User manual of SAT2LoD2 software Circle model version

This document is about the running of SAT2LoD2 (executable SAT2LoD2.exe), which is an open-source building LoD-2 reconstruction software corresponding to the paper "Automated LoD-2 model reconstruction from very-high-resolution satellite-derived digital surface model and orthophoto" (ISPRS Journal of Photogrammetry and Remote Sensing, 2021), and "Sat2LoD2: A Software For Automated Lod-2 Modeling From Satellite-Derived Orthophoto And Digital Surface Model" (ISPRS Congress, 2022). A update for circular building model is available now (Beta version), other than rectangular building, circular building (circle, half circle, sector, and ring shape can be detected and reconstructed.

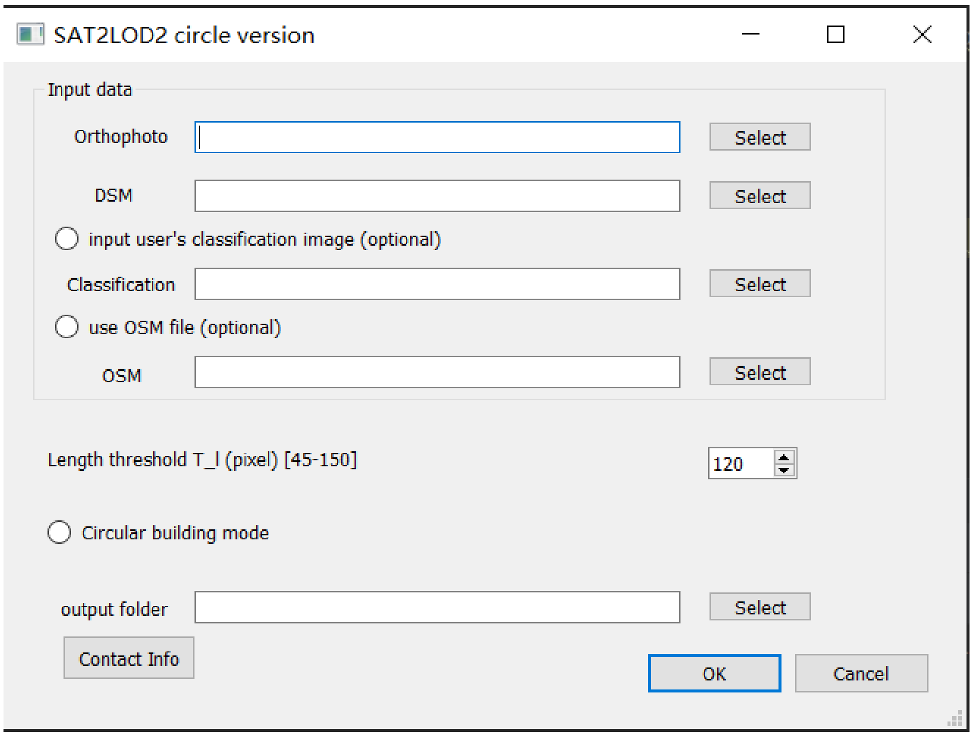
Requirement

A GPU with CUDA driver is required for user, if user wants to use building detection and classification function.

Input data

Launching model3d.exe to start the building LoD-2 reconstruction workflow. EXE file is in *./ software/SAT2LoD2_CU10/SAT2LoD2_circle.exe.* An example of input data is in *./software/example/input/* folder.

The main window is shown as following figure. If the input data are fulfilled, click on '*OK*' button to start processing.


SAT2LOD2 circle version

Input data

Orthophoto

DSM

input user's classification image (optional)

Classification

use OSM file (optional)

OSM

Length threshold T_l (pixel) [45-150] 120

Circular building mode

output folder

Figure 1. Main window of SAT2LoD2 circle version software

Required input data include: 1) *orthophoto* with RGB band (.png, .jpg, or .tif format, 3 bands, 8 bit image); and 2) *DSM* (digital surface model, .tif format, 1 band, 16 bit int or 32 bit single image), and the orthophoto and DSM should have the same row and column. The maximum size of *orthophoto* and *DSM* is 5000 * 5000 for generating mesh in a few minutes.

Optional input data include: 1) *classification image*, building class is labeled as 1 or 255 (.png, .jpg, or .tif format with 8 bit single band, shown in Figure 2, other types of objects need to be set as 0, and other types of ground objects need to be set as zeros value); and 2) *OpenStreetMap shapefile* for street lines (.shp format, shown in Figure 3), and the corresponding *.tfw* file, which has the same name as *orthophoto*, and the projection of both *OSM shape file* and *.tfw* file need to be WGS84 UTM Zone; 3) Circle building model mode for whether to detect circular building, may cost additional time for the area which does not have circular building.

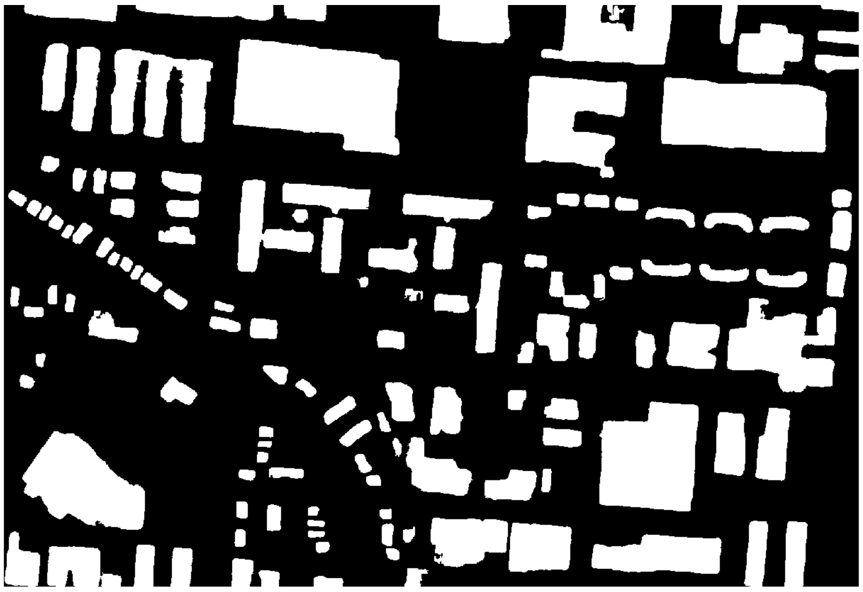


Figure 2. Sample of building classification image

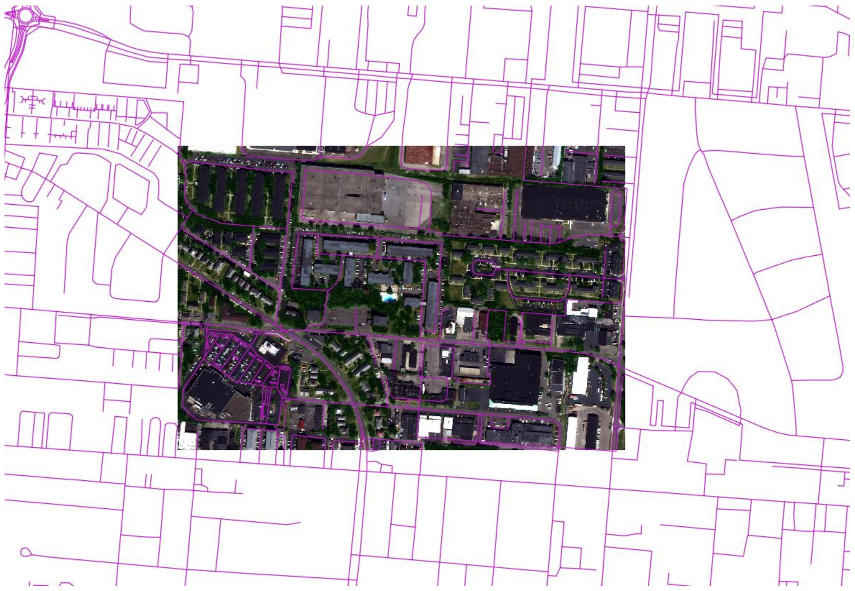


Figure 3. Sample of OpenStreetMap shape file

Building reconstruction parameters include: (please reference to the paper)

Parameter	Description	Range
Length threshold T_l (pixel)	A threshold of summed up length for determining building main orientations.	[45, 150]
Color difference threshold T_d (RGB)	A threshold of mean color differences ($\|\overline{C_1} - \overline{C_2}\|$) of the two rectangles to decide whether to merge two nearby rectangles in building decomposition.	[6, 20]
Mean height difference threshold T_{h1} (m)	A threshold of mean height difference ($\|\overline{H_1} - \overline{H_2}\|$) between two nearby rectangles to decide whether to merge two nearby rectangles in building decomposition.	[0.5, 1.5]
Gap threshold T_{h2} (m)	A threshold of dramatic height changes in a buffered region that cover the common edge between two nearby rectangles between two nearby rectangles.	[0.1, 0.3]
Vertical line threshold T_v (pixel)	A threshold to detect initial vertical line node during 2D circle detection.	[3, 6]

In current version of software, there is only Length threshold T_l (pixel) that user can directly edit in GUI, if user what to edit more parameters, please edit them in code.

Output folder is the folder path that LoD-2 building model and all other intermediate results will be stored. If this path is empty, the output file will be generated to the path of .exe file.

Building reconstruction workflow

There are six main steps in building LoD-2 reconstruction software:

1) **Building detection and segmentation**: generate the building segments from input orthophoto, if the input user's classification image ratio button is not selected. We adapt HRNet V2 (HRNet/HRNet-Semantic-Segmentation: The OCR approach is rephrased as Segmentation Transformer: https://arxiv.org/abs/1909.11065. This is an official implementation of semantic segmentation for HRNet. https://arxiv.org/abs/1908.07919 (github.com)) as the building segmentation algorithm, for extracting building segments with high accuracy and efficiency.
2) **Initial 2D building polygon extraction**: generate the building polygon (boundary) of each building segment, by following initial line extraction, line adjustment, and line refinement.
3) **Building rectangle decomposition**: generate the building rectangle base on the building polygon, by using a grid-based decomposition algorithm.
4) **Building rectangle orientation refinement**: refine the orientation of each building rectangle

by combining OpenStreetMap line segments.

5) **Circle detection**: detect the circular shape building (circle, half-circle, sector, ring), generate 2D parameter and radian of circles.
6) **Circle & rectangle refine**: Check the overlap between circles and rectangles, refine the 2D shape of them.
7) **Rectangle 3D model fitting**: fit and reconstruct the roof structure based on each building rectangle.
8) **Circular 3D model fitting:** fit and reconstruct the roof structure based on each building circle.
9) **Mesh generation**: transform building model into an .obj format. For irregular building (low IoU value with mask), directly generate mesh from DSM.

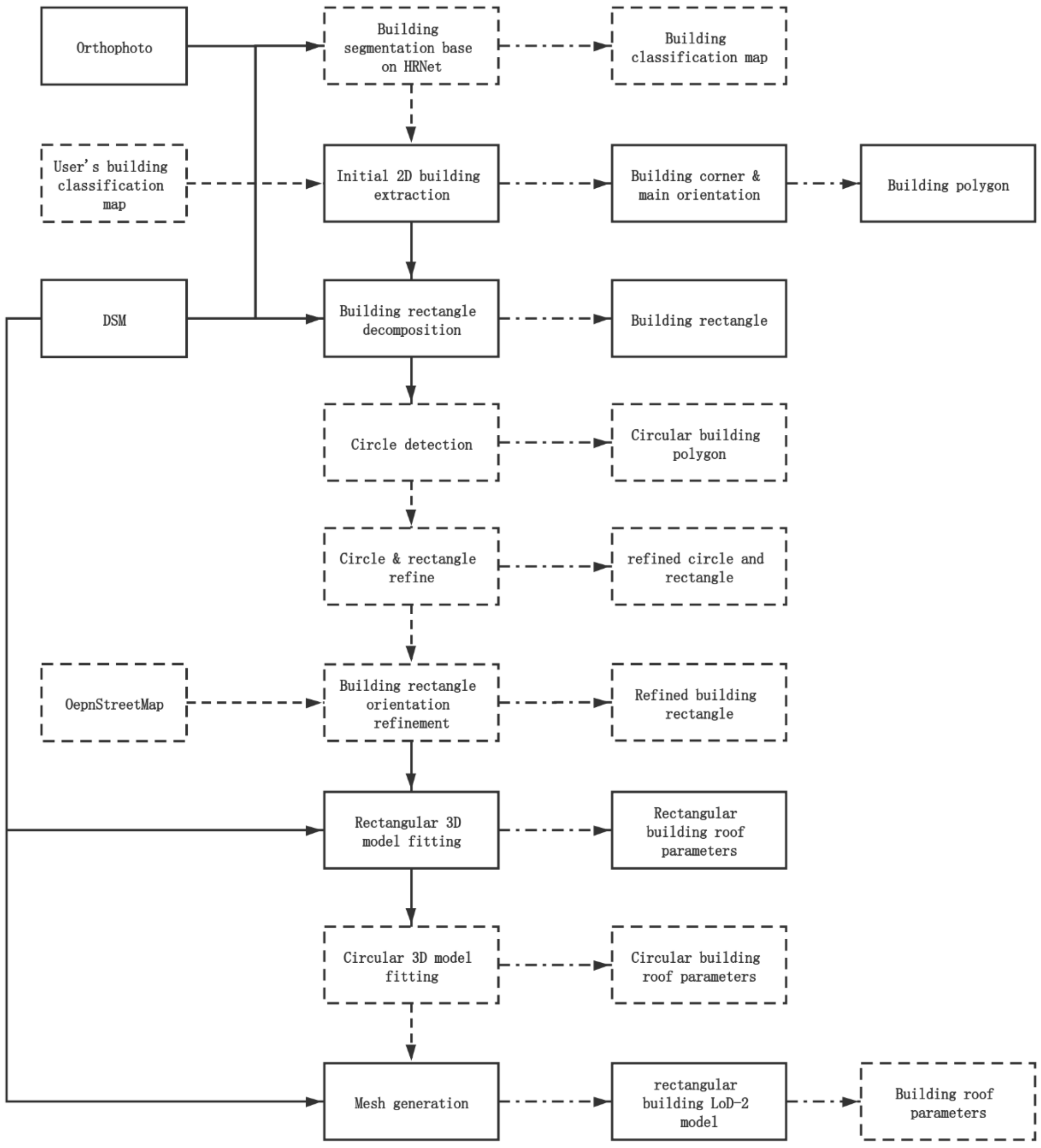

Orthophoto
Building segmentation base on HRNet
Building classification map
User's building classification map
Initial 2D building extraction
Building corner & main orientation
Building polygon
DSM
Building rectangle decomposition
Building rectangle
Circle detection
Circular building polygon
Circle & rectangle refine
refined circle and rectangle
OepnStreetMap
Building rectangle orientation refinement
Refined building rectangle
Rectangular 3D model fitting
Rectangular building roof parameters
Circular 3D model fitting
Circular building roof parameters
Mesh generation
rectangular building LoD-2 model
Building roof parameters

Figure 4. Workflow of the software

Output:

All output files will be at the **output folder** as selected in Main Window.

Patch folder: This folder includes the images and annotations for input orthophoto, which will be clipped as 512*512 images with 50% overlap.

class.png: Classification map for buildings, derived from orthophoto, by using HRNet as building segmentation method.

building_corner.json: The polygon nodes of each building, the data format of each node is:

```
[25, 1201.4596385681623, 483.15666353691796]
```

[number of segment, x, y].

building_polygon.json: The polygon lines of each building, the data format of each line is:

```
[89, 1071.6061133527417, 1074.5116773823315, 871.3054306969316, 840.2762669513455, 1, -1.47742880765086, 26.73013280924732]
```

[number of segment, x1, x2, y1, y2, number of line in a segment, orientation, length of line].

Main_ori.npy: The array of main orientation for each building segment.

boundary.png: Visualized building polygon (boundary) based on the orthophoto.

building_rectangle.json: The building rectangles of each building segment, the data format of each rectangle is:

```
[[16, 1, 169.28524627757633, 413.49085043401755, 178.90431610496617, 392.59890232820896,
189.26884881356713, 422.69169983412957, 198.88791864095697, 401.799751728321, 506, 0.41012734054149097]]
```

[number of segment, number of rectangle in a segment, x1, y1, x2, y2, x3, y3, x4, y4, orientation]

rectangle.png: Visualized building rectangle based on the orthophoto.

building_refinement.npy: The building rectangles after refinement, the data format of each rectangle is (n by 16):

[number of segment, number of rectangle in a segment, x value of center, y value of center, length, width, orientation, 0, x1, y1, x2, y2, x3, y3, x4, y4].

Shape2d.png: Visualized building rectangle after orientation refinement based on the orthophoto.

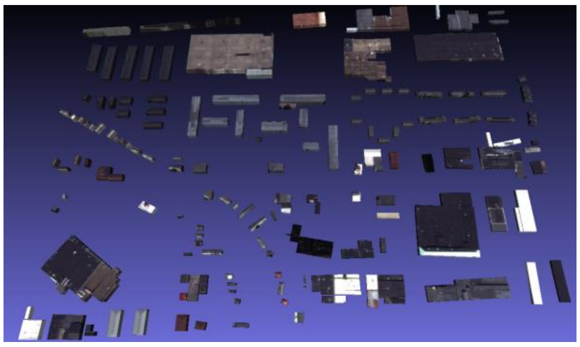
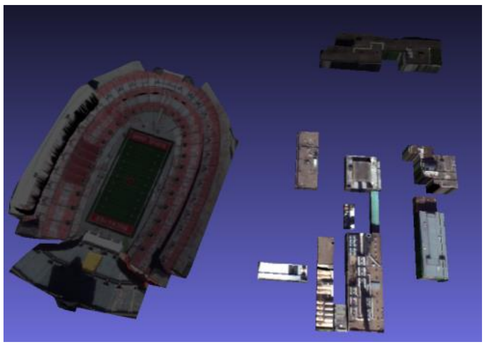
Circle2d.png: Visualized building circle after orientation refinement based on the orthophoto.

building_model3d.json: The building roof structure of each building rectangle, the data format is:

```
[5.0, 211.19618099084062, 212.59618099084062, 5.974999999999994, 5.974999999999994, 1.0, 0.3468099130053377]
```

[roof type (1: flat, 2: gable, 3: hip, 4: pyramid, 5: mansard), eave height, ridge height, length of hip 1, length of hip 2, hip direction, RMSE of original DSM].

building_model.obj, building_model.mtl, model_texture.jpg: LoD-2 building model with .obj format.

Notification: The points location of **building_corner.json**, **building_polygon.json**, **building_rectangle.json**, **building_refinement.npy** will have a (100, 100) offset than their original location in orthophoto and DSM, which means the point location (x, y) will be recorded as (x+100, y+100) in above files.

The example output files are shown in *./software/example/output/* folder. Typical processing time of example are about 4-5 minutes for 1500*1500 image, 12-13 minutes for 3000*3000 image.