www.cad-journal.net
Computer-Aided Design AND APPLICATIONS

3D Landscape Entity Modeling Based on Geometric Elements and Computer Aided Design

Pingping Liu[1], Yu Xu[2] and Lu Jiang[3]

[1]Department of Sports, Shaanxi Fashion Engineering University, Xi'an, Shaanxi 712046, China, liu_ping2023@163.com
[2]Department of Sports, Shaanxi Fashion Engineering University, Xi'an, Shaanxi 712046, China, xy168510544@163.com
[3]Jiangxi Science and Technology Normal University, NanChang, JiangXI 330038, China, 1020110905@jxstnu.edu.cn

Corresponding author: Lu Jiang, 1020110905@jxstnu.edu.cn

Abstract. Traditional landscape design methods are often limited to 2D plane drawings due to technical limitations, and it is difficult to truly and accurately show designers' ideas and expected effects. Computer-aided design (CAD) technology can generate 3D models quickly and accurately by using the powerful computing and processing capabilities of computers, so that designers can view and design landscape space more intuitively. The research goal is to explore a method combining geometric elements, CAD and machine learning (ML) to improve the efficiency of 3D landscape entity modeling. In this article, an optimization algorithm of 3D landscape entity modeling based on ML is proposed. By intelligently adjusting parameters, the algorithm significantly improves the efficiency of the modeling process and ensures the accuracy of the modeling. The results show that the algorithm is excellent in image feature detection and has high accuracy. In addition, the algorithm can also provide suggestions for optimizing the model according to the learning and analysis of the historical model, so that the final landscape model can meet the design requirements more.

Keywords: Geometric Elements; Computer Aided Design; Landscape Design; 3D Modeling
DOI: https://doi.org/10.14733/cadaps.2024.S14.1-16

1 INTRODUCTION

The continuous progress of sci & tech and the maturity of computer technology are profoundly changing the way of design and modeling. Traditional landscape design methods are often limited to 2D plane drawings due to technical limitations, and it is difficult to truly and accurately show the designer's ideas and expected effects. Shape programmable 3D Kirigami metamaterials are a new type of intelligent material that has the ability to undergo shape changes under specific environmental stimuli. This material combines Kirigami art and 3D printing technology, allowing it to undergo shape changes under external stimuli by embedding stretchable connection structures in the material. The programmable nature of this shape makes this material widely applicable in many fields, such as flexible electronic devices, biomedical devices, and robotics technology. Machine learning plays an important role in the design of shape programmable 3D Kirigami metamaterials. Firstly, machine learning can be used to establish precise physical models to describe the relationship between material shape changes and external stimuli. By training the model, the response behavior of the material and the factors that affect this behavior can be obtained. Secondly, machine learning can be used to optimize design to achieve optimal material performance. By simulating and evaluating a large number of design schemes, the optimal design scheme can be found to achieve the best shape change effect. In addition, machine learning can also be used to predict the performance of new materials to accelerate the research and development process. By training models, it is possible to predict the performance of new materials in various environments, thereby accelerating the development speed of materials [1].

Geometric modeling elements are the cornerstone of landscape design. By skillfully combining and transforming the basic geometric elements such as points, lines, surfaces and bodies, we can build a rich and diverse landscape space. With the development of technology, computer-aided design (CAD) has been widely applied in many fields, but there are still some challenges in the application of CAD in prosthetic socket design. The most important issue is how to consider real-time soft tissue deformation in the design. In addition, reverse engineering technology has also provided new possibilities for the design of prosthetic socket. Ballit et al. [2] explored how to parameterize the design of prosthetic sockets using computer-aided design based on real-time soft tissue deformation and reverse methods, and discussed the role of visual feedback in this process. Real time soft tissue deformation is a key issue that needs to be addressed in the design of prosthetic socket. Soft tissue deformation can affect the adaptability and stability of prosthetic sockets. By utilizing computer-aided design and finite element analysis, we can simulate and predict the behavior of soft tissue in the design of prosthetic sockets. Through this approach, we can optimize the design to meet the specific needs of patients. In landscape design, the application of geometric elements is not only reflected in shape shaping, but more importantly, it is to create a sense of space. For example, the reasonable use of lines can guide the line of sight and shape the depth of space; The combination of surfaces can create rich spatial levels and light and shadow effects.

Our world is undergoing a visual revolution from 2D planes to 3D solids. Among them, the reconstruction and visualization of 3D city models, as the core of this revolution, are gradually changing the way we understand, analyze, and make decisions. Buyukdemircioglu and Kocaman [3] explore the reconstruction and efficient visualization techniques of heterogeneous 3D city models, analyze their importance and application value. Utilize technologies such as deep learning and machine learning to learn the processed data and establish complex 3D models. For example, convolutional neural networks (CNN) have been widely used in image recognition and object detection, providing powerful tools for 3D model reconstruction. After model reconstruction, it needs to be optimized and updated to reflect changes in the urban environment. This requires regular data collection and the use of new algorithms and software to update the model. By adding interactive elements such as scaling, rotating, clicking, etc., users can more conveniently explore and understand 3D city models. Processing and displaying large-scale 3D urban data requires efficient computing and graphics processing techniques. For example, using distributed computing and GPU acceleration technology can effectively process large-scale data. The traditional landscape design method based on geometric elements is limited by the skill level and experience of designers, and it is often difficult to realize complex design ideas. In today's digital era, 3D solid modeling technology has become a key tool in many fields, such as scientific visualization, game development, industrial design, and architecture. Chatzivasileiadi et al. [4] explored the characteristics of 3D solid modeling software libraries for non-manifold modeling and computer-aided design and application. Non manifold modeling can better capture local details and features, which is crucial for accurate shape description and feature extraction. Non manifold modeling methods typically have faster computational speed than manifold modeling methods, which is particularly important when dealing with large-scale datasets. The 3D solid modeling software library for computer-aided design and application is a tool set for creating, modifying, and visualizing 3D solids. These software libraries typically provide a series of algorithms and tools to support complex 3D solid modeling tasks. However, the emergence of CAD has broken this limitation. CAD can quickly and accurately generate 3D models by using the powerful computing and processing capabilities of computers, so that designers can view and design landscape space more intuitively. Moreover, CAD can also realize parametric design, which makes design modification more convenient and greatly improves design efficiency.

Computer graphics has been widely applied in many fields, such as animation production, game development, virtual reality, and movie special effects. In this process, image modeling technology plays an important role. Image modeling technology is a method of describing and analyzing images through mathematical models, which can help us better understand and use images. Doungmala and Thai [5] explored the application of image modeling technology in the field of computer graphics. This technology describes and analyzes images by extracting their edges and contours. In computer graphics, contour-based modeling is widely used in fields such as animation production and game development. Through contour-based modeling, we can accurately describe the shape and structure of the image, thereby achieving precise operation of the image. This technology describes and analyzes images through deep learning algorithms. In computer graphics, deep learning-based modeling is widely used in fields such as image recognition and facial recognition. Through deep learning-based modeling, we can accurately describe the complex features of images, thereby achieving high-precision operations on images. The core element of landscape design is the shaping of landscape space. Therefore, it is of great significance to study the relationship between geometric modeling elements and them to create a better landscape space environment. With the continuous development of technology, computer-aided design (CAD) and intelligent technology have become important tools in landscape design. CAD technology can provide accurate 2D and 3D graphic designs, while intelligent technology can optimize and predict designs. Du [6] explored the application of CAD assisted intelligence technology in landscape design. Using CAD software, designers can establish accurate 3D models to better understand the spatial relationships and appearance of the design. This helps designers identify and solve problems in the early stages, improving design quality. Through the parameterization function of CAD software, designers can easily adjust and optimize design schemes. For example, designers can adjust the shape, size, and position of buildings by changing parameters to achieve the best design results. With the rapid development of technology, computer-aided design (CAD) has found widespread applications in many industries. Especially in the field of additional manufacturing, the importance of CAD is more prominent. Additional manufacturing, also known as 3D printing, is a process of manufacturing based on 3D models. Through this process, materials can be stacked layer by layer based on design degrees of freedom, thereby creating complex three-dimensional objects. Fuchs et al. [7] explore how to make necessary progress in additional manufacturing design using CAD. CAD software can also perform process planning and convert 3D models into formats suitable for 3D printing. During this process, designers can determine the optimal printing direction, support structure, and other parameters to improve printing quality and efficiency. Through the parameterized design function of CAD software, designers can adjust the design parameters of the model, such as wall thickness, filling density, etc., to optimize the structural performance of the product. CAD software can generate detailed product data, including geometric shapes, material properties, and manufacturing parameters, which can be used for monitoring and quality control of the production process.

Computer Aided Modeling Design (CAID) is a design method based on computer technology. It uses software such as CAD and CAE to achieve precise control of object shape, size, proportion, and other parameters, providing artists with a new creative approach. In sculpture art, CAID can help artists better grasp the spatial form, proportion, and details of sculpture during the creative process, improving the quality and expressiveness of sculpture works. Virtual reality technology can simulate real sculpture scenes, allowing artists to immerse themselves in the spatial effects of sculpture. Guo and Wang [8] use virtual reality technology to enable artists to promptly identify and correct spatial problems during the creative process, thereby improving the quality of their sculpture works.

Parametric design can quantify the shape, size, proportion, and other parameters of sculpture works, enabling artists to better control the spatial form of sculptures. At the same time, parametric design can also optimize the spatial effect of sculpture works by adjusting parameters, improving the expressive power of sculpture works. This not only makes the design faster and more accurate, but also can automatically optimize the design scheme in the design process, and improve the overall design quality and efficiency. This article will study the application of ML in data-driven landscape model generation, and discuss how to combine geometric elements with CAD to learn from a large amount of data and generate realistic landscape models. The algorithm improves the efficiency and accuracy of modeling process through the intelligent parameter adjustment of ML. In addition, the study will also discuss the application of ML in landscape model optimization, and put forward optimization suggestions with the help of learning and analyzing historical models, so that the final landscape model can better meet the design requirements. By combining geometric elements, CAD and ML technology, it is expected to bring more efficient and accurate innovative methods to the field of landscape design. Compared with traditional methods, this article has the following innovations:

(a) This article tries to apply ML technology to all aspects of landscape design, and puts forward a set of optimization methods of landscape design based on ML, which introduces new ideas and methods to the field of landscape design.

(b) By using a large quantity of historical landscape data, this study established a data-driven design model, which made the generation and optimization of new designs more evidence-based, and improved the accuracy and efficiency of design.

(c) The idea of multi-objective optimization is also introduced, and the multi-objective optimization of landscape model is realized by using ML technology, so that the final landscape model not only meets the design requirements, but also meets multiple design objectives.

Firstly, this article introduces the research background and purpose, and summarizes the related work. Then, the methods proposed in this article are expounded, including algorithm design based on ML, feature detection method and modeling optimization. Then, the efficiency of the algorithm are verified by experiments. Finally, the work of this article is summarized and the future research direction is pointed out.

2 THEORETICAL BASIS

The innovative practice of sustainable landscape education requires the use of new technologies and methods, and parametric assisted design is one of them. Through the training and application of parametric assisted design, students' design abilities and innovative thinking can be improved, while also improving the sustainability and efficiency of design. Hsu and Ou [9] use ecological simulation software to simulate the impact of different design schemes on the environment, thus evaluating and optimizing the environmental impact in the early stages of planning. By parameterized auxiliary design, energy consumption in different design schemes can be accurately calculated, providing a basis for energy-saving design. Parametric assisted design helps to accurately calculate water resource consumption in different design schemes, providing support for the rational utilization and management of water resources. Through parameterized design assistance, the impact of different design schemes on biodiversity can be simulated, thus protecting biodiversity as much as possible in the design. Through practical projects, students are encouraged to participate in practical sustainable landscape design, apply theoretical knowledge to practice, and enhance their practical abilities and innovative thinking. Strengthen the training and application of parameterized auxiliary design in sustainable landscape education, so that students can master this tool and apply it in design to improve the sustainability and efficiency of design. With the rapid development of digitization and automation technology, 3D modeling has been widely applied in many fields, especially in the design and manufacturing of mechanical parts. The 3D modeling method based on deep learning can learn and extract features from a large amount of data, thereby automatically completing model reconstruction. Lee et al. [10] explore a deep learning-based dataset and reconstruction method for 3D CAD models containing machining features of mechanical parts. Establishing a dataset of 3D CAD models containing machining features of mechanical parts is the foundation for deep learning. Firstly, it is necessary to collect a large amount of 3D CAD model data, which includes various types and sizes of mechanical parts, as well as their machining features. Then, preprocess these data, including data cleaning, annotation, and enhancement, to facilitate the training and application of deep learning algorithms. By using deep learning algorithms such as convolutional neural networks (CNN), machining features can be extracted from 3D CAD models, thereby improving the quality and accuracy of the model. By using deep learning algorithms such as generative adversarial networks (GAN), 3D CAD models can be automatically reconstructed based on the extracted features. This method can greatly shorten the reconstruction time of the model, while improving the accuracy and repeatability of the model.

In today's engineering design and scientific research, the demand for simulation and analysis of complex structures and systems is increasing. Among them, nonlinear variable geometry heterogeneous grid structure design is a widely used modeling method that can handle complex shape and material distribution problems. Letov and Zhao [11] introduced a geometric modeling framework for designing nonlinear variable geometry heterogeneous grid structures. The geometric modeling framework is a software system used to create and analyze nonlinear variable geometry heterogeneous grid structure designs. This framework is based on advanced computer graphics and computational geometry technology, providing an interactive environment that allows users to design and modify models in an intuitive manner. This framework integrates efficient computing algorithms and can quickly process large-scale data and complex simulations. In addition, it also supports parallel computing, making simulation and analysis of large-scale models more efficient. This framework has a user-friendly interface that allows users to easily create, modify, and visualize models. In addition, it also provides rich documentation and tutorials to help users quickly get started and learn how to use it. Bridges are an important component of the transportation network, and bridge piers are a key structural part of bridges. Their integrity is crucial for the safety and service life of bridges. However, due to various factors, bridge piers may experience cracks that affect their structural performance. Therefore, timely and accurate evaluation of cracks in bridge piers is very important. In recent years, the development of unmanned aerial vehicle (UAV) technology has provided a new approach for the detection and evaluation of bridge pier cracks. By combining 3D scene reconstruction and image processing techniques, Liu et al. [12] achieved efficient and accurate evaluation of bridge pier cracks. Unmanned aerial vehicles are high-altitude aircraft that can carry various sensors for aerial photography. By equipped with high-resolution cameras, unmanned aerial vehicles can obtain high-definition images of bridge piers. Then, using 3D scene reconstruction technology, we can recover the 3D model of the bridge pier from these images. Common 3D scene reconstruction methods include stereo vision, structured light, and so on. These methods obtain images from multiple perspectives and utilize computer vision technology to restore the three-dimensional geometric information of the scene.

In recent years, ML has made remarkable achievements in various fields, and its powerful learning and optimization ability has also been introduced into CAD 3D landscape entity modeling. Through the method of ML, we can learn and analyze a large quantity of landscape design data, extract useful design rules and strategies, and further optimize the design stage. Edge detection based methods utilize edge features for image matching, but edge detection algorithms are sensitive to noise and difficult to process complex ancient building images; The method based on region segmentation divides the image into several regions and matches them, but the accuracy and stability of the region segmentation algorithm need to be improved; The method based on texture analysis utilizes texture features for image matching, but the texture analysis algorithm has a significant impact on lighting changes and shadows. Firstly, a grid model is used to preprocess ancient building images to enhance the extraction effect of image features. The grid model divides the image into several small cells, and performs grayscale processing and smoothing on each cell to enhance the contrast and clarity of the image. Then, a multi density feature extraction method is used to extract features from the preprocessed image. The multi density feature extraction method extracts features of multiple densities based on the density distribution of image pixels, in order to better describe the features of the image. Finally, the extracted features are matched using matching algorithms to achieve feature matching of ancient architectural images.

With the continuous development of computer technology and artificial intelligence, human-computer interaction has become an indispensable part of people's daily lives. The traditional single input output mode human-machine interface can no longer meet people's needs, so multi-mode natural human-machine interface has emerged. Niu et al. [13] analyzed that new human-machine interfaces can better adapt to human natural interaction methods, improve interaction efficiency and user experience. Although significant progress has been made in multimodal natural human-machine interfaces, there are still some challenges and future development directions. Firstly, the reliability and stability of the multimodal natural human-machine interface still need to be improved. Secondly, how to better handle and understand users' intentions and emotional states is also an important task. In the future, multimodal natural human-machine interfaces will become more intelligent, personalized, and adaptive. By gaining a deeper understanding of user interaction methods and needs, a more efficient and convenient human-machine interaction system can be designed. Multi-mode natural human-machine interface is currently a research hotspot in the field of human-machine interaction. It has the advantages of improving interaction efficiency and user experience, and is widely used in various fields. However, there are still some challenges and future development directions. Accurate real number operations are an important tool for solid modeling, which can accurately describe many phenomena in the real world. Continuity is an important concept for describing changes in objects or phenomena, which can be used to create more realistic and accurate models. Sherman et al. [14] By using precise real number operations and continuity, we can better understand and simulate entities and their behavior in the real world. Meanwhile, by improving the robustness of the model, we can resist the interference of noise and outliers, thereby more accurately describing the essential behavior of the entity. By using continuous functions to describe the shape and appearance of objects, we can create more realistic and accurate models. For example, in computer graphics, continuous functions are used to describe the reflection and refraction of light on the surface of an object. When simulating the dynamic behavior of a system, continuity can help us more accurately describe the state changes of the system. For example, in ecosystem modeling, continuous functions are used to describe the growth and change of biological populations. Continuity can help us better understand and process signals such as sound and images when processing them.

Explore three-dimensional shapes through speech. This interactive approach provides users with new experiences and opens up applications in fields such as education, entertainment, design, and architecture. Vyas et al. [15] explored a preliminary case study on voice-based 3D shape exploration through scene modeling. Use existing speech recognition technology to convert users' speech into text. This step is the key to achieving voice-based interaction. Using 3D modeling tools, establish corresponding 3D shapes based on the text information input by the user. Integrate the established 3D shapes into specific scenes. This can include elements such as environment, lighting, texture, etc. to increase the realism of the visual effect. Through the feedback system, users can obtain more information about three-dimensional shapes during the exploration process. For example, they can view detailed descriptions of shapes or obtain more contextual information at specific points. In the field of plant landscape design, the application of CAD makes the design process more efficient and precise, while also providing the possibility for low-cost design. In plant landscape design, color effect is a crucial factor. Xu et al. [16] explored the color effects of low-cost plant landscape design in a CAD assisted collaborative design system. In plant landscape design, color can evoke people's psychological reactions, such as warmth and lightness. Reasonable use of color psychology effects can create a psychological atmosphere that meets people's needs. Color can affect the visual effect of a landscape, such as the sense of space and hierarchy. By combining different colors, a rich visual effect can be created, enhancing the artistic quality of the landscape. The color of plants not only beautifies the environment, but also has certain ecological benefits. Plants with certain colors can attract specific insects and promote ecological balance. By utilizing the powerful computing power of CAD, designers can quickly try various color schemes and find the best design solution. 3D Computer Aided Simulation (3D CFD) technology has become an important tool in the field of interior design. It can help designers design in virtual environments and predict and optimize the effectiveness of the design. This technology not only improves the efficiency and quality of design, but also reduces design costs, providing new possibilities for interior design teaching. Yang [17] explores how to optimize interior design teaching based on 3D computer-aided simulation technology. Through 3D CFD technology, students can create 3D models in a computer and view design effects in real-time. This allows students to have a more intuitive understanding of the design and examine the details from multiple perspectives. 3D CFD technology can simulate air flow, temperature distribution, lighting effects, etc., helping students predict the actual effects of design. This helps students identify problems and make improvements in the early stages of design. By analyzing practical interior design cases, students can better understand the application of 3D CFD technology in interior design. Teachers can guide students to analyze the strengths and weaknesses of case studies and discuss how to improve design solutions.

3 THE APPLICATION OF GEOMETRIC MODELING ELEMENTS IN LANDSCAPE SPACE DESIGN

(1) Machine learning (ML)

In landscape design, ML can be used to analyze and interpret a large quantity of historical landscape data and discover potential design rules and patterns. Through deep learning technology, the model can be trained to generate a realistic landscape entity model. These models can imitate and generate designs similar to the real landscape, which greatly improves the design efficiency.

(2) Geometric elements and computer aided design (CAD)

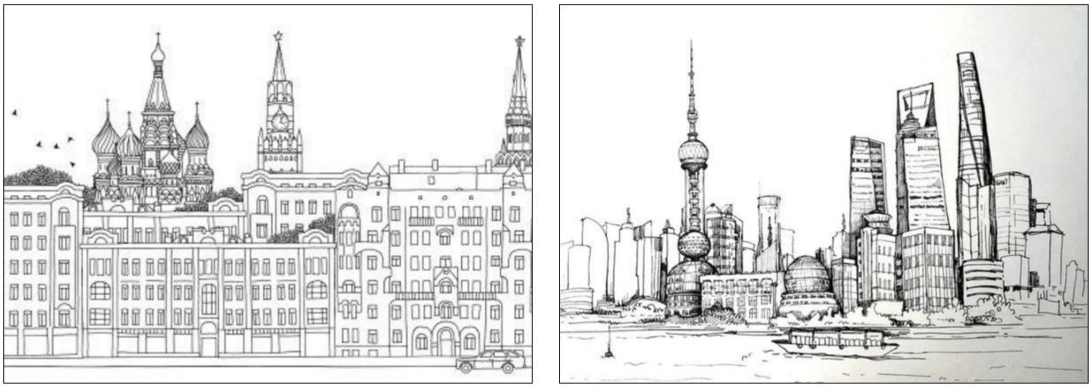
Geometric elements, such as points, lines, surfaces and bodies, are the basis of building 3D models. In landscape design, they can form landscape elements such as topography, architecture and vegetation. CAD is an important tool for landscape design. It helps designers to create, modify and optimize designs by using the powerful computing power and graphics processing power of computers. Combining geometric elements with CAD, we can create a fine and complex landscape entity model, making the design more realistic and accurate.

(3) Data-driven landscape design optimization method

Driven by big data, the data-driven design method gradually shows its advantages. In landscape design, a large quantity of historical landscape data can be used to establish a data-driven design model, which makes the generation and optimization of new designs more evidence-based. This method improves the accuracy and efficiency of design, but also reduces the subjectivity and uncertainty of design. Through the intelligent parameter adjustment of ML, the multi-objective optimization of landscape model can be realized to meet the multiple requirements of design.

Landscape space design is the core link of landscape design, which focuses on spatial layout, organization and shape shaping. As a concise and bright design language, geometric modeling elements play an important role in landscape space design. Geometric modeling elements include points, lines, surfaces, bodies and other basic elements, which have concise and lively morphological characteristics and can bring a sense of abstract beauty and order to landscape space. Using geometric lines to divide and organize space can create an orderly and dynamic layout. Geometrical surface elements are used to shape the terrain, creating a variety of terrain forms such as flatness, inclination and steps. This can not only enrich the layering of landscape space, but also provide different functions and experience.

The building facade is mainly composed of various lines, mainly horizontal lines and vertical lines. The horizontal line (Figure 1-a) is natural and relaxed, and its lines have the function of focusing, which can focus people's eyes on one point, thus highlighting a single entity. The vertical line (Figure 1-b) is tense and serious, which guides the line of sight in the same direction as the movement of people, making the line of sight very smooth. The vertical line divides the building into several units, and each unit has different characteristics, thus distracting people's eyes and appreciating them one by one. Their mutual combination and arrangement jointly affect the space of the landscape.



a b

Figure 1: Horizontal and vertical lines.

The application of geometric modeling elements can bring a simple and abstract aesthetic feature to landscape space. It can strengthen the sense of order and rhythm in the space and enhance the overall effect of the landscape. Moreover, the use of geometric modeling elements also needs to be moderate, too much use may make the landscape appear indifferent and artificial, and destroy the sense of harmony of nature. Through the reasonable application of geometric modeling elements, we can create rich and diverse, aesthetic and functional landscape spaces, and enhance people's viewing experience and use feeling. In actual design, designers should flexibly use geometric modeling elements according to project requirements and site conditions to create unique and wonderful landscape works.

Plane geometric elements play an important role in landscape design, especially in landscape ground pavement. These elements are presented in a planar form, and through ingenious combination and layout, rich and diverse landscape effects can be created. Their design often follows the principle of formal beauty in graphic design, paying attention to the harmony of style and color, and endowing the landscape space with unique visual charm and aesthetic feeling. In landscape pavement, the application of plane geometric elements can be expressed as pavement patterns with different shapes and sizes. For example, using geometric elements such as straight lines, curves, circles and squares, simple and atmospheric pavement lines can be designed, or complex and exquisite geometric patterns can be created. This design technique can not only enhance the visual effect of the ground, but also improve the overall quality of the space. In terms of style and color, they are usually consistent with buildings, vegetation, water bodies and other elements in the landscape, forming a unified and harmonious visual effect. Studying the application of plane geometric elements in landscape design can not only enrich the techniques and language of landscape design, but also enhance the visual effect and aesthetic feeling of landscape space.

Plane geometric elements are mostly manifested in the design of planar objects in the landscape. Common designs of this kind are mostly paved on the landscape floor. The geometric elements on the plane also conform to the law of formal beauty in graphic design, and their styles and colors are basically consistent with geometric modeling (Figure 2).

With the growth of technology, 3D landscape entity modeling has become an important part of landscape design. This section will discuss how to deeply apply ML technology to 3D landscape entity modeling, and combine geometric elements and CAD to propose a set of landscape design optimization methods based on ML to improve the efficiency and accuracy of the modeling process. In 3D landscape entity modeling, ML technology can be used to optimize the shape, structure and details of the model.

Figure 2: Geometric elements of a plane.

By learning a lot of landscape data through training models, a realistic 3D landscape model can be generated. This model not only has good visual effect, but also can truly reflect the characteristics of geographical environment and natural environment. In order to further improve the efficiency of 3D landscape entity modeling, geometric elements and CAD are combined. By using geometric elements, such as points, lines and surfaces, the basic structure and form of landscape can be defined. The extraction process of 3D landscape feature boundary line is shown in Figure 3.

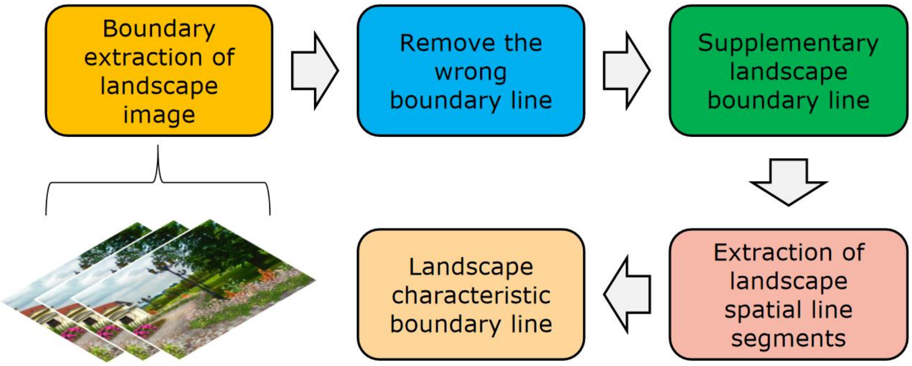


Figure 3: Feature boundary line extraction process.

First, we need to obtain 3D landscape data. These data can be obtained by laser scanning, tilt photogrammetry, satellite remote sensing, etc., and the existing 3D model database can also be used. Pre-processing the obtained data, including noise removal, smoothing and data standardization, to ensure the quality and consistency of the data. Divide 3D landscape data into different landscape areas or objects, such as buildings, trees, terrain and so on. For each landscape area or object, its 3D shape features are extracted. Moreover, we can also consider the characteristics of texture, color and semantics. Boundary detection: based on the extracted features, the boundary detection algorithm is used to identify the boundaries between different landscape areas. These algorithms usually determine the boundary by calculating the gradient and finding the local maximum in the gradient direction. From the detected boundaries, the characteristic boundary lines of the 3D landscape are extracted.

The template matching model of visual reconstruction of landscape space optimization design image is a model used to assist landscape space optimization design. Based on image processing and computer vision technology, it realizes the visual reconstruction of landscape design by template matching. The template matching model of visual reconstruction of landscape space optimization design image is shown in Figure 4.

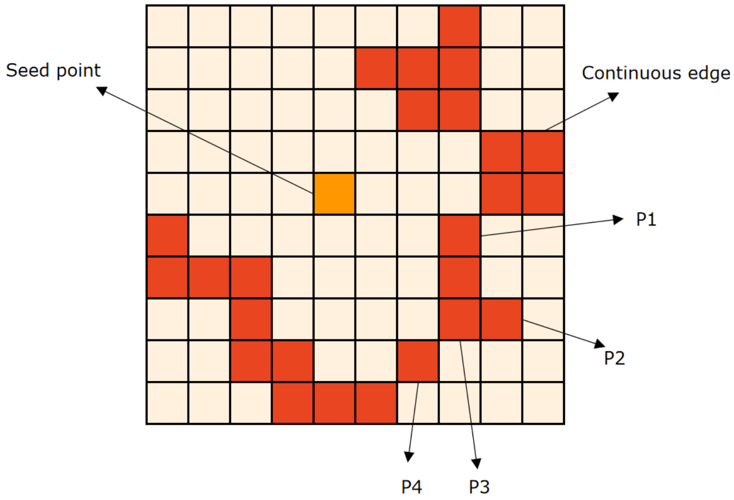


Figure 4: Template matching model for visual reconstruction of landscape space optimization design image.

First, build a template library containing various landscape elements and designs. These templates can be images based on real landscapes or idealized templates designed by designers manually. For the landscape space to be optimized, the key features are extracted by image processing technology. These features can include shape, color, texture, etc. for subsequent template matching. Based on the matched template, the landscape space to be optimized is reconstructed visually. This includes using the design and element information in the template to guide the optimization of landscape space, such as layout adjustment and element combination. Through image visual reconstruction, we can get an optimized design suggestion and show it to the designer in the form of graphics or images. Designers can adjust and modify according to the results of image visual reconstruction, and input the adjusted design into the model again for a new round of template matching and image visual reconstruction. The final optimized design can be output as images, 3D models or other visual forms. In addition, the model can also provide optimization suggestions, such as adjusting the position of elements, changing color matching, etc., to help designers achieve better landscape space optimization results.

The error function of 3D landscape feature detection is defined as:

$$\cos t\ \ u,v\ = \left\| u-v \right\| \times \max_{f\in T_u} \left\{ \min_{n\in T_{uv}} \ \ 1 - f\cdot normal \cdot n\cdot normal\ \ \div 2 \right\} \tag{1}$$

$\left\| u-v \right\|$ represents the distance between two u,v points, T_u represents all triangular surfaces adjacent to u point, and T_{uv} represents all triangular surfaces with uv as edges.

Let the plane P pass through the centroid $P^{'}$ of K nearest points, and the normal vector n satisfies $\left| n \right| = 1$. Therefore, the eigenvector corresponding to the smallest eigenvalue of M can be regarded as the normal vector of point P_i.

$$M=\sum_{i=1}^{K}\left(P_i-P'\right)\left(P_i-P'\right)^{T}/K \tag{2}$$

The angle between the normal N_{new} of the triangle and the normal N_{ini} in the original mesh is also smaller than the threshold ε:

$$\arccos\left(N_{new}\cdot N_{ini}\right)\leq\varepsilon \tag{3}$$

Suppose the original 3D model is $F(x,y,z)$, and the model after translation is $I(x,y,z)$:

$$\begin{aligned}I(x,y,z)&=F\left(x-m_p,y-m_p,z-m_p\right)\\&=F\left(\text{int}(c\times x),\text{int}(c\times y),\text{int}(c\times z)\right)\end{aligned} \tag{4}$$

$$c=1/k \tag{5}$$

In this study, the distribution of visual characteristics of the existing 3D landscape entity model is analyzed. This includes extracting visual features such as shape, structure, color and texture of the model, and counting the distribution of these features in the model. According to the distribution results of visual features, the geometric elements corresponding to these features are determined. Based on the extracted geometric elements, a set of modeling rules and parameter settings are established. These rules can be defined according to the statistical results of visual feature distribution, such as the connection mode between elements, the size and proportion of elements, etc. Parameter settings can include shape, color, texture, etc. to ensure that the final model is consistent with the visual characteristics of the original landscape entity. Using CAD, according to the modeling rules and parameter settings, the extracted geometric elements are combined and reconstructed to generate a new 3D landscape entity model.

The visual characteristics of 3D landscape entity modeling are as follows:

$$G(\vec{x})=\sum\nolimits_{j=1}^{p}G_j(\vec{x}) \tag{6}$$

The fuzzy closeness function of 3D landscape spatial image is:

$$fitness(\vec{x})=f(\vec{x})+(Ct)^{\alpha}\sum\nolimits_{j=1}^{p}G_j^{\beta}(\vec{x}) \tag{7}$$

Assuming that the P_N coordinate of the 3D landscape entity modeling is $\left(X_{P_N},Y_{P_N}\right)$, then compare the edge point coordinates $\left(x_k,y_k\right)$ and P_N of all 3D landscape entity modeling on L:

$$\begin{aligned}&When\ x_k>X_{P_N},i_L=i_L+1\\&When\ x_k<X_{P_N},i_L=i_L-1\\&When\ x_k=X_{P_N},i_L=i_L+0\end{aligned} \tag{8}$$

The fitness function of landscape information fusion is:

$$fitness(\vec{x})=\begin{cases}f(\vec{x}) & If\ feeasible\\1+rG(\vec{x}) & Otherwise\end{cases} \tag{9}$$

Constructing the visual resolution model of landscape space:

$$\begin{aligned}W_u(a,b)=e^{i2\pi k\ln a}\times\frac{K}{\sqrt{a}}&\left\{\left[\left[\frac{ae^{\frac{j2\pi f\min}{a}(b-b_a)}}{f_{\min}}-\frac{e^{\frac{j2\pi f\max}{a}(b-b_a)}}{f_{\max}}\right]\right.\right.\\&\left.\left.+j2\pi(b-b_a)\left[Ei\left(j2\pi f_{\max}(b-b_a)\right)-Ei\left(\frac{j2\pi f_{\min}}{a}(b-b_a)\right)\right]\right]\right\}\end{aligned} \tag{10}$$

Among them:

$$b_a = 1 - a\left(\frac{1}{af_{\max}} - \frac{T}{2}\right) \tag{11}$$

$Ei \cdot$ is the output of the visual information feature reorganization.

The core of this method is to correspond the distribution of visual features with geometric elements, and realize the reconstruction of the model through CAD. This method can make full use of the visual characteristics of 3D landscape entity modeling, and combine the simplicity of geometric elements and the flexibility of CAD to realize efficient and accurate 3D landscape entity modeling.

4 RESULT ANALYSIS AND DISCUSSION

3D landscape image data sets with different landscape characteristics, including urban buildings, natural scenery and other scenes, are selected to verify the adaptability of the algorithm. According to the requirements of this algorithm, different parameter configurations are set. The purpose of experimental design is to verify the modeling effect of this method in different scenarios, and compare with other methods to prove the advantages of this method. In order to verify the performance advantages of this algorithm, SVM algorithm in ML is selected as a comparative experiment and compared with this algorithm.

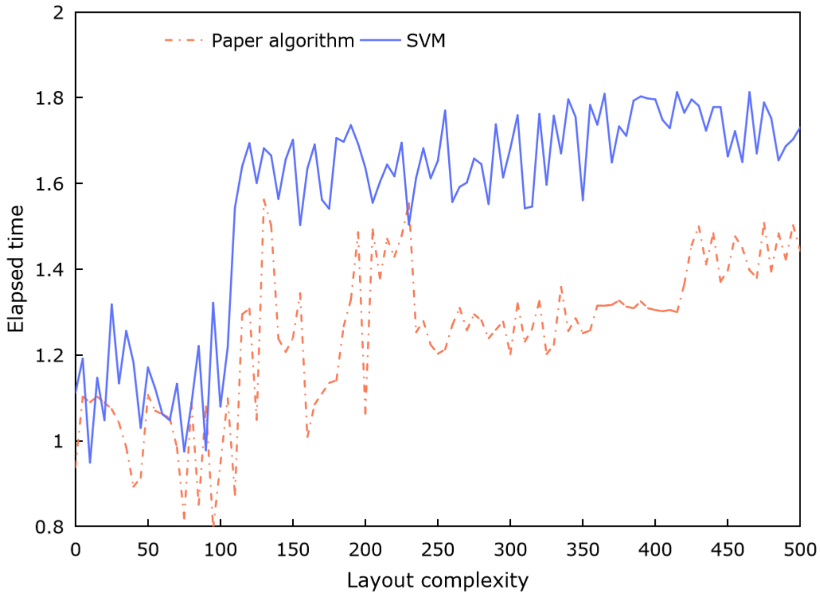
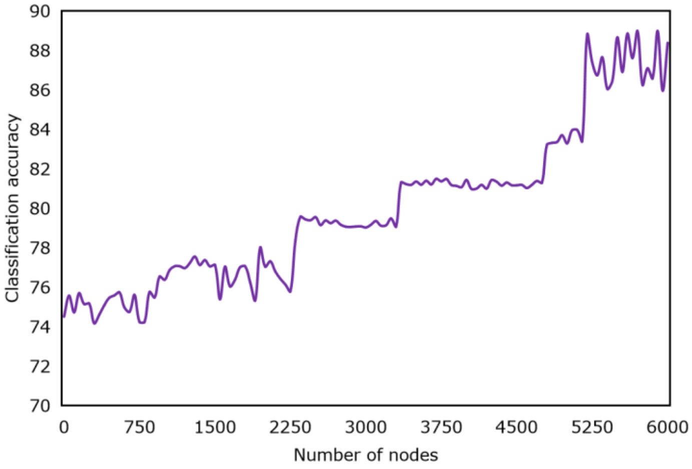


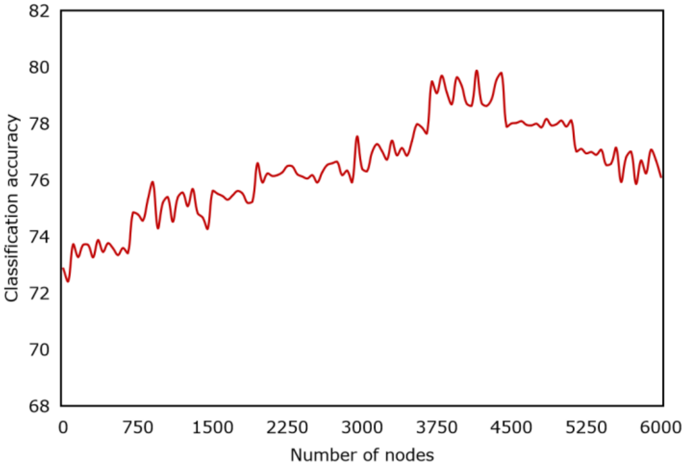
Figure 5: Calculation time comparison of algorithm.

Figure 5 illustrates the calculation time comparison of the algorithm. In the initial stage, the running time of this algorithm is almost the same as that of support vector machine (SVM), and may even be slightly inferior to SVM. With the complexity of landscape spatial optimization problems increasing, such as the increase of landscape elements and the complexity of design rules, the running time of SVM algorithm increases obviously. This may be because SVM needs more computing resources when dealing with high-dimensional and nonlinear problems. In contrast, the running time of this algorithm increases less when dealing with complex problems. The algorithm in this article adopts a more efficient calculation strategy, so that it can maintain a relatively stable running time when the complexity increases. This advantage may translate into faster design cycle and lower calculation cost in practical application.

Image feature detection is a key step in 3D landscape entity modeling, and its accuracy directly affects the subsequent design and optimization process. Higher accuracy means that the algorithm can identify and extract the key features in the landscape more accurately. Figure 6 shows the accuracy of different algorithms in image feature detection in 3D landscape entity modeling. Among them, Figure 6(a) represents the result of this algorithm, and Figure 6(b) represents the result of SVM algorithm.



(a) The algorithm in this article



(b) SVM algorithm

Figure 6: Accuracy of image feature detection.

The algorithm in this article shows high accuracy in image feature detection (Figure 6(a)). This is attributed to the specific feature detection method designed for landscape characteristics in the algorithm, which enables it to capture and represent the key features of the landscape more accurately. Relatively speaking, the feature detection accuracy of SVM algorithm in Figure 6 (b) is slightly lower than that of this algorithm. Although SVM is a powerful ML algorithm, it may not be as efficient and accurate as this algorithm when dealing with image feature detection of 3D landscape entity modeling.

Figure 7 shows the time required for 3D landscape modeling with different quantity of nodes for different numbers of 3D landscape images in the experiment.

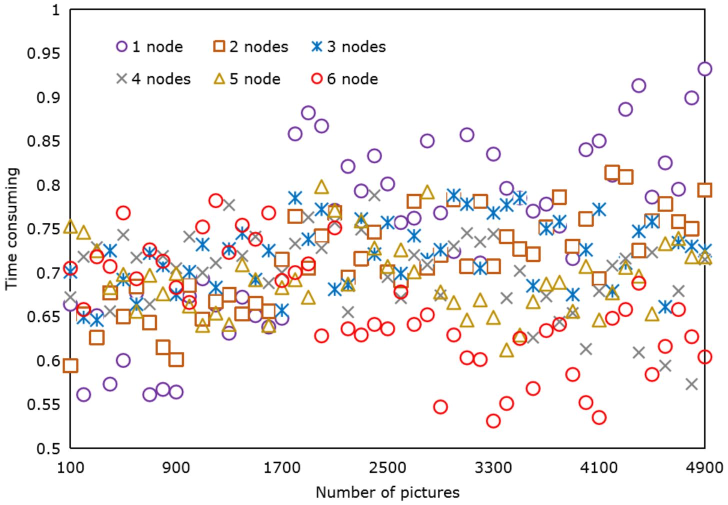


Figure 7: Image retrieval consumes time.

When the quantity of 3D landscape pictures is small, it is observed that with the increase of the quantity of nodes, the time required for modeling is also increasing. This is contrary to intuitive expectations. Analysis of the reasons, for a small quantity of pictures, because of its small amount of calculation, adding nodes means adding some extra expenses, such as communication between nodes, task allocation and so on. These extra expenses may exceed the benefits of parallel computing when the quantity of pictures is small, thus leading to an increase in time. With the increase of the quantity of 3D landscape pictures, we can see that when the quantity of pictures reaches a certain threshold, with the increase of the quantity of nodes, the time required for modeling begins to decrease. This is because for a large quantity of pictures, the calculation burden of a single node will be very heavy, while multiple nodes can process in parallel and share the calculation tasks. Although there is communication overhead between nodes, when the amount of calculation reaches a certain level, the benefits of parallel computing exceed the communication overhead, thus reducing the total time.

High-precision image feature detection can provide more accurate data input and make the generated landscape model more realistic. This is of great significance to landscape design, urban planning and other fields, and can provide more realistic visual effects and better design reference. By adjusting the quantity of nodes reasonably, the computing resources can be fully utilized and the modeling efficiency can be improved. This is very beneficial to deal with large-scale 3D landscape data, which can save time and calculation cost. The application of ML makes the modeling process more intelligent and automated. It can put forward optimization suggestions according to the study and analysis of historical models, so that the final landscape model can meet the design requirements better. 3D landscape entity modeling based on geometric elements and CAD combines the powerful optimization ability of ML, which provides a brand-new method for landscape design. This method overcomes the limitations of traditional design methods, and realizes automatic optimization in the design process, which greatly improves the design efficiency and accuracy. This new method will play an increasingly important role in future landscape design, helping to create richer and more exquisite landscape space.

5 CONCLUSION

The core element of landscape design is the shaping of landscape space. Therefore, it is of great significance to study the relationship between geometric modeling elements and them to create a better landscape space environment. By skillfully combining and transforming the basic geometric elements such as points, lines, surfaces and bodies, we can build a rich and diverse landscape space. In landscape design, the application of geometric elements is not only reflected in shape shaping, but more importantly, it is to create a sense of space. This article will study the application of ML in data-driven landscape model generation, and discuss how to combine geometric elements with CAD to learn from a large amount of data and generate realistic landscape models. The results show that this algorithm has high accuracy in image feature detection and can effectively capture and represent the key features of the landscape. In addition, by intelligently adjusting ML parameters, the modeling process and accuracy of the algorithm have been significantly improved, which further proves the effectiveness of ML in data-driven landscape model generation.

The intelligent parameter adjustment and optimization suggestions of ML further promote the automation and intelligent growth of 3D landscape entity modeling, and provide more powerful tools and support for landscape designers. In the future research, we can further explore how to improve the efficiency and accuracy of the algorithm when dealing with larger-scale data, and promote the continuous innovation of 3D landscape entity modeling technology.

Pingping Liu, https://orcid.org/0009-0006-8248-4361
Yu Xu, https://orcid.org/0009-0008-3215-6903
Lu Jiang, https://orcid.org/0009-0008-1819-310X

REFERENCES

[1] Alderete, N.-A.; Pathak, N.; Espinosa, H.-D.: Machine learning assisted design of shape-programmable 3D kirigami metamaterials, npj Computational Materials, 8(1), 2022, 191. https://doi.org/10.1038/s41524-022-00873-w
[2] Ballit, A.; Mougharbel, I.; Ghaziri, H.; Dao, T.-T.: Computer-aided parametric prosthetic socket design based on real-time soft tissue deformation and an inverse approach, The Visual Computer, 38(3), 2022, 919-937. https://doi.org/10.1007/s00371-021-02059-9
[3] Buyukdemircioglu, M.; Kocaman, S.: Reconstruction and efficient visualization of heterogeneous 3D city models, Remote Sensing, 12(13), 2020, 2128. https://doi.org/10.3390/rs12132128
[4] Chatzivasileiadi, A.; Wardhana, N.-M.; Jabi, W.; Aish, R.; Lannon, S.: Characteristics of 3D solid modeling software libraries for non-manifold modeling, Computer-Aided Design and Applications, 16(3), 2019, 496-518. http://dx.doi.org/10.14733/cadaps.2019.496-518
[5] Doungmala, P.; Thai, T.-H.: Investigation into the application of image modeling technology in the field of computer graphics, International Journal for Applied Information Management, 3(2), 2023, 82-90. https://doi.org/10.47738/ijaim.v3i2.53
[6] Du, J.: Application of CAD aided intelligent technology in landscape design, International Journal of Advanced Computer Science and Applications, 13(12), 2022, 1030-1037. https://doi.org/10.14569/IJACSA.2022.01312118
[7] Fuchs, D.; Bartz, R.; Kuschmitz, S.; Vietor, T.: Necessary advances in computer-aided design to leverage on additive manufacturing design freedom, International Journal on Interactive Design and Manufacturing (IJIDeM), 16(4), 2022, 1633-1651. https://doi.org/10.1109/ICNETIC59568.2023.00039
[8] Guo, S.; Wang, B.: Application of computer aided modeling design in the expression techniques of sculpture art space, Computer-Aided Design and Applications, 19(S3), 2021, 1-12. https://doi.org/10.14733/cadaps.2022.S3.1-12

[9] Hsu, C.-Y.; Ou, S.-J.: Innovative practice of sustainable landscape architecture education—Parametric-aided design and application, Sustainability, 14(8), 2022, 4627. https://doi.org/10.3390/su14084627
[10] Lee, H.; Lee, J.; Kim, H.; Mun, D.: Dataset and method for deep learning-based reconstruction of 3D CAD models containing machining features for mechanical parts, Journal of Computational Design and Engineering, 9(1), 2022, 114-127. https://doi.org/10.1093/jcde/qwab072
[11] Letov, N.; Zhao, Y.-F.: A geometric modelling framework to support the design of heterogeneous lattice structures with non-linearly varying geometry, Journal of Computational Design and Engineering, 9(5), 2022, 1565-1584. https://doi.org/10.1093/jcde/qwac076
[12] Liu, Y.-F.; Nie, X.; Fan, J.-S.; Liu, X.-G.: Image-based crack assessment of bridge piers using unmanned aerial vehicles and three-dimensional scene reconstruction, Computer-Aided Civil and Infrastructure Engineering, 35(5), 2020, 511-529. https://doi.org/10.1111/mice.12501
[13] Niu, H.; Van Leeuwen, C.; Hao, J.; Wang, G.; Lachmann, T.: Multimodal natural human–computer interfaces for computer-aided design: a review paper, Applied Sciences, 12(13), 2022, 6510. https://doi.org/10.3390/app12136510
[14] Sherman, B.; Michel, J.; Carbin, M.: Sound and robust solid modeling via exact real arithmetic and continuity, Proceedings of the ACM on Programming Languages, 3(ICFP), 2019, 1-29. https://doi.org/10.1145/3341703
[15] Vyas, S.; Chen, T.-J.; Mohanty, R.-R.; Krishnamurthy, V.-R.: Making-a-scene: a preliminary case study on speech-based 3D shape exploration through scene modeling, Journal of Computing and Information Science in Engineering, 22(6), 2022, 064501. https://doi.org/10.1115/1.4055239
[16] Xu, F.; Wang, Y.: Color Effect of low-cost plant landscape design under computer-aided collaborative design system, Computer-Aided Design and Applications, 19(S3), 2021, 23-32. https://doi.org/10.14733/cadaps.2022.S3.23-32
[17] Yang, J.: Teaching optimization of interior design based on three-dimensional computer-aided simulation, Computer-Aided Design and Applications, 18(S4), 2021, 72-83. https://doi.org/10.14733/cadaps.2021.S4.72-83