BUILDING RECONSTRUCTION USING LIDAR DATA

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ABSTRACT:

City modelling in 3D is an important research topic, practically with more different survey technologies to provide and handle data. In this paper, we introduce a new multi-stage process to produce a 3D city model using raw LIDAR data. First we need to locate building blocks from the data, especially when the building boundaries are not available. Then we need to the building shape, for example the roof structure of the building. Finally we reconstruct the buildings using Euler Operators which can preserve the topological connectivity Tse and Gold (2001). Synthetic data of an L-shaped building is used to demonstrate the methods.

1. INTRODUCTION

An increasing need for automated 3D city reconstruction models is being driven by a variety of applications, from tourism to disaster management. The three main issues are: display technology, data structures and data collection. Display technology, driven by games development, is now satisfactory even on modest computers. Data structures connecting the various portions of buildings and terrain have been well defined in Computer Aided Design (CAD), Computational Geometry and Geographic Information Systems, although they have only recently been integrated. The greatest remaining difficulty is in efficient data collection and modelling. This used to be a laborious manual procedure, but the arrival of LIDAR (Light Detection and Ranging) - airborne laser altimetry - now provides rapid elevation models of terrain and buildings. The remaining challenge is to convert this information into CAD-type models containing walls, roof planes and terrain which can be rapidly displayed from any 3D viewpoint.

It is common in current research to remove all buildings, trees and terrain objects from the raw LIDAR data and generate a bare earth model to start the 3D building reconstruction Vosselman (2003). Building boundaries are obtained by searching, with the help of additional data sources or existing cadastral data (Sohn and Dowman, 2003, 2004; Suveg and Vosselman, 2004, 2001; Vosselman and Dijkman, 2001). Then a pre-defined building shape is found by calculating the roof structures. Finally they use CAD software to create the building and paste it on top of the bare-earth model. Problems occur when no other data source is available for building outline extraction, the target building does not match any pre-defined building shape and topological connectivity between the building and the terrain surface is needed for further spatial analysis.

We used an alternative approach starting with raw LIDAR data which looks like a group of point clouds with x, y and z coordinates (figure 1). However the building footprint is not easy to recognise. We separated the high and low data points to locate the building blocks. Then we clustered the data points inside the building boundary to remodel the roof structure. The final step is to reconstruct the building from the terrain surface with persevered topological connectivity.

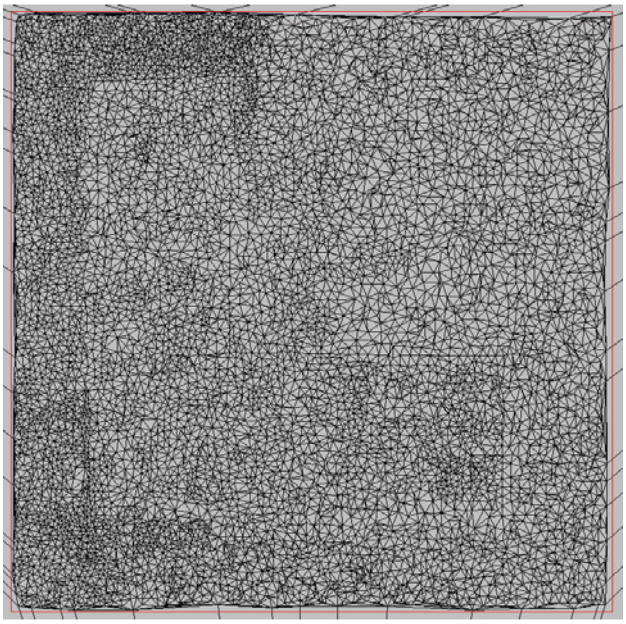

Figure 1: Raw LIDAR data points

2. BUILDING BLOCKS IDENTIFICATION

To identify building blocks, we separate the high from the low land. The LIDAR data is converted into a standard triangulated terrain model using the Delaunay triangulation. This produces a "lumpy" model of planar roof portions (due to elevation error in the data) as well as shows sloping wall portions (as vertical observations can not capture both the top and bottom of a wall). To improve this we use the Voronoi diagram, the dual of Delaunay triangulation.

The raw LIDAR data points are sampled into a lower resolution triangulation (figure 2). The vertical wall portions are captured by partitioning our map area into contiguous cells. We attempt to detect a vertical surface break in each Voronoi cell by using Principal Components Analysis to "look along" the potential wall segment. These segments are shifted to maximize the difference between the low and high areas. We split the cell along the segments and connect the edges between adjacent cells to form closed building boundaries (figure 3).

After the closed building boundary segments are found, we need to sharpen the building corners. The building wall segments are clustered by their direction (figure 4). We extract each group of the clustered wall segments and calculate an average line. The averaged line intersects with its neighbouring averaged line around the building to find the building corners (round points in figure 5). Figure 6 shows the building outline and the next step is to discover the roof structure.

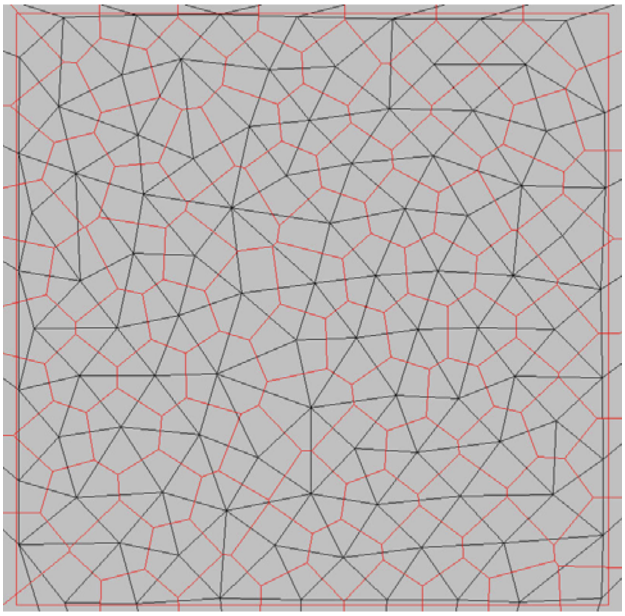

Figure 2: Data points in a lower resolution

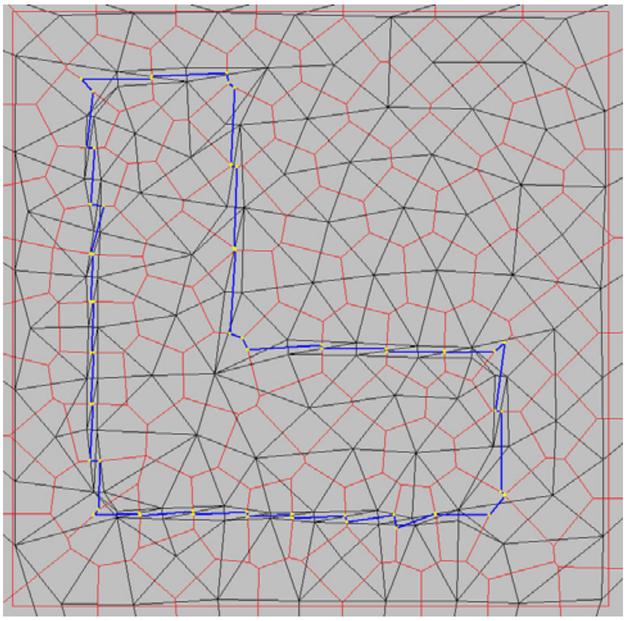

Figure 3: Closed building boundary

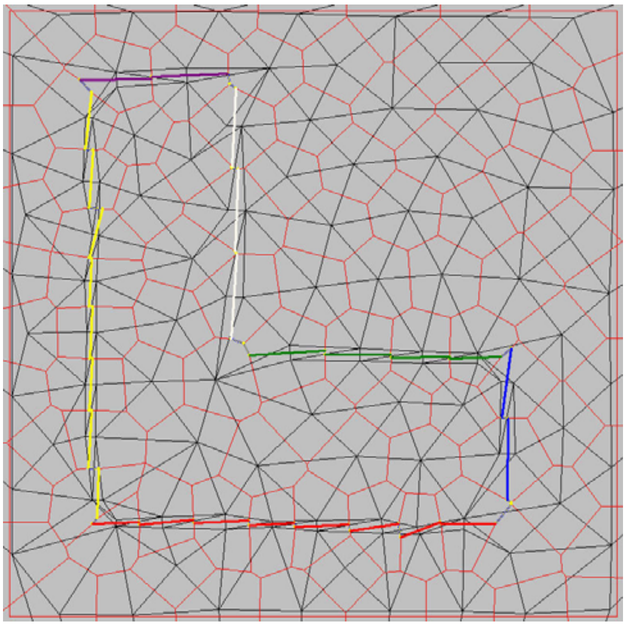

Figure 4: Clustered building wall segments

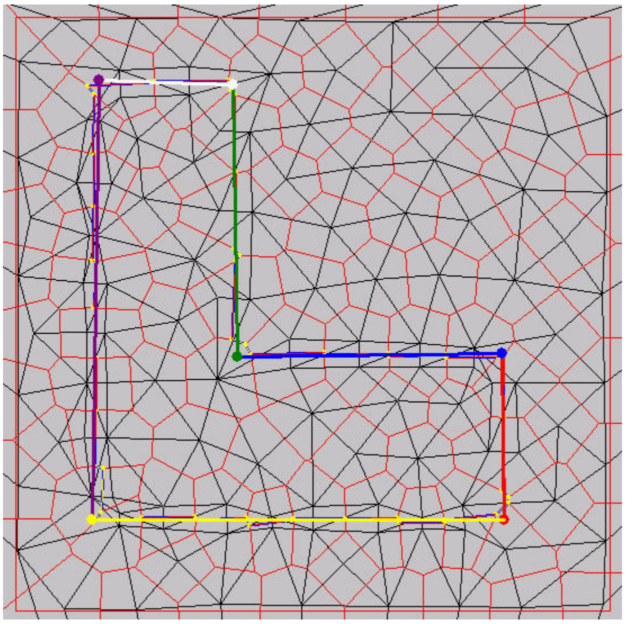

Figure 5: Averaged lines and building corners

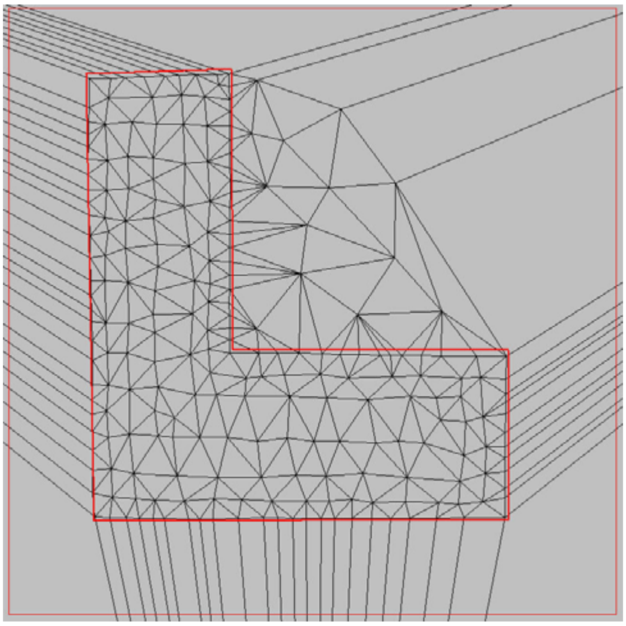

Figure 6: The building outline

3. BUILDING ROOFS RECOGNITION

We then examine all interior LIDAR observations and triangles to identify planar faces. An L-shaped cross-hipped roof is used to demonstrate the method. Data points are extracted and clustered to find the roof structure. The result is a set of clusters, each representing a single roof plane, and each with a common description of the plane (its orientation and an averaged "visible"' point on it). These planar descriptions are then connected to form a building model giving all the intersections between the roof planes and the walls.

3.1 Orientation Clustering

The first step is to calculate the vector normals (perpendiculars) of each interior triangle and plot them on the unit hemisphere (figures 7 and 8). This will show clusters for triangles which have similar orientations (although these may not all be part of a single planar roof).

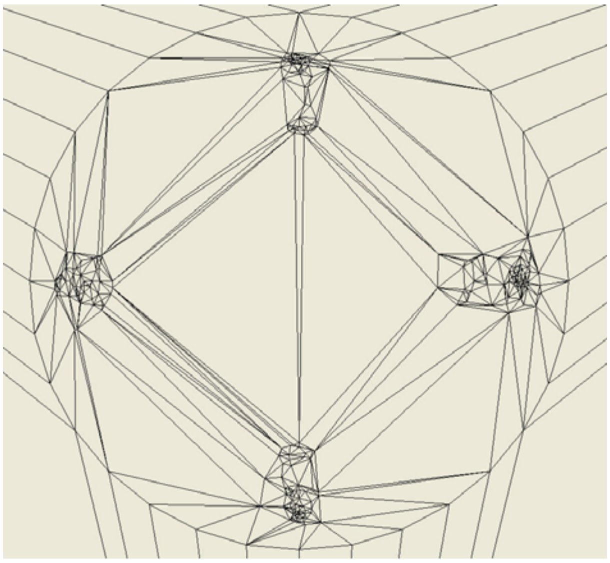

Figure 7: 2D view of normal vectors on the unit hemisphere

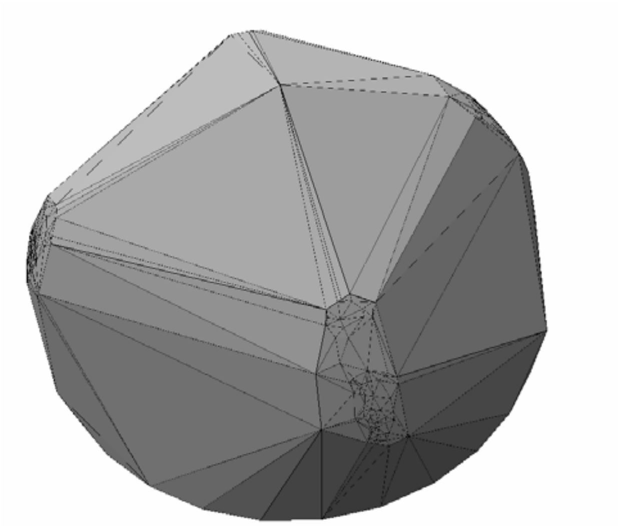

Figure 8: 3D view of normal vectors on the unit hemisphere

The normal vectors on the hemisphere are clustered using the Minimum Spanning Tree (MST). If the normal vectors are within a tolerance, they will be assigned to the same group. Each cluster is then tested to see if it is part of a single plane, or of two parallel planes - if so the cluster is partitioned. Coplanar triangles or data points occur in separate roof portions, these must be partitioned again.

Figure 9 shows four groups of normal vectors which means that the triangles are facing four different directions. Four groups of normal vectors may contain more than four roof planes because more than one roof plane can face in the same direction on a building.

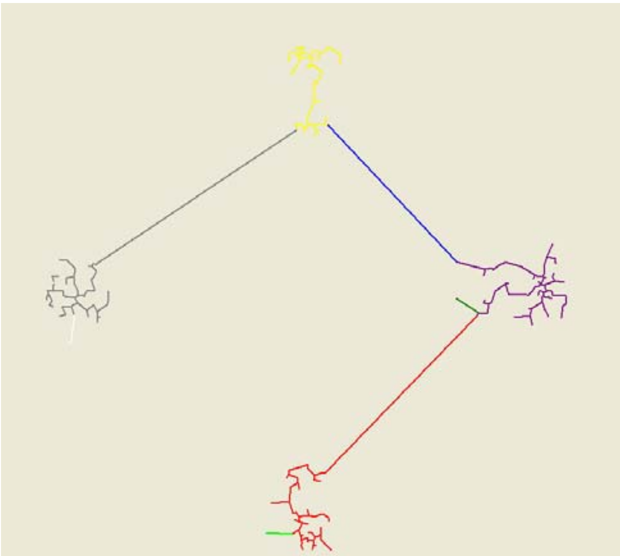

Figure 9: Orientation clustering of normal vectors in 2D view

3.2 Perpendicular to Orientation Clustering

To cluster triangles facing the same direction, we calculate the average normal vectors of each group of triangles (the darker triangles in figure 10). Then we project the centre point of the triangles (solid thin red lines in figure 11) onto its averaged normal vector (dashed thick line in figure 11). They are in the same group if the projected centre points are close to each other.

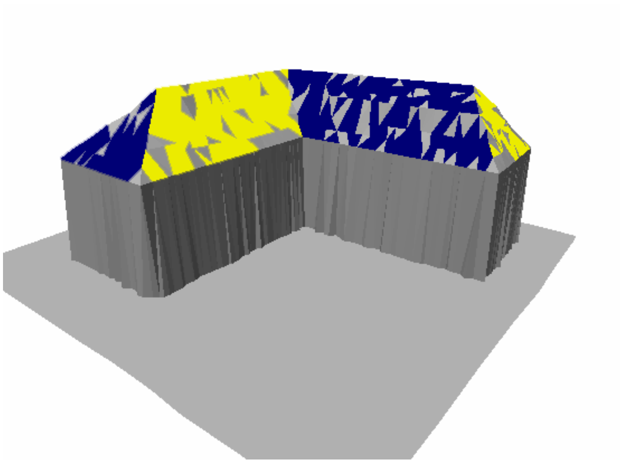

Figure 10: The darker triangles face the same direction

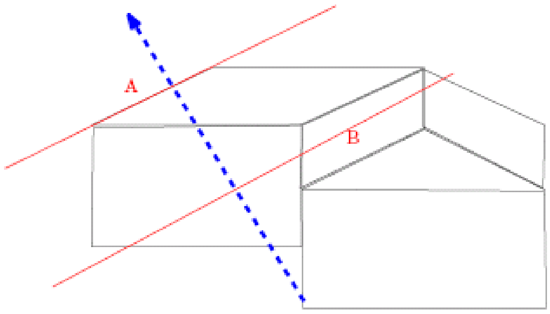

Figure 11: Triangles on roofs A and B projected onto the averaged normal vector (thick dashed line)

The same method is used to separate the building extension because there is a height different between the extended and the main building. In figure 12 triangles on roof A (the main building) and B (the extension) are projected onto its averaged normal vector (dashed thick line) and they can be clustered in two groups according to the projected locations.

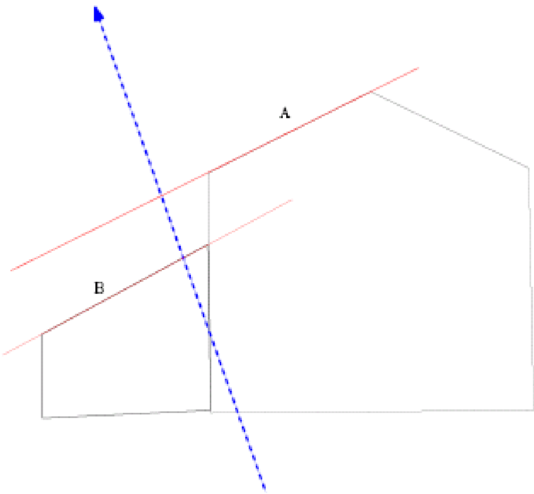

Figure 12: Triangles on roofs are projected on its averaged normal vector (thick dash line)

3.3 Geographical Location Clustering

After the first two clustering methods, some roof planes can still be clustered in a wrong group. In figure 13 triangles on roof A and B are actually on two roof planes, but they are still in the same cluster. Geographical location clustering is used to separate them. A Delaunay triangulation is created using the centre point under the same group of triangles. The centre points are clustered by the MST. If the centre points of the triangles are close to each other, they will be clustered into the same group.

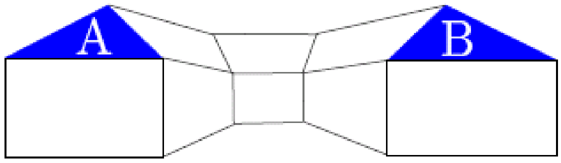

Figure 13: A building with complicated hipped roofs

Finally each cluster of triangles represents a roof plane. The roof structure is found by intersecting these roof planes. Figure 14 shows the intersection points (square points) between the roof planes and the vertical walls of the building. This is directly converted into a CAD model with planar faces that is then merged with the adjacent terrain.

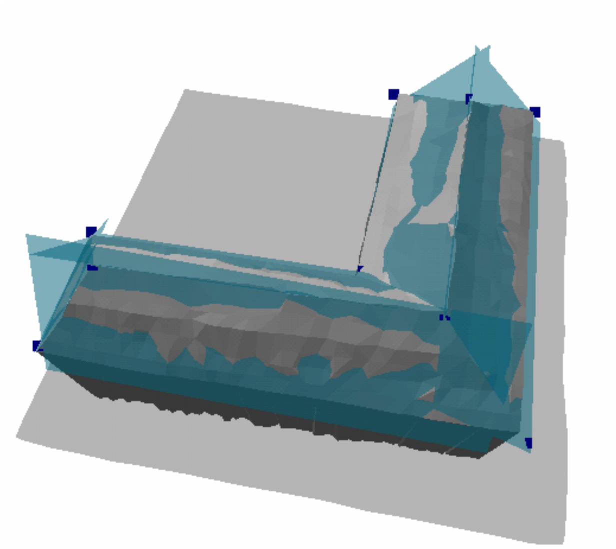

Figure 14: Square points are the intersection points

4. BUILDING RECONSTRUCTION

We have got the building footprint and roof structure, then we extrude the building from the terrain surface. We had been successfully using CAD-type Euler Operators to reconstruct our buildings with guaranteed topological connectivity Tse and Gold (2001). Our model is based on the Quad-Edge data structure. Then we implement the Euler Operators using the Quad-Edge data structure and the triangulation operators using the Euler Operators. Finally we use additional Euler Operators to extrude and modify the buildings Tse and Gold (2004). Figure

15 shows the reconstructed L-shaped building with a cross-hipped roof structure.

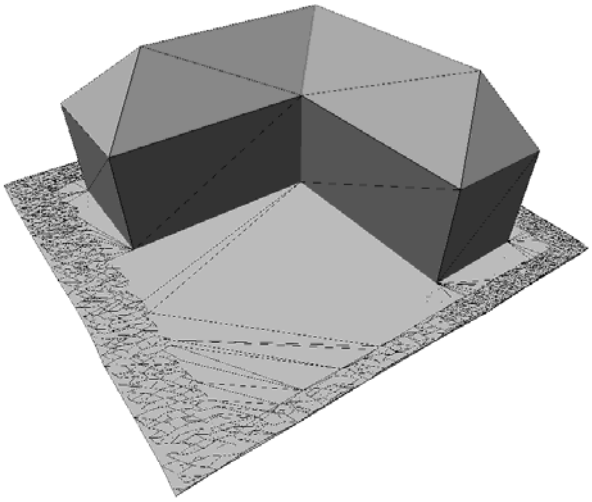

Figure 15: An extruded L-shaped building

5. CONCLUSION

Using the Delaunay triangulation and Voronoi diagram shows an alternative approach to reconstruct 3D building models with raw LIDAR data automatically. Figures 16 and 17 show two examples of extracting roof planes from real LIDAR data, with a significant noise component.

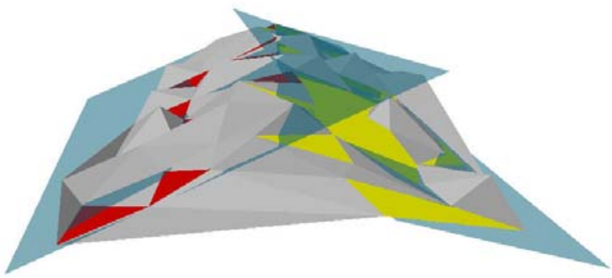

Figure 16 Two roofs planes are found

An advantage of this approach is that no initial model of the building shape is presumed. The approach is particularly useful where rapid 3D city models are desired, as little manual intervention is required for many building types, although extensions can be developed for cylindrical roof portions, etc. We believe that this work could be very helpful for applications in rapid visualization, for disaster management, visibility analysis and radio transmission questions, to name but a few.

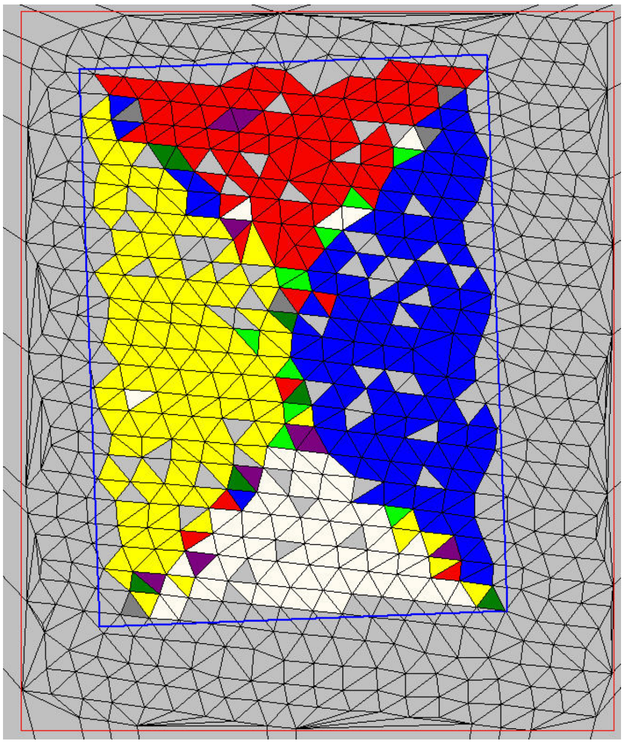

Figure 17: Four roof planes are found

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Figure 17: Four roof planes are found

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