



Integrating IndoorGML with outdoors: Automatic routing graph generation for indoor-outdoor transitional space for seamless navigation

ISPRS Scientific Initiatives 2023
Final Report

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29 Feb, 2024.

Summary

The indoor and outdoor transitional space plays an important role in seamless navigation. Although IndoorGML has been proposed for modeling of indoor navigable space, there still is a lack of solid scientific foundations and efficient tools to perform space subdivision for the indoor and outdoor connecting space and to find navigable space linking indoor and outdoor environments. To address this gap, in this scientific initiative we focus on modeling of the indoor and outdoor transitional space and have developed an approach based on a global subdivision model GeoSOT-3D to derive navigable space. A python tool has been developed to build IndoorGML models and to automatically construct routing graphs for the indoor-outdoor connecting space. The developments from this project will greatly advance the capability of IndoorGML in representing navigable space for seamless integration of indoor-outdoor navigation.

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1 Introduction

The indoor-outdoor transitional space plays a very important role in seamless navigation for pedestrians. However, the intermediate space between inside and outside of buildings contains various urban objects (e.g., stairs, walls, and grass) and varies with sizes and forms, which makes it difficult to identify the navigable spaces that can link indoor and outdoor environments. The complexity of indoor-outdoor transitional space also makes it very difficult for the existing standards (such as IndoorGML [Li, 2016]) to capture navigable space. While clear boundaries can be defined for indoor environments based on architecture components (e.g., rooms, walls, and doors), no clear boundaries exist for outdoor environments. Therefore, a unified framework, which can be used for representation of indoor-outdoor transitional space, is needed to support seamless navigation for pedestrians.

In this project we focus on connection of indoor and outdoor spaces and aim to provide a tool which can automatically construct navigation graphs of the indoor-outdoor transitional space to support seamless navigation.

2 Proposed approach

To achieve the objective above, in this project we have adopted a global grid system, named GeoSOT-3D, to performance space subdivision for the indoor-outdoor transitional space and constructed the navigation graphs based on IndoorGML models. GeoSOT-3D is one of Discrete Global Grid Systems (DGGS) [Purss et al., 2017] within OGC¹ and discretizes the surface of the Earth into a set of cells. In this project we have used GeoSOT-3D [Cheng et al., 2016, Li et al., 2016] to divide the connecting space between indoor and outdoor environments and to generate voxel models. We have developed a python tool which can create the voxel models based on point clouds, identify navigable space by taking into account space semantics (such as grass, grounds, and obstacles) and finally build IndoorGML models.

2.1 IndoorGML

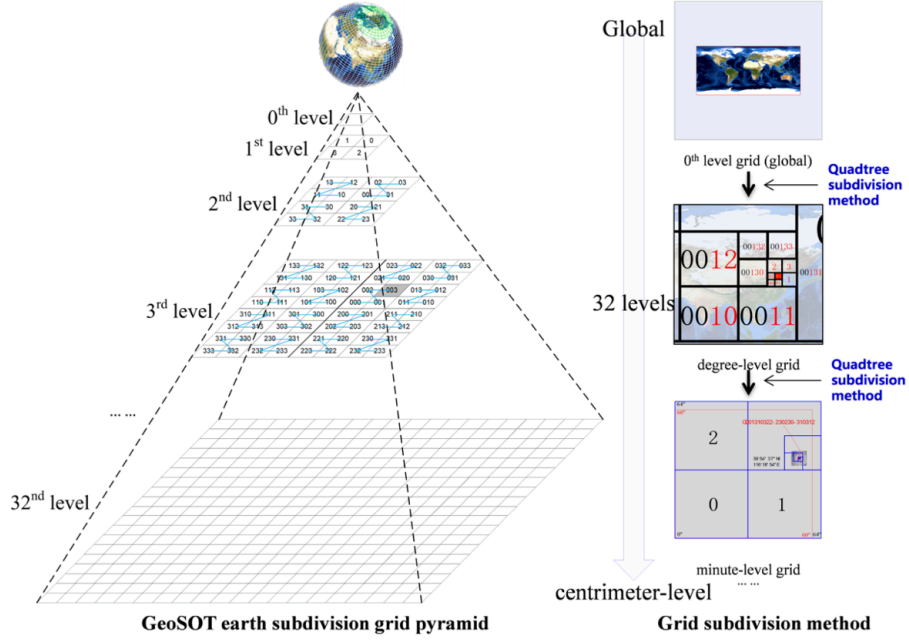
IndoorGML is one of OGC standards and focuses on modeling of indoor spaces for navigation purposes. It provides a concept to capture the topological elements between indoor spaces [Li, 2016].

2.2 DGGS and GeoSOT-3D

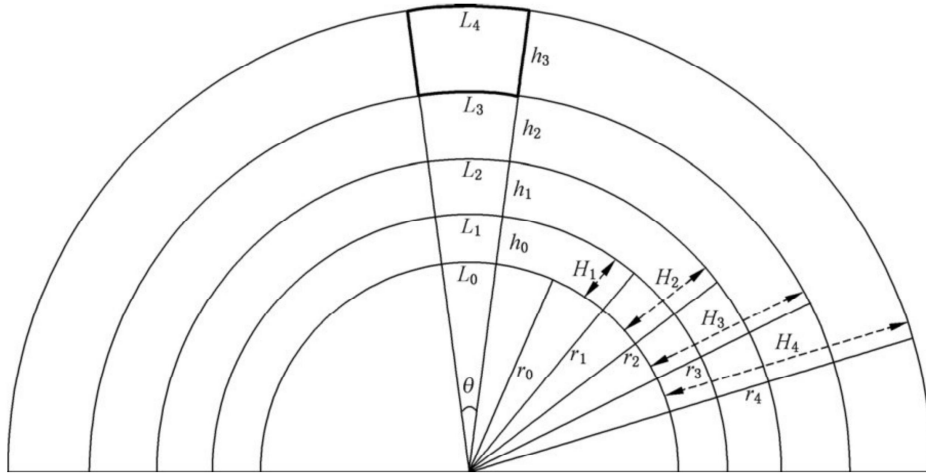
GeoSOT-3D [Cheng et al., 2016, Li et al., 2016, Han et al., 2022] is one of Discrete Global Grid Systems (DGGS) developed for global subdivision. Within GeoSOT-3D, the earth is divided into 3D grids where spatial locations are binary encoded (as shown in Figure 1a). The binary 3D code consists of three parts and each part corresponds to longitude, latitude and height respectively. The total length of binary 3D code is 96 bits and each part is represented by 32 bits. For example, the binary code for longitude of $116^{\circ}18'54.8''$ in a level-27 grid is "00111010001001011011011001100000", where the first "0" is the east longitude code, the degree value 116 is converted to "01110100", the minute value 18 is converted to "010010", and the second value 54.8 is converted to "11011011001100000". Note the representative code after 27 bits is taken as 0 because the grid level is 27. The same holds for latitude.

For the subdivision of height, totally 32 levels are divided, with 16 levels for the underground and 16 levels for the above ground. It is defined that the grid cell height is equal to the equator contour length of the same level (i.e., $h_i = L_i$), as shown in Figure 1b. By using Formula (1), the geodetic height is converted to degrees (ranging from -256° to 256°), which is then binary coded (as it is done for latitude and longitude).

¹<https://ogcapi.ogc.org/dggs/>



(a) The global subdivision for longitude and latitude (from [Han et al., 2022]).



(b) The global subdivision for height (from GB/T 40087-2021).

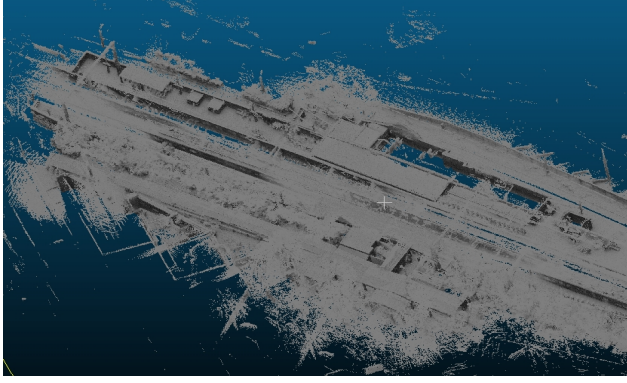
Figure 1: The overview of the GeoSOT-3D global subdivision.

$$n = \frac{\theta}{\theta_0} \log_{1+\theta_0} \left(\frac{H + r_0}{r_0} \right) \quad (1)$$

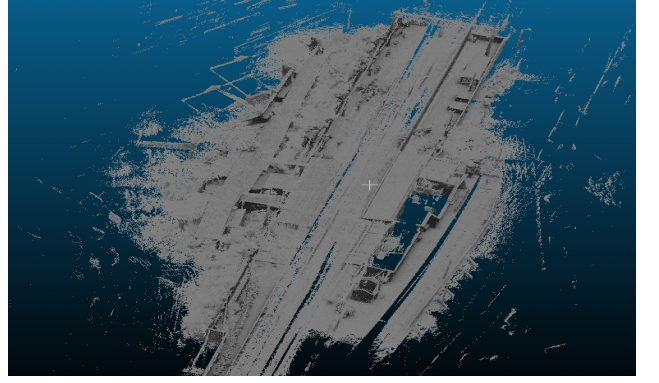
where θ is the latitude (longitude) difference, θ_0 is $\frac{\pi}{180}$, r_0 is the equator radius, and H is the geodetic height.

The binary codes for longitude, latitude, and height are combined according to Morton 3D². In this study, we adopt the combined binary 3D code to capture the geo-locations of objects, which can be used for 3D space construction and distance calculations. For more details about the GeoSOT-3D subdivision, please refer to [Cheng et al., 2016, Zhang and Li, 2022, GB/T 40087-2021].

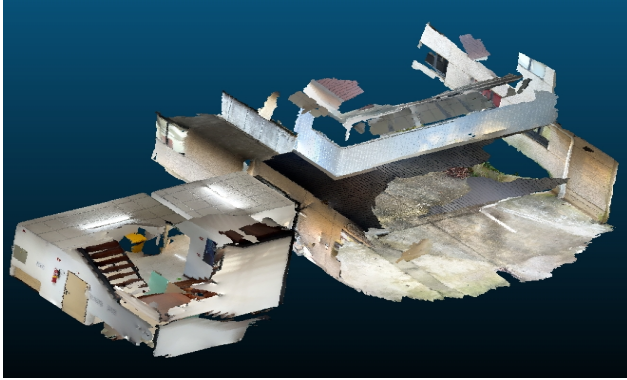
²<https://github.com/Jianningli/Morton3D>



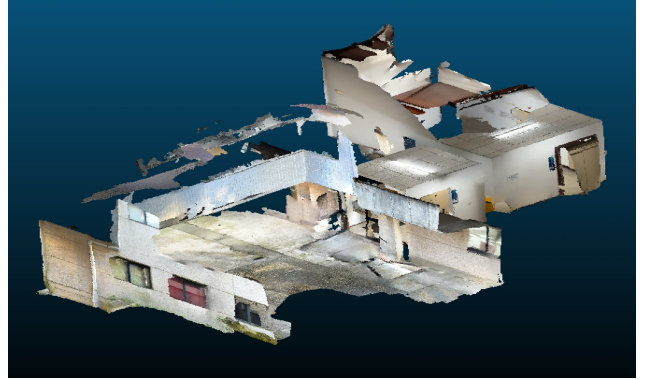
(a1)



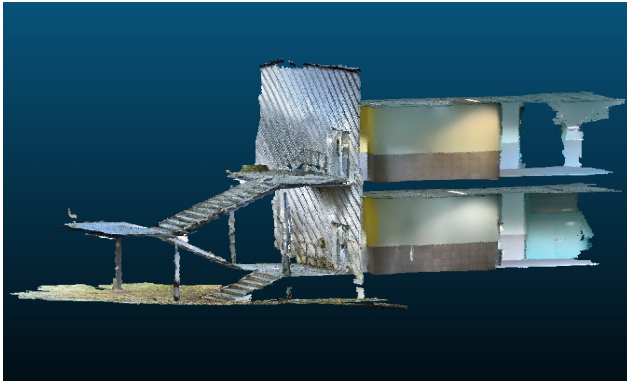
(a2)



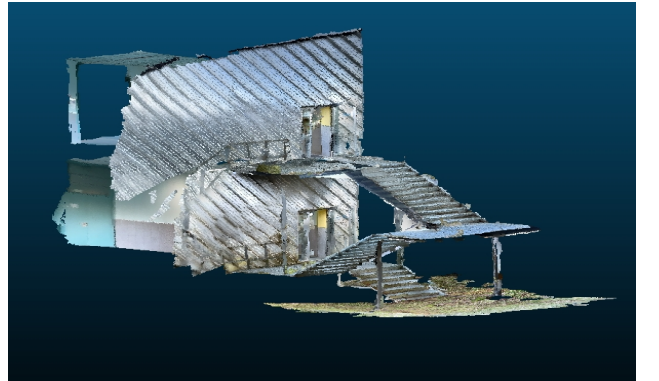
(b1)



(b2)



(c1)



(c2)

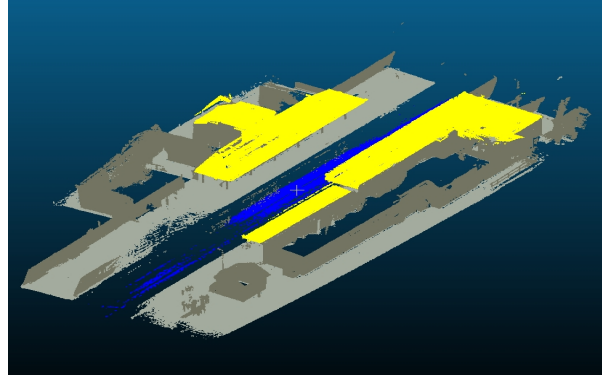
Figure 2: The collected point clouds: a) the Cheltenham Station (CS) in Australia; b) a research center building (Building 1) in the University of Vigo; c) a university school building (Building 2) in the University of Vigo.

3 Data and method

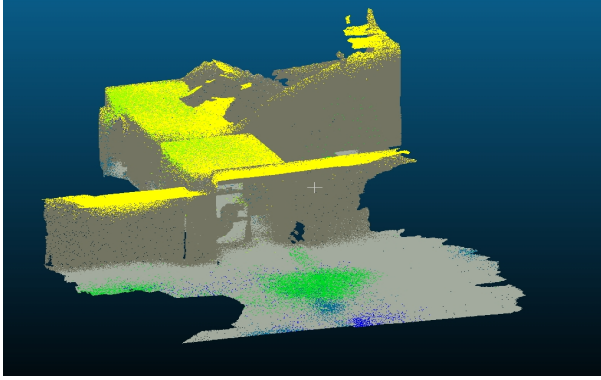
3.1 Collection and preprocessing of point clouds

Totally three point cloud datasets have been collected by using Terrestrial Laser Scanners and iPhone (Figure 2): 1) the Cheltenham Station (CS) in Victoria, Australia (AU); 2) a research center building (Building 1) in the University of Vigo (UV), Spain; 3) a university school building (Building 2) in UV, Spain. They not only cover indoor environments but also capture the indoor-outdoor transitional space that connects the roads and the entrances. In this study, the collected point clouds have been georeferenced via CloudCompare³ and semantically segmented into different classes (e.g., roads, vegetation, and grounds) by using PointNet++ [Qi et al., 2017]. The PointNet++ framework

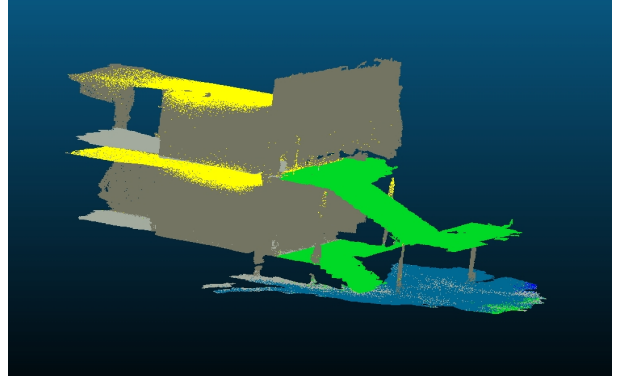
³<https://www.cloudcompare.org/>



(a)



(b)



(c)

Figure 3: The results of point cloud semantic segmentation: a) the CS in AU; b) Building 1 in UV; c) Building 2 in UV.

has been demonstrated to be efficient and robust in labelling raw point clouds. The segmentation results are shown in Figure 3.

3.2 Generation of voxel models

Based on the Python packages (e.g., Numpy⁴ and Pandas⁵), we have developed a tools to voxelize point clouds and to generate the voxel models according to the GeoSOT-3D subdivision framework (with grid level of 28, voxel width about 0.25 m, and voxel height about 0.24 m). The generated voxel models are shown in Section 4.1. The developed tool first excludes all voxels that are identified as obstacles (e.g., walls) and then excludes the voxels that have voxels above to derive free space. After that it performs region growing to generate navigable space for pedestrians based on the connectivity between voxels. The details of the developed tool has been published in the GitHub repository (see Section 6).

3.3 Generation of IndoorGML models

The voxels, which are generated based on GeoSOT-3D and available for pedestrian navigation, are transformed into an IndoorGML model. Each voxel corresponds to a cell in the IndoorGML model. Each transition in the model is associated with the GeoSOT-3D codes of the connected cells.

4 Results

We have applied the developed python tool to the collected point cloud datasets and generated the voxel models as well as IndoorGML models (see Section 4.1 and 4.2). We have also tested the tool

⁴<https://github.com/numpy/numpy>

⁵<https://github.com/pandas-dev/pandas>

with some routing cases (see Section 4.3).

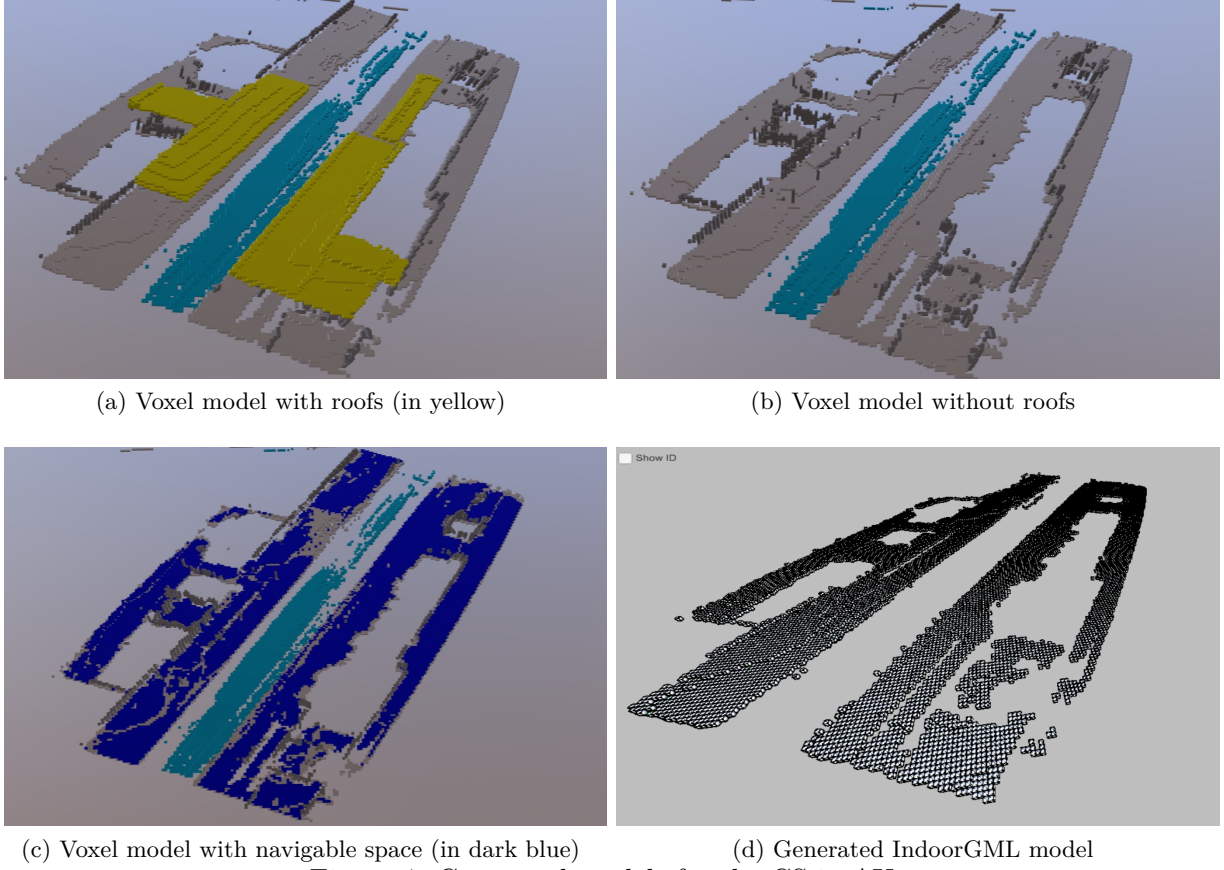


Figure 4: Generated models for the CS in AU

4.1 Visualization of voxel models

The generated voxels are visualized in the GLTF/GLB format⁶ and are colored differently according to their availability for pedestrian navigation (Figure 4a-c, Figure 5a-c, and Figure 6a-c). The light blue voxels are space that can not be used by pedestrians. The dark grey voxels represent obstacles (e.g., walls) that should be avoided by pedestrians. The dark blue voxels are generated based on the voxels available for pedestrian navigation, such as stairs (in brown), vegetation (in green), and ground (in light grey), and will be used for generation of IndoorGML models (Section 4.2).

4.2 Visualization of IndoorGML models

The voxels, which are generated based on GeoSOT-3D and available for pedestrian navigation, are transformed into an IndoorGML model (see Figure 4d, Figure 5d, and Figure 6d). Each cell in the IndoorGML model corresponds to a voxel in the navigable space. Each transition in the model is represented by a link and used to connect cells.

4.3 Visualization of routing results

We performed the shortest routing based on the IndoorGML models generated from above. For calculation of the distance between voxels, the Manhattan distance is used in this study. A big advantage of using the Manhattan distance is that it simply computes the number of voxels along each dimension and allows for fast computation of distance in the GeoSOT-3D binary space. Figure 7 shows the routing results for each studied building.

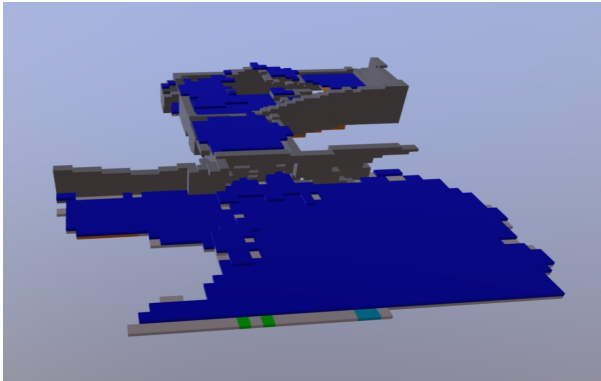
⁶<https://github.com/KhronosGroup/glTF>



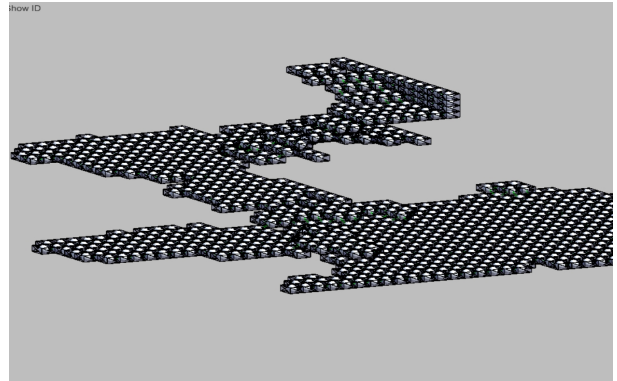
(a) Voxel model with roofs (in yellow)



(b) Voxel model without roofs



(c) Voxel model with navigable space (in dark blue)

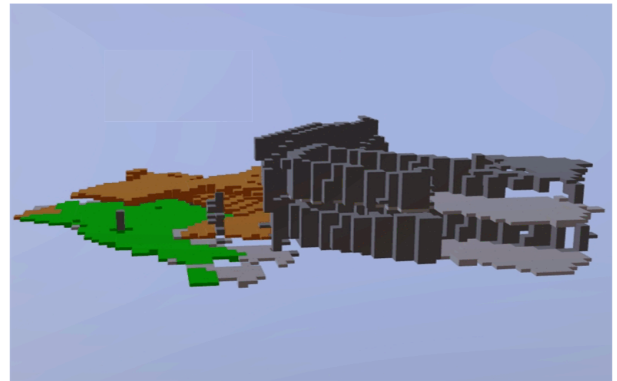


(d) Generated IndoorGML model

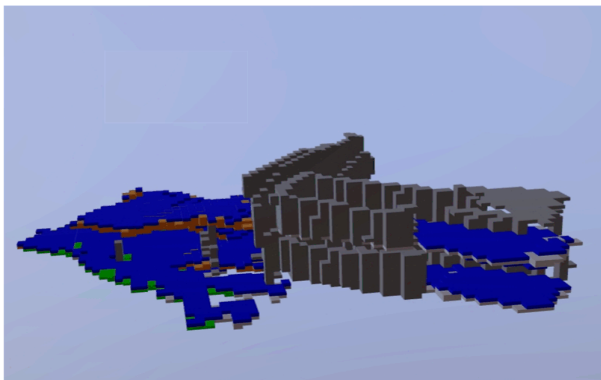
Figure 5: Generated models for Building 1 in UV.



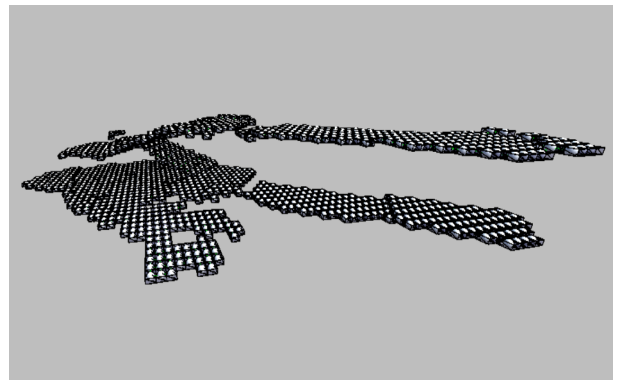
(a) Voxel model with roofs (in yellow)



(b) Voxel model without roofs

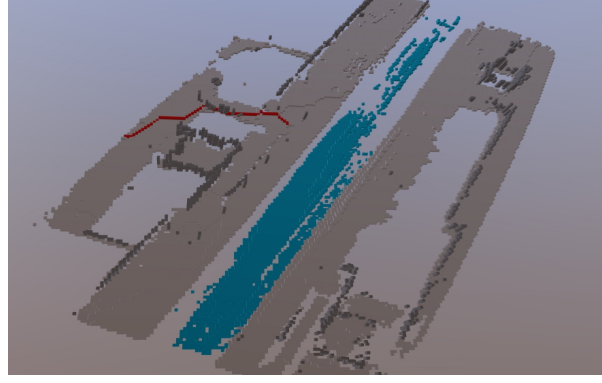


(c) Voxel model with navigable space (in dark blue)

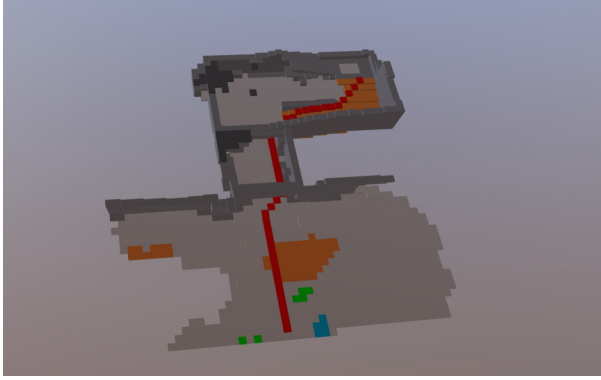


(d) Generated IndoorGML model

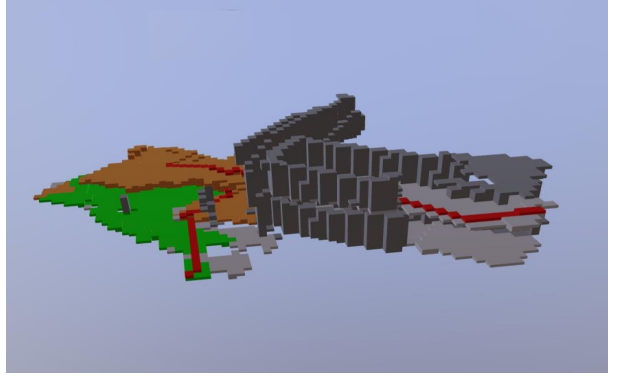
Figure 6: Generated models for Building 2 in UV.



(a)



(b)



(c)

Figure 7: The routing results: a) the CS in AU; b) Building 1 in UV ; c) Building 2 in UV. The calculated routes are colored in red.

5 Conclusions and recommendations for future research

In this project, we focus on modeling of indoor-outdoor transitional space and have developed an approach to automatically construct routing graphs of the indoor-outdoor transitional space to support seamless navigation. We have used point clouds to capture both indoor and outdoor environments and applied PointNet++ to carry out semantic segmentation. Base on the GeoSOT-3D framework, a python tool has been developed to perform space subdivision of the indoor-outdoor connecting space, to derive the navigable space, and to generate IndoorGML models. The routing testing results show the potential of the proposed approach in supporting seamless navigation.

Based on the results of this project, some issues should be mentioned and need to be further investigated:

- The proposed approach depends heavily on semantic segmentation of point clouds. A misclassification of points of certain architectural components could lead to loss of navigable space. Thus coupling point clouds with other data sources (e.g., camera images) is required to ensure the successful generation of navigable space.
- Investigation of the influence of irregularity of the voxels on routing. The voxels generated from GeoSOT-3D are not regular, which could influence the calculation of distance between voxels. How to take the irregularity of voxels into routing should still be studied.
- Research on voxel generation for other types of agents like wheelchair users. In such case the slope of voxels should be considered for deriving navigable space. The situation can be more complex if dynamic obstacles are involved.

6 Main output

- (1) A project webpage containing the details of this project, <https://tgis-lab.github.io/project/integrating-indoorgml-with-outdoors/>
- (2) A data repository containing the datasets used in this project, <https://doi.org/10.6084/m9.figshare.25323826>
- (3) A GitHub repository containing the source codes of the python tool developed from this project, <https://github.com/tgis-lab/geopcd2indoorgml>
- (4) A journal paper written based on the above results and to be submitted to an international journal
- (5) A conference paper published in the ISPRS Geospatial Week (GSW) 2023:
Wang, Z., Zlatanova, S., Mostafavi, M. A., Khoshelham, K., Díaz-Vilariño, L., & Li, K. J. (2023). Automatic Generation of Routing Graphs for Indoor-Outdoor Transitional Space to Support Seamless Navigation. ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 10, 487-492.

7 Project Expenses

The total grant received from ISPRS for this project was CHF 8,500 (CNY 64,100). The project expenses are summarized in the following table.

1	Personnel	27,000 CNY
2	Hardware for data processing and management	31,080 CNY
3	ISPRS GSW2023 and OGC event registration fees	5,845 CNY
4	Management fees	6,000 CNY
Total		69,925 CNY

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