technology and urban landscape design based on multimedia art perspective," *Int. J. Multimedia Ubiquitous Eng.*, vol. 11, no. 10, pp. 371–380, Oct. 2016.

[26] N. Fujisawa, T. Miyazaki, and K. Nakazawa, "A study on the application to examination of sunshine simulation technique and urban landscape design using BIM and GIS," *AIJ J. Technol. Des.*, vol. 21, no. 47, pp. 355–360, Feb. 2015.

[27] M. X. Peng, L. Y. Tang, and D. Y. Yu, "Recommendation and 3D simulation of urban green space landscape scheme," *J. Fuzhou Univ. (Natural Sci. Ed.)*, vol. 47, no. 5, pp. 617–623, Oct. 2019.

[28] T. Hammadi, "The role of urban landscape design in enhancing people's outdoor places and spaces," *Int. J. Adv. Res.*, vol. 5, no. 9, pp. 1084–1099, Sep. 2017.

[29] R. Cooke, "Urban and landscape design in the arabian gulf region: A new paradigm for sustainability," *Proc. Inst. Civil Eng., Civil Eng.*, vol. 171, no. 6, pp. 57–64, Nov. 2018.

[30] Z. Shen, Y. Ma, K. Sugihara, Z. Lei, and E. Shi, "Technical possibilities of cloud-based virtual reality implementing software as a service for online collaboration in urban planning," *Int. J. Commun., Netw. Syst. Sci.*, vol. 07, no. 11, pp. 463–473, 2014.

[31] L. Jiang, M. Masullo, L. Maffei, F. Meng, and M. Vorländer, "A demonstrator tool of Web-based virtual reality for participatory evaluation of urban sound environment," *Landscape Urban Planning*, vol. 170, pp. 276–282, Feb. 2018.

[32] D. Men, D. Liu, and Y. Li, "Visualized optical sensors based on two/three-dimensional photonic crystals for biochemicals," *Sci. Bull.*, vol. 61, no. 17, pp. 1358–1371, Sep. 2016.

XING LIU was born in Wuhan, Hubei, China, in 1984. She received the bachelor's and master's degrees from the Hubei University of Technology, in 2007 and 2010, respectively. She currently works with the Wuchang University of Technology. She has published two core articles and presided over five provincial-level projects. Her research interest includes environmental design.