Identification of walkable space using a point cloud and its trajectory

Automatic generation of indoor navigation maps based on semantical enrichment of point cloud data by the trajectory of a mobile laser scanner

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Bart Staats

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The work in this thesis was made in cooperation with:

3D geoinformation group
Department of Urbanism
Faculty of Architecture and the Built Environment
Delft University of Technology

CGI Nederland

Geometius

Supervisors:	Prof.Dr. Sisi Zlatanova
	Dr. Abdoulaye Diakité
	Robert Voûte (CGI Nederland)
Data collection:	Rob Bik (Geometius)

Abbreviations

GNSS	=	Global Navigation Satellite System
MLS	=	Mobile Laser Scanner
TLS	=	Terrestrial Laser Scanner
Indoor navigation map	=	A map of the indoor environment containing navigatable elements which makes it possible for path
roadmap	=	A map with route planning capabilities

1 Introduction

Nowadays outdoor navigation systems are well used in all kinds of applications. These systems use GNSS to determine the position of the user. With this position and a roadmap, the route to the destination can be found in an efficient way. It is also possible to position a user inside a building. The indoor navigation systems are still limited available due to various reasons. Firstly, because it is impossible for GNSS signals to be received inside buildings. Companies like Blooloc or Essensium solve this problem by installing extra infrastructure. Therefore these systems are only available in a few buildings whereas the satellite systems produces a worldwide positioning system at once. Secondly, the indoor environment is far more complex than the outdoor environment (Zlatanova, Liu, Sithole, Zhao, & Mortari, 2014). This makes the production of indoor navigation maps challenging and time consuming. To increase the production of indoor navigation maps a lot of research is done to automate this process. Most research focus on the available 2D floorplans and only few of them use the complex 3D representations (Zlatanova et al., 2014).

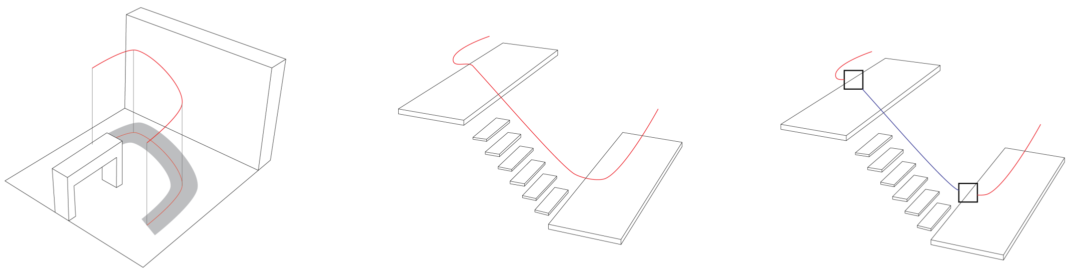
Using 2D floorplans has its limitations. First of all, the 2D maps are already a simplification of the complex 3D environment which can lead to difficulties in representation and connectivity between floors (Zlatanova et al., 2014). Secondly, the maps who are available do not always contain furniture and most existing methods only focus on the reconstruction of the indoor space with less attention to obstacle detection (Díaz-Vilariño, Boguslawskib, Khoshelhamc, Lorenzod, & Mahdjoubib, 2016). Thirdly, most floorplans are out of date or are not available at all (Turner, Cheng, & Zakhor, 2015). This problem is created right after the building is delivered and users change the configuration of the furniture or restructure the complete indoor space after a few years. A possible solution is to update all the changes in the original map by hand. Obviously, this method is time consuming, inefficient and costly.

A possible solution for this problem is found in the use of terrestrial laser scanning (TLS) devices. The interior of a building can now be captured more quickly (Díaz-Vilariño et al., 2016). Because of the number of rooms and the occlusion of elements capturing the whole building with a TLS still requires a lot of scan positions and time. Therefore recent developments introduced mobile laser scanning (MLS) devices. These devices scan the environment continuously along a trajectory which makes them more time efficient (Holenstein, Zlot, & Bosse, 2011). Scanning the inside of a building is now a matter of hours.

The MLS device saves the scanned environments in point clouds. These point clouds only contain the local x, y and z coordinate of the points and represent an unstructured space. To structure these points in space a voxel approach can be used. When a certain amount of points is present in a voxel, this voxel is noted as occupied and will be stored. This transforms the unstructured environment of a point cloud into a structured voxel space (Vo, Truong-Hong, Laefer, & Bertolotto, 2015). The representation of the voxelized point cloud depends on the voxel size. A small voxel size increases the representation but also increases the amount of voxels and increases the computation time. A good balance between the two is important to get the right results in a reasonable amount of time.

With the MLS device the inside of a building is captured more quickly than manually updating a map. The result of this scanning is no map but a point cloud. The next challenge is to identify different building components like floors, stairs, walls and furniture based on these point clouds. Many approaches are built on a set of constraints, like a Manhattan world assumption or horizontal floors (Fichtner, 2016; Khoshelham & Díaz-Vilariño, 2014; Macher, Landes, & Grussenmeyer, 2016). Furthermore the detection of stairs is difficult, as can be seen in (Fichtner, 2016; Koopman, 2016). These constraints and limitations are not problematic for a regular office building but are in more complex environments.

Beside the point cloud, the MLS also stores the trajectory of the scanner. The position of the scanner along this trajectory is used in other research to clean point clouds, to determine the scanner position or to improve a delaunay triangulation (Holenstein et al., 2011; Verbree & van Oosterom, 2001). These are good examples of making use of the scanner trajectory but the scanner trajectory contains more information. If the MLS scanner is controlled by a human operator, the points directly beneath the trajectory of the scanner represent human walkable points see Figure 1.1a (Yan et al., 2016). If the operator changes floors using stairs, the trajectory contains a height difference. This height difference says something about whether a crossed surface is flat or not-flat and therefore could be used to identify points that belong to stairs or ramps Figure 1.1b. If doors and stairs can be identified, the trajectory also contains space to space connection information Figure 1.1c. All this semantical information is already available in the scanner trajectory but is unfortunately not yet used in existing methods. Therefore this MSc thesis will investigate the usability of the MLS trajectory to identify the walkable spaces of the interior of a building.



(a) Walkable points below a trajectory

(b) Stair detection

(c) Connection information

Figure 1.1: Sementical information present in a MLS trajectory

1.1 Research question

As described in the introduction, the trajectory of the MLS scanner contains a lot of semantical information. This MSc thesis will investigate if this trajectory could be used to identify human navigable space. The following research question will be answered:

Which walkable space could be identified from a voxelized point cloud using the trajectory of a mobile laser scanner?

1.1.1 Sub questions

Before the research question can be answered, the following sub questions need to be investigated:

1 What are the characteristics of a walkable space?
2 How could the trajectory of a mobile laser scanner be used to identify walkable spaces?
3 How can the walkable area identified by a mobile laser scanner trajectory, be subdivided into different spaces?
4 In what way does the voxel size influence the performance and accuracy of the generated walkable space?
5 How can the generated information be aligned with existing indoor standards?

1.2 Scientific relevance

As discussed earlier, many approaches build on a set of constraints like a Manhattan world or only flat surfaces. Because of the complexity of buildings and the used methods they need to apply these constraints. The trajectory of the MLS is captured together with the point cloud. Analyzing and using this trajectory to identify elements does not need constraints because the complexity of the interior space is already present in the trajectory. As far as the author knew there is no other research that uses the trajectory for this purpose. Therefore this approach is a new method in the field of the automatic reconstruction of interiors of buildings from a point cloud.

In literature the path planning algorithms like A* plan the shortest path from A to B see Figure 1.2. But there are also more types of paths like a path with the most free space, a path with the nicest view or other types of path planning. It is still unclear how these new algorithms should work. The shortest path of Figure 1.2 is not the most human preferable route. A human will not walk that close to a wall if there is more free space in the hallway. That is where the trajectory of the MLS could help. The MLS trajectory is captured by a human and therefore follows the human preferred navigational path.

If the human walkable space in a voxel model is identified. The voxels below the trajectory could get a more preferred state. When the path is now calculated the algorithm takes this preference into account and the route from A to B will be influenced by the MLS trajectory. Therefore the new planned path follows a more human walkable path.

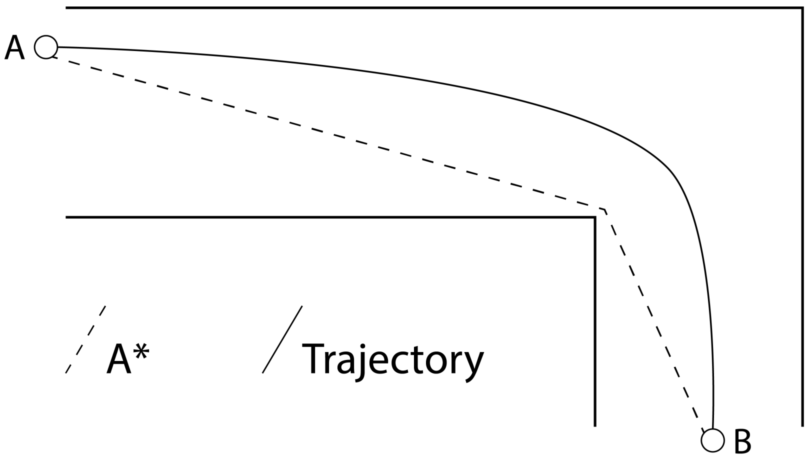


Figure 1.2: Shortest path planning and a MLS trajectory

1.3 Scope

This MSc master thesis investigates if the trajectory could be used for the automatic generation of indoor navigation maps from point cloud data. This will be done with a voxelized point cloud. The new path planning algorithm will not be investigated.

1.4 Reading Guide

In chapter 2 the current methodology's and existing methods to identify walkable spaces in point clouds will be discussed. The chapter after that chapter 3 will discuss the methodology which will be used to find an answer to the stated research question. The tools and data are introduced in chapter 4. The last chapter chapter 5 discusses the schedule for the rest of the graduation period.

2 Related work

In this chapter the usable related work is described. First of all, the voxelization is investigated. Second, the region growing algorithm is defined and as last the identifications of doors will be explained.

2.1 Voxelization

As discussed in chapter 1 the voxelization of a point cloud has its advantages. Vo et al used the voxel representation to semantically enrich a point cloud. Their method exists of a voxel stage and an refinement stage where the points in the voxels are used. The voxel representation improved the method in three ways. First of all, the number of voxels is much smaller than the number of points which makes the region growing algorithm in a future step much faster. Secondly, the normal computation of the points could be defined with the points in the neighboring voxels which avoids an expensive k-nearest-neighbor search. Thirdly, the voxel grid possesses a spatial structure, which makes searching for neighbor voxels rapid and easy (Vo et al., 2015).

This is also acknowledged by Nourian et al. According to them the voxelization process creates connectivity and topological relations in a systematic way. This topological connection can be established in three relations:
- 6-connected voxel relation: which contains the relation between the adjacent faces of the voxels
- 8-connection voxel relation: which contains the relation between the adjacent edges of the voxels
- 26-connected voxel relation: which contains the relation between the vertices of the voxels (Nourian, Gonçalves, Zlatanova, Arroyo, & Ohori, 2016). As can be seen in Figure 2.1

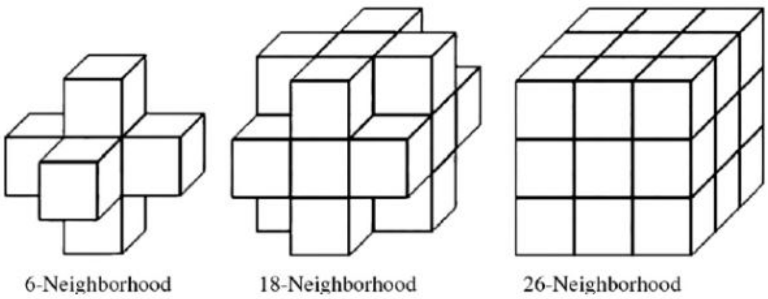


Figure 2.1: 6, 8 and 26 voxel relations (Kinkingnéhun et al., 2007)

Nourian et al. describes furthermore a method for the voxelization of point clouds (Nourian et al., 2016). This method exists of the following steps:
1. The creation of a bounding box
2. Computation of the x,y and z array and the size of the voxels
3. Incrementally checking the unvisited voxels
4. If these voxel contains points: save the voxel as a tuple of the current [I,j,k]

2.2 Region growing

There are two different methods for surfaced based region growing: bottom-up and top-down. The bottom-up methods use seed-points to group points with the same type of attributes. Top-down methods are searching for larger groups of points and then try to fit planes to create a single surface (Rabbani, Van Den Heuvel, & Vosselmann, 2006). Vo et al. applied a bottom-up approach to a voxelized point cloud by determining seed voxel. The normal vector of the points inside the voxels were calculated and with this value, the neighboring voxels are grouped together (Vo et al., 2015).

2.3 Door identification

There are a lot of approaches for the detection of doors in point clouds but only a few of them use the trajectory of a MLS. Nikoohemat et al. identifies doors by first of all voxelizing the point cloud and after that applying three basic rules:

1. A door center is an empty space
2. Above the door center there are points present
3. There should be a trajectory close by

With these rules the doors could be identified in an efficient way (Nikoohemat, 2016)

Figure 2.2: Door centre detection (Nikoohemat, 2016)

3 Methodology

In this chapter the methodology will be introduced. First of all, the verb space will be defined. Secondly, the overview of the methodology will be introduced. Finally, the steps of the methodology will be described in more detail.

3.1 What is a space?

The word space means something different for everyone. Zlatanova et al. describe space as:

> "the environment in which humans store resources (items of interest) and engage in navigation activities." (Zlatanova, Liu, & Sithole, 2013)

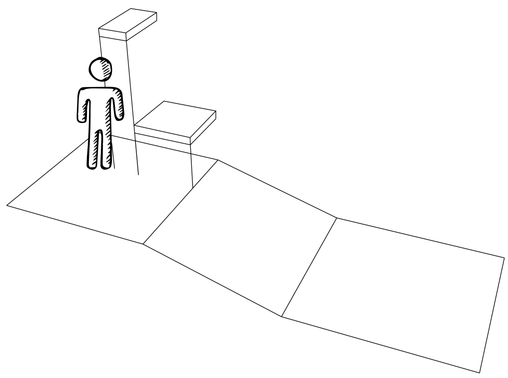
Ekholm and Fridqvist investigated what space means for the construction context. Their most broad definition of space is:

> "A space is by most of us thought of as an empty volume, enclosed in some respect - materially or Experientially" (Ekholm & Fridqvist, 2000)

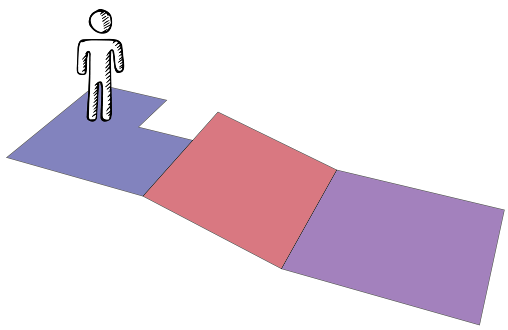
What does space means in this MSc thesis? Figure 3.1a represents a simplified indoor environment. This environment contains of two flat floors connected by a sloped floor, a piece of furniture and a pipe at an elevation of 2,30 meters above the floor. In this MSc thesis a space is defined by the following definition: A space is an 3D indoor environment where a pedestrian can navigate to which is higher than 2,30 meter, on the same connected walking height or connected walking angle and unobstructed by doors or other kinds of room separations.

Each space has to be on the same walking height or walking angle. As can be seen in Figure 3.1b the walkable floor exists of three components: two flat floors and a sloped floor. The two flat surfaces are not on the same level and are not connected. The sloped floor contains the same walking angle which means that every step results in the same change of height of the pedestrian. Therefore these three components are organized as three spaces.

The space below the furniture cannot be accessed on a normal walking way. The space is therefore not navigable and need to be removed from the final movable space see Figure 3.1b. The pipe above the floor is above 2,30 meters. The human can walk below it and this space is therefore still navigable.



(a) Indoor environment



(b) Indoor environment divided in spaces

Figure 3.1: Definition of space

3.2 Research methodology

The final output of this methodology is the identification of the available walkable space inside a building based on the point cloud, semantically enriched by the trajectory of a mobile laser scanner in a voxelized space.
The methodology starts with the data captured by the MLS scanner: a point cloud and its trajectory of the interior space of a building. First of all, the point cloud will be voxelized and the trajectory will be analyzed to detect stairs, flat surfaces and sloped surfaces. After this, walkable seed voxels will be identified and region grown into walkable surface patches. Because the MLS scans the whole building, the space below furniture or building elements lower than 2,30 needs to be subtracted from the walkable surface patches. After this step the empty surface patches represent a 3D pedestrian walkable space. In the last step, doors will be identified. With these doors rooms from the region grown spaces could be split into room spaces. The final result is a voxelized navigable map of the indoor space see Figure 3.2.

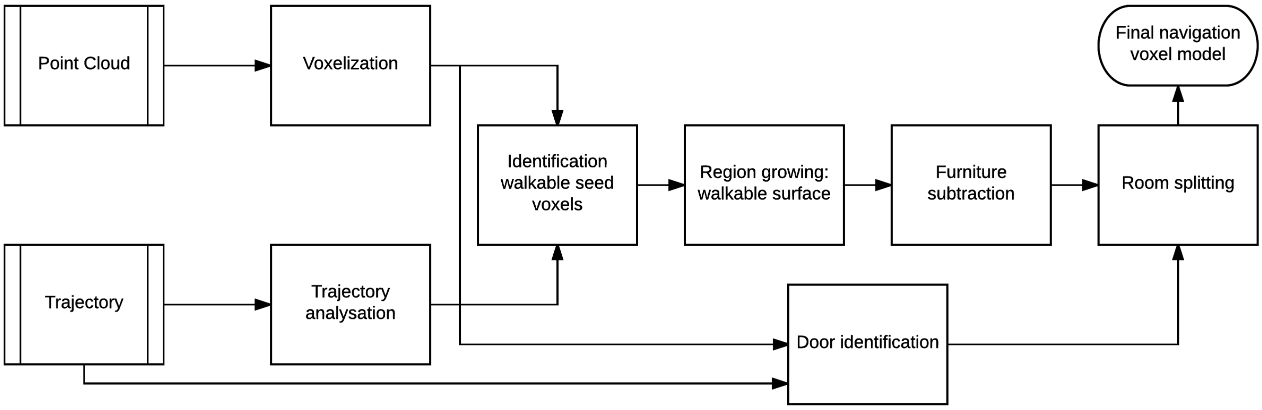


Figure 3.2: Proposed methodology to derive a voxelized navigable map of an indoor environment

3.2.1 Voxelization of point cloud

The voxelization will make use of the approach of Nourian et al. as described in the § 2.1 (Nourian et al., 2016). As discussed in the chapter 1 the voxel size is important for the representation of building elements. If the voxel size is to large important features could be missed which could lead to misinterpretations see Figure 3.3. If the voxel size is to small, the computation time will increase.

Figure 3.3: Representation of voxelization, from left to right large voxels to small voxels (Venuti, 2103)

3.2.2 Trajectory analysation

The trajectory of the MLS is saved as a polyline see Figure 3.4. This polyline will be analyzed per line section. If the height difference correspond to the given parameters of stairs or slopes, the trajectory could be divided in flat surfaces, slopes and stairs.

Figure 3.4: Trajectory of the MLS scanner

3.2.3 Identify walkable seed voxels

As shown by Yan et al. the trajectory of a MLS can be used to identify seed voxels as can be seen in Figure 3.5 (Yan et al., 2016).

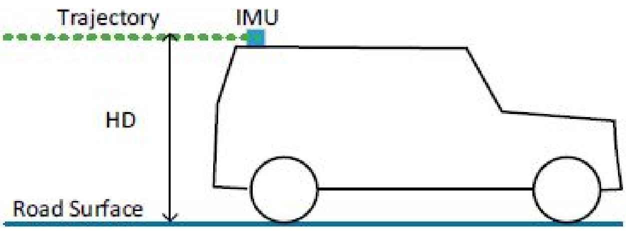


Figure 3.5: Connecting path to seed points (Yan et al., 2016)

3.2.4 Region growing

Because the methodology works with a voxelized point cloud a spatial grid is introduced. Therefore the region growing process does not need curvature values of points with a k-nearest neighbor algorithms (Vo et al., 2015). The adjacent face voxels on the 4 sides could be found in an easy way see Figure 3.6. Therefore the voxel size is crucial because small elevated surfaces should also be represented in the voxelized model.

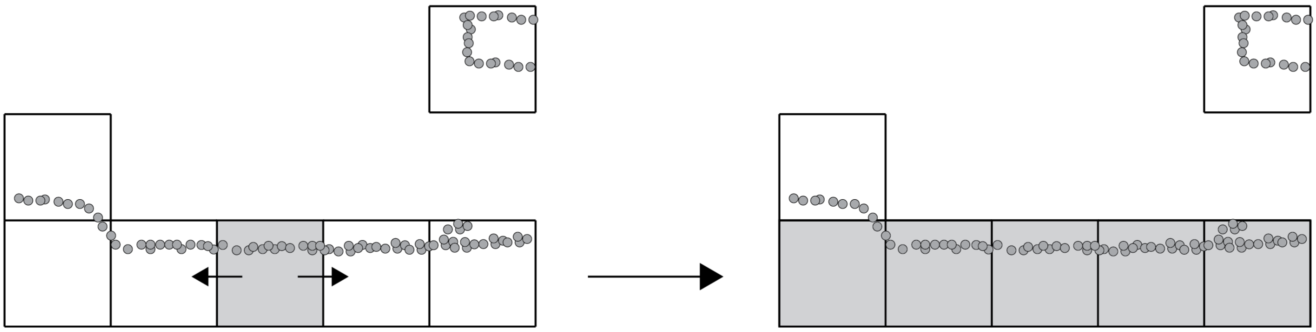


Figure 3.6: Voxel region growing

3.2.5 Furniture substraction

After the region growing process, the navigable indoor surface is merged to patches. Because the MLS scans the whole building, the space below furniture or building elements lower than 2,30 needs to be subtracted from the walkable surface patches. This could be done by checking the existence of voxels above the current voxel up to 2,30 meters. If a voxel is present, a pedestrian cannot walk at this voxel and need to be removed from the surface patch. The navigable surface patches are transformed to navigable space with this process.

3.2.6 Door identification

The door identification process will be done along the trajectory of the MLS. The method of Nikoohemat et al. will be used (Nikoohemat, 2016).

3.2.7 Room splitting

If different rooms are connected to one hallway they will be grouped to one space. In reality they are different rooms. So they also need to be split in different spaces as described in **??**. This is the final step in the methodology.

4 Tools and Data

This chapter will explain the used tools and data for the implementation of the proposed methodology.

4.1 Tools

For the testing of the proposed methodology the Python programming environment will be used. The data will be visualized using ParaView http://www.paraview.org/ and stored in a PostGIS database.

4.2 Data

The methodology will be tested on a point cloud of the Orange Hall located in the faculty of Architecture of the Delft University of Technology. This space is selected because of its complexity. In the middle of the room an orange build up with stairs, workplaces and lounge zones is realized. The orange hall is connected to the rest of the building by two ramps and one small stair. The data is collected with the ZEB REVO point cloud scanner, which is borrowed from Geometius. The data collection is done with the help of Rob Bik.

The data collection happened during opening hours, that is why there are also persons represented in the point cloud. These persons produced a lot of noise as can be seen in Figure 4.1. The cleaning of the point cloud data is discussed with the supervisors. The discussion lead to the following conclusion: Cleaning is tricky, only check if voxels are floating and delete them otherwise it is not that important and no goal of the MSc thesis.

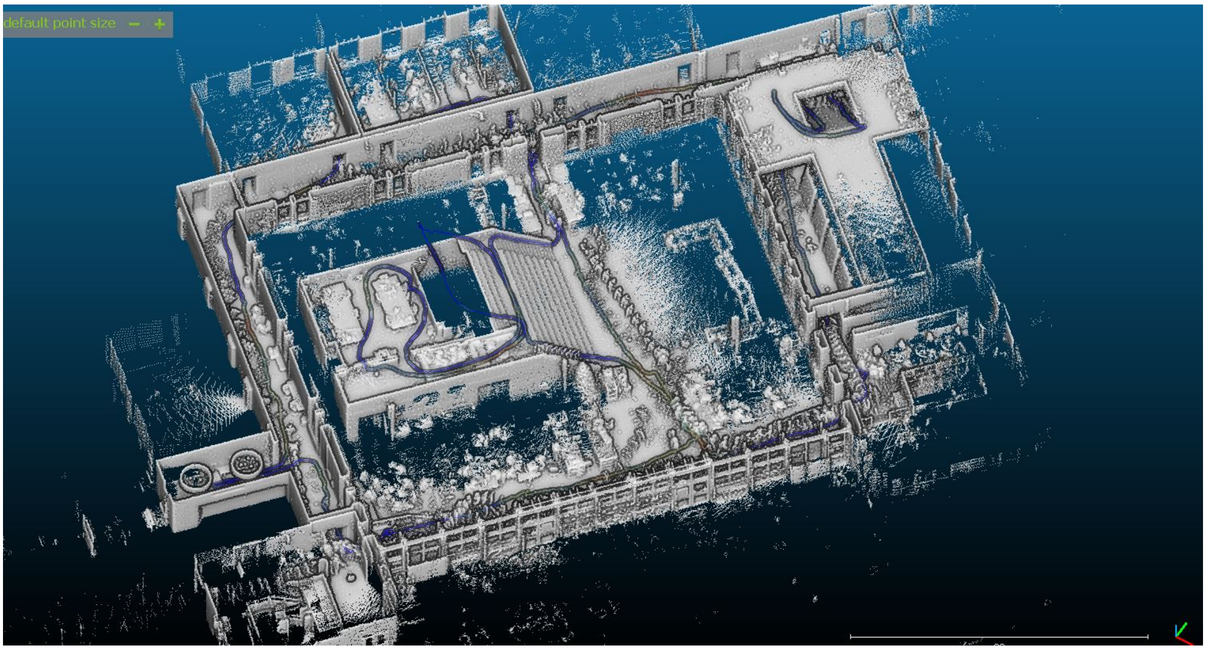


Figure 4.1: Point cloud and trajectory data of main floor orange hall

5 Schedule

In this chapter the schedule of the remaining graduation period is described.

5.1 Activities

In chapter 3 the proposed methodology is explained. The methodology is composed of the following tasks:
- Voxelization of the point cloud
- Trajectory analysis: stairs, floors and sloped floors
- Identify walkable seed voxels - Region growing: walkable surfaces
- Subtract furniture
- Identify doors
- Room splitting
- Final navigation voxel model

5.2 Schedule

Planning of the remaining graduation period

Month	Period	Activity
January	First half	P2
	Second half	- Voxelization of the point cloud
		- Trajectory analysis
		- Visualization
February	First half	- Identify walkable seed voxels
		- Region growing: walkable surfaces
	Second half	- Region growing: walkable surfaces
		- Subtract furniture
March	First half	- Subtract furniture
		- Identify doors
	Second half	P3: Colloquium midterm
April	First half	- Room splitting
	Second half	- Writing report
May	First half	- Writing report
	Second half	P4: Formal Process Assessment
June	First half	
	Second half	P5: Public presentation and final assessment

5.3 Meetings

Meetings will be held with the first supervisor Dr.ing. S. Zlatanova every two weeks. Additional meetings will be organized with the second supervisor A.A. Diakite.

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