Design of Outdoor Space Environment of Residential Area Based on B-Rep to CSG Conversion Algorithm Model

Licui Zhang[1]

[1]School of Architecture and Artistic Design, Hebei Academy of Fine Arts, Shijiazhuang, Hebei 050700, China, zlc@hbafa.edu.cn

Corresponding author: Licui Zhang, zlc@hbafa.edu.cn

Abstract. The construction of 3D software models can improve the clarity of data processing results. By presenting a more intuitive appearance. This article simulates, measures and analyzes the living space environment of outdoor residents based on this software. Basic data scanning and recording were conducted. and chooses the CAD software based on BRep→CSG conversion algorithm model to realize the construction of the solid model. According to the experimental results, the 3D model stitching characteristics can be obtained by selecting 8 feature points for matching in four random matches. In addition, compared with the conventional CAD software, the CAD software based on BRep→CSG conversion algorithm model can effectively improve the model conversion efficiency and shorten the conversion time, the decomposition results are more consistent with the model characteristics, and the final presented 3D model is more consistent with the actual environment.

Keywords: 3D CDA; Residential Area; Outdoor Space; Environmental Design
DOI: https://doi.org/10.14733/cadaps.2023.S11.83-92

1 INTRODUCTION

As people's demand and requirements for housing increase, the environment in residential areas has become people's quality of living and happiness. In the past, designers used to show and express their environmental design concepts and ideas through pen and paper, but their audiences were unable to understand the design ideas in such a monolithic form. More and more knowledge-based tools are being used in computer-aided engineering environments. Brockmanöller et al. [1] described a computer-aided engineering environment (CAE). This is a tool and software system used for designing, analyzing, simulating, and optimizing engineering systems. The computer-aided engineering environment of engineering design, manufacturing, and testing, and reduce human errors. And it can provide detailed information about the design scheme, thereby improving the quality and reliability of the design. Chen et al. [2] believe that computer-aided engineering software can help designers better understand the requirements of product design, improve the quality and efficiency of design. This system can shorten the product development time by shortening the design and analysis cycle. In the product design process, virtual prototyping can be used to predict the reliability of a product throughout its entire lifecycle, thereby helping designers better carry out product design and optimization. Da et al. [3] simulated various experimental schemes and used this system to identify potential problems in advance in engineering. Before product manufacturing or engineering construction, computer-aided engineering software helps designers identify potential problems, thereby improving product quality and reliability. In order to better carry out product design and optimization. Deng et al [4] studied the digital city landscape planning design under the spatial information technology. It expounds the theoretical knowledge of in-depth study of spatial information technology and digital city landscape planning design. Collecting urban vegetation data maps through remote sensing images, and finally analyzing the planning and design of digital urban landscapes. In addition, CAD software can realize the digital transformation of design, help designers to complete the large and inefficient tasks, improve the accuracy of data calculation, significantly shorten the working time, and enrich the way of environmental design presentation, shorten the gap between the design effect and the actual environment, so CAD is widely used in the design field [5]. The system also facilitates communication between landscape designers. A design solution can reach another requester in just a few minutes or even seconds. The application of computer technology makes the transmission of design solutions more convenient and efficient, and designers can directly communicate and communicate through video on the computer without having to meet. Greatly saving valuable time for landscape designers [6]. However, at present, the application of CAD software in the field of environmental design of residential outdoor spaces mainly tends to the use of a single function, and in the face of different planning and design needs it is impossible to effectively select the appropriate function or to choose the appropriate technology for combined application, and there is a lack of development and research on the in-depth application of its technology and functions in environmental design [7].

2 DEVELOPMENT AND STATUS OF CAD SOFTWARE APPLICATION IN DESIGN

The development of CAD software in the field of design software system technology. At the beginning of the system development, it was mainly a simple wireframe system. In terms of expression, it could only complete the basic geometric modeling expression. Due to the lack of solid surface information, some functions could not be realized. To address the issue of significant differences in multidimensional urban landscape design. Liu et al. [8] proposed a nonlinear theory to improve the accuracy and reliability of landscape design. The use of computer technology and digital technology can help designers better understand the spatial structure and form of cities, thereby enabling better landscape design and optimization. Computer technology can help designers more accurately measure and analyze data on landscape elements, thereby better meeting the requirements of architectural design. Xu and Wang [9] found that nonlinear theory can reduce design errors and waste. Computer technology can help designers design and analyze faster, thereby reducing design errors and waste. By improving design efficiency and quality, and reducing the time and effort invested by designers. Yoffe et al. [10] discussed how to improve the innovation and flexibility of urban landscape design. The results indicate that computer technology can help designers better design and optimize, thereby improving design innovation and flexibility. Designers can use computer technology to innovate and optimize design solutions, thereby better meeting different design needs and scenarios. Yu et al. [11] reducing design errors and waste, improving design efficiency and quality, and enhancing design innovation and flexibility. Zhang and Deng [12] established the use of computer technology to better design and optimize to meet different design needs and scenarios, thereby better meeting the needs and aesthetics of modern people. The development of CAD software systems can be seen from the fact that they have been dedicated to the development from two-dimensional design to three-dimensional model construction, which is an important research direction in the field of design.

With the maturity of 3D CAD software systems, they are widely used in manufacturing, construction, medical fields, and environmental fields. The 3D CAD software can realize the construction of solid models of mechanical parts by surface modeling, wireframe modeling and solid modeling, and the decomposition of the base structure and the change of parameters of the part design by the software [13]. Zhao [14] utilizes immersive technologies virtual reality, and virtual landscape research parameter-driven integrated construction. In addition, some researchers have considered the complexity of outdoor environmental conditions and combined 3D laser scanning technology to obtain the basic data of the relevant buildings through a reasonable and effective arrangement of point clouds and to realize the construction of 3D models in CAD software through the conversion of data formats.

3 ANALYSIS AND METHOD OF DESIGNING OUTDOOR SPACE OF RESIDENTIAL AREA BASED ON 3D CAD SOFTWARE

3.1 Outdoor Spatial Analysis of Residential Area

In the past, the environmental ignored the analysis of the living population, which made the planning rationality of different areas in the environmental design relatively low and did not meet the needs of the actual living population. Therefore, this paper analyzes the demand for space relative to the living population before the design of outdoor space in residential areas. Figure 1 shows the analysis of the composition of the population in a residential area. The data in the figure shows that the residential area can be divided into the elderly, middle-aged people, young people and children by age criteria, and the latter three account for a relatively high proportion. At the same time, the population structure of this residential area has the highest number of family households, followed by young tenants, and there are more people who live in long term rent.

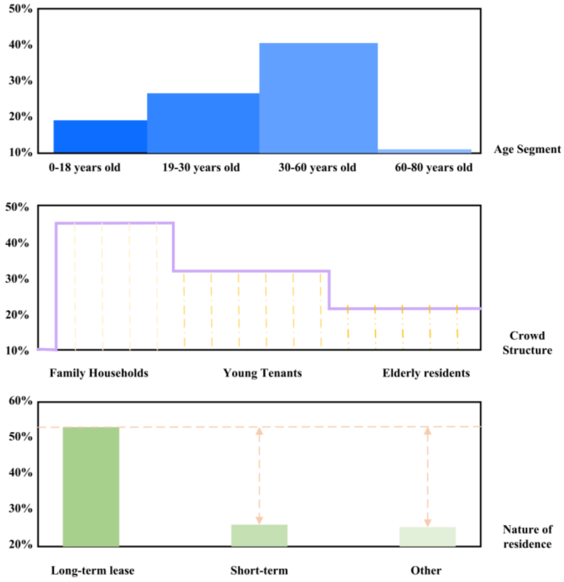

Figure 1: Results of the analysis of the composition of the residential population in a residential area.

Figure 2 shows the activity analysis of the residential population in the residential area. From the results of Figure 2, it can be seen that the outdoor activities of the residential population can be divided into three types of activities: necessary activities such as going to school, going to work, shopping, etc.; selective activities such as walking, outdoor rest, contact with the natural environment to soothe the mood, etc.; and social activities such as playing among children and communication among adults and other contact behaviors. Although there are some differences in the activity behaviors of different age groups, there are intersections between the overall activity trajectories, and there is a certain consistency in the use and demand for outdoor space.

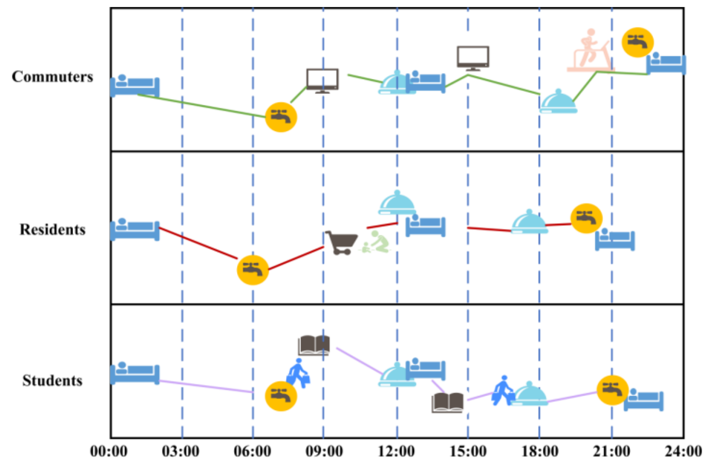

Figure 2: Results of the analysis of the activities of the residential population in a residential area.

Based on the analysis of the activities of the residential groups, the results of the analysis of the spatial needs of different residential groups are shown in Figure 3. The results show that the spatial needs of the elderly group are mainly focused on commercial space where goods can be sold, space for cultural and recreational facilities, and space for leisure and sports; while the outdoor space needed by the younger children in the family group is mainly focused on shopping space, entertainment space, educational space and social space; while when the children in the family group are older, such as secondary school students, they themselves generate the demand for outdoor space When the children in the family group are older, such as middle school students, they will have their own needs for outdoor space, mainly focusing on leisure and sports space and social space; office workers, due to their work, keep their free time in the same direction as middle school students, so their needs for outdoor space also focus on leisure and sports space, social space and shopping space.

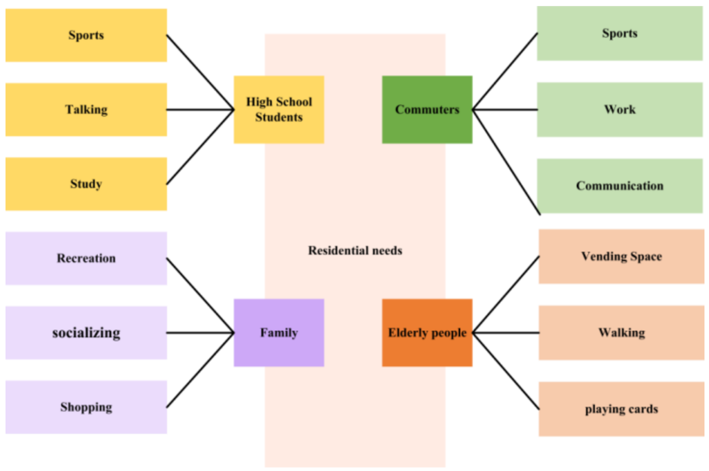

Figure 3: Results of spatial demand analysis of living population.

3.2 3D CAD Software Entity Model Construction

The point cloud data of outdoor space of residential area is obtained by 3D laser scanning technology and used as the base data for 3D CAD software to build 3D solid model. Acquiring point cloud data in outdoor space, it is affected by various environmental factors, and there are certain noise and outlier points in the acquired point cloud data, which will affect the accuracy of 3D model stitching afterwards. In the alignment point cloud, the point cloud features of each station are extracted according to the distribution characteristics of the normal vectors before the point cloud data are stitched together. At the same time, considering the variability in the shape characteristics of outdoor space buildings and scenery in residential areas, the following accuracy of different feature points will be carried out. The number of feature points selected in the experiment is [3,10], and the mean and medium error results are shown in Figures 4 and 5. The data in Figure 4 show that there is a large variability between three and four times matching of feature points, and the four times random matching results, the matching results are higher than other numbers of matching results and show a larger degree of volatility; while the number of feature points is 5, 7 and 8 will produce a larger matching error.

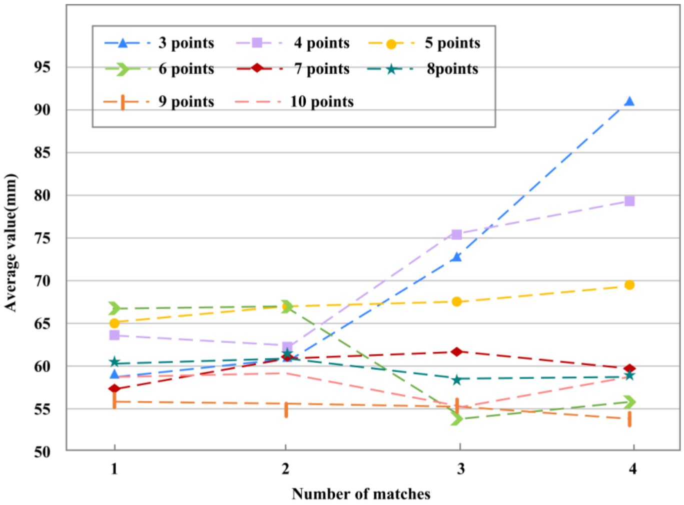

Figure 4: Comparison results of the mean value of feature point errors with different matching times.

The data in Figure 5 show that the dispersion of the matching path is still relatively large for the number of feature points 3 and 4, while is 8 and 9 when the matching dispersion is the smallest and the stability is the best, where the medium error for the number 9 is higher than that for the number 8.

According to the comparison results in Figure 4 and Figure 5, when four random matches are selected, the number of feature points is chosen to be 8 for matching, and the results have higher mean concentration, smaller dispersion magnitude of the medium error, and relatively higher stability, which can present better 3D model stitching characteristics.

Shapir and Vossler have studied the problem systematically and proposed definitions, theorems and algorithms to build a systematic knowledge system. The two core concepts of this knowledge system are canonical intersection terms and describability theorems. The canonical intersection terms of the set $G=\{g_1,g_2,\dots,g_i\}$ are shown in (1) and (2):

$$\prod_h = \cap_{n=1}^{i_*} g_n \tag{1}$$

$$g_n = k_n or \bar{k}_n \tag{2}$$

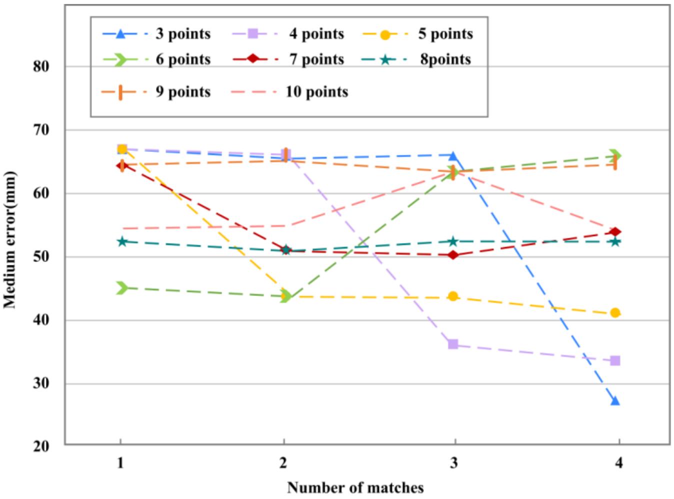

Figure 5: Comparison results of feature point errors with different matching times.

According to (1) and (2), the set G is $2i$, where the empty set and the canonical intersection terms of the non-empty set constitute a subset of one or more subsets with connectedness.

If a half-space CSG exists, denoted by $\Phi(k_1, k_2, ..., k_i)$ and the entity symbol S, then the half-space set $K = \{k_1, k_2, ..., k_i\}$ can describe the entity when and only if two conditions need to be satisfied:

First, let the boundary be denoted as ∂, satisfying the condition as shown in (3):

$$\partial(S) \subseteq \partial(k_1) \cup \partial(k_2) \cup ... \cup \partial(k_i) \tag{3}$$

The second condition to be satisfied is that each canonical intersection term in the half-space set contains connected subsets that are on the same side of the entity.

When the above describability theorem is satisfied, the CSG expression for the entity S is shown in (4):

$$S = R^i \cdot \sum_{n=1}^{i_{ni}} \prod_n^{ni} + \varnothing \cdot \prod_n^{out} = \sum_{n=1}^{i_{ni}} \prod_n^{ni} \tag{4}$$

The non-empty canonical intersection term contained in the entity is described as $\prod_n^{ni}$, and the non-empty canonical intersection term contained in $\bar{S}$ is denoted as $\prod_n^{out}$.

The above method enables to derive a representation of the entity CSG, but it is usually not a result of simplification, and some half-spaces have multiple unnecessary occurrences, so it needs to be simplified by principal implication. Let the main implication of an entity based on the set $K = \{k_1, k_2, ..., k_i\}$ be described as Ψ if and only if it satisfies the following two conditions:

First, the entity S is implied as Ψ as shown in (5):

$$\begin{cases} \Psi \subseteq S \\ \Psi = g_n \cap^* \ldots \cap^* g_m \end{cases} \tag{5}$$

where $g_{n \ldots m} = k_{n \ldots m} or \overline{k}_{n \ldots m}$.

Second, after any item in the Ψ expression is deleted, the remaining part of the expression described by S is no longer implied by the entity.

When the number of occurrences of each half-space in the CSG expression is only this, then it is the most simplified state, so based on this idea simplification can be achieved by dominating the half-space. If the entity S is represented as in (6)

$$S = S_1 \cup^* h \tag{6}$$

where h is denoted as a half-space with separateness or as the complement of that space, when $S_1 \subset S$, h is the dominant half-space of S , which is also the main implication of that entity, so that the following decomposition theorem exists for it: when the entity S in the half-space set $H = \{h_1, h_2, \ldots, h_i\}$ can be described, if $h_l \in H$ is the dominant half-space of that entity, as shown in (7):

$$S = h_l \cup^* S' \tag{7}$$

If $h_l \in H$ is the dominant half-space of the entity $\overline{S}$, then as shown in (8)

$$S = \overline{h_l} \cup^* S' \tag{8}$$

and can be described at S' in $H' = \{h_1, h_2, \ldots, h_i\} - \{h_l\}$.

If the entity S can be described in its corresponding natural half-space set, an efficient representation can be obtained by the computational method of CSG expressions, but the corresponding entity cannot always be described in the natural half-space set, so the concept of segmented half-space is proposed, i.e., the half-space necessary for defying entities that do not belong to the natural half-space set, as shown in Figure 6.

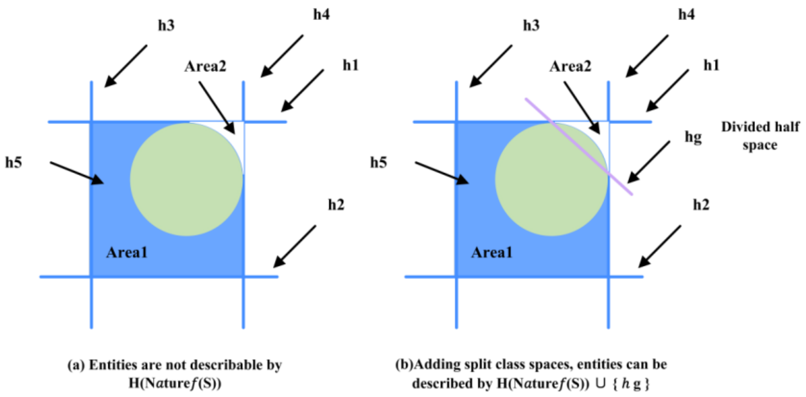

Figure 6: Complementary partition half-space.

Based on the research results of the above knowledge system, some scholars proposed the BRep→ CSG conversion algorithm based on the basic concepts of conversion element and partition interface. The method needs to determine the partition interface of 3D entities first, obtain the set of decomposed conversion elements, realize BRep→CSG conversion by processing the conversion elements one by one, and merge the final results.

4 RESULTS OF THE DESIGN OF OUTDOOR SPACE IN RESIDENTIAL AREA BASED ON 3D CAD SOFTWARE

In order to better test the conversion performance of 3D CAD software entity model construction based on BRep→CSG conversion algorithm, three models are selected for conversion in this paper, and the conversion time of this algorithm and previous algorithms are compared. The structure of model 1 among the three selected models is simple, and the structure of model 2 and model 3 is gradually complicated. The conversion time results are shown in Figure 7. The results in the figure show that overall the conversion time of the three models with different structural complexity, the conversion is shorter. Model 1 is a model with simple structure, and the conversion time of this paper's algorithm improves about 33% compared with previous algorithms, while the conversion times of Model 2 and Model 3 with increased structural complexity improve about 66% and 75%, respectively. This is mainly because the BRep→CSG conversion algorithm prefers the decomposition of models with higher complexity, so the complexity of the CSG representation of the decomposition result is higher than the previous algorithms when performing models with relatively simple structure, and the time improvement is limited but more in line with the characteristics of the models. From the conversion time of models 2 and 3, it can be seen that the higher the complexity of the model to be converted, the more speed-up effect, the more obvious the effect is, so the algorithm in this paper has obvious time advantage in decomposing the model, and is also more in line with the characteristics of the model, and can provide good technical support for the design of outdoor space environment in residential areas.

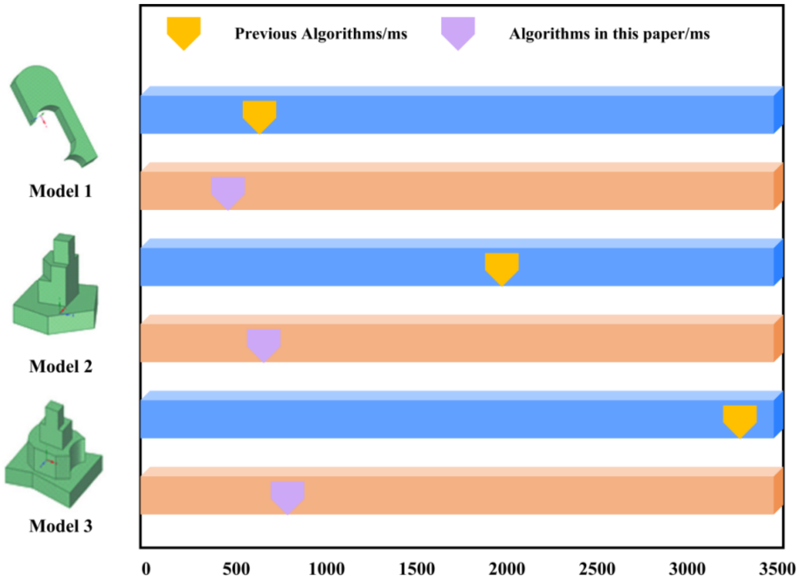

Figure 7: Comparison results of conversion time of three models.

As shown in Figure 8, the two-dimensional floor plan and three-dimensional floor plan of the outdoor space environment design of residential areas are compared, from which it can be seen that although the two-dimensional floor plan can show the design and planning of the outdoor space environment of residential areas globally, the visual presentation effect is not as good as the three-dimensional model, and the three-dimensional model can be rendered accordingly according to the actual environmental conditions, with better visual presentation effect, clearer and more intuitive data presentation, and less error with the actual The visual presentation is better, the data is clearer and more intuitive, and the error with the actual environment is smaller.

Global two-dimensional plan

Global 3D model drawing

Local two-dimensional plan

Local 3D model drawing

Figure 8: Comparison of two-dimensional plan and three-dimensional plan of outdoor space environment design in residential areas.

5 CONCLUSION

This paper realizes the design of outdoor space environment of residential area through 3D CAD software based on the analysis result of the demand of occupants of a residential area. Meanwhile software entity modeling, this paper selects CAD software based on BRep→CSG conversion algorithm model. The experimental results show that compared with the previous algorithms, the BRep→CSG conversion algorithm can significantly reduce the conversion time of the model, and the conversion results are more consistent with the characteristics of the model and more suitable for the actual situation. In addition, the outdoor space environment design drawings of residential areas completed by the 3D CAD software are more visually appealing, the data presentation is more intuitive, and the rendering effect is more suitable for the actual environment.

Licui Zhang, https://orcid.org/0000-0002-1881-2782

REFERENCES

[1] Brockmöller, T.; Siqueira, R.; Gembarski, P.-C.; Mozgova, I.; Lachmayer, R.: Computer-aided engineering environment for designing tailored forming components, Metals, 10(12), 2020, 1589. https://doi.org/10.3390/met10121589
[2] Chen, B.; Hu, J.; Qi, J.; Chen, W.: A computer-aided approach improving the Axiomatic Design theory with the distributed design resource environment, AI EDAM, 34(1), 2020, 80-103. https://doi.org/10.1017/S0890060419000283
[3] Da, H.-L.; Hong, Y.-L.; Wei, L.; Guo, J.-J.; En, Z.-L.: Application of flipped classroom based on the Rain Classroom in the teaching of computer-aided landscape design, Computer Applications in Engineering Education, 28(2), 2020, 357-366. https://doi.org/10.1002/cae.22198
[4] Deng, Y.; Xie, L.; Xing, C.; Cai, L.: Digital city landscape planning and design based on spatial information technology, Neural Computing and Applications, 34(12), 2022, 9429-9440. https://doi.org/10.1007/s00521-021-06377-w
[5] Jia, J.: Computer-Aided Design Method of Parametric Model for Landscape Planning, Computer-Aided Design and Applications, 19(S3), 2022, 55-64. https://doi.org/10.14733/cadaps.2022.S3.55-64
[6] Jiang, W.; Zhang, Y.: Application of 3D visualization in landscape design teaching, International Journal of Emerging Technologies in Learning (Online), 14(6), 2019, 53-62. https://doi.org/10.3991/ijet.v14i06.10156
[7] Lallawmzuali, R.; Pal, A.-K.: Computer Aided Design and Drafting in Landscape Architecture, Current Journal of Applied Science and Technology, 42(5), 2023, 1-11. https://doi.org/10.9734/cjast/2023/v42i54066
[8] Liu, C.; Lin, M.; Rauf, H.-L.; Shareef, S.-S.: Parameter simulation of multidimensional urban landscape design based on nonlinear theory, Nonlinear Engineering, 10(1), 2021, 583-591. https://doi.org/10.1515/nleng-2021-0049
[9] 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
[10] Yoffe, H.; Plaut, P.; Grobman, Y.-J.: Towards sustainability evaluation of urban landscapes using big data: a case study of Israel's architecture, engineering and construction industry, Landscape Research, 47(1), 2022, 49-67. https://doi.org/10.1080/01426397.2021.1970123
[11] Yu, X.; Ergun, K.; Cherkasova, L.; Rosing, T.-Š.: Optimizing sensor deployment and maintenance costs for large-scale environmental monitoring, IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems, 39(11), 2020, 3918-3930. https://doi.org/10.1109/TCAD.2020.3012232
[12] Zhang, M.; Deng, X.: Color effect of landscape architecture design under computer aided collaborative design system, Computer-Aided Design and Applications, 19(S3), 2021, 13-22. https://doi.org/10.14733/cadaps.2022.S3.13-22
[13] Zhang, R.-Y.; Li, J.-T.; Zhao, J.-X.; Zhao, Z.; Zhang, L.-C.; Yun, C.; Tang, P.-F.: The oblique triangle configuration of three parallel screws for femoral neck fracture fixation using computer-aided design modules, Scientific Reports, 12(1), 2022, 1-7. https://doi.org/10.1038/s41598-021-03666-1
[14] Zhao, X.: Application of 3D CAD in landscape architecture design and optimization of hierarchical details, Computer-Aided Design and Applications, 18(S1), 2020, 120-132. https://doi.org/10.14733/cadaps.2021.s1.120-132