Calculation Method for Carbon Sequestration of Urban Green Space Vegetation – Based on Point Cloud Technology

Yu Huiping[1], Huang Ruonan[1], Zhang Jiaqi[1], Yuan Yangyang[1*]
[1]Southeast University, Nanjing/China
[*]Southeast University, Nanjing/China · yyy@seu.edu.cn

Abstract: In the context of China's carbon peaking and neutrality goals, green space is important for sustaining urban ecosystems, which perform the functions of emission reduction and sequestration enhancement. As a result, the carbon sequestration benefits of urban green space have become an important research topic. Furthermore, carbon sequestration is an important indicator for evaluating the benefits of urban green areas. However, most existing calculation methods are based on manual measurements or satellite remote sensing data, which are inefficient and have low accuracy. Our research develops a method to calculate the carbon sequestration of urban green space vegetation based on point cloud technology and the integrated use of several digital software platforms. First, the point cloud data were acquired by light detection and ranging, and preliminary processing was performed; second, based on the characteristics of urban green space vegetation structure, we used manual segmentation and individual tree segmentation to classify tree, shrub, and ground cover data, and perform voxelization and surface mesh modeling to obtain tree and shrub volume and ground cover three-dimensional surface area; and third, we imported the relevant data using the carbon sequestration calculation formula to obtain the carbon sequestration of each vegetation type and total carbon sequestration of green space vegetation. In the last step, we applied the method to a case study of Mei'an green space in a college campus in Nanjing, China. The proposed method can model vegetation more accurately and efficiently than previous methods and provides an effective way to calculate the carbon sequestration by vegetation in urban green space.

Keywords: Landscape architecture, urban green space, point cloud, carbon sequestration; voxel modeling

1 Introduction

Industrialization and the rapid expansion of cities have led to a rapid increase in the amount of carbon dioxide and other greenhouse gases in the atmosphere, leading to global warming, which has resulted in frequent extreme weather events, rising sea levels, and a sharp decline in biodiversity, all of which seriously threaten human survival (SOLECKI et al. 2013). The Intergovernmental Panel on Climate Change was established internationally as early as 1988 to address climate change and promote sustainable urban development. The Paris Agreement in 2015 put forward the requirements for countries to reduce carbon emissions, promote carbon sequestration benefits, and achieve carbon neutrality. The European Union and developed countries, such as the United Kingdom and France, have set timeframes for achieving carbon neutrality after reaching peak carbon dioxide emissions (COMMISSION 2020, JUSTICE 2019, KINGDOM 2022). China has also proposed "peak carbon dioxide emissions and carbon neutrality goals," aiming to achieve "peak carbon dioxide emissions" by 2030 and "carbon neutrality" by 2060 (ZHANG et al. 2021). Vegetation and other green space components can abate, absorb, and store carbon dioxide (ZHANG et al. 2022). As an important part of the urban ecosystem, green space performs the vital function of carbon sequestration and is the primary

Journal of Digital Landscape Architecture, 8-2023, pp. 142-157. © Wichmann Verlag, VDE VERLAG GMBH · Berlin · Offenbach. ISBN 978-3-87907-740-3, ISSN 2367-4253, e-ISSN 2511-624X, doi:10.14627/537740016.

means of neutralizing urban carbon emissions. Thus, the carbon sequestration benefits of urban green space have become an important research topic.

A point cloud is an extensive collection of points that contain attribute information, including three-dimensional (3D) spatial coordinate details, colors, and materials (YANG & HAN 2018). It is acquired using light detection and ranging (LiDAR), which includes an airborne laser scanner (ALS) and terrestrial laser scanner (TLS). ALS can acquire a large range of point cloud data but has relatively low accuracy. Moreover, the vegetation information in lower space cannot be accurately obtained due to the occlusion of the vegetation canopy. Although the scanning range of TLS is limited, it can accurately scan information about lower vegetation. The acquired point cloud data have the characteristics of high accuracy and high density (XU et al. 2021), which are more suitable for small- and medium-sized urban green spaces. Compared with traditional manual measurements for vegetation data, the acquisition of point cloud data by LiDAR has the advantages of high efficiency and accuracy, no physical contact with and damage to the measured object, and accessible data viewing and processing (YANG et al. 2018). Additionally, the high reproducibility of point cloud data in reflecting the 3D structural information of plants (MALHI et al. 2018) makes it a promising technique for plant modeling (LIVNY et al. 2010, MILENNOVIĆ et al. 2012) and capturing plant data (MEDEIROS et al. 2017, Sun et al. 2018).

In terms of plant modeling, research on the application of point clouds has primarily concerned algorithm-based simulations of realistic plant morphology. For example, interactive segmentation and spatial colonization algorithms are used to segment and model tree point clouds (ZHANG et al. 2021). However, further quantitative analyses and applications of plant modeling are still required. Point cloud can also be used for measuring living vegetation volume (LVV) based on the application of plant modeling. LVV refers to the volume of space occupied by the stems and leaves during plant growth and is an important indicator of the ecological benefits of urban vegetation (ZHOU & SUN 1995). LVV can be applied for calculating the vegetation carbon sequestration benefits. Several studies have used point cloud technology for LVV measurement. For example, point cloud data can be used to obtain plant crown diameter and height, and LVV can be calculated using the volume calculation formula (MARZULLI et al. 2020). Alternatively, the convex hull method can be used to approximately simulate the plant shape and calculate the LVV (LIU et al. 2016, LU & GAO 2018). However, the process is generally complex, and the accuracy of plant simulation requires further improvement.

Carbon sequestration refers to the process, activity, and mechanism of absorbing and storing atmospheric carbon dioxide (HOUGHTON et al. 1995). Carbon sequestration of urban green space vegetation refers to the process of absorbing and storing carbon elements through photosynthesis by urban green space vegetation. It is an essential indicator for evaluating the benefits of urban green spaces. Existing methods for calculating the carbon sequestration of urban green space vegetation mainly include sample inventory, photosynthetic rate integration, micrometeorology evaluation, and remote sensing estimation (FANG et al. 2007, LIU et al. 2021). Most of the primary data originate from manual measurement or satellite remote sensing, which results in a large and complicated calculation process, and results with low efficiency and less accuracy (XIE et al. 2022). This is because manual measurement data cannot accurately describe complex lifeforms, such as plants, and remote sensing data cannot obtain information on the vertical structure of the forest understory, thus, making it difficult to accurately reflect the spatial characteristics of urban green space vegetation. In addition, remote sensing is mainly used for carbon sequestration calculations of large-scale green spaces (ZHANG et al. 2022). In recent years, scholars in China and abroad have attempted to use LiDAR to obtain 3D point cloud data and combine the data with digital modeling to reflect the spatial characteristics of green areas accurately (MÜNZINGER et al. 2022). This technology can accurately identify the morphological characteristics of vegetation, topography, and other elements, thereby overcoming the limitations of conventional manual measurement and conventional manual measurement methods (FERNÁNDEZ-SARRÍA et al. 2013). Additionally, it can meet the needs of accurate quantitative analysis while providing a new technical means for calculating the amount of carbon sequestration in urban green spaces.

In this study, we explored a method for calculating the carbon sequestration of urban green space vegetation based on point cloud technology. We selected a green space known as Mei'an on a college campus in Nanjing, China, as the research area and used LiDAR to obtain 3D point cloud data. We used several software platforms, including Cloud Compare, Trimble RealWorks, Rhinoceros 3D, Grasshopper, and MATLAB, to classify and process the point cloud data, construct a 3D vegetation model, and measure the total carbon sequestration of vegetation in the Mei'an green space. This paper proposes an efficient and accurate method for calculating the carbon sequestration of urban green space vegetation and discusses the advantages of point cloud technology in improving the accuracy and ease of operation of vegetation modeling and visualizing the carbon sequestration calculation results.

2 Methods

In this study, we developed a carbon sequestration calculation method for urban green space vegetation based on point cloud technology, which includes four main components (Figure 1). First, we used LiDAR to obtain the point cloud data of the site and performed preliminary processing of the data. Second, we classified the point cloud data according to the requirements of urban green space vegetation composition and carbon sequestration classification calculation and extracted the vegetation point cloud data. Third, we performed voxelization modeling and surface mesh modeling for point cloud data of trees, shrubs, and ground cover. We then obtained the volume of tree and shrub crown and the surface area covered by each vegetation type. Finally, the carbon sequestration of the different vegetation types was obtained using the corresponding carbon sequestration calculation formula and aggregated to obtain the total carbon sequestration of the green space.

2.1 Data Acquisition

We selected LiDAR to collect point cloud data within the study area for small- and medium-sized urban green spaces. After scanning the sample sites using the substation method, the obtained data were aligned and merged to obtain the original point cloud data. We obtained accurate point cloud data by data cleaning and accurate resampling of the original point cloud data using professional software for point cloud processing.

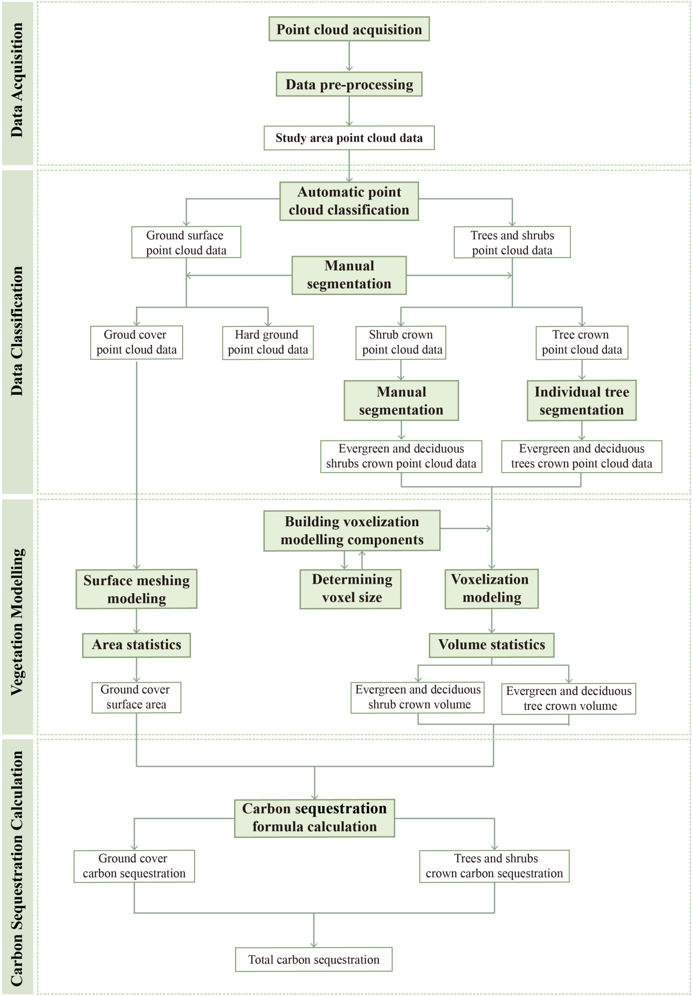


Fig. 1: Methodology flowchart

2.2 Data Classification

The carbon sequestration benefits for different types of vegetation differ (YAO et al. 2017). To improve the accuracy of calculating the carbon sequestration of green space vegetation, this study divided the pre-processed point cloud data into five types according to the vegetation structure and attribute characteristics, namely evergreen trees, deciduous trees, evergreen shrubs, deciduous shrubs, and ground cover. The operation comprised two processes: point cloud database classification using Trimble RealWorks software and segmentation for individual trees using the watershed algorithm.

In the base classification stage, the data were classified into four groups of point clouds: ground, high vegetation, building, and remaining, using the automatic classification function of the Trimble RealWorks software. High vegetation referred to vegetation with a specific height, including trees and shrubs, and others referred to point cloud data other than the ground surface, high vegetation, and buildings. The point cloud data of buildings and others were not necessary for the calculation of carbon sequestration of green space vegetation and thus, were excluded. Because an inevitable error exists in the automatic software classification, it was necessary to manually confirm and filter the surface and high vegetation point cloud data and further separate the surface, tree, and shrub point cloud data. Subsequently, we removed the hard ground point cloud data from the surface point cloud data to obtain ground cover point cloud data. The growth conditions of trees are complicated, as the tree crowns are interspersed with each other; therefore, manual classification is difficult. To improve the segmentation efficiency, we used a segmentation method for individual trees before categorization. However, the shrubs in urban green space are were small in size, mostly clumped and planted in patches; therefore, classifying them manually into two categories, namely, evergreen and deciduous shrubs, was suitable.

Individual tree segmentation was performed using the watershed algorithm. First, the previously classified surface and tree point cloud data were used to generate a digital elevation model and digital surface model using a triangulated irregular network and inverse distance weight. The canopy height model was obtained by subtracting the two values. Regarding this, we used the watershed algorithm to obtain the individual tree segmentation results. Subsequently, the segmentation results were identified and categorized by referring to the current vegetation distribution map of the site to obtain the point cloud data of evergreen and deciduous trees at the site. While calculating LVV, we considered only the crown part. Therefore, the point cloud data of the tree outside the crown were excluded by segmenting the point cloud data.

2.3 Vegetation Modeling

The carbon sequestration benefit of a single plant is proportional to its volume (DONG & WAN 2019); therefore, the calculation accuracy of vegetation volume needs to be improved. Since most trees and shrubs in urban green spaces have complex and irregular forms, and there are many gaps inside the tree crowns, it is difficult to accurately model the plant form and calculate the volume. Therefore, we used the voxelization modeling method for modeling trees and shrubs and calculated the volume accordingly. A voxel is an extension of a two-dimensional (2D) pixel in a 3D space (KAUFMAN et al. 1993). Voxelization modeling refers to the generation of multiple voxels based on the spatial distribution of plant point clouds to simulate plant morphology. Plant volume can be obtained by accumulating the volumes of multiple voxels. This method is highly accurate, convenient, and efficient. For ground cover, which is generally low in height and tightly integrated with the terrain, carbon sequestration is mostly calculated based on the surface area (YIN et al. 2020). Point cloud data have a high degree of reproduction in terrain modeling, which can calculate a relatively accurate 3D surface area of the ground cover and reduce the errors caused by the use of the 2D surface area to calculate ground cover carbon sequestration. In this study, we used Rhinoceros 3D software to model the surface mesh of the surface point cloud data and then calculated the 3D surface area of the ground cover. The software can avoid the errors caused by calculating the surface area based on 2D projections.

2.4 Voxelization Modeling of Trees and Shrubs

Voxelization model generation and volume calculation of trees and shrubs were achieved by building components using Rhinoceros 3D and Grasshopper software (Figure 2). The accuracy of the simulated plant volume using the voxelization model is closely related to the voxel edge length. Owing to the limitation of the density of the original point cloud and the uneven distribution of the point cloud, a small voxel edge length leads to increased gaps between voxels with subsequent volume loss; therefore, the actual plant morphology cannot be effectively reflected. Thus, the accuracy of the volume calculation is affected. A large voxel edge length results in a coarse simulation of plant morphology, consequently, resulting in a large volume. To ensure modeling accuracy, we constructed a power function relationship between the ratio of plant crown diameter to voxel edge length and plant volume to assist in determining the length of the voxel edge (WEI et al. 2013).Considering that the plant crown diameter is essentially constant and has no effect on the power function curve trend, it can be directly set to a constant of 1. The equation is as follows:

$$X = \frac{1}{k} \tag{1}$$

$$Y = V_k \tag{2}$$

where k is the voxel edge length in m and V_k is the volume of the plant corresponding to the k voxel edge length setting in m^3.

Urban green space contains a wide range of plant species that vary in form and size. To ensure that the k-value is applied to all trees and shrubs in the sample area, several trees of different species and several trees of the same species were selected as samples for the voxel edge length test. To improve the efficiency of the computation, Grasshopper software was used to build a circular test path (Fig. 3), which enabled automatic voxelization modeling of the plant point cloud data at different k-values, data computation, and an output of a list of X- and Y-values. MATLAB software was used to visualize the data results and generate analysis curves to obtain suitable k-values by comparing the power function curves. The point cloud data of evergreen and deciduous trees and evergreen and deciduous shrubs were then used to generate separate voxelization models using Grasshopper software. Finally, the total volume of each plant type was obtained by multiplying the individual voxel volume by the number of valid voxels in the corresponding voxelization model, which can be calculated directly by the software.

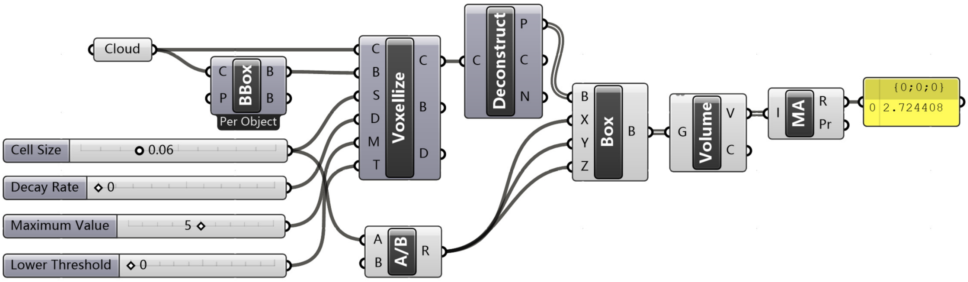
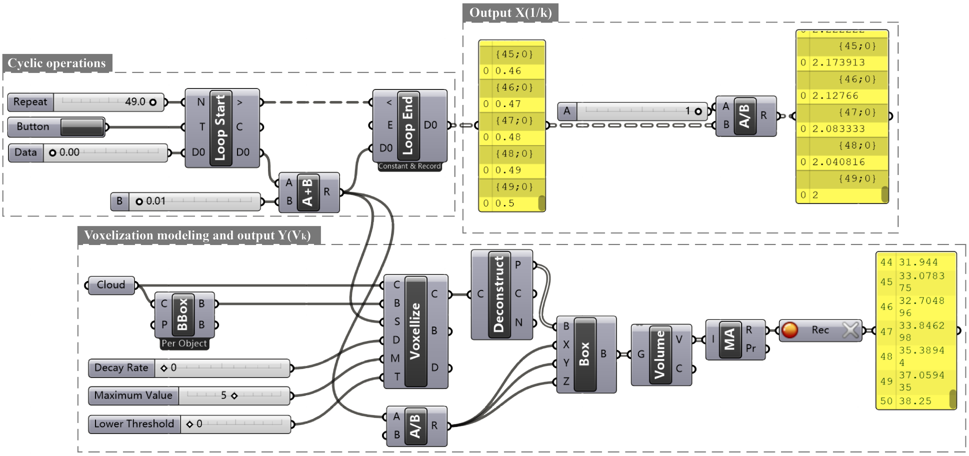

Cell Size 0.06
Decay Rate 0
Maximum Value 5
Lower Threshold 0
{0;0;0}
0 2.724408

Fig. 2: Grasshopper components for voxelization modeling of trees and shrubs



```
{45;0}
0 0.46
{46;0}
0 0.47
{47;0}
0 0.48
{48;0}
0 0.49
{49;0}
0 0.5
```

```
{45;0}
0 2.173913
{46;0}
0 2.12766
{47;0}
0 2.083333
{48;0}
0 2.040816
{49;0}
0 2
```

```
44 31.944
45 33.0783
   75
46 32.7048
   96
47 33.8462
   98
48 35.3894
   4
49 37.0594
   35
50 38.25
```

Fig. 3: Grasshopper components for k-value cycling test with automatic voxelization modeling

2.5 Ground Cover Surface Meshing Modeling

Most of the ground cover in urban green areas grows close to the ground surface, and the undulation of the ground surface has a considerable impact on the ground cover area statistics. Therefore, the 3D surface area should be calculated accurately. Triangular grid modeling is a commonly used method to model the surface of point cloud data; however, its drawback is that the generated surface is uneven, which leads to a sizeable calculated surface area. Moreover, the ground cover point cloud data will be affected by other plants or ground debris during collection and classification, and the local point cloud has a certain degree of irregular undulation, which affects the accuracy of triangle grid modeling. The patch tool in Rhinoceros 3D generates smooth surfaces based on the point cloud distribution and obtains a more accurate surface area. Therefore, in this study, we used this tool to model the ground cover on a grid and used the area statistics tool to obtain the 3D surface area.

2.6 Carbon Sequestration Calculation

The total annual average carbon sequestration of urban green space vegetation comprises the annual average carbon sequestration of trees and shrubs and the annual average carbon sequestration of ground cover. The carbon sequestration of trees and shrubs was calculated as follows:

$$C_{ts} = S_{ts} \times V_{ts} \tag{3}$$

where C_{ts} is the average annual carbon sequestration of trees and shrubs, in kg; S_{ts} is the average annual carbon dioxide absorption of trees and shrubs (ZHOU & SUN 1995) in kg/(m^2·a); and V_{ts} is the LVV of trees and shrubs, in m^2.

$$C_g = S_g \times A_g \tag{4}$$

where C_g is the annual average carbon sequestration of ground cover in kg, S_g is the annual average carbon sequestration rate of ground cover (YIN et al. 2020) in kg/(m^2·a), and A_g is the surface area of ground cover in m^2.

3 Results and Discussion

3.1 Case Study Background

The campus is located in Xuanwu District, Nanjing, China. The specific Mei’an green space case study location is in the northwest corner of the campus (Figure 4), covering an area of approximately 4,697 m², of which 3,037 m² is green space. The vegetation structure in green spaces is complex, with a multi-level community of trees, shrubs, and grasses, including evergreen and deciduous types. The primary tree species included *Platanus acerifolia*, *Metasequoia glyptostroboides*, *Ligustrum lucidum*, *Osmanthus fragrans*, *Chimonanthus praecox*, *Prunus yedoensis*, and *Trachycarpus fortunei*. In addition, the green space had been planted earlier, and after years of growth, the site area was highly dense in vegetation, and the plant branches were intertwined; therefore, it was challenging to identify the point cloud data of single plants.

Fig. 4: Study area: (a) Campus plan, (b) Mei‘an green space plan, and (c) photographs of Mei‘an green space

3.2 Data Processing

We used the Trimble TX8 laser scanner to obtain 3D point cloud data within the study area by scanning in a substation manner (Figure 5). The parameters of the laser scanner were set to a scanning distance of 340 m, scanning speed of 1 million points/s, and scanning accuracy of ≤2 mm. In total, 79,455,618 points for the study area were obtained from the scanned data. After applying the pre-processing methods, such as registration and data cleaning, to the point cloud data, the automatic classification function of the Trimble RealWorks software was combined with manual recognition to separate the ground cover, and evergreen and deciduous shrub point cloud data. The point cloud data of trees were obtained by segmenting individual trees based on the watershed algorithm, and the point cloud data of 62 trees were identified. Among them, 30 evergreen trees and 32 deciduous trees were categorized and integrated to obtain the evergreen and deciduous tree point cloud data for the site (Figure 6). To calculate LVV, the point cloud data for the crown of evergreen and deciduous trees were obtained by manually segmenting the trunk point cloud data, excluding the crown.

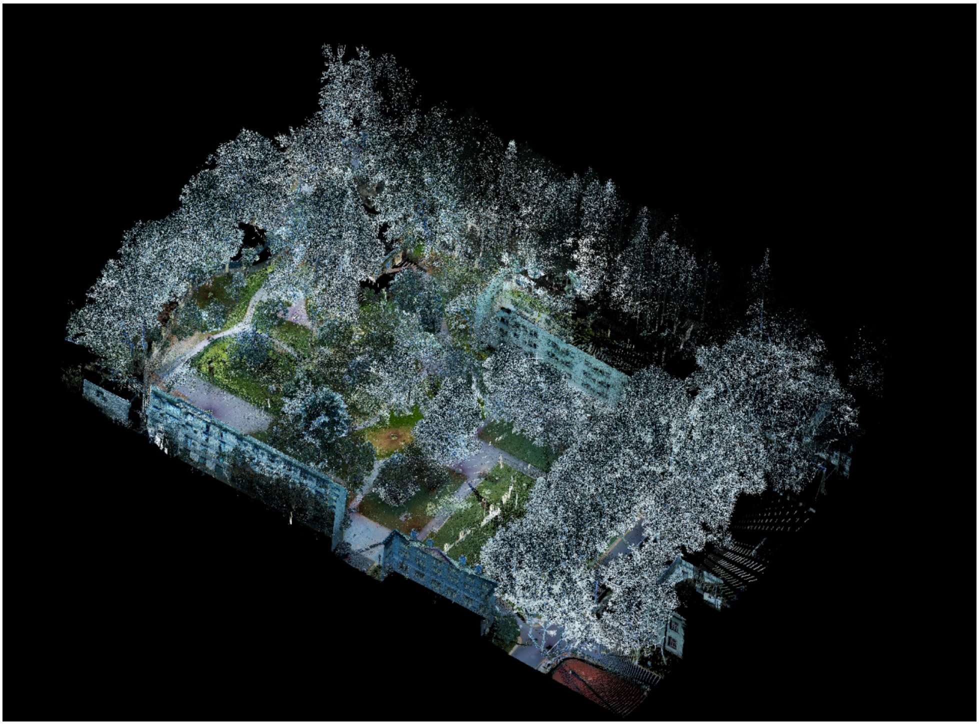


Fig. 5: Point cloud data of Mei'an acquired by LiDAR

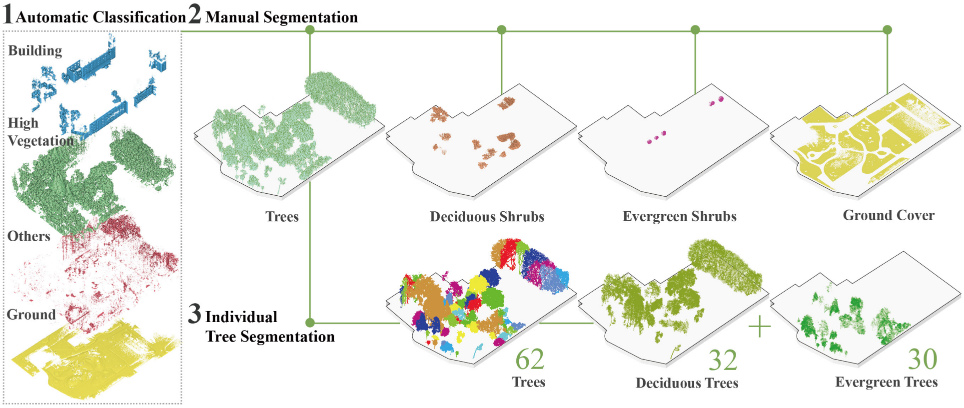
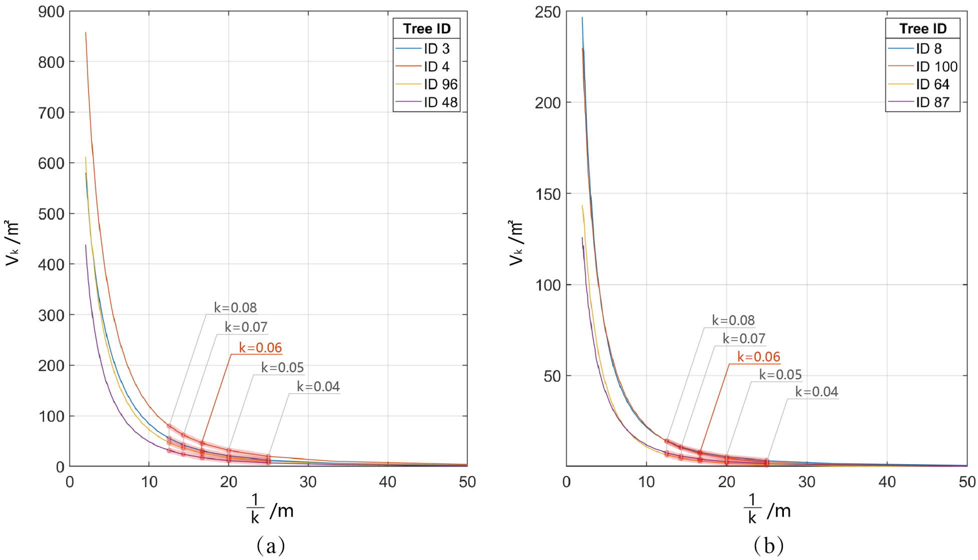


Fig. 6: Point cloud data classification

3.3 Voxelization Modeling and Surface Mesh Modeling

The vegetation modeling for the study consisted of two components: voxelization modeling of trees and shrubs and mesh modeling of ground cover. In the voxelization modeling stage, several samples were first selected to test the voxel edge length k-values and determine the specific values. The diameter at breast height of trees in urban green spaces is mainly in the 0.05 – 0.4 m range (SHI et al. 2016); thus, the k-value test was limited to 0.02 – 0.5 m. From the point cloud data of a single tree obtained by single tree segmentation, four trees of different species and four of the same species were selected as test samples and imported into the Rhinoceros 3D software. The k-value cyclic test components built into Grasshopper were then used to calculate the X- (1/k) and Y-(Vk)-values at different k-values, and the output data were used to generate the corresponding data curves using MATLAB software (Figure 7). The results showed that X and Y for samples were all power functions, with the Y-value decreasing as the X-value increased. The convergence point of the decreasing Y-value for each sample was located at k = 0.04 – 0.08 m interval. By comparing the voxelization model of k-values in this interval with the actual plant morphology, a k-value of 0.06 m was selected as the voxel edge length for plant modeling (Figure 8). The determined k-value and tree and shrub crown point cloud data were input into the voxelization modeling Grasshopper components to generate the evergreen tree, deciduous tree, evergreen shrub, and deciduous shrub crown point cloud voxelization models. Mesh modeling of the ground cover was carried out using the Rhinoceros 3D software. First, the ground cover point cloud data were imported, and the patch tool was used to generate a surface mesh for each ground cover. Second, the ground cover boundaries were projected onto the surface, and the redundant mesh was cut off to obtain a mesh model of each ground cover (Figure 9).



(a) (b)

Fig. 7: Test curves for k-values. (a) Test curves for k-values of several samples from different tree species and (b) test curves for k-values of several samples from the same tree species

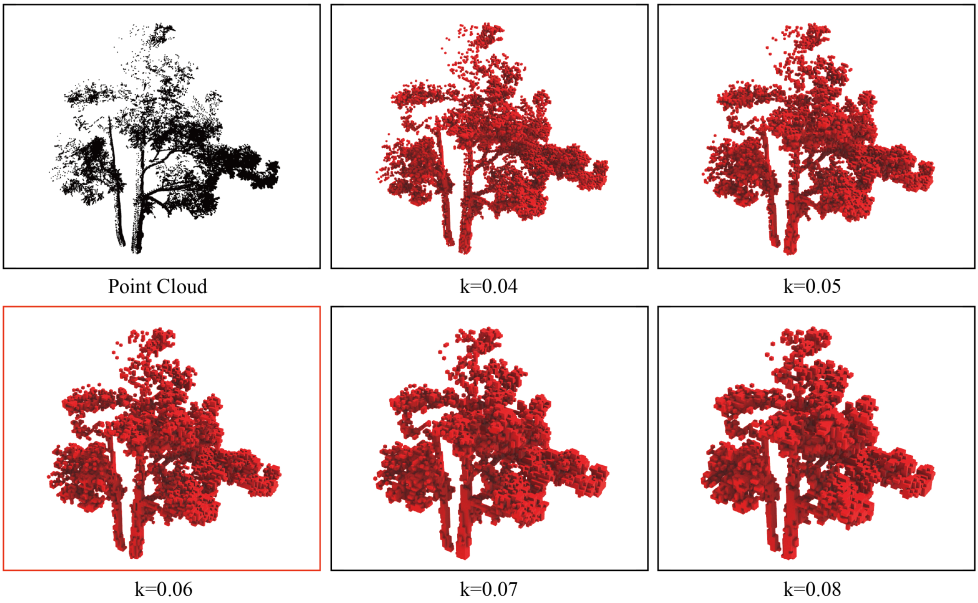


Fig. 8: Comparison of voxelization modeling of different k-values (k=0.04–0.08)

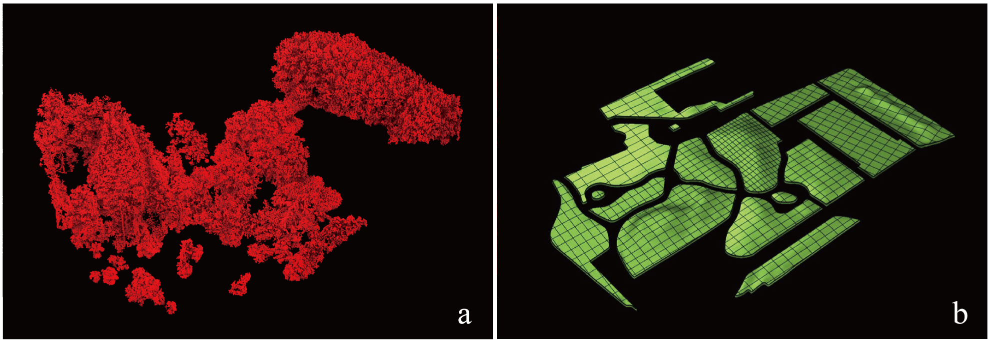


Fig. 9: Vegetation model of the Mei'an green space based on point cloud data. (a) Tree and shrub voxelization model and (b) ground-cover surface-mesh model.

3.4 Carbon Sequestration Calculation and Analysis

We measured the volume of trees and shrubs and the 3D surface area of ground cover separately, and input them into the formula to obtain the total vegetation carbon sequestration. The corresponding results are shown in Table 1. The total annual average carbon sequestration of vegetation was 3342.86 kg, of which the carbon sequestration of deciduous trees was 1045.30 kg, accounting for the highest proportion of the total carbon sequestration of green space vegetation. The carbon sequestration of evergreen shrubs was 10.57 kg, accounting for the lowest proportion (Figure 10). On this basis, the carbon sequestration calculation results were further analyzed by visualization methods (Figure 11), which reflected the carbon sequestration benefits of each vegetation type more clearly and intuitively. we observed that the carbon sequestration of vegetation showed uneven spatial distribution, and was more in areas with rich vegetation layers, undulating terrains, and large slopes.

Table 1: Carbon sequestration of vegetation in the Mei’an green space

Vegetation types	**Calculation formula**	**Average annual CO_2 absorption S_{ts}/(kg/(m^3·a))** **Average annual rate of ground cover carbon sequestration S_g/(kg/(m^2·a))**	**Volume (m^3)**	**3D surface area (m^2)**	**Carbon sequestration (kg/a)**
Evergreen trees	$C_{ts} = S_{ts} \times V_{ts}(3)$	4.85	184.18	/	893.27
Deciduous trees		2.62	398.97	/	1045.30
Evergreen shrubs		4.85	2.18	/	10.57
Deciduous shrubs		2.62	65.15	/	170.69
Ground cover	$C_g = S_g \times A_g(4)$	0.4	/	3,057.55	1,223.02
Total	/	/	/	/	**3,342.86**

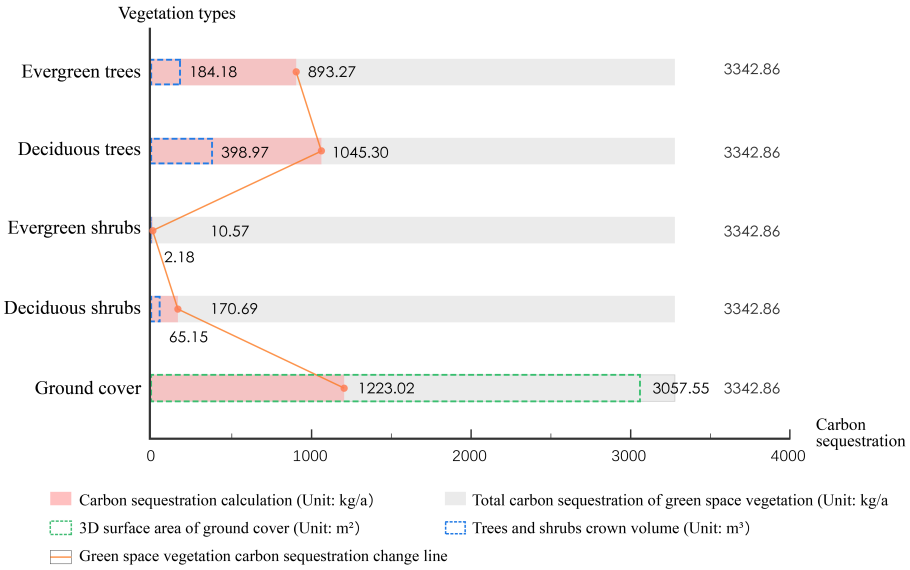


Fig. 10: Histogram of the carbon sequestration calculation for the Mei’an green space vegetation

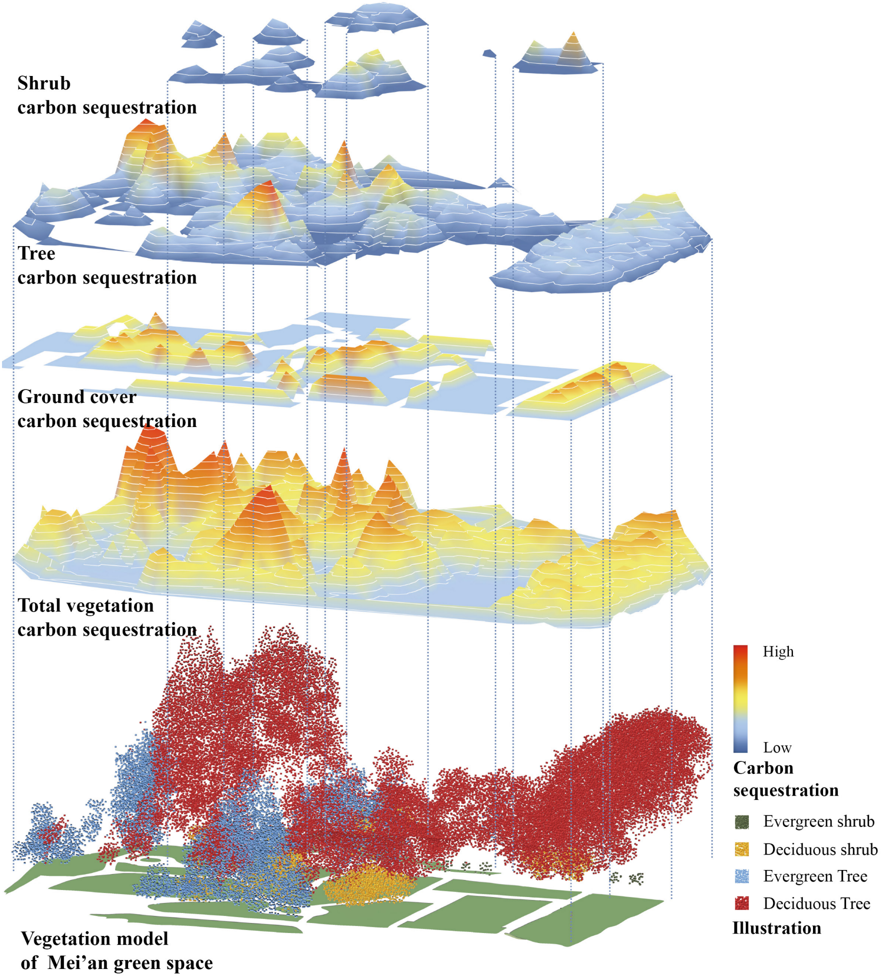


Fig. 11: Visualization of the carbon sequestration of the Mei'an green space vegetation

4 Conclusion

In this study, we developed a point cloud-based method for calculating carbon sequestration in urban green spaces. Using several software platforms, including Trimble RealWorks, Rhinoceros 3D, Grasshopper, and MATLAB, as along with voxelization and mesh modeling methods, the classification of green space vegetation point cloud data, plant modeling, carbon sequestration calculation, and visualization were achieved. The features and advantages of this method are reflected in two aspects.

1) Calculation accuracy

In the volume calculation of plants, the traditional geometric simulation method is limited by the tree species. It considers the crown of a tree as a regular geometry with geometric formulas selected according to different crown shapes. The results of the calculations are inaccurate, and the operation is complex. The use of the convex hull method to calculate the LVV does not consider the gap within the crown of a tree, but only the outer surface of the tree crown and the accuracy of the results is uncertain. This study calculates the volume of urban green space vegetation through voxelization modeling, which not only eliminates the limitation of tree crown shape in volume calculation but also can effectively solve the problem arising from the gap between tree leaves and branches, resulting in a more accurate calculation. For the calculation of ground cover carbon sequestration, compared to the previous method of using projected areas for calculation, the use of point cloud data for the construction of a 3D mesh model of the ground surface results in an accurate 3D surface area of the ground cover. In addition, the method considers the influence of topographic factors.

2) Process efficiency

In this study, we used Rhinoceros 3D and Grasshopper software to build components as computing modules for batch rapid voxelization modeling and calculation of volume of different tree and shrub species. The entire process of this method can be completed by a single researcher. The process is efficient and easy to use as it eliminates the need for time-consuming field data collection and avoids tedious data processing and calculations.

There are limitations in the data acquisition and processing component of this study owing to the limitations of the equipment and technology involved. The density of the point cloud data and voxel size can impact modeling accuracy. The acquisition and processing of ultra-high-precision point cloud data remains challenging owing to the need for scanning and computing equipment. However, contemporary point cloud data processing software lacks accuracy in classification. It fails to identify plant species, requiring a combination of manual screening for calibration, which reduces the efficiency of data processing to some extent.

With the advancement of laser scanning equipment and supporting software and hardware technology, the above problems can be gradually optimized and solved. In the future, the application of point cloud-based green space carbon sequestration calculation methods on larger scales can be further explored, for example, by combining unmanned aerial vehicle tilt photography for large-scale green space point cloud data acquisition and carbon sequestration calculation. Various methods for calculating carbon sequestration can also be explored, such as calculating leaf area index based on point cloud data or calculating biomass by combining point cloud data with the wood volume method, thus, enabling the calculation of vegetation carbon sequestration. In addition, by measuring and analyzing a large number of plant samples, the construction of a more comprehensive and accurate standard conversion amount of plant carbon sequestration and the construction of a database on the carbon sequestration benefits of different tree species need to be studied urgently.

**This research has been financially supported by the National Natural Science Foundation of China (No. 51838003).*

References

European Commission (2020), European Climate Law. https://climate.ec.europa.eu/eu-action/european-green-deal/european-climate-law_en.

DONG, Y. J. & WAN, F. X. (2019), Ecological Benefits and Value Assessment of Forest Stands Based on Three-Dimensional Green Volume – A Case Study of Pujiang Country Park of Shanghai. Research of Soil and Water Conservation, 26 (03), 347-352. https://doi.org/10.13869/j.cnki.rswc.2019.03.051.

FANG, J., GUO, Z., PIAO, S. & CHEN, A. (2007), Terrestrial Vegetation Carbon Sinks in China, 1981-2000. Science in China Series D: Earth Sciences, 50 (9), 1341-1350.

FERNÁNDEZ-SARRÍA, A., MARTÍNEZ, L., VELÁZQUEZ-MARTÍ, B., SAJDAK, M., ESTORNELL, J. & RECIO, J. (2013), Different Methodologies for Calculating Crown Volumes of Platanus Hispanica Trees Using Terrestrial Laser Scanner and A Comparison with Classical Dendrometric Measurements. Computers and electronics in agriculture, 90, 176-185.

FEDERAL MINISTRY OF JUSTICE (2019), Federal Climate Change Act. https://www.gesetze-im-internet.de/englisch_ksg/englisch_ksg.html.

HOUGHTON, J., T., MEIRA, L., G., FILHO & CALLANDER, B., A. (1995), IPCC 1996. Climate change. The Silence of Climate change. Contribution of Working Group I to The Secondary Assessment Report of The Intergovernmental Panel on Climate Change.

KAUFMAN, A., COHEN, D. & YAGEL, R. (1993), Volume Graphics [Article]. Computer, 26 (7), 51-64. https://doi.org/10.1109/mc.1993.274942.

LIU, F., FENG, Z. K., YANG, L.Y., XU, W. H., HUANG, X. D. & FENG, H. Y. (2016), Estimation of Tree Crown Volume Based on 3D Laser Point Clouds Data. Transactions of the Chinese Society for Agricultural Machinery, 47 (03), 328-334. https://kns.cnki.net/kcms/detail/11.1964.s.20160118.1446.028.html.

LIU, Z., PAN, Y., SONG, T., HU, B., WANG, L. & WANG, Y. (2021), Eddy Covariance Measurements of Ozone Flux Above and Below A Southern Subtropical Forest Canopy. Science of The Total Environment, 791, 148338.

LIVNY, Y., YAN, F., OLSON, M., CHEN, B., ZHANG, H. & EL-SANA, J. (2010), Automatic Reconstruction of Tree Skeletal Structures from Point Clouds. In: ACM SIGGRAPH Asia 2010 papers (pp. 1-8).

LU, Z. & GAO, F. (2018), Research on Crowm Volume Calculation Based on 3D Laser Scanning. Journal of Green Science and Technology (02), 178-180. https://doi.org/10.16663/j.cnki.lskj.2018.02.070.

MALHI, Y., JACKSON, T., BENTLEY, L. P., LAU, A., SHENKIN, A., HEROLD, M., CALDERS, K., BARTHOLOMEUS, H. & DISNEY, M. I. (2018), New Perspectives on The Ecology of Tree Structure and Tree Communities Through Terrestrial Laser Scanning [Review]. Interface Focus, 8 (2), Article 20170052. https://doi.org/10.1098/rsfs.2017.0052.

MARZULLI, M. I., RAUMONEN, P., GRECO, R., PERSIA, M. & TARTARINO, P. (2020). Estimating Tree stem Diameters and Volume from Smartphone Photogrammetric Point Clouds [Article]. Forestry, 93 (3), 411-429. https://doi.org/10.1093/forestry/cpz067.

MEDEIROS, H., KIM, D., SUN, J., SESHADRI, H., AKBAR, S. A., ELFIKY, N. M. & PARK, J. (2017), Modeling Dormant Fruit Trees for Agricultural Automation. Journal of Field Robotics, 34 (7), 1203-1224.

MILENNOVIĆ, M., EYSN, L., HOLLAUS, M., KAREL, W. & PFEIFER, N. (2012), Modeling The Tree Branch Structure at Very High Resolution. SilviLaser.

MÜNZINGER, M., PRECHTEL, N. & BEHNISCH, M. (2022), Mapping The Urban Forest in Detail: From LiDAR Point Clouds to 3D Tree Models. Urban Forestry & Urban Greening, 74, 127637.

SHI, Y., JIN, H. X., BAO, Z. Y. & GE, Y. (2016), Tree Structure Characteristics of Urban Built-up Area in China. Chinese Landscape Architecture, 32 (06), 77-82.

SOLECKI, W., SETO, K. C. & MARCOTULLIO, P. J. (2013), It's Time for An Urbanization Science [Article]. Environment, 55 (1), 12-17. https://doi.org/10.1080/00139157.2013.748387.

SUN, S., LI, C., PATERSON, A. H., JIANG, Y., XU, R., ROBERTSON, J. S., SNIDER, J. L. & CHEE, P. W. (2018), In-field High Throughput Phenotyping and Cotton Plant Growth Analysis Using LiDAR. Frontiers in Plant Science, 9, 16.

THE PARLIAMENT OF UNITED KINGDOM (2022.12.04). Climate Change Act 2008. https://www.legislation.gov.uk/ukpga/2008/27/contents.

WEI, X. H., WANG, Y. G., ZHENG, J., WANG, M. & FENG, Z. K. (2013), Tree Crown Volume Calculation Based on 3D Laser Scanning Point Clouds Data. Transactions of the Chinese Society for Agricultural Machinery, 44 (07), 235-240.

XIE, L. J., BAI, Z. K., YANG, F. Y., CHEN, M. J., FU, S. & MAO, Y. C. (2022), Research Progress on Carbon Sink Assessment Methods of Terrestrial Ecosystems at Home and Abroad Under the Background of Carbon Neutrality. Earth Science Frontiers, 1-17. https://doi.org/10.13745/j.esf.sf.2022.2.78.

XU, D., WANG, H., XU, W., LUAN, Z. & XU, X. (2021), LiDAR Applications to Estimate Forest Biomass at Individual Tree Scale: Opportunities, Challenges and Future Perspectives. Forests, 12 (5), 550.

YANG, C. & HAN, F. (2018), Digital Heritage Landscape: Research On Spatial Character of the Grand Rockery of Yuyuan Garden in Shanghai Based on 3D Point Cloud Technologies. Chinese Landscape Architecture, 34 (11), 20-24.

YANG, C., HAN, F. & LIU, C. (2018), Research on Methods for Recording and Visualising Spatial Information of Rural Landscape Heritage with Point Cloud Technology. Landscape Architecture, 25 (05), 37-42. https://doi.org/10.14085/j.fjyl.2018.05.0037.06.

YAO, J. Y., WANG, G. Y., LI, C. R. & YU, H. P. (2017), Characteristics of Net Ecosystem CO2 Exchange Over Typical Vegetation Types Above Different Regions. Journal of Lanzhou University (Natural Sciences), 53(05), 622-627. https://doi.org/10.13885/j.issn.0455-2059.2017.05.010.

ZHANG, S. C., WANG, K., YANG, X. Y. & XU, W. (2021), Research on Emission Goal of Carbon Peak and Carbon Neutral in Building Secto. Building Science, 37 (08), 189-198. https://doi.org/10.13614/j.cnki.11-1962/tu.2021.08.25.

ZHANG, X. J., LI, D., J., LIU, S., H., WANG, H., LI, X., H., LI, C., L., ZONG, J., B. & WANG, Y., X. (2022), Application Progress of Remote Sensing Technology in the Realization of “Double Carbon” Goal. Spaceraft Recovery & Remote Sensing, 43 (06), 106-118.

ZHANG, Y., MENG, W., YUN, H., XU, W., HU, B., HE, M., MO, X. & ZHANG, L. (2022), Is Urban Green Space A Carbon Sink or Source? – A Case Study of China Based on LCA Method. Environmental Impact Assessment Review, 94, 106766.

ZHANG, Y. K., YU, W. J., ZHAO, X.Z., LV, Y. X., FENG, W. H., LI, Z. R. & HU, S. J. (2021), Interactive Tree Segmentation and Modeling From ALS Point Clouds. Journal of Graphics, 42 (04), 599-607.

ZHOU, J. H., SUN, T. Z. (1995), Sanwei Lvse Shengwuliang De Yaogan Moshi Yanjiu Yu Lvhua Huanjing Xiaoyi Gusuan [Remote Sensing Model Study of Living Vegetation Volume and Estimation of Environmental Benefits of Greening]. National Remote Sensing Bulletin (03), 162-174.