A crowdsourcing method for 3D furniture based on parameterized template

Biyun Qiao¹,²*, Qun Sun¹,², Hongyuan He¹,²

¹School of Earth Science and Information Physics, Central South University, Changsha 410083, China
²Key Laboratory of Metallogenic Prediction of Nonferrous Metals and Geological Environment Monitoring (Central South University), Ministry of Education, Changsha 410083, China

*Corresponding author: qiaoby@csu.edu.cn

Abstract. With the rapid development of indoor positioning and intelligent robotics technologies, fine-grained location services are approaching. The existing 3D indoor information acquisition and expression methods of furniture are complex and inefficient and cannot meet the needs of high-precision indoor location services. Therefore, this paper proposed a parameterized crowdsourcing method for indoor 3D furniture data based on a model library. This method used a set of classifications and codes of indoor furniture facilities, constructed multilevel feature expression parameters for indoor objects, established an indoor 3D furniture facility model library, and obtained 3D indoor furniture data using the “template + parameters” crowdsourcing method. An indoor furniture data organization model based on 3D parameters was established to manage, store and update indoor furniture facility data. In order to verify the effectiveness of the method, a 3D crowdsourcing system was developed. In the system, the building model was used as the basis for labeling, and the indoor room was the basic unit. The system realizes the functions of indoor scene browsing, 3D furniture data labeling and fast updating. The experimental results prove the feasibility of the crowdsourcing method and provide a new idea for using crowdsourcing for existing indoor 3D data.

1. Introduction

Human beings spend 85% of their time in indoor spaces [1], for living, working shopping and so on. With the rapid development of indoor positioning and intelligent robotics technologies, indoor location-based service is approaching to us [2]. Intelligent robotic elderly refinement care services at centimeter-level have been urgent application needs with tremendous market prospects. Refinement indoor location-based service needs the rich and refined information of 3D indoor features, include not only the building components, e.g., doors, windows, stairs, walls, etc., but also the location and distribution of the furniture and other facilities. Indoor spaces (especially shopping malls, stations, hospitals, etc., which are large and have many facilities) will be just a huge spatial entity if the information about indoor furniture is missing. Therefore, the acquisition and expression of indoor 3D data is an important research hotspot in the field of geographic information.
3D laser scanning and other ground-based professional data acquisition methods are capable of creating highly accurate indoor 3D models [3][4] which have been used for specific indoor data acquisition and modeling such as ancient buildings and large airports [5][6][7]. However, 3D laser scanning technology is difficult and inefficient to process data, and requires manual modeling with professional modeling software to obtain a complete indoor 3D model [8][9]. Due to the mobility of indoor furniture, 3D laser scanning technology is too expensive and inefficient to be used in ordinary office buildings and residential buildings.

More than a decade ago, crowdsourced geographic data was identified as a new source of information [10] and it has achieved great success in the acquisition of 2D spatial data [11]. The free crowdsourced data has been applied in many domains, e.g., public transportation [12][13], disaster management [14][15], Location-based services [16][17], etc. The success of crowdsourcing for 2D spatial data has prompted it to become a new way of acquiring indoor 3D spatial data as well [18]. For example, residents can become volunteers for indoor data contribution. OSM was extended in 2012 with IndoorOSM, which supports the reporting of interior building elements such as rooms, stairs, doors and windows in terms of floors [19]. In [20] propose a floor plan reconstruction system that leverages crowdsourced data from mobile users (Jigsaw). In [21] designed and implemented a public indoor map service and update system based on OpenStreetMap. However, most of the volunteers do not have professional 3D modeling ability to accurately describe furniture spatial information, which makes the crowdsourcing is difficult to quickly extend from 2D outdoor space to 3D indoor data acquisition and expression.

In fact, furniture with the same function has a similar composition structure. If it is possible to express the 3D information of furniture in parameters according to their functional and spatial characteristics. Then the public is expected to describe the furniture based on the provided furniture parameters and visualization templates. This paper proposes a parametric crowdsourcing method for 3D furniture data. Classifying furniture and designing characteristic parameters of similar furniture and establish 3D model templates of furniture. The spatial data of furniture is crowdsourced by the method of “3D model template + parameters”. This paper proposes a method to manage the 3D spatial information and semantic information of furniture, and provides an efficient and low-cost data acquisition method for indoor furniture.

The remainder of this paper is organized as follows. Section 2 reviews the related work about indoor data organization and indoor crowdsourcing. Section 3 introduces the methodology of the furniture parametric crowdsourcing. Furniture data organization are in Section 4. Section 5 is the indoor furniture 3d labeling experiments. Section 6 concludes the paper.

2. Methods

2.1. Furniture Parametric Crowdsourcing Principle
By furniture is meant free-standing or built-in units which are used for storing, lying, sitting, working and eating. According to the ISO Furniture standards, furniture can be divided into four categories: cabinets, beds, tables, and seating furniture in this paper. The detailed functions and characteristics of each type of furniture are described in Table 1.

| Class     | Function                                      | Examples                  |
|-----------|-----------------------------------------------|---------------------------|
| Cabinets  | Closed or semi-closed furniture for storing   | wardrobes, bookcases     |
| Beds      | Sleep or lie down for rest                    | double beds, bunk beds    |
| Tables    | Furniture for people to work, store           | dining tables, office tables|
| Seating furniture | Furniture for people to lean on to work or rest | sofas, armchairs |

In addition to the basic function for human use, furniture also has a decorative function, and the appearance of furniture is very rich in details. However, what needs to be expressed in GIS is the space...
occupancy information of objects, this paper mainly crowdsources the basic occupancy parameters and more detailed shape parameters of furniture.

Furniture generally has three basic parameters of length, width and height, but the length, width and height can only roughly determine the occupancy of furniture, which can meet some navigation application services that consider furniture as indoor obstacles. However, smart home applications such as robotic elderly services need to determine the detailed shape of furniture. This paper designs a 3D indoor furniture parametric acquisition and expression method, as shown in Figure 1. First of all, according to the spatial characteristics of various types of furniture to establish 3D models with professional modeling software, as a template. Users can make rough and refined 3D spatial parameterized description of furniture according to the template.

**Figure 1.** The parametric expression of 3D indoor furniture

The spatial information of indoor 3D furniture objects includes the category of the object, model style information and 3D parameter information. In this paper, the spatial parameter information of furniture object is expressed as follows:

\[
I = F \left\{ \text{Class}(T, N), \text{Them}(C, E, F), \text{Model}(M), \text{Space}(S_r, S_e) \right\}
\]  

(1)

In Eq. (1), Class means the category of furniture objects, T denotes the furniture category subdivided according to the spatial structure characteristics of furniture; N denotes the specific functional name of furniture, such as wardrobe, sofa, etc.

Them means the other attributes of the furniture object information, C denotes the material of the furniture object, this paper initially summarizes furniture material as wood, metal and plastic for the users to choose. E denotes whether the furniture in the indoor space has movable, for example, some closets, bars connected with walls are not movable, E = 0 means not movable, E = 1 means movable. F denotes whether the furniture object has scalability in the interior space, for example, some cabinets, folding chairs will occupy extra indoor space when used; E=0 means not scalable, E=1 means scalable.

Model means the model style of furniture objects, according to the class and structural characteristics of furniture to build 3D models, which constitute a library of furniture templates, M denotes the model ID of furniture in the model library.
Space \((S_r, S_e)\) means the 3D information of the furniture expressed in a parametric form. \(S_r\) is the spatial occupation information of the furniture object as a whole, and \(S_e\) denotes the refined shape parameters of the furniture. In the following section, the 3D parameters of the furniture are described in detail.

2.2. Furniture space parameters

2.2.1. 3D furniture space occupancy parameters. The occupancy information \(S_r\) of furniture object can be expressed as Eq. (2):

\[
S_r = S(L, W, H)
\]  

(2)

For furniture objects with a regular appearance, the spatial occupation parameters \(S_r\) are shown in Figure 2a, where parameters \(L\), \(W\), and \(H\) are the length, width, and height of the outer surface of the furniture model, respectively. For irregular furniture objects, their spatial occupation parameters \(S_r\) are shown in Figure 2b, where \(L\), \(W\), and \(H\) are the length, width, and height of the outer rectangular body of the furniture model, respectively.

![Figure 2. Example of furniture occupancy parameters](image)

2.2.2. Spatially refined shape parameters of furniture objects. The refined shape parameters \(S_e\) needs to be further refine the shape of the furniture based on spatial occupation parameters \(S_r\). The formal expressions of the refined parameters \(S_e\) for different class of furniture and the model schematic of each parameter for furniture are shown in Table 2. If an object does not have a certain feature, the parameter value is indicated by "-1". If there are multiple parameter values for the same feature, they are described in order from bottom to top and left to right, and are represented as an array.
Table 2. Formal expression of the refined parameter $S_e$ for furniture

| Type           | Features                                                   | Formal expression of the $S_e$                                                                 | Characteristic parameter schematics |
|----------------|------------------------------------------------------------|-----------------------------------------------------------------------------------------------|-------------------------------------|
| Cabinet        | 1. Openness                                                | $S_e = \text{Cabinets}(L_1, L_2, W_1, H_1, H_2, H_3, H_4, S_1, S_2, O)$                    | $S_2 = 3, O = 1$                    |
|                | 2. Cabinet door and drawer layout features                 |                                                                                               | $S_1 = (1, 2), S_2 = 3, O = 0$      |
|                |                                                            |                                                                                               |                                     |
| Beds           | 1. Ordinary single bunk bed and bed head                   | $S_e = \text{Beds}(L_1, W_1, H_1, H_2, H_3, L_2, W_2, H_4, H_5, S)$                      |                                     |
|                | 2. Bunk bed                                                |                                                                                               |                                     |
|                | 3. Bed with fence                                          |                                                                                               |                                     |
|                | 1. the shape of the table (rectangular or round)           |                                                                                               |                                     |
|                | 2. whether has drawers or cabinets                         |                                                                                               |                                     |
|                | 1. Chair seat, armrest, and backrest                       |                                                                                               |                                     |
|                | 2. Seat surface shape and footrest height                  |                                                                                               |                                     |
| Tables         |                                                            | $S_e = \text{Tables}(L_1, W_1, D, A, B, H_1, H_2, L_3, H_3, H_4, S_1)$                     | $S_3 = 3, S_2 = 1$                  |
| Seating furniture |                                                            |                                                                                               |                                     |
|                |                                                            | $S_e = \text{Seatings}(L_1, W_1, D, L_2, H_1, H_2, H_3, H_4)$                              |                                     |

1. Cabinet furniture is mainly composed of three parts: doors, compartments and drawers, so when establishing the expression of refine shape parameters, the main consideration is the openness of the cabinet, the layout characteristics of the cabinet doors, compartments and drawers. The refined characteristic parameters of Cabinet furniture can be expressed as $S_e = \text{Cabinets}$ (horizontal door length $L_1$, horizontal drawer/compartment length $L_2$, cabinet internal width $W_1$, vertical door height $H_1$, vertical drawer/compartment height $H_2$, cabinet bottom height from floor $H_3$, drawer top height from floor $H_4$, cabinet door top height from floor $H_5$, horizontal cabinet door, drawer/compartment column number $S_1$, vertical cabinet door, drawer/compartment column number $S_2$, openness $O$: 1=open, 0=closed).
(2) Bed furniture is mainly divided into three categories: ordinary single/double beds, bunk beds, and beds with fence. Ordinary beds mainly have two parts: the head and body. Bunk beds can be split into three parts: lower, upper and connecting ladder. Bed with fence consist of two parts: the bed body and fence. The refined characteristic parameters of Bed furniture can be expressed as $S_{e} = \text{Beds} (\text{bed length } L_1, (\text{lower}) \text{ bed width } W_1, \text{bed bottom height from the ground } H_1, (\text{lower}) \text{ bed height } H_2, \text{bed head height } H_3, \text{width of bunk bed connecting ladder } L_2, \text{bunk bed upper width } W_2, \text{bunk bed upper height from the ground } H_4, \text{bunk bed upper guardrail height } H_5, \text{bed fence height } H_6, \text{whether there is storage under the bed: } S=1 \text{ for true, } S=2 \text{ for false}).$

(3) The main characteristics of Table furniture are the shape of the table surface (mainly rectangular, round, and oval), and whether there are cabinets and drawers with storage functions underneath. The refined characteristic parameters of Table furniture can be expressed as $S_{e} = \text{Tables} (\text{rectangular table surface length } L_1, \text{rectangular table surface width } W_1, \text{round table top diameter } D, \text{oval table edge long axis length } A, \text{oval table top short axis length } B, \text{table surface height from the ground } H_1, \text{table bottom shelf height from the ground } H_2, \text{table left drawer/cabinet width } L_2, \text{table right drawer/cabinet width } L_3, \text{single drawer/cabinet height } H_3, \text{drawer/cabinet top height from the ground } H_4, \text{Number of drawer/cabinet rows } S_1, \text{number of drawer/cabinet columns } S_2)$.

(4) Seating furniture is divided into chairs and stools according to the presence or absence of a backrest. The characteristics of chairs include seat, armrests, and backrest. The characteristics of stools include the shape of the seat surface (mainly round and rectangular) and the location of the footrest. The refined feature parameters of chairs and stools can be expressed as $S_{e} = \text{Seating} (\text{rectangular chair/stool seat surface length } L_1, \text{rectangular chair/stool seat surface width } W_1, \text{round chair/stool seat surface diameter } D, \text{chair back inside length } L_2, \text{chair/stool seat surface height from the ground } H_1, \text{chair/stool lower footrest height from the ground } H_2, \text{chair armrest height } H_3, \text{chair back height } H_4$).

2.3. *Furniture model library construction*

The model library is constructed to allow users to easily retrieve and labeling the properties and spatial information of furniture. Therefore, it is necessary to subdivide diverse indoor furniture into types according to the specific use and appearance of furniture, which is the common name of furniture in daily life. This paper refers to the building furniture entity types summarized in the CityGML standard and expand them in Figure 3. In order to facilitate the management and expansion of the model library, a uniform 5-digit code is used to represent the furniture model template. These 3D models are built using SketchUP and Figure 4 shows the model template of closet numbered 10101. To help understanding and labeling, the specific meaning of each parameter is marked on the model template.
3. **Indoor furniture data organization**

Indoor furniture data includes spatial data, attribute data and metadata. The spatial data include the 3D information occupied by the furniture (S_r and S_e) and the location information (relative location and absolute location). The relative position of furniture in the room is indispensable for indoor location services, and it is not easy for the user to provide the absolute position of furniture in the indoor environment, instead the relative position is relatively easy to judge. In this paper, the room is used as
the basic scene unit of indoor crowdsourcing, and the relative location of furniture is referenced to the room and the absolute position is the geographic coordinates. The attribute data include the ID, category, name, model ID, room ID and other information of furniture. The metadata include the user ID, user name, labeling time and other labeling related information of furniture.

The UML (Unified Modeling Language) is used to describe the indoor furniture 3D data storage model taking into account the 3D spatial information, as shown in Figure 5. FurnitureTemplate describes the furniture 3D labeling model template for the labeling volunteers to select and visualize the 3D model. FurnitureType is used to describe the furniture classification. Room is used to describe the information of the labeling scenes, which is a spatial division of the building object. User is used to describe the basic information of the users. FurnitureObjects is used to describe the spatial location information, attribute information and labeling-related information of the furniture labeled by the volunteer. SpatialInformation can be used to describe the spatial location information and 3D parametric information of furniture objects. SpaceOccupancy describes the spatial occupancy parameter information of furniture. The 3D FineShapeParameters of each type of furniture are used to describe the spatial refined shape parameter of different categories of furniture.

Figure 5. Furniture data class diagram

4. Crowdsourcing Experiments
To verify the effectiveness of the furniture crowdsourcing method proposed in this paper, an indoor crowdsourcing module was developed based on WebGL. The module is based on CesiumJS for 3D scene visualization and a PostgreSQL database based on 3DCityDB for data storage. 3DCityDB completely maps the CityGML data model to a spatial relational database; as long as the relational model of the database is understood, the structure of the database can be extended and application-specific type tables and attribute fields can be added. The 3D City Database content can be directly exported in KML,
COLLADA, and glTF formats for the visualisation in a broad range of applications like Google Earth, ArcGIS, and the WebGL-based Cesium Virtual Globe.

The Building_furniture in Citygml LoD4 is used to describe the indoor furniture, and its description of furniture is relatively brief, which cannot meet the storage requirements of furniture 3D data, so the data model of Building_furniture needs to be extended. In this paper, CityGML is extended based on 3DCityDB to store furniture data and building data in an integrated way. The specific operations are: 1) extending the furniture table attribute fields, 2) creating new feature parameter tables for each type of furniture.

In this paper use the Geographic Information Building of Central South University as the experimental site to conduct indoor 3D furniture labeling experiments, Labeling of the student desks and chairs therein. The real length, width, height and detailed characteristic parameters of the student desks in the laboratory of the geomatics building were measured using the distance measurement function of a cell phone. First, one enters the crowdsourcing platform and locates the room 301 in the building. Then, he or she clicks on the model labeling, selects the desk model template in the furniture model library window. Then fill in the 3D spatial parameters of the measured desks and chairs and the relative coordinates in the room. Finally, the model is placed in the correct position for visualization. The labeling process is shown in Figure 6, and the completed scenes are shown in Figure 7. The attribute information and spatial information of the objects are stored in the database after the labeling is completed. The experiment proves that the Cesium-based crowdsourcing platform can realize integrated indoor and outdoor 3D data browsing, and the “model + parameters” crowdsourcing method can effectively collect and manage the 3D information of indoor furniture objects.

**Figure 6.** Furniture 3D labelling
5. Conclusion
To address the difficulty of acquiring and updating indoor 3D furniture data, this paper proposes a crowdsourcing labeling method based on the "model library + parameters" method without professional modeling. First, the common furniture types in the building are systematically classified and parametrically expressed, and different levels of feature expression parameters are designed for the furniture objects, including occupancy parameters and refined shape parameters. Second, a parametric-based furniture data labeling, storage and organization model is established to manage the attribute information, spatial information and crowdsourcing records contained in furniture objects, and easy to integrate with building data and other urban facility data. Finally, a 3D visualization labeling platform based on Cesium is developed to integrate the attribute information and spatial information of furniture objects into an intuitive type selection and parameter labeling scheme, providing users with a convenient way to contribute data. The experiments show that the method can acquire indoor 3D furniture data without the subsequent complex professional data processing and professional modeling ability. The method in this paper has a certain application and reference value for crowdsourcing and modeling of indoor 3D spatial data.

Acknowledgments
This work was financially funded by the National Natural Science Foundation of China (Project No. 41971360).

References
[1] Cheema, M.A. Indoor Location-Based Services: Challenges and Opportunities. SIGSPATIAL Special 2018, 10, 10–17.
[2] Ghawana, T.; Aleksandrov, M.; Zlatanova, S. 3D Geospatial Indoor Navigation for Disaster Risk Reduction and Response in Urban Environment. ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci. 2018, IV–4, 49–57.
[3] Dongzhen, J.; Khoon, T.Y.; Zheng, Z.; Qi, Z. Indoor 3D Modeling and Visualization with a 3D Terrestrial Laser Scanner. In 3D Geo-Information Sciences; Springer: Berlin/Heidelberg, Germany, 2009; pp. 247–255.
[4] Arayici, Y. An Approach for Real World Data Modelling with the 3D Terrestrial Laser Scanner for Built Environment. Automation in Construction 2007, 16, 816–829.
[5] Hou, M.; Li, S.; Jiang, L.; Wu, Y.; Hu, Y.; Yang, S.; Zhang, X. A New Method of Gold Foil
Damage Detection in Stone Carving Relics Based on Multi-Temporal 3D LiDAR Point Clouds.
IJGI 2016, 5, 60.

[6] Yang, B.; Zang, Y.; Dong, Z.; Huang, R. An Automated Method to Register Airborne and Terrestrial Laser Scanning Point Clouds. ISPRS Journal of Photogrammetry and Remote Sensing 2015, 109, 62–76.

[7] Wang, C.; Hou, S.; Wen, C.; Gong, Z.; Li, Q.; Sun, X.; Li, J. Semantic Line Framework-Based Indoor Building Modeling Using Backpacked Laser Scanning Point Cloud. ISPRS Journal of Photogrammetry and Remote Sensing 2018, 143, 150–166.

[8] Lee, S.Y.; Majid, Z.; Setan, H. 3D Data Acquisition for Indoor Assets Using Terrestrial Laser Scanning. ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci. 2013, II-2/W1, 221–226.

[9] Ingman, M.; Virtanen, J.-P.; Vaaja, M.T.; Hyppii, H. A Comparison of Low-Cost Sensor Systems in Automatic Cloud-Based Indoor 3D Modeling. Remote Sensing 2020, 12, 2624.

[10] Goodchild, M.F.; Fu, P.; Rich, P. Sharing Geographic Information: An Assessment of the Geospatial One-Stop. Annals of the Association of American Geographers 2007, 97, 250–266.

[11] Heipke, C. Crowdsourcing Geospatial Data. ISPRS Journal of Photogrammetry and Remote Sensing 2010, 65, 550–557.

[12] Mancini, A.; Zingaretti, P. Point to Point Navigation for People with Mobility Impairments. In Proceedings of the 2014 IEEE/ASME 10th International Conference on Mechatronic and Embedded Systems and Applications (MESA); IEEE: Senigallia, Italy, September 2014; pp. 1–6.

[13] Czogalla, O.; Naumann, S. Pedestrian Guidance for Public Transport Users in Indoor Stations Using Smartphones. In Proceedings of the 2015 IEEE 18th International Conference on Intelligent Transportation Systems; IEEE: Gran Canaria, Spain, September 2015; pp. 2539–2544.

[14] Poiani, T.H.; Rocha, R.D.S.; Degrossi, L.C.; de Albuquerque, J.P. Potential of Collaborative Mapping for Disaster Relief: A Case Study of OpenStreetMap in the Nepal Earthquake 2015. In Proceedings of the 2016 49th Hawaii International Conference on System Sciences (HICSS); IEEE: Koloa, HI, January 2016; pp. 188–197.

[15] Rahman, K.M.; Alam, T.; Chowdhury, M. Location Based Early Disaster Warning and Evacuation System on Mobile Phones Using OpenStreetMap. In Proceedings of the 2012 IEEE Conference on Open Systems; IEEE: Kuala Lumpur, Malaysia, October 2012; pp. 1–6.

[16] Das, R. C.; Alam, T. Location Based Emergency Medical Assistance System Using OpenstreetMap. In Proceedings of the 2014 International Conference on Informatics, Electronics & Vision (ICIEV); IEEE: Dhaka, Bangladesh, May 2014; pp. 1–5.

[17] Krisp, J.M.; Keler, A. Car Navigation – Computing Routes That Avoid Complicated Crossings. International Journal of Geographical Information Science 2015, 29, 1988–2000.

[18] Basiri, A.; Haklay, M.; Foody, G.; Mooney, P. Crowdsourced Geospatial Data Quality: Challenges and Future Directions. International Journal of Geographical Information Science 2019, 33, 1588–1593.

[19] Fadli, F.; Kutty, N.; Wang, Z.; Zlatanova, S.; Mahdjoubi, L.; Boguslawski, P.; Zverovich, V. Extending Indoor Open Street Mapping Environments to Navigable 3D CityGML Building Models: Emergency Response Assessment. Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci. 2018, XLII–4, 161–168.

[20] Gao, R.; Zhao, M.; Ye, T.; Ye, F.; Luo, G.; Wang, Y.; Bian, K.; Wang, T.; Li, X. Multi-Story Indoor Floor Plan Reconstruction via Mobile Crowdsensing. IEEE Trans. on Mobile Comput. 2016, 15, 1427–1442.

[21] Yue, H.; Wu, H. Update Method of Indoor Maps Based on Volunteered Geographic Information (VGI). In Proceedings of the 2018 26th International Conference on Geoinformatics; IEEE: Kunming, June 2018; pp. 1–5.