BUILDING EXTRACTION AND RECONSTRUCTION FROM LIDAR DATA

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ABSTRACT

This paper presents an approach for building extraction and reconstruction from high quality terrain surface, such as LIDAR data generated surface. The approach takes terrain surface data as input and goes through edge detection, edge classification, building points extraction, TIN model generation, and building reconstruction to extract and reconstruct buildings and building related information. For building detection, it detects edges from the surface data and classifies edges to distinguish building edges from other edges based on their geometry and shapes, including orthogonality, parallelism, circularity and symmetry. The classified building edges are then used as boundaries to extract building points and TIN models are generated with the extracted points. Each building has its own TIN model and its surfaces are derived from the TIN model. The test results demonstrate that the approach is capable to extract and reconstruct 3-D building models from high quality terrain surface. The paper presents the concept, algorithms and processes/procedures of the approach and discusses its advantages and limitations. The paper also shows experimental results and discusses the performance/effects of the geometric and shape constraints utilized in the experiments. At the end, the paper concludes with some thoughts for future development.

1. INTRODUCTION

Over the last decade, many research and development efforts have been put into extracting and reconstructing building from images (mono and stereo) and DEMs (Haala and Hahn 1995, Schenk 1995, Henricsson et al. 1996, Weidner 1996, Fritsch and Amen 1998). However, the contribution from DEMs, especially DEMs generated through image matching, has been very limited (Moons, 1997), because of the poor quality of such kind DEMs. Building reconstruction is a 3-D modeling process, therefore 3-D information should be used whenever available. The lacking of independent and reliable elevation information has made the task more difficult. Several years ago, LIDAR (LIght Detection And Ranging) data started to become available for researchers. It didn't take long for them to realize the great value in LIDAR data and use LIDAR data in building extraction and reconstruction (Ackermann 1996, Haala et al. 1998, Wang 1998). The high quality of LIDAR data guaranties the reliability of the provided 3-D information. The high quality of LIDAR data is reflected in several aspects: 1. high accuracy. A typical LIDAR system can provide data with 15 cm vertical accuracy and less than 50 cm horizontal accuracy, 2. High consistency of the accuracy, i.e., the accuracy is same everywhere, and 3. High consistency in coverage, i.e., points are evenly distributed in the covered area. This paper presents an approach for building extraction and reconstruction using LIDAR data generated surface. The approach was developed by Zheng Wang partially for his Ph.D. dissertation.

The approach utilizes 3-D corners and their relative orientations/associations to reconstruct or model a building. At current stage, approach only extracts and reconstructs buildings that have right corners and parallel egdes. The approach first detects edges or contours from a surface data (in elevation image format) and then uses shape and geometrical properties, including symmetry, circularity, orthogonality, and parallelism to classify edges/contours into building and non-building edges/contours, respectively. Since most buildings have simple/regular shapes, which other natural features (such as trees) do not have, shape has been selected as one of the properties to separate buildings from other objects. After the edge classification, the approach makes a TIN model for each building with a group of 3-D points. Each group of 3-D points is extracted by using the corresponding building edge as boundary, which means all the points in the group belong to the same building. Then, the TIN model of each building is used to generate surfaces of the building, where the surfaces are represented by 3-D planes. Finally, the tri-intersections of the surfaces form the 3-D building corners and their relative orientations/associations.

2. AN EDGE AND TIN BASED APPROACH (ETBA) FOR BUILDING EXTRACTION AND RECONSTRUCTION

ETBA consists of two components: an edge-based building classification process and a TIN-based building reconstruction process.

2.1 Edge-Based Building Classification

Buildings are extracted by edge analysis and classification. Since contours have the same properties regarding shape and geometry as edges have, ETBA can work with contours as well. For simplification, edges are used to represent both of them in the rest portion of the paper. Edges are detected from an elevation image generated by a terrain surface data. Detected edges usually represent buildings and other objects that stand out of the ground surface. The purpose of edge analysis and classification is to separate buildings from other objects, mainly trees, by using shape and geometric information contained in edges. The edge analysis is responsible for quantitatively deriving shape and geometric measurements from edges. And, the classification takes care of extracting building edges based on their shape and geometric measurements.

Geometric properties, such as orthogonality and parallelism, have been widely used as constraints for building extraction in many previous researches. In this approach, besides orthogonality and parallelism, symmetry and circularity are two additional properties to be used. Here, the circularity is defined as the ratio of an edge's length (L) over its area (A): $C=L^2/A$. For a circle, $C=4B$, and for a square, $C=16$. Instead of line segments, this approach uses closed edges, which allows analyzing the symmetry and circularity of an object. Symmetry and circularity describe an object's shape as a whole, and only a closed edge can represent it. Since almost all building edges are closed, this constraint actually only filter out non-building edges. Circularity is chosen because it is a measure of object boundary's complexity for covering an area. Most buildings have simpler boundaries than tree edges have, which means that the circularity of a building edge is smaller. Usually for an equal length, a building edge covers a larger area than a tree edge does. Symmetry is selected for object classification because most buildings have symmetric or semi-symmetric (i.e., symmetric referring only to one axis) shapes, but most non-building objects do not have symmetry. ETBA uses 3rd-order normalized moments to represent symmetry. There is one problem, however, with the traditional normalized moments: they are only invariant to translation and scale changes, but variant to rotation. Since the symmetry of an object is measured against the axes of the coordinate system where the object is located, a rotation will change the measure of the symmetry of the object. Therefore, a rotation, which can rotate an object to its symmetric orientation, has to be applied to the object before symmetry can be calculated. Such a rotation makes an orientation normalization. In mechanics, there is an *inertia-tensor-based* rotation that can rotate an object to its principal axis so that around the axis the object will rotate with minimum inertia (Jähne, 1995). This approach borrows the *inertia-tensor* concept and applies it to obtain the orientation normalization. A flowchart of the edge-based building classification is given in figure 1.

Edges

Generic Geometric Condition Checks
(Size, Height, and Closure)

Orientation Normalization

Moments (Symmetry) and
Circularity Computations

Classification on Symmetry & Circularity

Straight Segments Extraction

Right Corners Detection

Orthogonality & Parallel Checks
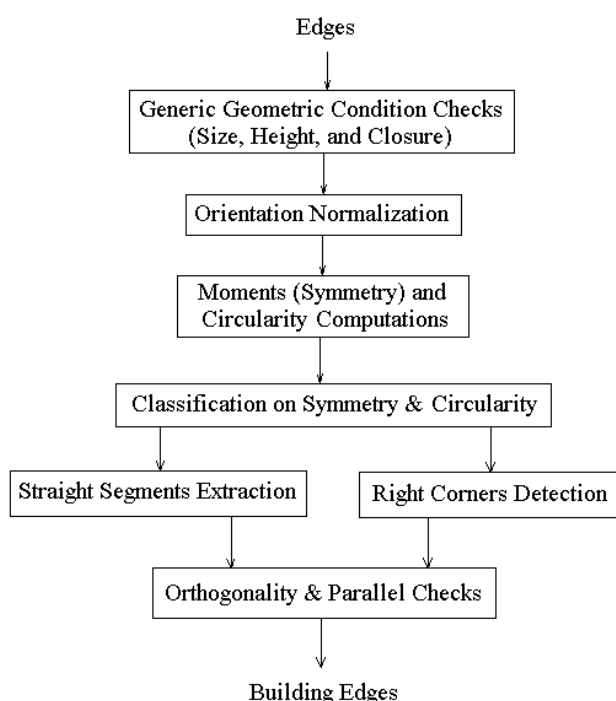
Building Edges

Figure 1. A flowchart of the edge-based building classification

z2.2 TIN-Based Building Reconstruction

To reconstruct a building, this approach generates building surfaces and their orientations first and then uses the tri-intersections of the surfaces to derive building corners and their relative orientations and associations. The derived corners are used to reconstruct the building. Here, a surface is a plane defined by its orientation and position. Building surfaces include ground floor surface as well. The surfaces of a building are derived from triangles of a TIN model that is created from the points of the building. Figure 2 shows the framework of the TIN-based building reconstruction. In figure 2, the reconstruction starts with a set of 3-D points that belong to a building. The 3-D points are extracted by using the corresponding building edge as boundary. A TIN model is created first, then every triangle in the TIN model is converted to a plane and all converted planes are grouped based on their orientations. Planes that have similar orientation are grouped together and an average plane is derived for each group of planes by a least squares error fitting process in iterations. In each iteration, points with large error residuals will be removed and remaining points will be processed to fit to a new plane. Iteration stops when no further points are removed. Final planes are generated after another grouping of average planes and spatial intersections of final planes define the corners needed to describe a building. This approach has advantages in several aspects. First, converting triangles in a TIN model to planes will make every converted plane be related to a building surface, i.e., a roof, a wall, or ground. Although each plane may not accurately fit to a building surface, there will be no irrelevant planes. Additionally, this method will make vertical surfaces (walls) extraction possible. Triangles or planes formed by points around boundaries of a building and points along roof edges of the building will represent vertical walls. Second, the approach is not noise critical, although it is still noise sensitive, because the surfaces are generated from a least squares error fitting process. Third, the approach can recover edges and corners of a building roof even if the spacing of the data is so large that no points are actually on edges or corners. This is made possible because edges can be recovered by intersection lines between two neighboring planes and corners can be recovered by intersection points of tri-planes. Fourth, the approach generates surfaces that can be easily used for future building verification and reconstruction. For instance, building roof edges determined by surface intersections can be projected onto an image, if available, to be verified. And fifth, ridges formed by roof surfaces represent surface orientation discontinuities.
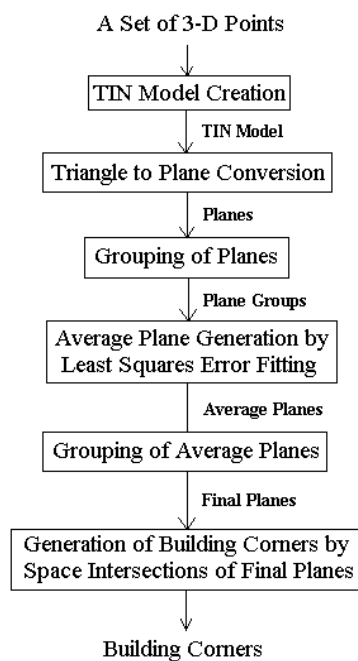
A Set of 3-D Points

↓

TIN Model Creation

TIN Model
↓

Triangle to Plane Conversion

Planes
↓

Grouping of Planes

Plane Groups
↓

Average Plane Generation by Least Squares Error Fitting

Average Planes
↓

Grouping of Average Planes

Final Planes
↓

Generation of Building Corners by Space Intersections of Final Planes

↓

Building Corners

Figure 2. A flowchart of the TIN-based building reconstruction.

3. EXPERIMENTAL RESULTS

Four real LIDAR data sets covering an industrial area were selected for the test. The data sets were provided by Earthdata Technoligies. An area of roughly 650m x 650m was cropped out of the data sets. The cropped area had nine buildings ranging from large to medium to small sizes. The area also had many trees. Because each of those four data sets had a point spacing of 5 meters, which was too coarse to detect small buildings, the four data sets were merged together to create a single data set with an average point spacing of 1.25 meters. Figure 3 is an elevation image of the test area generated by the merged data set. All the buildings in the area have rectangular or near rectangular shape with peaked roof, flat roof, and multiple level flat roof, respectively. An aerial photo of the area was also obtained from a

USGS digital ortho of quarter quad (DOQQ) and is displayed in figure 4. In the aerial photo, buildings can be recognized and they match the rectangular humps in the elevation image.
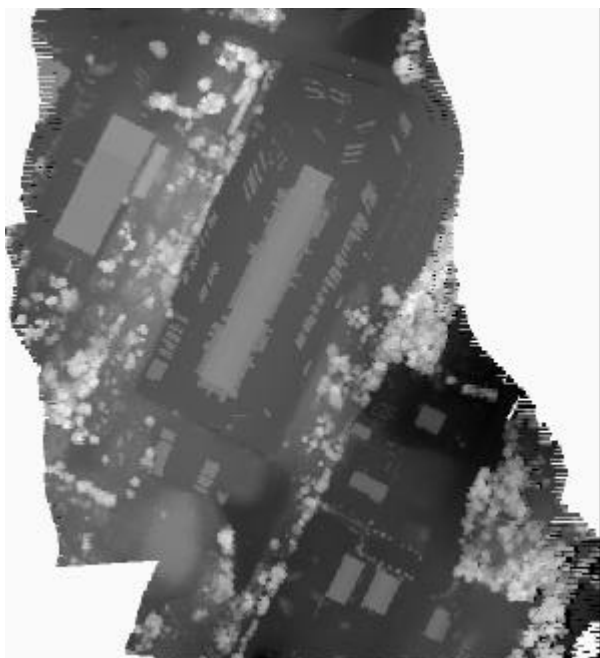

Figure 3. An elevation image of the test LIDAR data set.

Figure 4. An aerial photo of the test area.

To obtain the best results, both edges and contours were generated from the test LIDAR data set. A comparison between edges and contours clearly indicated that the contours were in much better shape than the edges in terms of sharp right corners and straight segments. Because of this, contours were used for the rest of the test, see figure 5.
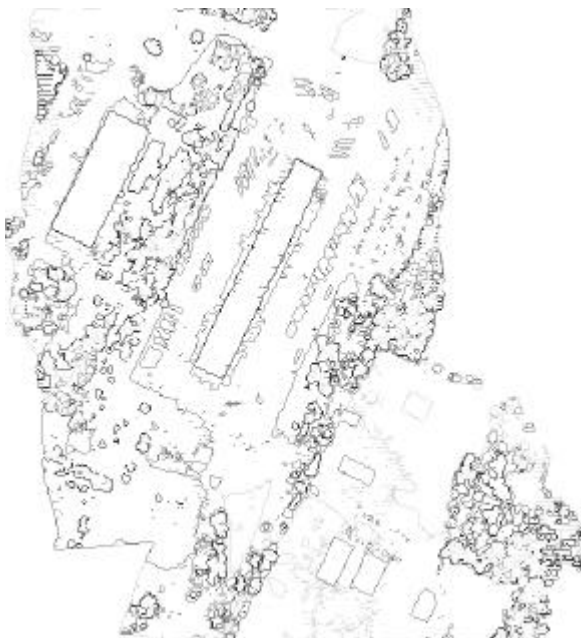
Figure 5. Contours generated from the elevation image.
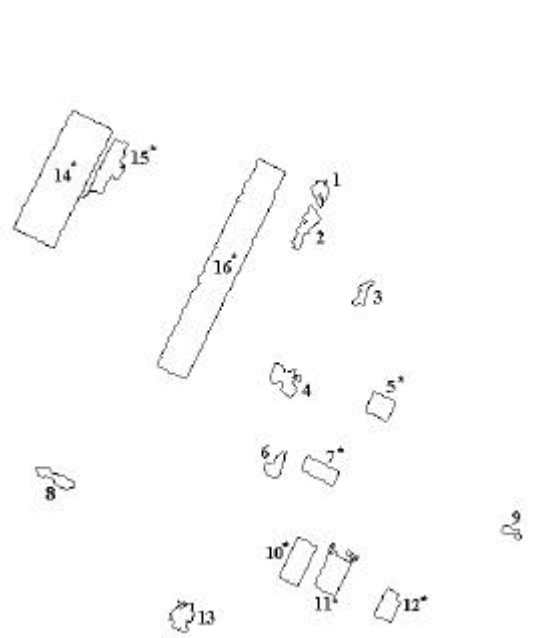
Figure 6. Contour classification results. Contours marked with * were the final building contours.

There were total forty-one qualified contours and they were classified into building contours and non-building contours. Table 1 gives a statistics of all forty-one contours in six categories after symmetry and circularity classification. Of the total forty-one contours, sixteen of them were classified as building contours, see figure 6. The rest

twenty-five contours, including one building, were classified as non-building contours for various reasons: three of them had length problems, either too long or too short; two of them were not closed; four of them were nonsymmetric; fifteen of them had too large circularity values; and one of them was acturally a pit. The misclassified building was caused by nearby trees. Several observations can be made from the statistics. First, the results in table 1 demonstrates that the shape and generic condition-based analysis and classification was very effective to get rid of many non-building objects. In the total forty-one contours, eight of them were true building contours and the remaining thirty-three were non-building objects. This process successfully elliminated 75 percent (twenty-five out of thirty-three) of the total non-building objects. Second, fifteen out of total twenty-five rejected contours were caused by circularity problem. The circularity seemed to be more effective than symmetry to separate building contours from non-building contours. Third, after the symmetry and circularity classification half of the classified building contours actually belonged to non-building objects. But, all those non-building contours had the same high symmetry and low circularity as the true building contours, which means symmetry and circularity alone were not enough to completely divide buildings and non-building objects. To complete the classification, further filtering based on orthogonality and parallism was applied to the remaining contours. At the end, eight final building contours were extracted, which are shown in figure 6 as contours marked with *.

Bldg Contour	Length	Closure	Symmetry	Circularity	Pit
16	3	2	4	15	1

Table 1. A statistics of 41 contours

After building contours were classified, they were used to extract building points. Following the procedure described in section 2, TIN models were generated and building surfaces and corners were derived. Figures 7-14 show the reconstructed buildings together with their corresponding TIN models. Please note that the buildings are plotted with different scales.
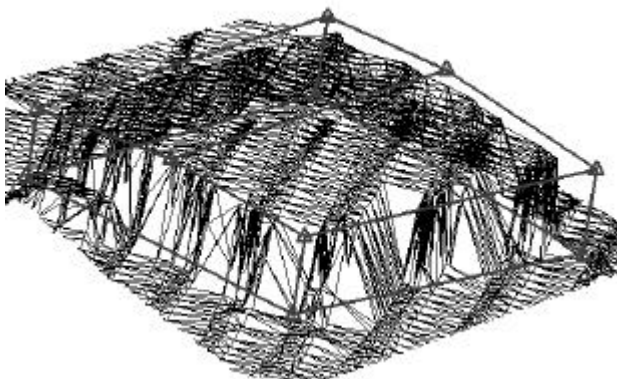

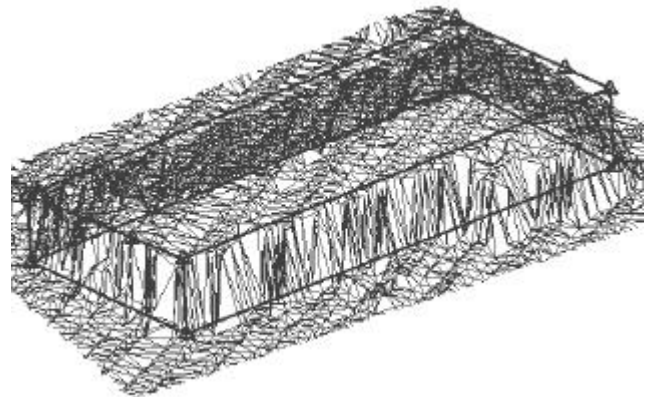Figure 7. Corners, structure and TIN of Building 5.

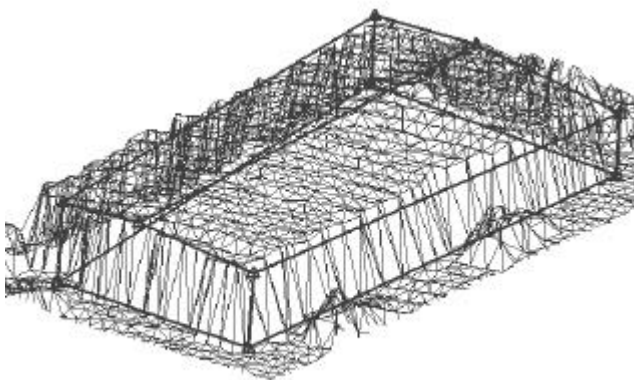Figure 8. Corners, structure and TIN of Building 7.

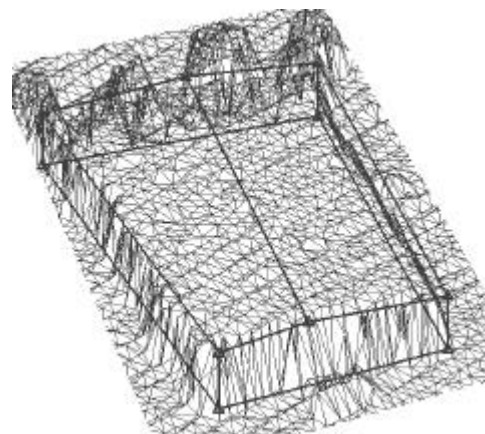Figure 9. Corners, structure and TIN of Building 10.

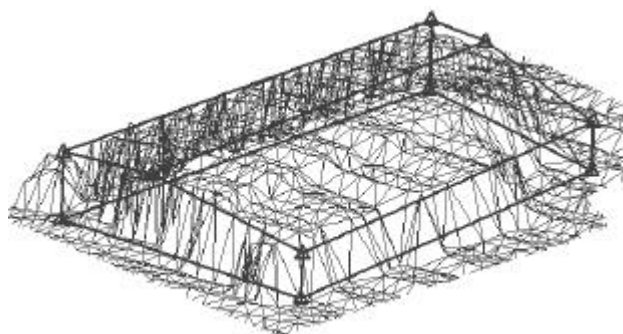Figure 10. Corners, structure and TIN of Building 11.

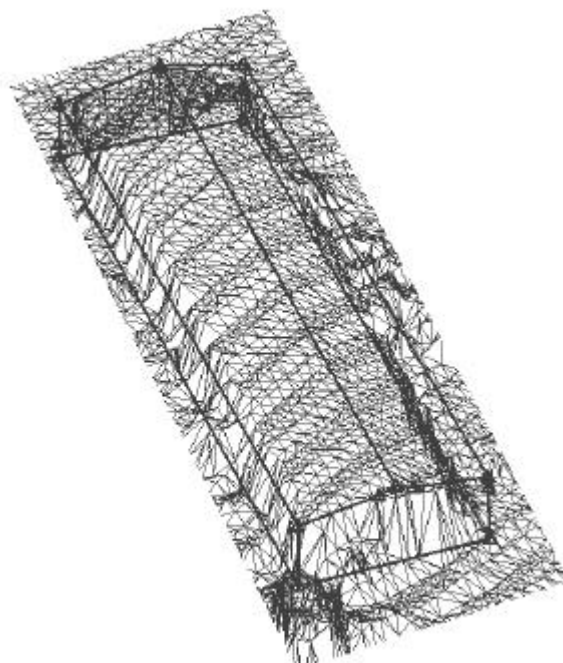Figure 11. Corners, structure and TIN of Building 12.
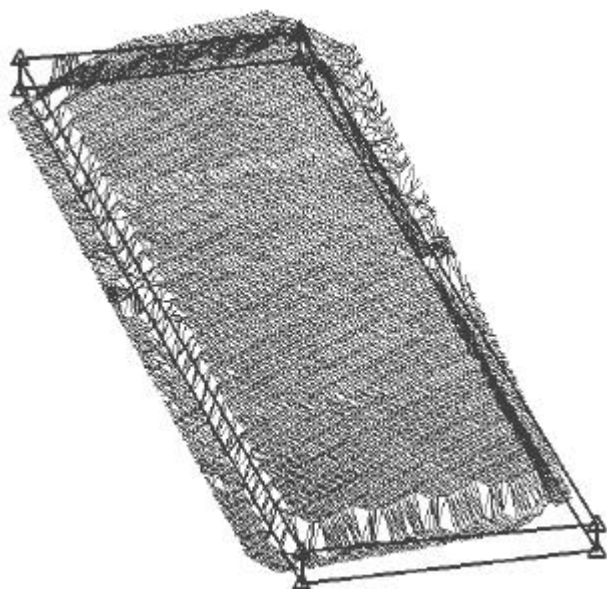

Figure 12. Corners, structure and TIN of Building 15.

Figure 13. Corners, structure and TIN of Building 14.

Figure 14. Corners, structure and TIN of Building 16.

4. CONCLUSION AND FUTURE DEVELOPMENTS

The approach has been successfully tested with real world data. The test results demonstrate that the approach is capable to extract and reconstruct buildings from high quality terrain surface, such as LIDAR data generated surface. The approach utilizes closed edges to analyze object shapes with properties like symmetry and circularity. The combination of symmetry, circularity, orthogonality, and parallelism provides very effective and sufficient measures to classify buildings. The successful tests with the real LIDAR data on the classification processes demonstrate the practical capability of the processes. The TIN-model-based method has shown to be an effective way to generate building surfaces with normal, real world data sets, i.e., data sets with some noise. It is the contribution of closed edges

that allows us to generate a TIN model with only the points that belong to the model. This contribution also allows us to work in a local or model-based coordinate system and make the separation of planes or building walls much easier. Also, the output building corners are in a format readily compatible with most GIS packages. Although it is indicated that only elevation data may not be enough to complete the building reconstruction in many cases, the elevation data should and can play a major role in the building reconstruction. Other information, such as multiple returns of LIDAR data and photography, will help to complete the reconstruction and can provide evidence to confirm or verify certain results.

Some observations have been made from the test results. First, although symmetry and circularity can effectively eliminate many non-building edges, alone they cannot completely finish the task. It seems that the best role for symmetry and circularity is to pre-classify edges, i.e., to use them to quickly reduce the number of candidate building edges. And second, some LIDAR systems, such as EarthData Technology's LIDAR system, collect multiple returns, which is a very effective tool to separate trees from buildings. Such kind LIDAR systems receive multiple returns on trees and single returns on buildings and open ground. When multiple returns of LIDAR data are available, the edge detection for building recognition purposes should be applied to the single return points only, since building surfaces should reflect only one return. By doing so, separating buildings from standing by trees may become a very simple and easy task. Further investigation is needed to explore the full use of multiple return information. Based on the results achieved by this approach, several future tests and developments have been considered, including:

- To fine turn processing parameters to produce better fit building surfaces and corners.
- To test the approach using buildings of more complex shapes, such as L- and U-shaped buildings, to further evaluate the capability of the approach.
- To investigate how other information, such as multiple returns and photography, can be incorporated to achieve better results or to confirm or verify the results generated from a surface data.

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