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Indoor Space Modeling and Parametric Component Construction Based on 3D Laser Point Cloud Data

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Abstract: In order to enhance modeling efficiency and accuracy, we utilized 3D laser point cloud data for indoor space modeling. Point cloud data was obtained with a 3D laser scanner and optimized with Autodesk Recap and Revit software to extract geometric information about the indoor environment. Furthermore, we proposed a method for constructing indoor elements based on parametric components. The research outcomes of this paper will offer new methods and tools for indoor space modeling and design. The approach of indoor space modeling based on 3D laser point cloud data and parametric component construction can enhance modeling efficiency and accuracy, providing architects, interior designers, and decorators with a better working platform and design reference.

Keywords: 3D laser scanning technology; Indoor space; point cloud data; Building information modeling (BIM)

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1. Introduction

As technology continues to advance and the scope of applications expands, there is a growing demand for the modeling of indoor spaces and the construction of components. Indoor space modeling refers to the transformation of real-world indoor environments into digital three-dimensional models for the purpose of analysis, visualization, and various applications. Parametric component construction, on the other hand, involves generating component models that meet specific requirements through computer programs, using adjustable parameters or rules.

In the past, indoor space modeling and component construction heavily relied on manual measurements and manual modeling, which were time-consuming, labor-intensive, and prone to errors. However, with the emergence and maturity of 3D laser scanning technology, based on 3D laser point cloud data, indoor space modeling and parametric component construction have become rapid, efficient, and highly accurate [1]. 3D laser scanning technology involves the use of laser scanners or laser scanning cameras to capture a vast amount of point cloud data of the target indoor space. These point cloud data contain rich geometric and topological information, accurately reflecting the shape, structure, and details of the indoor environment. Parametric component construction leverages point cloud data and modeling algorithms to automatically generate component models that comply with specific rules and parameters.

Therefore, we aimed explore how to acquire point cloud data of indoor spaces using 3D laser scanning technology and achieve precise modeling of indoor spaces and automated generation of components through point cloud processing and parametric modeling methods through this study. This will significantly enhance the efficiency and accuracy of indoor space modeling and component construction, providing robust support and application foundations for fields such as architectural design, interior decoration, cultural heritage preservation, and more.

2. Introduction to 3D laser scanning technology and its advantages

A 3D laser scanner is a device capable of capturing three-dimensional point cloud data of indoor or outdoor environments. The 3D laser scanner described in this paper operates based on time-of-flight measurement and involves the following key steps. (i) Emission of laser beam: The scanner emits a laser beam, typically in the infrared spectrum. (ii) Reception of reflected signals: When the laser beam strikes surfaces on the target object, some of the light is reflected back and is received by the scanner's receiver. (iii) Calculation of time or phase difference: Using either the time of flight or phase measurement, the scanner calculates the time or phase difference required for the laser beam to travel from emission to reception; this information is used to determine the distance to the target object. (iv) Scanning point cloud data: During the scanning process, the scanner continuously changes the direction of the laser beam. By collecting and combining the acquired point cloud data, a comprehensive three-dimensional point cloud of the entire scene is generated. (v) Data processing: The obtained point cloud data can be subjected to various processing steps using algorithms and software; these steps may include filtering, registration, segmentation, and more, ultimately resulting in the generation of high-quality three-dimensional models.

3D laser scanning technology offers advantages such as high precision, non-contact measurement, efficiency, comprehensiveness, completeness, and visualization, among others. These advantages have led to its widespread application in fields such as architecture, design, engineering, cultural heritage preservation, manufacturing, and more. Additionally, it has driven progress and innovation in these areas.

3. Project overview and technical roadmap

To validate the effectiveness of the methods presented in this paper for establishing indoor models and parametric components, a residential indoor space within a residential community was selected as the experimental subject. The floor plan of the indoor space is shown in **Figure 1**. This indoor space is divided into two levels, connected by a three-turn staircase. The second floor space includes sloping beams and an attic. Using manual measurement methods would be extremely time-consuming and labor-intensive, and using drones for surveying would be challenging due to the indoor environment.

Considering the advantages and disadvantages of different surveying methods and based on the on-site conditions and technical feasibility, ground-based 3D laser scanning was chosen as the method for three-dimensional modeling of the indoor space.

The equipment used for this experiment is the FARO Focus3D X330 3D scanner. The detailed specifications of the scanner include the following: scanning element (laser module), scanning range (0–330 m), scanning medium (any), scanning speed (976,000 points/second), scanning light source (infrared laser), instrument size (240 × 200 × 100 mm), instrument weight (5.2 kg), instrument interface (USB 2.0 or Wi-Fi), instrument pixels (70 million), optical resolution (600 × 1200 dpi), operating temperature (5–40°C), and operating humidity (non-condensing). The software tools used for data processing and integration were Autodesk Recap and Revit. The specific technical roadmap is shown in **Figure 2**.

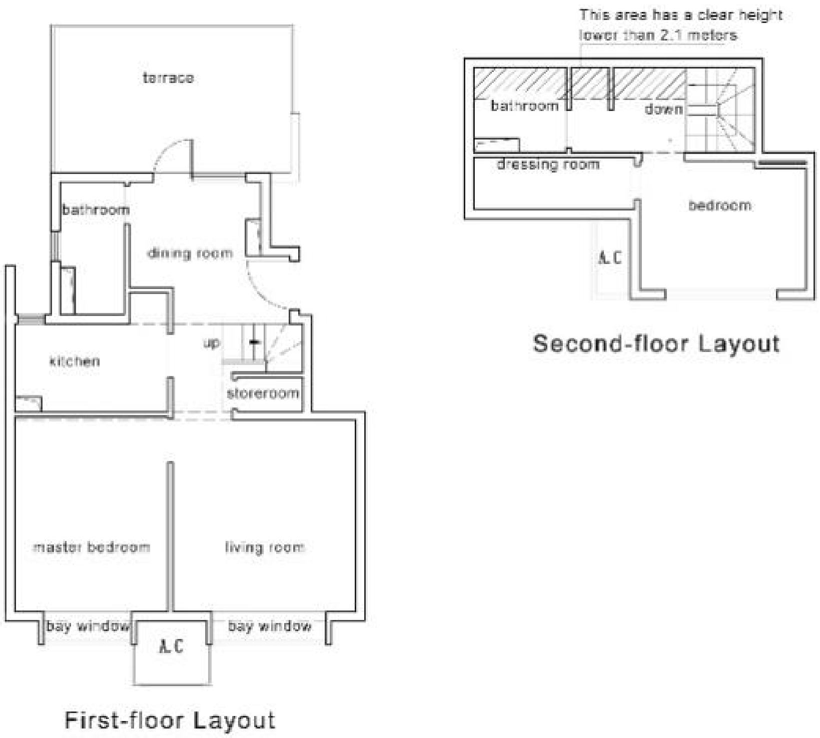


Figure 1. Project floor plan

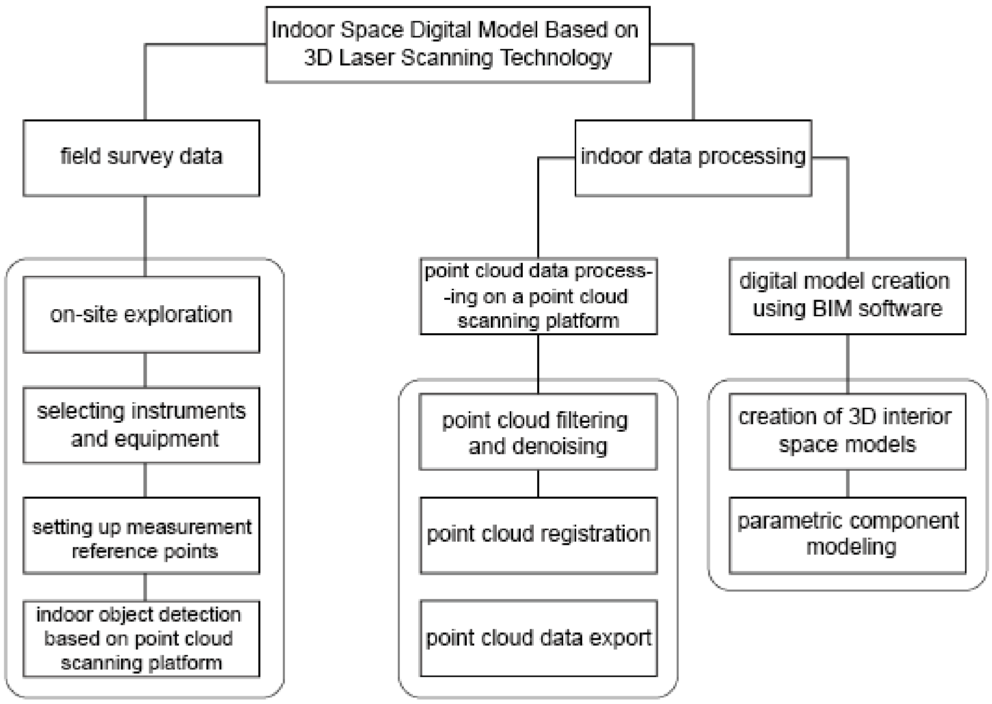


Figure 2. Technical roadmap

4. Field data collection

4.1. Site layout

Site layout is crucial before conducting the scanning process. Firstly, based on the requirements of the scanning task and the characteristics of the indoor space, the indoor area was divided into multiple scanning regions. Each region included the objects to be scanned while avoiding overlap or omissions as much as possible. Then, the scanners were placed at suitable positions. Several factors that were considered include the field of view, scanner height, scanner angles, and accessibility. The scanner covered the target area and achieve the desired scan density and angles.

As shown in **Figure 3**, point cloud data from two adjacent spaces are required, with Station 1 and Station 2 being set up for data collection. The diagonal region represents the overlapping area between the scan ranges of Station 1 and Station 2. Typically, in order to successfully stitch together data from two scanning areas, the overlapping region should be at least 30%. As shown on the left side of the image below, if the overlapping area between the two stations is too small, there won't be enough data for successful stitching. Therefore, it was necessary to set up a Station 3 at the connection point between the two spaces. Station 3 can bridge the data from Station 1 and Station 2, significantly increasing the overlap rate between the two stations, enabling successful connection [2]. The final station layout is shown in **Figure 4**, where solid circle markers represent data collection stations, and hollow circle markers represent station connection points.

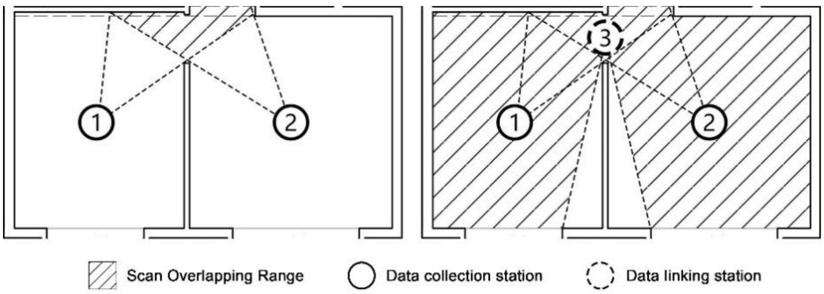


Figure 3. Scan overlap area comparison

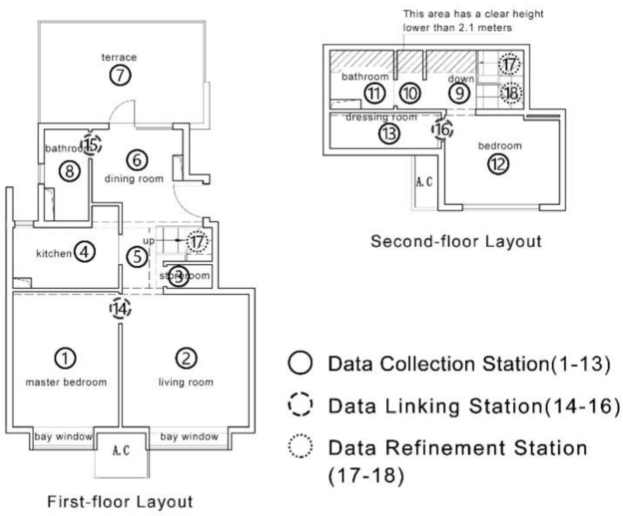


Figure 4. Scanner station layout diagram

4.2. Equipment installation

The legs of the tripod were extended and secured to be parallel with the ground. The tripod's height was adjusted to the preset level, ensuring that the scanning range includes reference points. A safety tether was used to secure the scanner to the tripod, ensuring the consistency and stability of the scan data. An SD card was inserted into the device to store the captured point cloud data. Once the instrument was placed on the station, the instrument's built-in level was used to confirm that the scanner is in a level position to prevent any errors in the scan data.

4.3. Scanning process

Once the instrument was set up, the operator clicked the start button on the main interface, and then moved away from the scanning area. The scanner started scanning automatically. During the scanning process, it was important to avoid any individuals entering the scanning area to reduce noise and prevent occlusion of data. Periodically, the calibration status of the scanner was checked to ensure the accuracy and consistency of data collection. Finally, data collection was completed at all stations, and the field data acquisition work was concluded.

5. Indoor data processing

5.1. Point cloud data processing

For the processed point cloud data, Autodesk Recap was used for stitching and noise reduction. Recap is a professional 3D point cloud processing and modeling software developed by Autodesk. Recap can integrate large amounts of point cloud data and generate high-quality digital models and visualizations.

The generated data files were imported into Revit for indoor space modeling and the creation of parametric components. Revit is a building information modeling (BIM) software also developed by Autodesk, used in fields such as architectural design, structural design, MEP (mechanical, electrical, and plumbing) design, and construction. The workflow for indoor data processing is described below.

(i) Data import and pre-processing

The unprocessed FLS format point cloud data was imported into Recap, The point cloud data were then pre-processed to improve its quality. This preprocessing includes point cloud filtering and noise reduction.

(a) Point cloud filtering

Point cloud filtering involves smoothing the point cloud data and removing excess noise and outliers. Filters can be applied based on attributes such as point position, intensity, and color to enhance the point cloud quality.

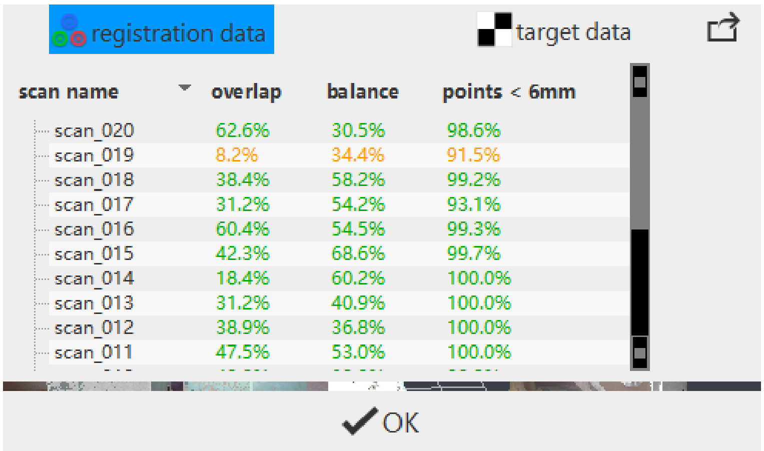
(b) Noise reduction

Noise reduction involves cutting the point cloud data within a defined geometric range, retaining only the necessary data within the specified area.

(ii) Point cloud registration and feature extraction

After preprocessing the point cloud data, Recap software performs point cloud registration to align the point clouds. This process is automatically conducted by Recap and employs the iterative closest point (ICP) algorithm to find the best rigid transformation that aligns the point clouds from different positions. Once registered, the point cloud data is in the same coordinate system [3].

After point cloud alignment, there may still be some slight mismatches or drifts. Recap further optimizes the matching precision through registration operations. Recap provides a registration data (**Figure 5**), which displays three metrics: “Overlap,” “Balance,” and “Points < 6mm.” These metrics evaluate the overlap between point cloud data from multiple scan positions, the uniformity of point distribution, and the precision of the data.



scan name	overlap	balance	points < 6mm
scan_020	62.6%	30.5%	98.6%
scan_019	8.2%	34.4%	91.5%
scan_018	38.4%	58.2%	99.2%
scan_017	31.2%	54.2%	93.1%
scan_016	60.4%	54.5%	99.3%
scan_015	42.3%	68.6%	99.7%
scan_014	18.4%	60.2%	100.0%
scan_013	31.2%	40.9%	100.0%
scan_012	38.9%	36.8%	100.0%
scan_011	47.5%	53.0%	100.0%

Figure 5. Registration data

Once the registration is complete, all point cloud data will be stitched together and placed within the previously defined coordinate system. At this stage, excess noise or unwanted point cloud data can still be removed by selecting and deleting them. Recap provides several automated feature extraction tools that can identify and extract features with specific geometric shapes or attributes within the point cloud data. These features may include walls, floors, ceilings, columns, and more.

After completing the above steps, a complete point cloud data model of the indoor space is formed. The final indoor point cloud data model is illustrated in the following images (**Figure 6** and **Figure 7**). Recap offers various analysis tools, such as volume calculations, point cloud measurements, and cross-sectional analysis. These tools can be used to extract various information about the indoor space, such as volume, area, height, and more. Once the point cloud data processing is complete, you can export the results in the desired formats, such as CAD files (DWG, DXF), BIM models (RVT, RCP), or other 3D model files (OBJ, FBX, etc.).

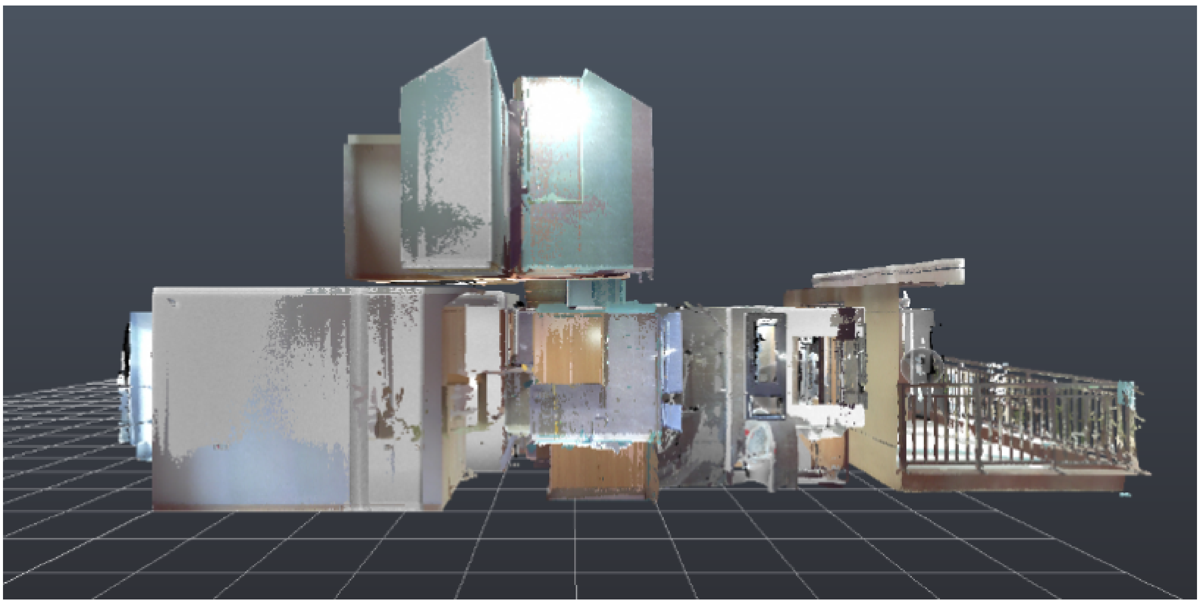


Figure 6. Indoor space 3D laser scanning point cloud data (overall)

Figure 7. Indoor space 3D laser scanning point cloud data (partial)

5.2. Establishment of three-dimensional indoor space model and construction of parametric components

(1) Importing and aligning point cloud data

After processing the point cloud data, the data was imported using a built-in function of Revit. Then, the imported point cloud data was aligned with the model base point by dragging the point cloud data or using Revit's modification tools. Common feature points, edges, or planes could be selected for aligning the point cloud data.

(2) Creating model elements

After importing the point cloud model, the process began with creating the basic geometric shapes of the model in Revit, such as walls, floors, and ceilings. Point cloud data served as a reference to help determine the position and shape of these basic elements. Geometric shapes were drawn in Revit based on the information from the point cloud data and were modeled according to the measured dimensions and positions. Parameters and attributes for these elements were set as required[4].

In Revit, by drawing floor plans and defining parameters such as dimensions, positions, and attributes for elements, the software will automatically create corresponding 3D models. This workflow, based on parametric modeling, links the drawing of floor plans to the creation of 3D models, allowing designers to more intuitively understand and adjust the spatial relationships and geometric shapes of architectural elements.

(3) Creation of parametric components

After creating the model, the next step involved using Revit's parametric modeling feature to transform the created model elements into parametric components. Revit offers a range of predefined component types, including doors, windows, and furniture, among others. Parameters were then defined for the selected component type. Parameters served as the fundamental units for controlling component properties, encompassing dimensions, materials, types, and more. Depending on the characteristics and design requirements of the component, appropriate parameter types, such as length, width, height, and material, were selected.

During the definition of parameters for components, parameters were associated with the geometric features of the model elements. This was done by selecting the geometric elements of the component and linking them to the appropriate parameters, ensuring that changes in parameters automatically affected the geometric shape of the component. (**Figure 8**).

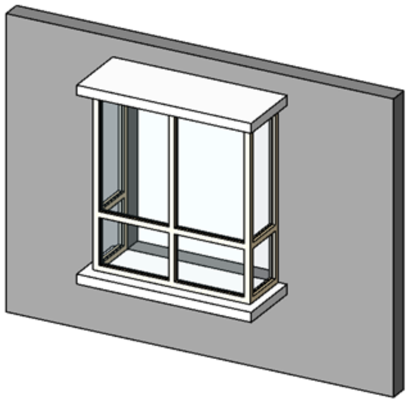


Figure 8. Parametric bay window

Then, a type catalog was created for the component type. A type catalog is a collection of component types with similar features. By defining a type catalog, component types could be better organized and managed, simplifying subsequent parametric modeling and use. Numerical values of parameters were adjusted to automatically modify the component's dimensions, shape, and material properties. The component was further fine-tuned by modifying parameter values based on design requirements and changes.

(4) Editing, optimization, and drawing output

After completing the model construction, further editing and optimization of the model involved using Revit's editing tools to adjust the dimensions, positions, and properties of elements. The model's appearance and visual effects were enhanced by adding materials, textures, and colors. Once the model construction was finished, Revit was used to generate various drawings and outputs (**Figure 9**). Views, sections, and profiles were defined to present the model from different perspectives and scales. This included creating floor plans, elevations, sections, as well as 3D views for design presentations, construction drawings, and visual displays.

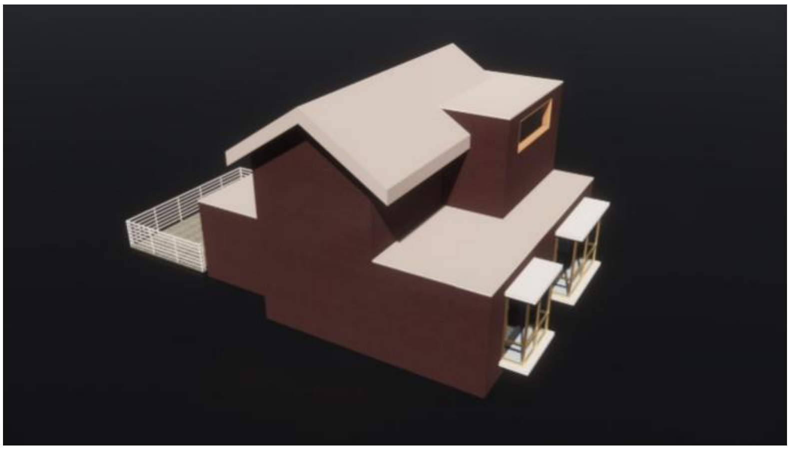


Figure 9. Indoor space 3D model

6. Conclusion

This research aimed to achieve indoor space modeling and parametric component creation based on three-dimensional laser point cloud data. High-precision point cloud data was acquired using a laser scanner, and

Autodesk Recap and Revit software were employed for data processing and modeling. Through the processing and analysis of point cloud data, we successfully reconstructed a three-dimensional model of indoor space and utilized parametric component technology for component creation and optimization. This provides more accurate, efficient, and visual tools and methods for interior design, construction, and maintenance.

However, there are still challenges and areas for improvement that need further exploration. Firstly, the processing and modeling of point cloud data still require significant manual intervention and operations, particularly during the point cloud registration and segmentation stages. Therefore, the development of automated and intelligent algorithms and tools is an important direction to reduce human effort and improve efficiency. Secondly, the current point cloud data processing and modeling mainly focus on static indoor environments, and challenges remain for dynamic and complex scenarios such as human activities and moving objects. Effectively processing and utilizing dynamic information to make modeling results more realistic and reliable is one of the future research directions.

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Disclosure statement

The authors declare no conflict of interest.

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