# Automatic Generation of Building Primitives Using Multi-Source Data


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**Abstract:** Although many researchers have studied building reconstruction from remotely sensory data, most approaches are not yet satisfactory in terms of the degree of automation, the reconstructed details and the accuracy. With the innovation of sensory technology, more advanced sensors are now available and getting cheaper. This paper describes a framework for automatic generation of 3D building models from the data acquired from multi-sources, specifically, airborne LIDAR, digital camera, and a digital map. By combining these data, we derive building primitives in 3D space. The core primitives are step and intersection edges from images, step edges from building boundary of digital maps, patches and intersection edges from LIDAR data, and step edges from DSM generated from the LIDAR data. Then, we group these elements and refine the grouping results to generate polyhedral models of buildings. This framework was partially implemented and applied to real data. The experiment results show that the framework can open a possibility of automatic building reconstruction.


**Keywords:** building primitive, 3D edges, planar patches, LIDAR, digital map, image


## 1. Introduction

With innovative technical improvement, the means of data acquisition has become wider. It has been general to use LIDAR sensors that acquire the 3D coordinates of the points on objects by transmitting the active laser signal to the objects and receiving the reflected signals from the object surface. Also, since users have required more advanced geographic information beyond those available from 2D map, the study on reconstructing the real world with more detail 3D models becomes very active.

Reconstruction of buildings from various sensors has been studied in recent years. In 90's, most studies were photogrammetric approaches and after that, many studies have been based on LIDAR sensor. Building reconstruction using LIDAR data only, however, has some problems because LIDAR data retains relatively low point density, causing low spatial resolution. Another kind of data used for building reconstruction is the existing digital maps. The digital map explicitly includes the 2D boundaries of building, which can be a good initial data for 3D building reconstruction.

To reconstruct 3D buildings, many studies based on various sensory data have been performed. Many studies were based on aerial images. Baillard and Zisserman [1] reconstructed polyhedral models using the edges between planar roof patches. The main idea is to obtain the half planes to the left and right of a detected dihedral line segment. The advantage is that only relatively local information is exploited [2]. In recent research, Suveg and Vosselman [3] reconstructed buildings using aerial images and 2D ground plans. They generated the 3D volumetric primitives using the 3D corners extracted from 2D digital map and filtered by images. 75% of all objects were extracted using this method.

Building reconstruction from LIDAR data are very active these days. Rottensteiner and Briese [4] extracted roof faces from DSM and derived the intersection and step edges from the regularized DSM. Additionally, images were used to detect small buildings. In recent studies for extracting the roof faces, Lodha and Kumar [5] applied K-Mean algorithm to refine LIDAR points and to detect the planar roof faces. Since users should assign the number K indicating the number of point clusters, this approach is a semi-automatic method.

In this paper, we proposed a method to generate building primitives for realizing the automatic of building reconstruction using multi-source data, that is, LIDAR data, aerial images and a digital map. The proposed approach focuses on automatically generating the 3D geometric primitives constituting buildings, such as planar patches, intersection and step edges, and corners. The generated primitives can then be grouped and refined to create polyhedral building models.

## 2. Overview of the Proposed Building Reconstruction Process

To reconstruct the polyhedral model automatically, there were a lot of studies using various data and algorithms. However, none of them could propose the perfect methodology particularly in terms of automation. It is impossible to reconstruct perfectly the existing object in real world. In this paper, we propose an automatic method to generate building primitives using aerial LIDAR data, aerial images and a digital map.

Prior to describing the whole process, it is necessary to bring up the properties of each data. LIDAR data is constituted by numerous points and each point has horizontal and vertical coordinates. DSM (Digital Surface Model) and planar patches can be derived from LIDAR data. Building shapes can be represented roughly using them but their spatial resolution is relatively low, and definitively LIDAR sensor cannot detect the edges of buildings. Aerial image can offer a brightness value for each pixel and hence it is easy to detect the edges of buildings, and the spatial resolution is relatively high. But it needs the stereo image pair for getting the 3D information. Using a digital map, the horizontal coordinates of building boundary can be extracted from its building layer.

At first, we extract the coordinates of building boundary from a digital map to establish ROI (Region Of Interest) for the images and LIDAR data, and it offers the edges of buildings. Edges could also be derived from the DSM and the images. Since theses edges have only two dimensions, they should be converted into 3D edges using LIDAR data (DSM, planar patches). Moreover the edges constructed by intersecting two adjacent planar patches, so called the intersection edges, can be also derived from the planar patches. The boundary edges of buildings are called step edges. Roof face can be reconstructed by grouping these edges and LIDAR patches and refining the grouping results. To reconstruct 3D polyhedral models of buildings, it is necessary to add hypothesized patches for vertical walls, which are usually not detected from LIDAR data.

The followings describe how to group the building primitives and build up the polyhedral models. The main processes are to generate polygons by grouping the edges and patches, to refine the generated polygons, to derive the hypothesized patches and to group all the primitives into polyhedrons. The polygons should be generated by grouping 3D edges and planar patches, where the grouping criteria are *proximity* and *connectivity* among the primitives. Here, the 3D edges can be derived by projecting 2D edges extracted from the digital map or the images to the planar patches extracted from LIDAR data. Some patches may not be extracted because of the properties of the sensors or the insufficient performance of the patch segmentation algorithms. These areas will be filled with the patches generated hypothetically, so called hypothesized patches.

The entire process for building reconstruction is presented in Fig. 1. Among these processes, we focus on generating the three dimensional building primitives in this paper.

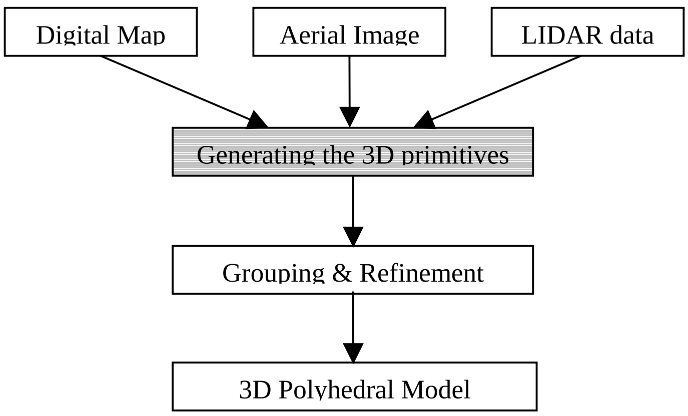


**Figure 1. Building reconstruction process**

## 3. Generation of Building Primitives

The input data for the generation of the building primitives are a digital map (particularly, the building layer), aerial stereo-images and airborne LIDAR data covering the same area. The main primitives generated from these data are the 3D edges and planar patches. The generation process consists of two main steps, extracting 2D primitives and converting them into 3D primitives. Table 1 shows the primitive generated at each step according to their source data. Figure 2 shows the generation procedure of building primitives. In Table 1 and Fig.2, the shaded primitives are the terminal primitives actually used for building reconstruction but the other primitives are intermediate ones.

**Table 1. Building primitives generated at each step according to the their source data**

| Input | 1st extraction | 2D primitives | 3D primitives |
|---|---|---|---|
| Digital map | ROI | | |
| | Building Boundary coordinates | Step edges(2D) | 3D Step edges |
| | | Corners(2D) | 3D Corners |
| LIDAR data | DSM | Step edges(2D) | 3D Step edges |
| | Patches | | 3D intersection edges |
| Images | Edges (image domain) | Edges(2D) | 3D step edges |
| | | | 3D intersection edges |

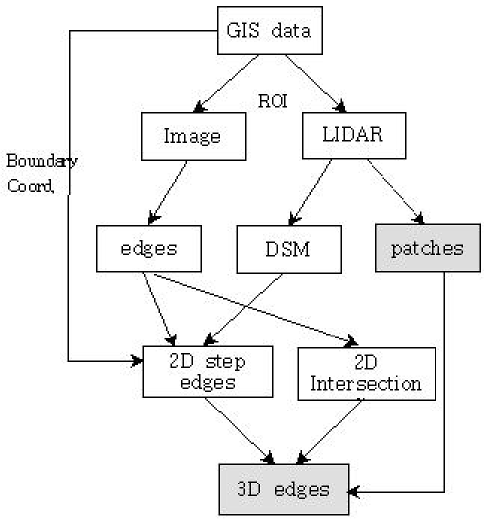


**Figure 2. The generation procedure of building primitives**

### 1) Planar patches and DSM from LIDAR data

Since the LIDAR data is the unique source providing vertical coordinates without cumbersome post-processing, planar patches and DSM are generated from them at first so that they can be used as the vertical reference for others.

Planar patches are segmented from the LIDAR data, that is, clouds of numerous 3D points. The segmentation process starts with establishing the adjacency among the LIDAR point irregularly distributed in 3D space. A point cluster is constructed for every point by gathering a small number of points adjacent to the point. Each cluster is approximated to a plane. The clusters with relatively small fitting errors are selected as seed clusters, from each of which a planar patch is then growing with the adjacent points added to the cluster. During the growing step, every adjacent point to the growing patch is tested about whether the point is statistically consistent with the patch. This growing process for a patch continues until no more adjacent point can pass this test. This grown point cluster called a patch is then verified by checking the size of the cluster and the fitting errors. For the verified patch, its boundaries are computed by determining the outlines of the point cluster. More details in these procedures are presented by Lee [6].

DSM is made by interpolating the elevations of LIDAR points into a regular grid. The interpolation may deteriorate the accuracy of the original LIDAR points and hence the accuracy DSM is generally lower than that of the planar patches. Hence, DSM is used only for the areas that are not be covered by patches due to the incomplete segmentation results while for the other areas planar patches are used. Figure 2 shows the planar patches and DSM generated from LIDAR data.

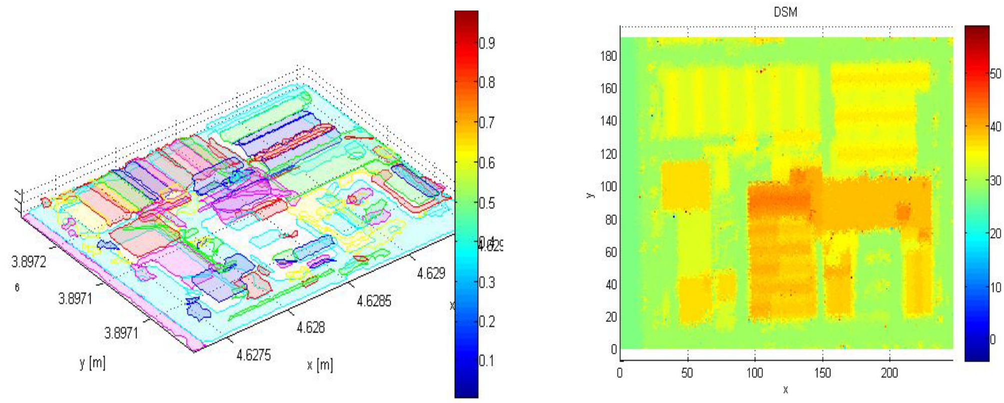


**Figure 3. Patches and DSM generated from LIDAR data**

## 2) Step edges from digital map

The boundaries of buildings are extracted from the building layer of a digital map, as shown in Fig. 4. Each boundary is represented with a 2D polygon constructed with edges and corners. The boundary does not include any 3D information. A boundary often undesirably includes several adjacent buildings with the same polygon. From these boundaries, we derive the region of interest (ROI), step edges and corners.

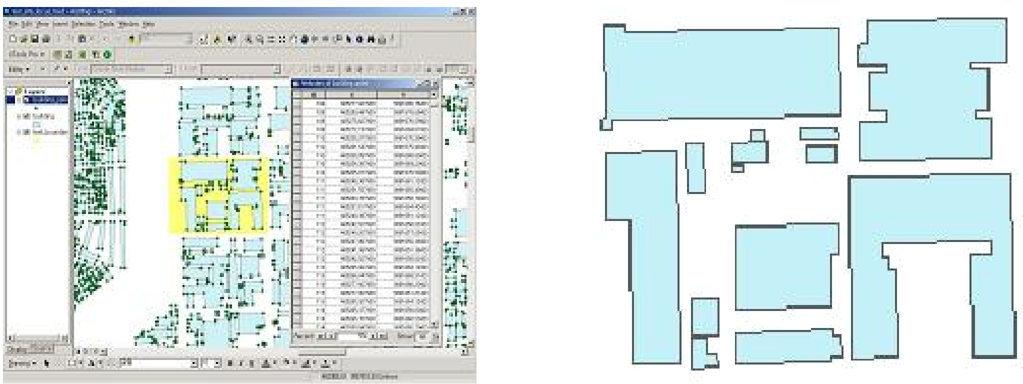

**Figure 4. Building coordinates acquisition**

All of the edges in the building boundary are classified as step edges formed by the intersections between vertical walls and roof faces of buildings. It is because the boundary in the digital map represents only outer lines of each building. These edges have horizontal information without vertical value so they aren't real step edges. Based on LIDAR data retaining 3D information, these 2D edges are converted to 3D edges.

Such 2D edge from digital map will be projected to at least two or more planar patches segmented from LIDAR data. For example, an edge in building outlines can be projected to both the building roof face and the ground patch. In this way, a 2D edge can be converted into several 3D edges. Also, some buildings have non-flat roof. In this case, the edge of the building should be separated into several segments because the roof consists of more than one patch. To overcome these problems, we divide the 2D edges to short line segments, each of which is 0.5 m long. After projecting these segments to the patches, we connect the segments that are projected to the same patch and thus very close to each other. Patches segmented from LIDAR data may not cover the entire surface. In these uncovered areas, DSM is used as the vertical reference instead of the patches. The 2D edges were divided into line segments, the length of which is equal to the interval of the DSM grid.

Using this conversion method, we converted the 2D edges shown in Fig. 4 into 3D step edges by projecting the 2D edges to the planar patches and DSM shown in Fig. 3. The converted 3D step edges are shown in Fig. 5.

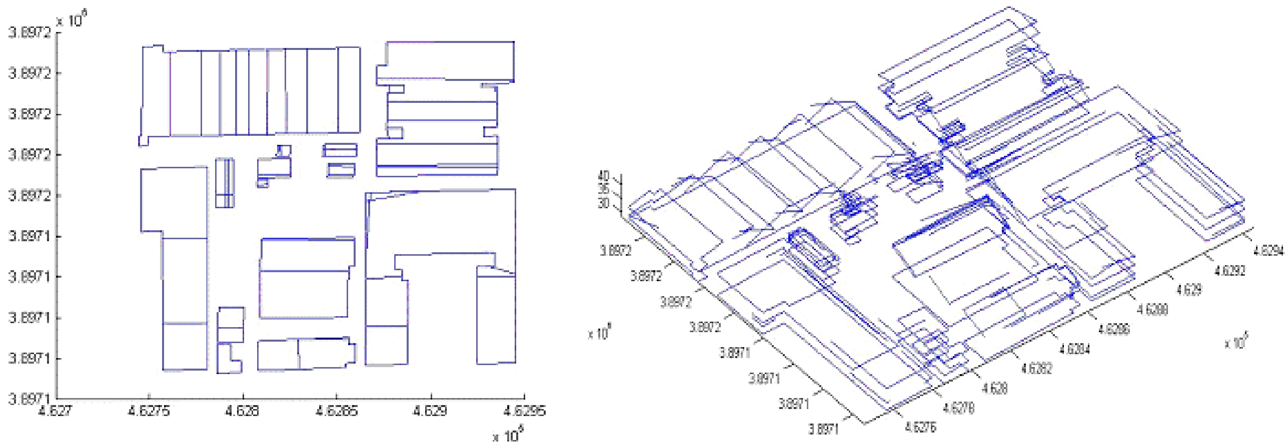


Figure 5. 3D step edges converted from 2D edges

### 3) Edges from images

3D edges are generated by projecting 2D edge extracted from images to the planar patches and DSM generated from the LIDAR data. These 3D edges include both step and intersection edges. The generation process of the 3D edges is as follows:

From the images, edge pixels showing the great change of the gray value comparing to its neighboring pixels can be detected using an edge operator such as Canny detector. These edge pixels are then linked based on their proximity. A sequence of the linked edge pixels is called an edge. For example, Fig. 6 shows the sample image and the edge extracted from this image. These edges include only 2D information. The next step is converting these 2D edges into 3D edges.

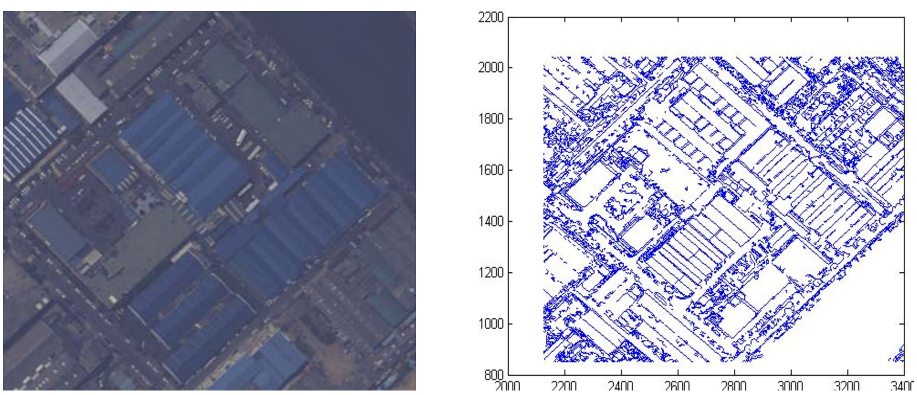


Figure 6. Aerial image and it's Edge

Each image point constituting the 2D edges should be transformed to the ground point. The exterior orientation parameters of the images are assumed to be given since they can be directly measured by the on-board GPS/INS systems or indirectly determined though the aerial triangulation process. The ground point can be then determined using a ray-tracing algorithm that derives the intersection point between the ground surface and the straight line linking the image point and the perspective center, so called the collinear line, as presented in Fig. 7.

For converting a point on the image to the ground, the corresponding patches should be selected among the segmented patches. The selection process starts with determining the elevation range of the entire test area. Based on the elevation range along the straight line linking the image point and the perspective center, we can determine the horizontal range, as shown in Fig. 7. Within this horizontal range, we recomputed the elevation ranges and then the horizontal range also. This process continues until only a few patches exist in the horizontal range. Then, they are finally the patches corresponding to the image point.

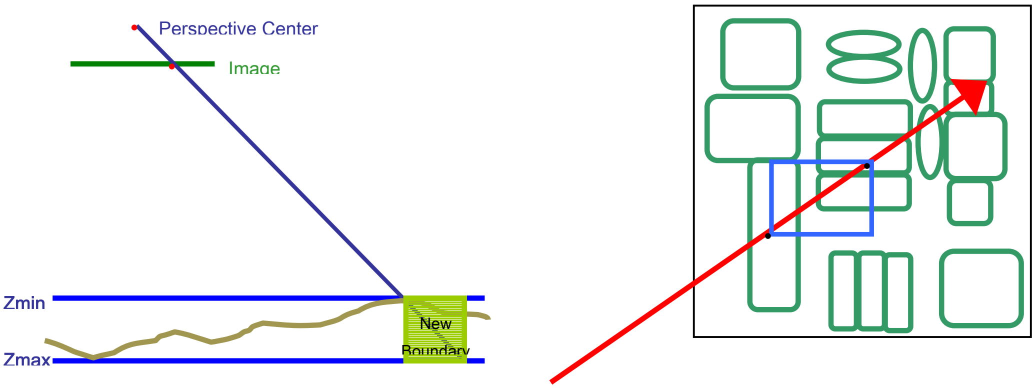


**Figure 7. Conversion of an image point to the ground point**

After selecting the corresponding patches, the ground point can be computed by finding the intersection between the collinear line and the patch. This computation is based on the system of linear equations in Eq. (1-2), where Eq. (1) expresses the plane equation of the patch and Eq. (2) the straight line equation of the collinear line.

$$n \cdot p = d \qquad (1)$$

$$p = \lambda R^T P + Pc \, , \qquad (2)$$

where n = normal vector of plane parameter
p = $[x\ y\ z]^T$
d = normal vector
$\lambda$ =scale
R = rotation matrix
P = Image point in image coordinate
Pc = perspective center

When Eq. (2) is applied to Eq. (1), the unknown $\lambda$ can be expressed as

$$\lambda = \frac{d - n \cdot Pc}{n \cdot R^T P} \, . \qquad (3)$$

Using this equation, the intersection point *P* can be computed as

$$p = \left( \frac{d - n \cdot Pc}{n \cdot R^T P} \right) R^T P + Pc \, . \qquad (4)$$

These procedures of selecting the corresponding patches and computing the intersection points with them are summarized as the flow chart in Fig. 8. The 3D edges constructed using these procedures are shown in Fig. 9.

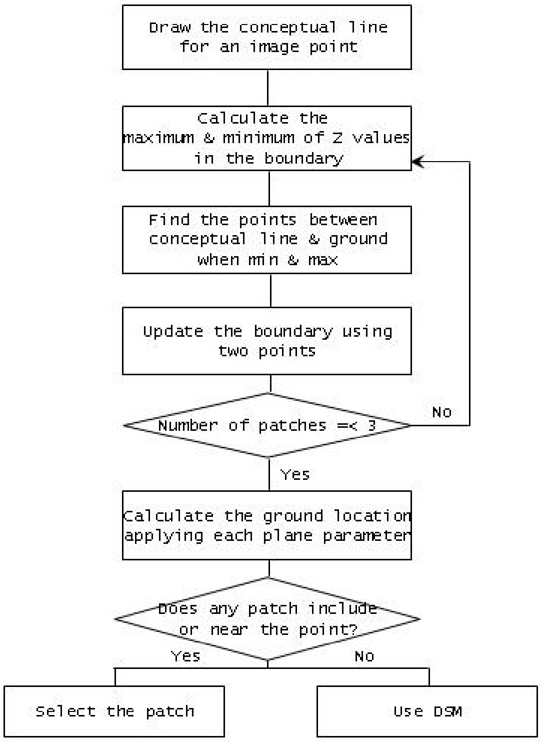


**Figure 8. Procedure of selecting patches**

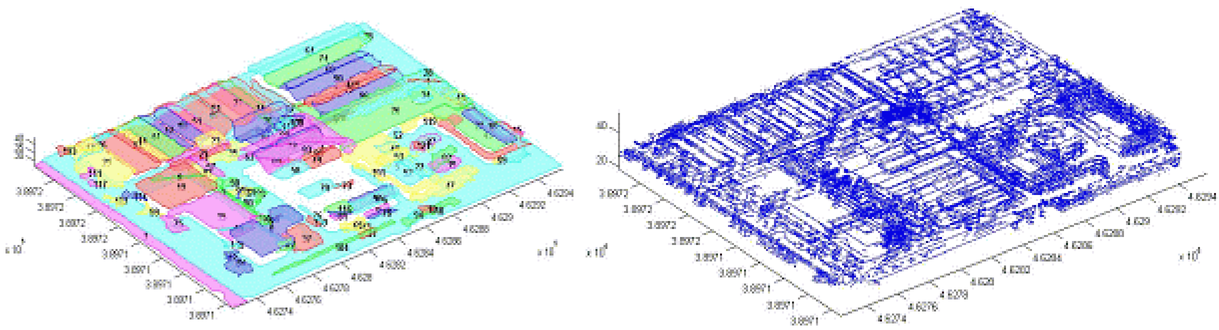

**Figure 9. Patches from LIDAR data (left) and 3D edges from image (right)**

In the areas that no patch covers, DSM took the role of the patches. The method is almost the same as that based on patches except DSM being used for the ground instead of the patches. The iteration would be stopped when the boundary becomes smaller than a grid cell.

### 4) Edges from LIDAR data

As previously stated, planar patches and DSM are generated from LIDAR data. They are not only used for referring to vertical information but also for deriving other building primitives. Edges can be extracted from not only digital map and image but also LIDAR data. Both intersection and step edges can be extracted.

Intersection edges were the straight line segment intersected by the adjacent planar patches constituting the roof face. It could be determined by connectivity and proximity of patches. It is assumed that the proximity among the patches consisting a building would be so high. If two patches are very close to each other and the surface normal vectors of neighboring patches are sufficiently different, they forms an intersection edge. If the surface normal vectors are parallel, the intersection edge could not be determined even though the proximity is very high. An intersection edge is derived from two patches if the angle between the two surface normal vector is larger that 10 degree and the distance between the patches is less than 3 m. Fig. 10 shows the angle and distance between two adjacent patches.

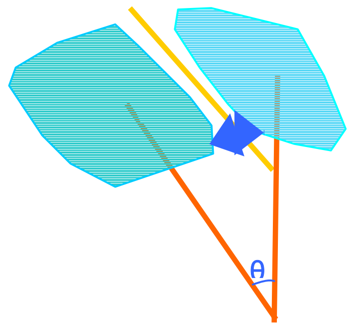


**Figure 10. Intersection edge**

Step edges also could be extracted from LIDAR data. They were made by Canny operator like images because the height distribution was represented as constant grid in DSM. Although these edges came from LIDAR data, they lost their vertical information during the procedure of edge detection. So it required converting to 3D edges, and the processing is same as digital map's case (using patches or DSM). The edges extracted from DSM are shown in Fig. 11.

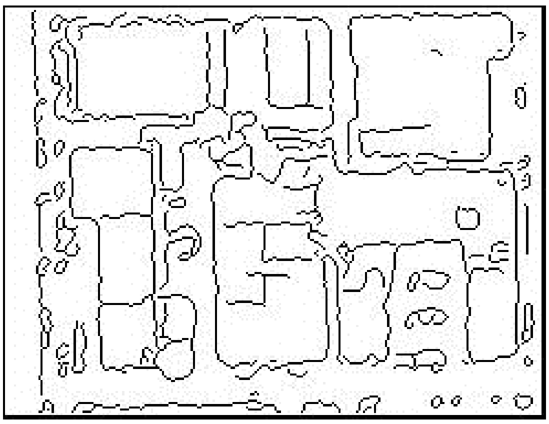

**Figure 11. Edges from DSM**

## 4. Conclusion

This paper has an aim at presenting our methodology for automatic generation of building primitives and verifying the possibility of method through some simple test. Each data has its own strength and weakness. In addition, data acquisition rate in accordance with any object or location depends on the sensors. From this reason, we used the multi-source data in order to overcome the problems and implemented the automatic generation of the primitives.

Building primitives are the edges and patches, being generated from digital map, images and LIDAR data. Horizontal values could be extracted by every data but only LIDAR data has vertical values. To produce the 3D primitives, we combined image data and digital map with LIDAR data. These building primitives could be good elements for reconstruction of building as we suggested.

In this paper, we carried out the some test about generation of primitives and we just suggested the method of grouping. We plan to study on the grouping side from now on. When the study finished, we expect to improve the automatic building reconstruction as much as possible.

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