LIDAR DATA VISUALIZATION AND PROCESSING
WITH CLOUDCOMPARE

PREREQUISITES

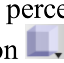
- Basic knowledge of LiDAR technology and LiDAR data
- No programming skills needed

BEFORE YOU BEGIN

1. Visit CloudCompare website to download and install the software.
2. Download the following datasets:
    - `20140326_18TWL850045_epsg2263.laz `: tile 18TWL850045 of the USGS Post Sandy NYC LiDAR data transformed to the NAD83 / EPSG:2263 New York Long Island CRS
    - `d15-compare.bin` : 2 aerial LiDAR points clouds collected in 2007 and 2015 by Laefer et al., covering the Trinity College Dublin's Graduates Memorial Building in Dublin, Ireland.

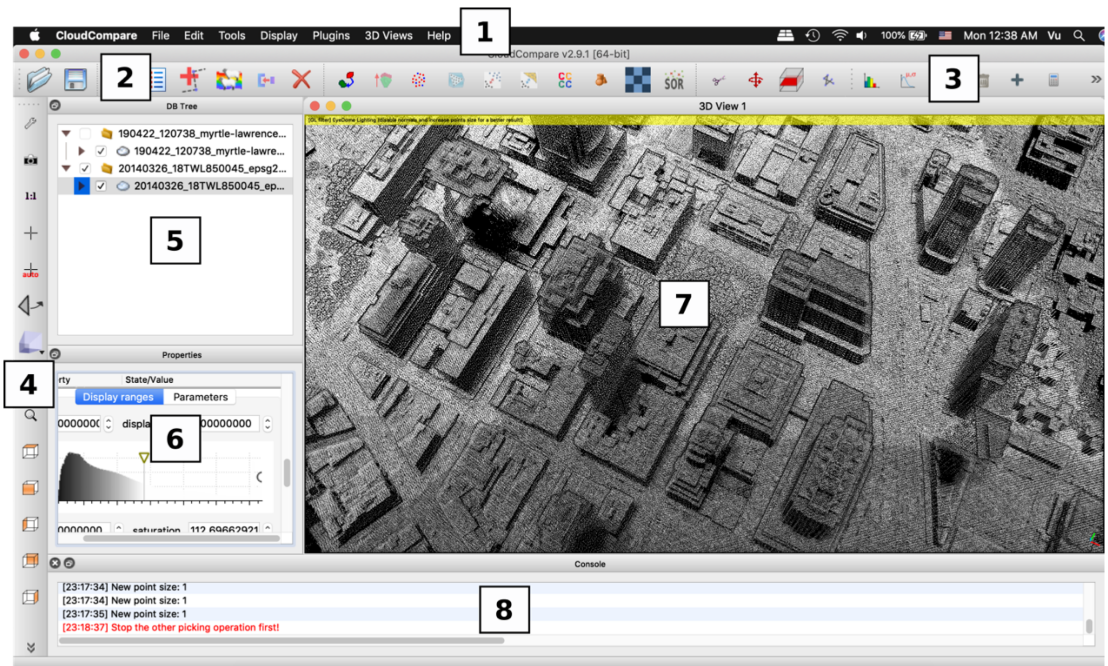
EXERCISE 1: GET STARTED WITH CLOUDCOMPARE

This exercise guides you through the process of opening a point cloud dataset and configuring CloudCompare for the data viewing. This is also an opportunity for you to get familiar with the Graphical User Interface (GUI) of the software.

1. Open CloudCompare
2. Open file `20140326_18TWL850045_epsg2263.laz`:
    - Go to the *File* menu and select *Open*. Navigate to the directory containing the file, select the file, and click *Open*.
    - In the *Standard fields* of the *Open LAS File* window, select the fields (aka attributes) you want to load (e.g. Time, Intensity), and click *Apply*. If you want to reuse the selection for files you will open later, click *Apply All*.
    - In the *Global shift/scale* window, you can modify the shift and scale parameters or you can accept CloudCompare's suggestion and proceed by clicking *Yes*. If you want to reuse the selection for files you will open later, click *Yes to All*. The shift and scale parameters suggested by CloudCompare are based on the spatial extent of the data, which is stored in the LAS file header.
3. Turn off the point cloud's color and apply eye dome lighting to improve the visual clarity.
    - In the *DB Tree* on the top-left corner of the GUI, select the point cloud you just open. The point cloud is named `20140326_18TWL850045_epsg2263` based on the file name with a cloud icon in front of it.
    - In the *Properties View* right under the *DB Tree*, look for field *Colors*. Change the value of field *Colors* to *None*.
    - Go to the *Display* menu at the top of the GUI, select *Shaders and Filters \ E.D.L (shader).* E.D.L. (Eye Dome Lighting) is a synthetic, non-photorealistic, shading technique to improve depth perception.
    - Click on the *View Mode* icon  in the *View Toolbar* on the left side of your screen and select *Object-center perspective.* In the perspective mode, objects far away from the view point are rendered smaller than those nearby.

4. Get yourself familiar with the GUI:
    - Locate the following components of the GUI:

☐ [1] *Main Menus*
☐ [2] *Main Toolbar* (quick access to main editing and processing tools)
☐ [3] *Scalar Field Toolbar* (quick access to scalar field manipulation tools)
☐ [4] *View Toolbar* (quick access to display-related tools)
☐ [5] *DB (Database) Tree* (for selection and activation of entities and their features)
☐ [6] *Properties View* (information of selected entities)
☐ [7] *3D View*
☐ [8] *Console*



- Mouse actions within the 3D view:

☐ Scroll button: zoom in/out
☐ Left click and drag: rotate
☐ Right click and drag: pan

5. Try to perform the following:
    - Identify the number of points in the point cloud (hint: search the *Properties View*).
    - Identify the scalar fields loaded in the software (hint: search for section *Scalar Fields* in the *Properties View*).
    - Change the point size (hint: search for section *Cloud* in the *Properties View*, and look for field *Point size*)
    - Locate and zoom to 370 Jay St. building.

Tips

1. To set a new rotation center:
    - Disable the *Auto-pick rotation center* function  in the left toolbox

- Click the *Pick rotation center* icon in the left toolbox
- Click on a point in the point cloud that you want to set as the new rotation center

2. If for any reason the point cloud moves away from your *3D View* window, you can bring it back by selecting your point cloud (the cloud icon with the file name (e.g. 20140326_18TWL...) in the *DB Tree* panel) and press *Z* on the keyboard or click on the magnifier icon (*Zoom and center on selected entities*) on your left toolbox.

EXERCISE 2: VISUALIZATION

In this exercise, you will create 3 different types of visualization from the point cloud dataset already imported to CloudCompare in Exercise 1.

- Point cloud colored by intensity
- Point cloud colored by elevation
- Point cloud colored by synthetic ambient occlusion

Intensity

LiDAR intensity is related to the surface reflectance. Tree, asphalt are examples of low reflectance objects. Limestone, marble, and retroreflective paint are highly reflective and return high intensity. In this section, you will color a point cloud by intensity and observe the difference in the surface reflectance within the dataset.

1. In the *DB Tree*, select the point cloud you want to manipulate (i.e. `20140326_18TWL850045_epsg2263` in this exercise).
2. In the *Properties View*, look for field *Colors* and change the value to *Scalar field*. This tells CloudCompare to color your point cloud by a scalar field.
3. Scroll down to section *Scalar Fields* in the *Properties View* and change the value of field *Active* to *Intensity*. This tells CloudCompare to use the scalar field of Intensity to color your point cloud.
4. Go to the *Display* menu and select *Shaders & filters \ Remove Filter*. This removes the EDL shading you applied previously so that the synthetic shading does not interfere with the colors representing the intensity values.
5. Zoom to the Metrotech commons area in front of Dibner library and observe the difference in laser intensity between the trees and the building roofs.
6. In the *Properties View*, go to section *Color Scale* and change the current color scale from *Grey* to *Blue>Green>Yellow>Red* and to *Viridis*.
7. In the *Properties View*, go to section *SF display params* and change the display and saturation ranges.
    - Points having intensity values inside the display range (the 2 values at the top) are colorized. Points outside the display range are visualized in white.
    - The saturation values (the 2 values at the bottom) defines the mapping from the scalar values to the colors. The min (max) scalar value of the saturation range maps to the min (max) value of the color scale.

Elevation

CloudCompare can only color a point cloud either by RBG color attributes or a scalar attribute. To color a point cloud by elevation (i.e. the z-coordinate), you first need to convert the z-coordinate to a new scalar field (called 'Coord. Z'), and color the point cloud by the new scalar field of `Z`.

1. In the *DB Tree*, select the point cloud you want to manipulate (i.e. `20140326_18TWL850045_epsg2263` in this exercise).

2. Go to *Edit* menu and select *Scalar Fields \ Export coordinate(s) to SF(s)*. Select `Z` as the coordinate to export and click *OK*. This creates a new scalar field from the Z coordinates (i.e. the elevation).
3. Check section *Scalar Fields* in the *Properties View*, you should now see a new scalar field named `Coord. Z`, which is automatically set as the active scalar field.
4. You should also see that the point cloud in the *3D View* is now colored by the elevation.
5. Change the saturation range and the color scale to obtain an optimal visualization.
6. You may switch on the EDL shading to improve the depth perception (*Display \ Shaders & filters \ E.D.L. shader*).
7. Observe the data in the new color mode. You no longer see the difference in the surface reflectance (i.e. the radiometric aspect). Instead, you see the geometric aspect of the data (e.g. shape and size).

Ambient occlusion

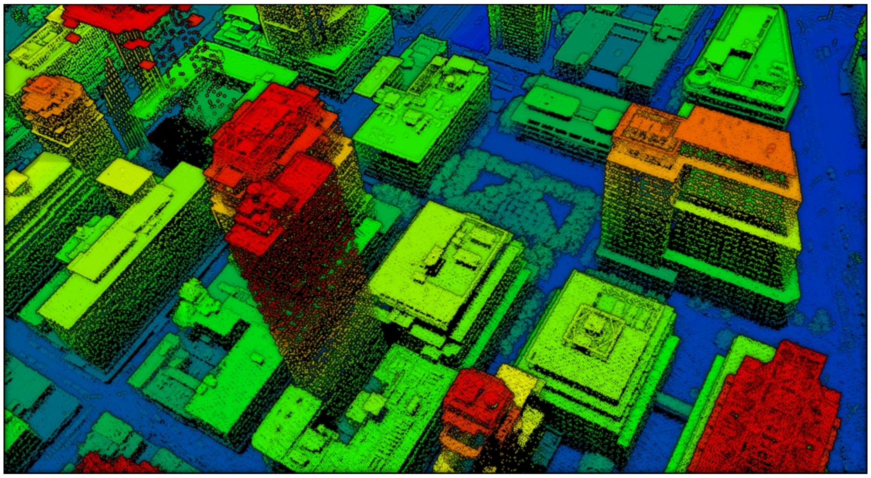
Ambient occlusion is a common rendering technique, which visualizes a 3D scene based on the level of illumination the scene received from an ambient light source (often modeled by a hemisphere representing an open sky vault). Ambient occlusion has been found as an effective method for rendering point cloud. Geometric details in ambient occlusion images appear clearer compared to elevation-based visualization. More details can be found in "Visualisation of urban airborne laser scanning data with occlusion images" by Hinks et al. (2015).

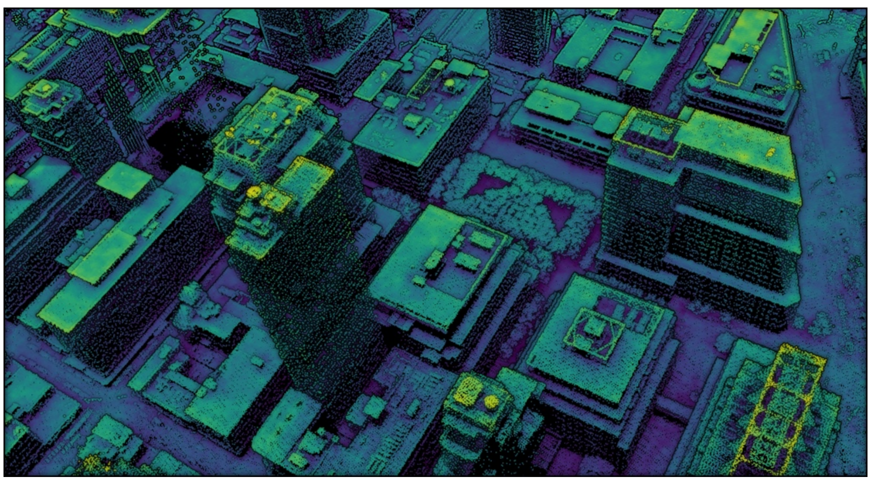
1. In the *DB Tree*, select the point cloud you want to manipulate (i.e. `20140326_18TWL850045_epsg2263` in this exercise).
2. From the *Plugins* menu, select *P.C.V. (Ambient Occlusion)*.
3. In the *ShadeVis* window, change the number of sample rays (i.e. *Count*) to 50 and check the *Only northern hemisphere (+Z)* box. A higher number of sample rays would result in a higher quality ambient occlusion result at a cost of higher computational time. If the *+Z* box is unchecked, samples ray will be cast from both the "sky" (+Z) and the "underground" (-Z), which would result in unrealistic visualization for airborne LiDAR data.
4. The computation may take a while. Once it finishes, check section *Scalar Fields* in the *Properties View*. You should now see a new scalar field created and named 'Illuminance (PCV)'. The values of this scalar field range from 0.0 (totally occluded) to 1.0 (totally illuminated).
5. You may change the color scale. You may keep or remove the EDL shading.
6. Observe the data in the new color mode. Compared to the elevation-based visualization, you should now see more geometric details such as details on the roofs and objects at the ground level. To switch the color mode the elevation and the ambient occlusion modes, change the active scalar field in section *Scalar Fields* in the *Properties View*.

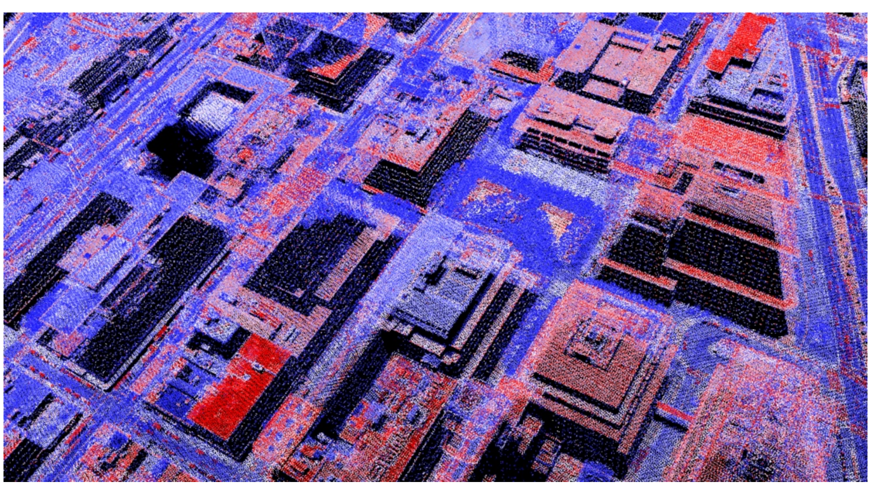
Tips

1. To export a visualization to a raster image, go to the *Display* menu and select *Render to File*. This allows you to produce high resolution images better than taking a screenshot. By setting a higher *Zoom* value in the *Render to file window*, you can increase the resolution of the produced image.
2. If you find a good view point (i.e. camera position) and want to save the view to return to it later, go to the *Display* menu and select *Save viewport as object*. A new *Viewport* entity should be created in the *DB Tree* to store your current view point. To return to a view point saved previously, click on the corresponding *Viewport* in the *DB Tree*, look for the *Apply viewport* field in the *Properties View* and click *Apply*.

Label the color mode and the color scale for each of the following images



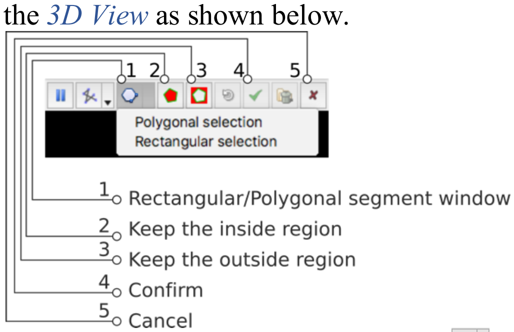




EXERCISE 3: SEGMENT, MERGE AND MEASUREMENT

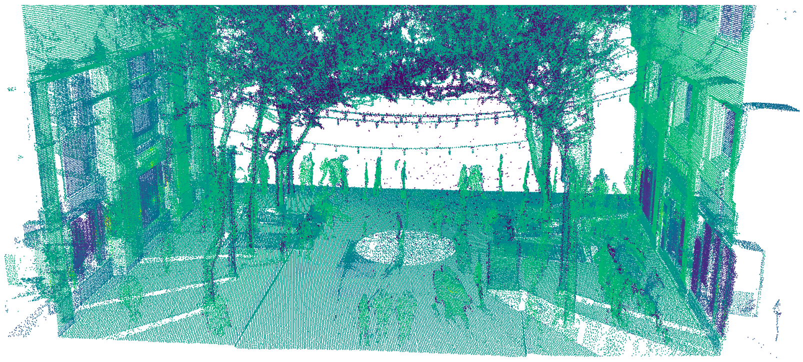
In this exercise, you will learn a number of basic tools to make use of the point cloud data.

1. Given that you are having the USGS aerial LiDAR point cloud in CloudCompare, let's add a terrestrial dataset.
    - Download and unzip file `190422_120738_myrtle-lawrence_vox050_epsg2263.zip` from this link: https://bit.ly/2VxrkdD. All of the other datasets collected for the class will be uploaded to this folder.
    - In CloudCompare, go to *Files \ Open*. Navigate to the directory containing the point cloud data file and click *OK* to open the file.
    - An *Open Ascii File* window shows up as the file you are opening is in a CSV, text format. Inside that window, set the first 3 fields of the file as X, Y, Z-coordinates and the remaining as scalar fields. Set the separator to ",". Set the number of lines to skip (*Skip lines*) to 1 to skip the file header and click *Apply*.
    - In the *Global shift/scale* window, select *Last input* to reuse the parameters previously used when opening the LAZ file. As the 2 point clouds are already registered in the same CRS, it is important to use the same set of shift and scale parameters. Click *Yes* to load the file.
    - In the *DB Tree*, rename the 2 point clouds to `als` (aerial laser scan, for the LAZ file imported earlier) and `tls` (terrestrial laser scan, for the text file recently imported). To rename an entity, double click on the entity and type in a new name. Move the 2 point clouds to the same folder in the *DB Tree* and rename the folder to`metrotech`. Moving entities in the *DB Tree* can be done by drag and drop.
    - Color the `tls` and `als` point cloud by elevation.
    - Zoom close to an area where the TLS dataset is available and observe the difference it makes. You may use the check boxes in the *DB Tree* to toggle the point cloud's visibility.
2. Segment a small portion of the TLS dataset to have a closer look.
    - In the *View* toolbar, click the *Set Top View* icon to switch to a top view. This top view, together with the orthographic mode let you look straight down to the ground surface. Select the `tls` point cloud in the *DB Tree* and zoom in to the area you want to segment (e.g. the segment of Lawrence St. between Five Guys and Chipotle Mexican Grill).
    - Select *Edit \ Segment* from the main menu bar. The segment window pops up at the top-right corner of the *3D View* as shown below.



    - Draw a clipping window using either the rectangular or the polygonal segment window [1] and keep the inside region [2]. Click the confirm icon [4] to finish the segment.
    - The `tls` point cloud is now segmented into 2 point clouds: 'tls.segmented' contains the points inside the segment window, and 'tls.remaining' contains the remaining points (outside the window).
    - Switch off `tls.remaining` and 'als'.

- Switch to a front view (use the *View toolbar*) and zoom close to the `tls.segmented` point cloud. You may set the rotation center to a point in the newly segmented point cloud.



3. Take measurements.
    - Select the `tls.segmented` in the *DB Tree*.
    - Go to *Tools \ Point picking*. The *Measurement* toolbar pops up at the top-right corner of your *3D View*.

☐ Pick a point to read its coordinates and the value of the active scalar field
☐ Draw and measure a linear segment
☐ Draw and measure a triangle

    - Practice the following

☐ Measure the curb heights on both sides of Lawrence St.
☐ Measure the clearance under the electric cables.

    - When you finish, click this icon to close the Measurement toolbar.
4. Merge the `tls.remaining` and `tls.segmented` and rename the resulting point cloud as `tls`
    - Hold the `shift` key on your keyboard and select the 2 point clouds: `tls.remaining` and `tls.segmented`. Select Edit \ Merge. CloudCompare will ask whether a new scalar field should be added to distinguish the point clouds being merged. If you do not plan to split the segments again, you may select *No*.
    - Double click on the merged point cloud and rename it to `tls`.

EXERCISE 4: SCALAR FIELD MANIPULATION

You can think of a point cloud as a spreadsheet with each row is a point record, and each column is a scalar field. In Exercise 1, you have created new scalar fields from the point cloud's z-coordinate and from an ambient occlusion simulation. In this exercise, you will perform some further manipulations with scalar fields:

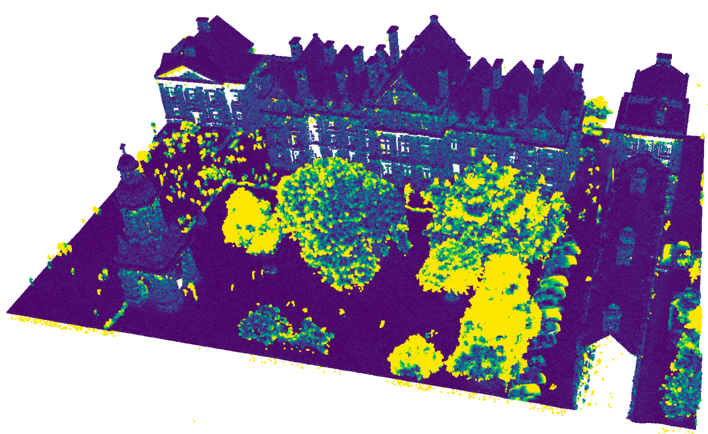
1. Create a histogram to analyze the distribution of a scalar field.
    - Segment a portion of the `tls` point cloud on which you expect a relatively homogeneous distribution of laser reflectance (e.g. building façade, pavement, road surface, human objects).
    - Select the segment.
    - In the *Properties View*, set the active scalar field to "Reflectance".
    - Select *Edit \ Scalar Fields \ Show histograms*. You should see a histogram showing the distribution of the reflectance values within the selected segment.
2. Filter a point cloud by a scalar field

- Select the point cloud you want to manipulate.
- Go to *Edit \ Scalar Fields \ Filter by value*. Specify the range you want to filter in the window popped up.
- Click *Split* will partition the selected point cloud to 2 portions, one containing points having scalar values inside the specified range and the other one outside. If *Export* is selected, a new point cloud is created, which contains only points satisfying the specified range.

EXERCISE 6: COMPUTE DISTANCES BETWEEN 2 POINT CLOUDS

If a scene is scanned twice, changes can be detected by computing the spatial distances between the corresponding point pairs selected from the 2 scans. Comparing point clouds was the initial purpose of the software CloudCompare. In this exercise, you will compare 2 high-resolution aerial scans of Dublin city in Ireland, which were collected 8 years apart (2007 and 2015).

1. Open a new CloudCompare instance or empty the *DB Tree* in your existing CloudCompare instance.
2. Select *Files \ Open* and open the `d15-compare.bin` file. The file is in the native binary format of CloudCompare so there is no additional settings required.
3. In the *DB Tree*, you should see 2 point clouds: `2015 - Cloud` and `2007 - Cloud`.
4. Toggle the point clouds and observe the changes.
5. Hold the shift key on your keyboard and select both of the clouds.
6. Go to *Tools \ Distances \ Cloud/Cloud Dist*. The comparison is not symmetric (i.e. compare A to B and B to A result in 2 different results). You need to specify the point cloud used as the reference and the point cloud to compare against the reference. In this exercise, you will compare the 2015 point cloud (i.e. `compared`) against the 2007 point cloud (`reference`).
7. In the *Distance Computation* window, set the *Maximum distance* to 1. This tells CloudCompare to skip any pairs further than 1 distance unit (in this particular point cloud: 1 meter). Click *Compute* again and click *OK* to go back to the viewer.
8. A new scalar field named "C2C absolute distance[<1]" is created for the `compared` point cloud (2015 - Cloud).
9. You can change the color scale, display range, and saturation range as you have done with other scalar fields. An example of the result is shown below.



EXERCISE 7: PREPARING A POINT CLOUD FOR SHARING ON SKETCHFAB

Sketchfab is a platform to publish, share, discover, buy, and sell 3D, VR, and AR content. This exercise guides you through a few simple steps to prepare your point cloud and share on Sketchfab. As you will use a free, individual account, you are restricted to a data size less than 5 million points.

1. Select a point cloud segment having less than 5 million points. You may use CloudCompare (*Edit \ Subsample*) or PDAL to subsample the data if needed.
2. Color the point cloud the way you find optimal for your purpose.
3. If the color is created from a scalar field, you need to convert it to RGB color values (*Edit \ Scalar fields \ Convert to RGB*).
4. To reduce the file size, remove all scalar fields as the scalar fields are not usable when being uploaded to Sketchfab (*Edit \ Scalar fields \ Delete all (!)).*
5. Save the point cloud as a PLY file: Select *File \ Save* and specify PLY mesh (*.ply) as the output format.
6. If the file is large (i.e. approaches 5 million points), you need to compress the PLY into a zip file. The file size should be smaller than 50 MB. The file is now ready for upload.
7. Uploading a PLY file on Sketchfab is straight forward.
   - You need to create an account on sketchfab.com or use the group's account.
   - Choose *Upload* from the home page.
   - Drag and drop the PLY/ZIP file you prepared to the upload window.
   - After uploading, you need to name your model, configure the settings (e.g. background, point size, additional lighting, VR setting), and click *Publish*.
   - You may annotate your point cloud with additional information using markdown.