Constructing 3D City Models by Merging Ground-Based and Airborne Views

Cristian Frueh and Avideh Zakhor
Video and Image Processing Lab, U.C. Berkeley

Presented by Saikrishnan Ramachandran and Matteo Mannino

Objective

Develop a fast approach to automated generation of textured 3D city models with both the high details observed from a terrestrial view, and the complete coverage observed from an aerial view.

Introduction

Terrestrial (Ground Based View)

Advantages:

- High level of detail for ground and building facade

Disadvantages:

- Lacks building top information and range due to occlusion
- Difficult to construct large areas

Introduction

Aerial view

Advantages:

- Provide accurate building footprints
- Can be rectified into orthoprojections to merge many images over a large area.

Disadvantages:

- Lacks detail (it is essentially a height map)

Introduction

Applications

- Urban Planning
- Virtual Heritage Conservation
- Training and Simulation for Urban Terrorism Scenarios

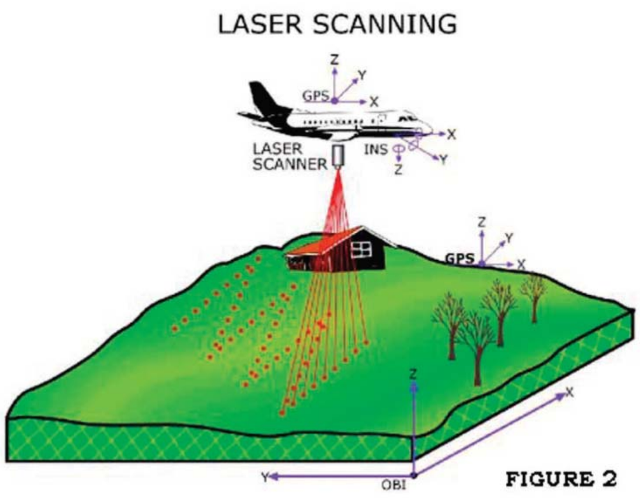
Data Acquistion

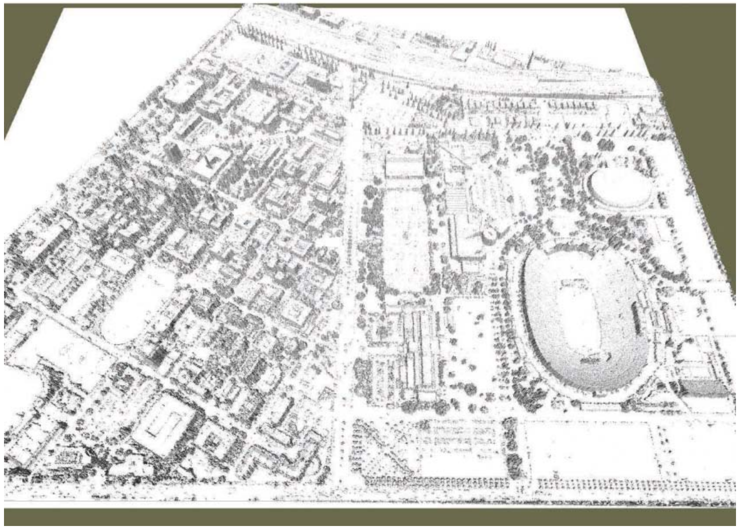
- Lidar Capture System

  An aircraft flies over an area emitting pulses and measuring their reflection, attempting to create a grid of points.

  Pros: Avoid errors caused by shadows of trees and perspective shift.

  Cons: Due to predictable roll and tilt of the aircraft, the grid is not uniform and must be treated as an unstructured set of 3D vertices in space.

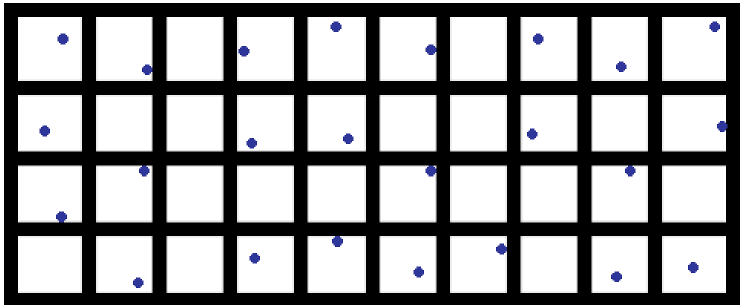




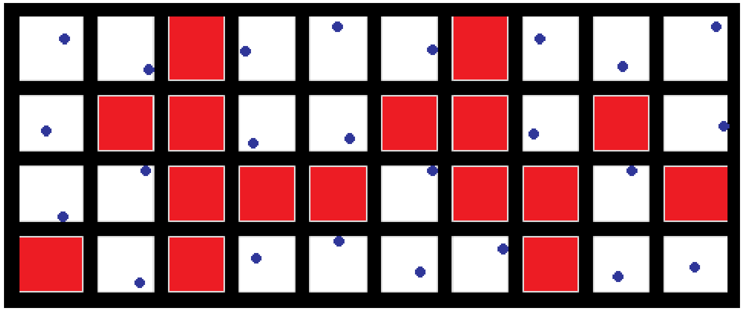
Scan Point Resampling

Resample grid points to row-column structure - Balance spatial resolution and percentage of structure elements without sample points.

Scans have accuracy of 30 cm, with a raw spot spacing of 1.3 meters or less. For this case, choose 1m x 1m grid cells for approx. 50% of the elements without samples.



The example shows 16 out of 40 (40%) elements without samples.



Digital Surface Map

Samples-to-Image algorithm for DSM:

For each grid element:

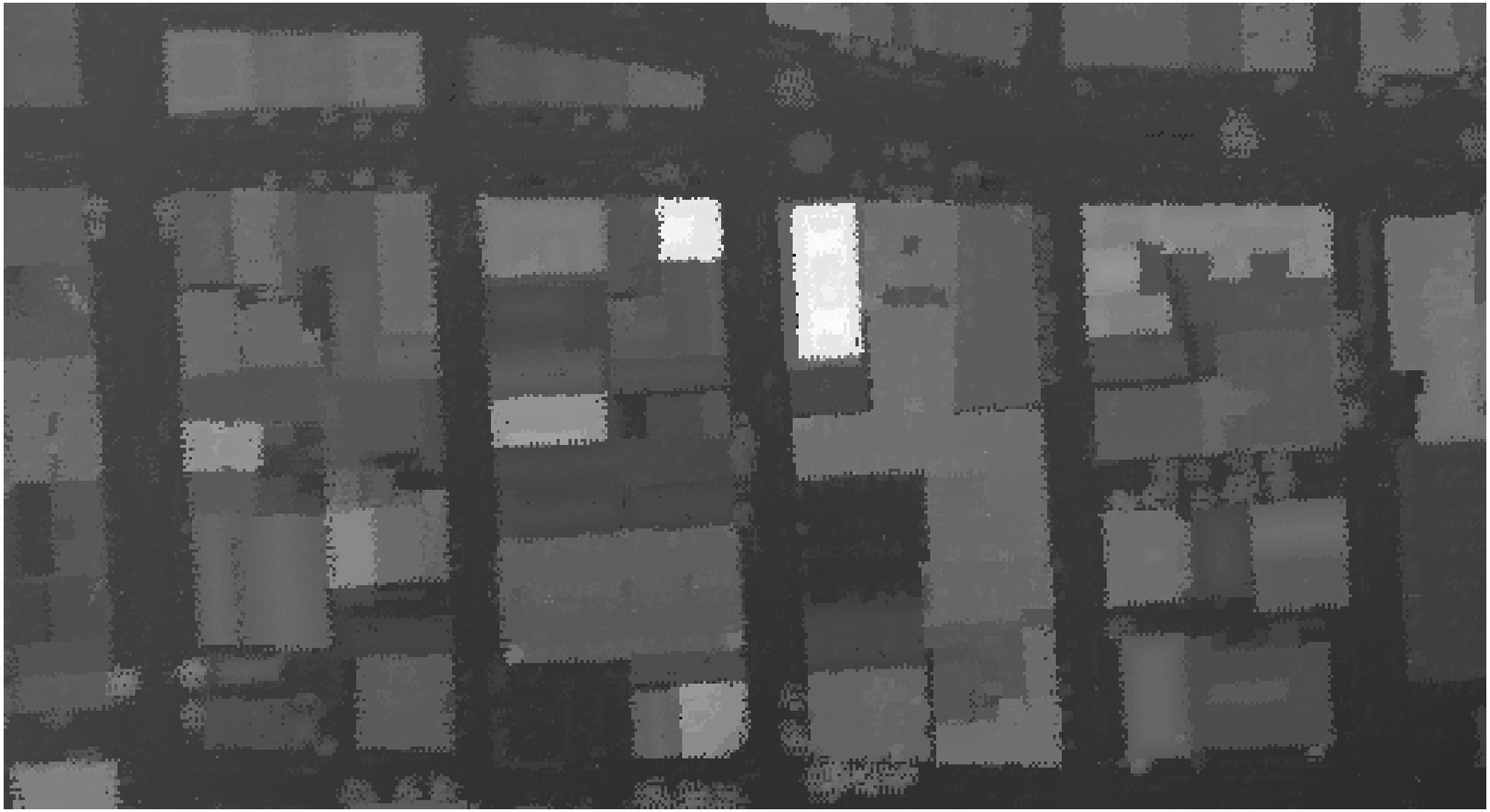
Case 1: One sample occupies on element.
Height value of sample is chosen.

Case 2: Multiple
samples occupy an element.
The maximum height value is chosen
- Overhanging rooftops are preserved over side walls

Case 3: No samples occupy an element.
Select height value of the nearest
neighbor (nearest-neighbor interpolation)
- Preserve sharp edges

Digital Surface Map

Image of Digital Surface Map (DSM)



Processing the DSM

Problems with current DSM:

- DSM doesn't just contain rooftops and terrain shape, but other objects such as cars and trees that cannot be reconstructed due to undersampling and resolution.
- Scan points below overhanging roofs cause ambiguous altitude levels. (results in "jittery" edges)

Processing the DSM

Fixes:

Region growing algorithm based on depth discontinuity.

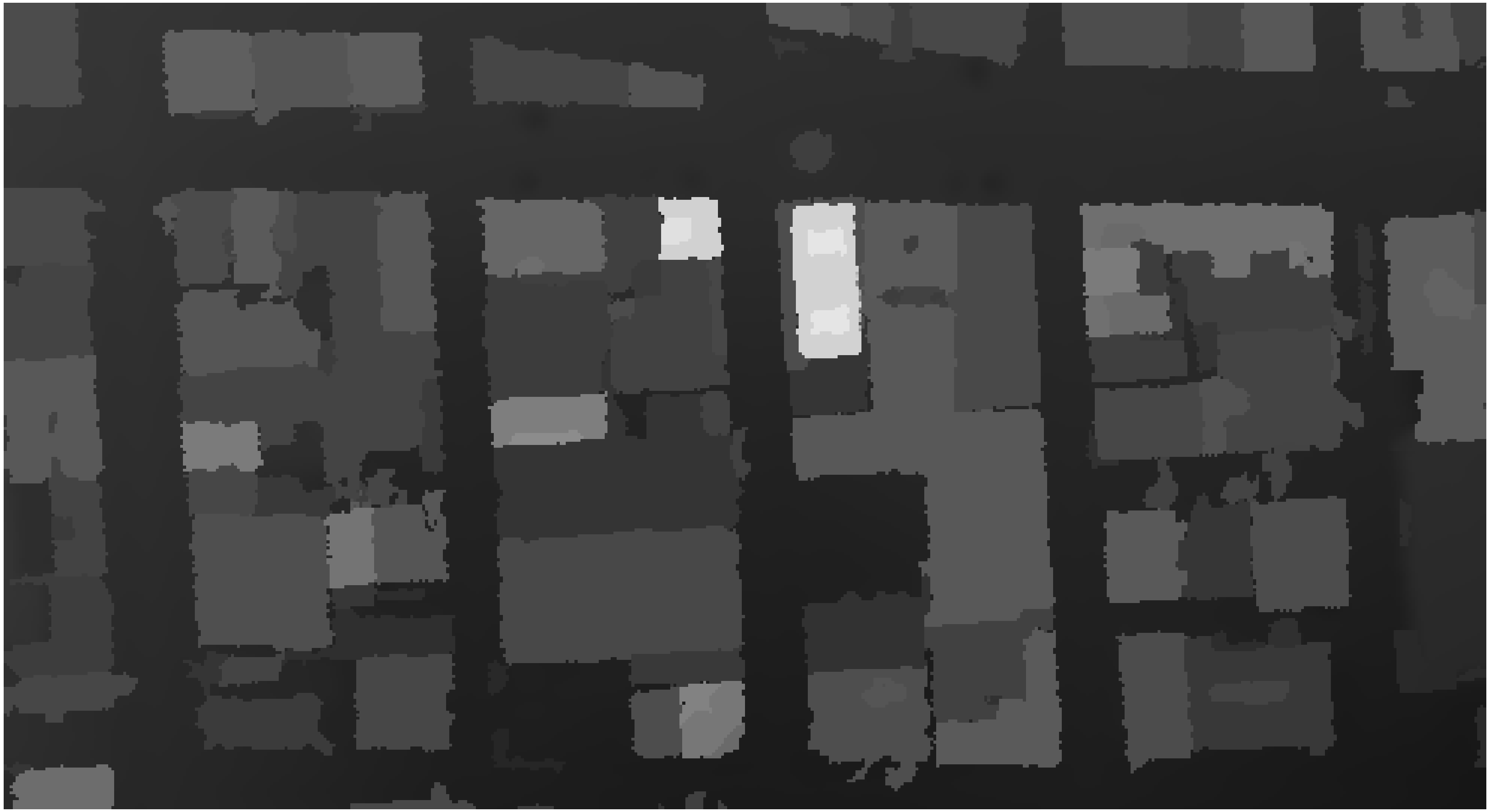
1. Eliminates depth discontinuity between neighboring pixels
2. Segments image into large planar regions and small regions, then unites the small regions with corresponding large regions

- Eliminates bumpy-ness from ground level cars and trees.
- Removes undesired small objects on rooftops

However, we lose some unique geometry as a result.

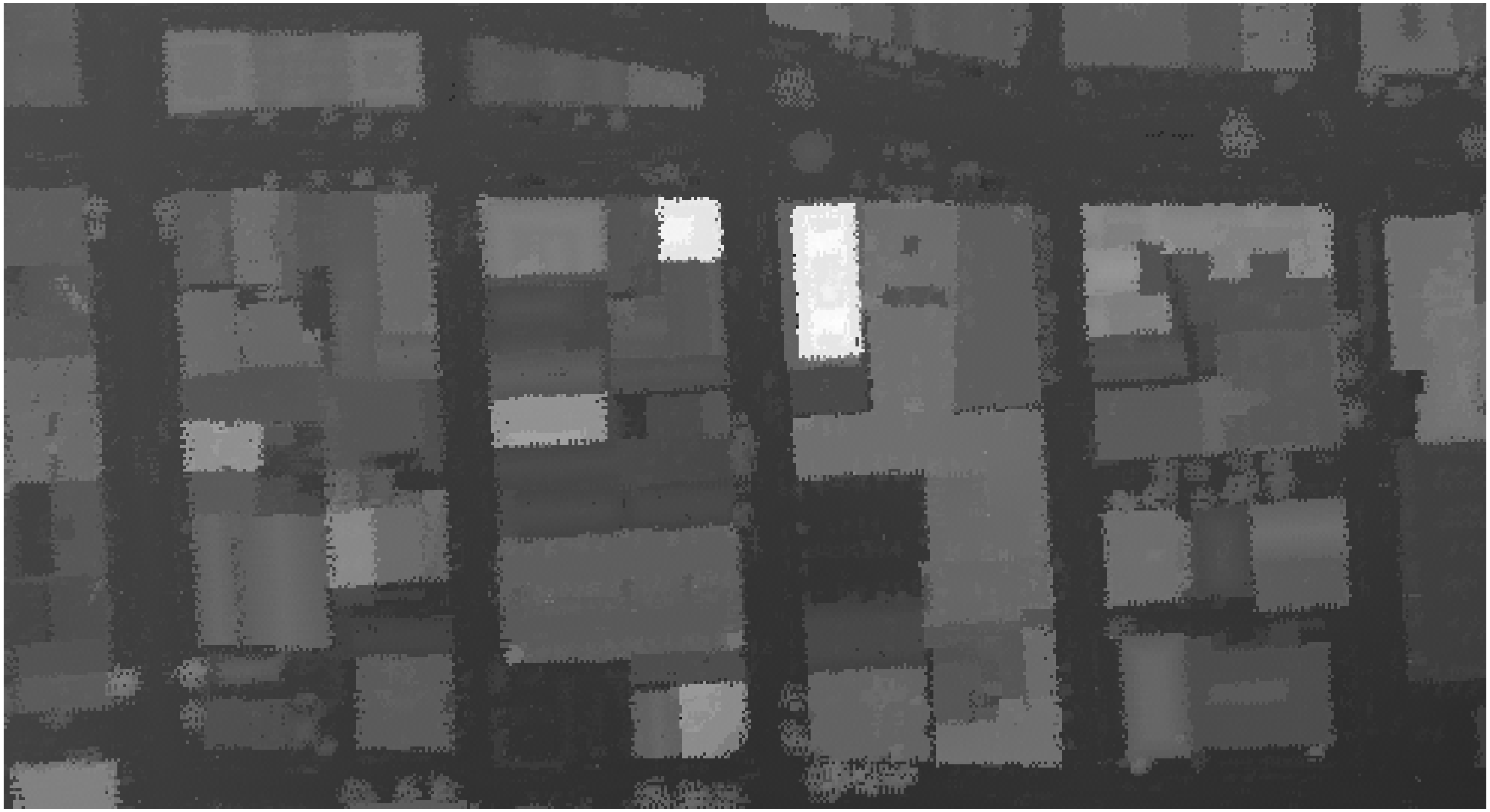
Processing the DSM

(After) Region growing



Processing the DSM

(Before) Digital Surface Map (DSM)



Processing the DSM

Finer Fixes:

Use RANSAC to fine tune edges (Random Sample Consensus).

1. Re-segment new DSM
2. Obtain set of boundary points
3. Use RANSAC to fit a line to the points
   - If a line cannot be fit within a certain error, the edge remains unchanged
4. Add line to the uppermost plane, making it the new boundary

Processing the DSM

Segments with white RANSAC lines

Processing DSM

Simple edge detection

1. Define discontinuity to be a height difference *below* exceeding some threshold between two pixels:

   z(current pixel) – z(neighbor pixel) > threshold

   This way the outermost pixels of the taller objects are marked
2. Mark pixel as an edge if at least one discontinuity in a neighboring pixel occurs

Processing DSM

Edges

Processing DSM

Estimate Ground Level

1. Apply Exponential filter to the ground level plane.

$$H(n,m) = A*\exp(distance(x,y))$$

Processing DSM

Ground Level Estimate (Grey patches– Areas with ground level estimates)

Create Mesh

Mesh Creation

1. Use direct DSM image to triangulate mesh. Two triangles per 1 meter X 1 meter block.
2. Since we have many planar surfaces, the mesh can be drastically reduced. Qslim algorithm is used:

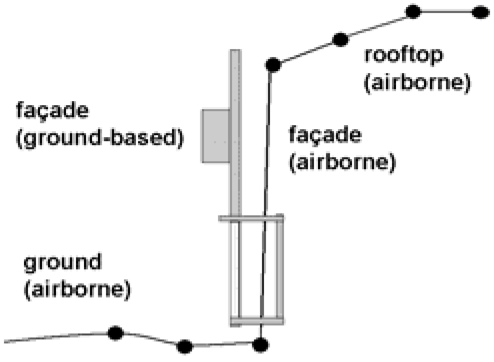
   M. Garland and P. Heckbert, “Surface Simplification Using Quadric Error Metrics”, SIGGRAPH ‘97, Los Angeles, 1997, pp. 209-216

Texture Map

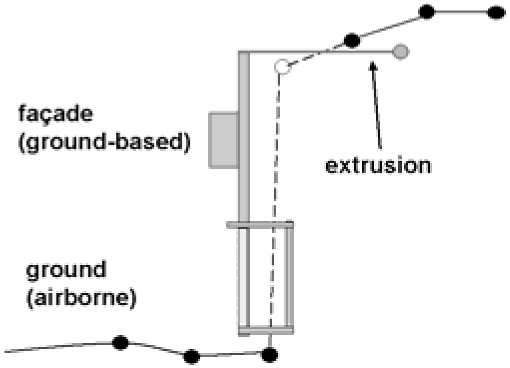
1. Manually select points on an existing aerial photo that correspond to points on the DSM.
2. Use Lowe's algorithm to compute the optimal camera prose by minimizing the difference between computed projections and selected correspondence points.

   D. G. Lowe, "Fitting paramtrized three dimensional models to images", Trans. On pattern analysis and machine intelligence, vol. 13, No. 5, 1991, pp. 441-450

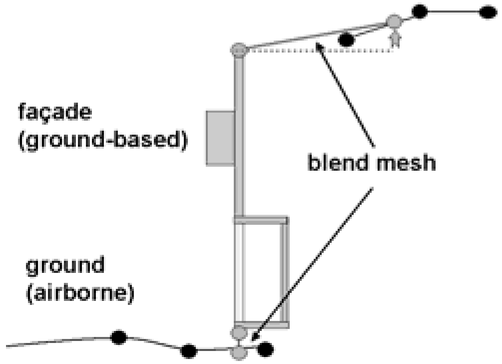
Final Blend



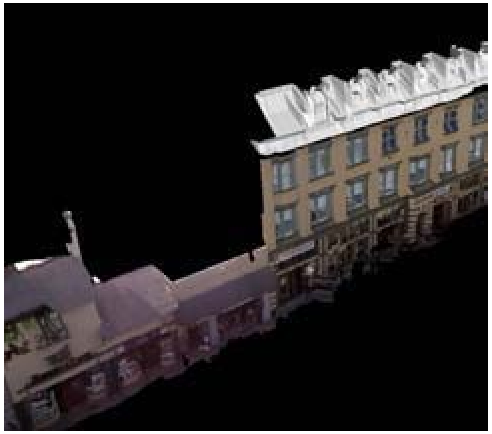
façade
(ground-based)
façade
(airborne)
rooftop
(airborne)
ground
(airborne)

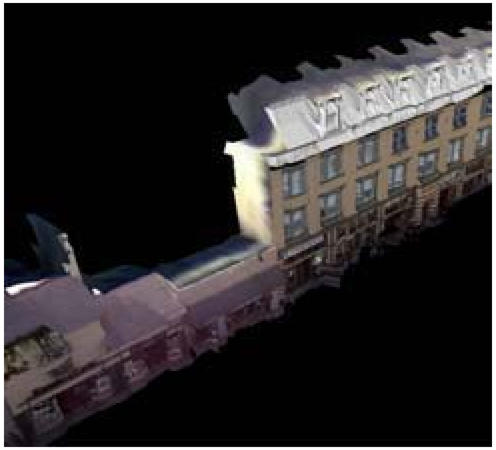


façade
(ground-based)
extrusion
ground
(airborne)

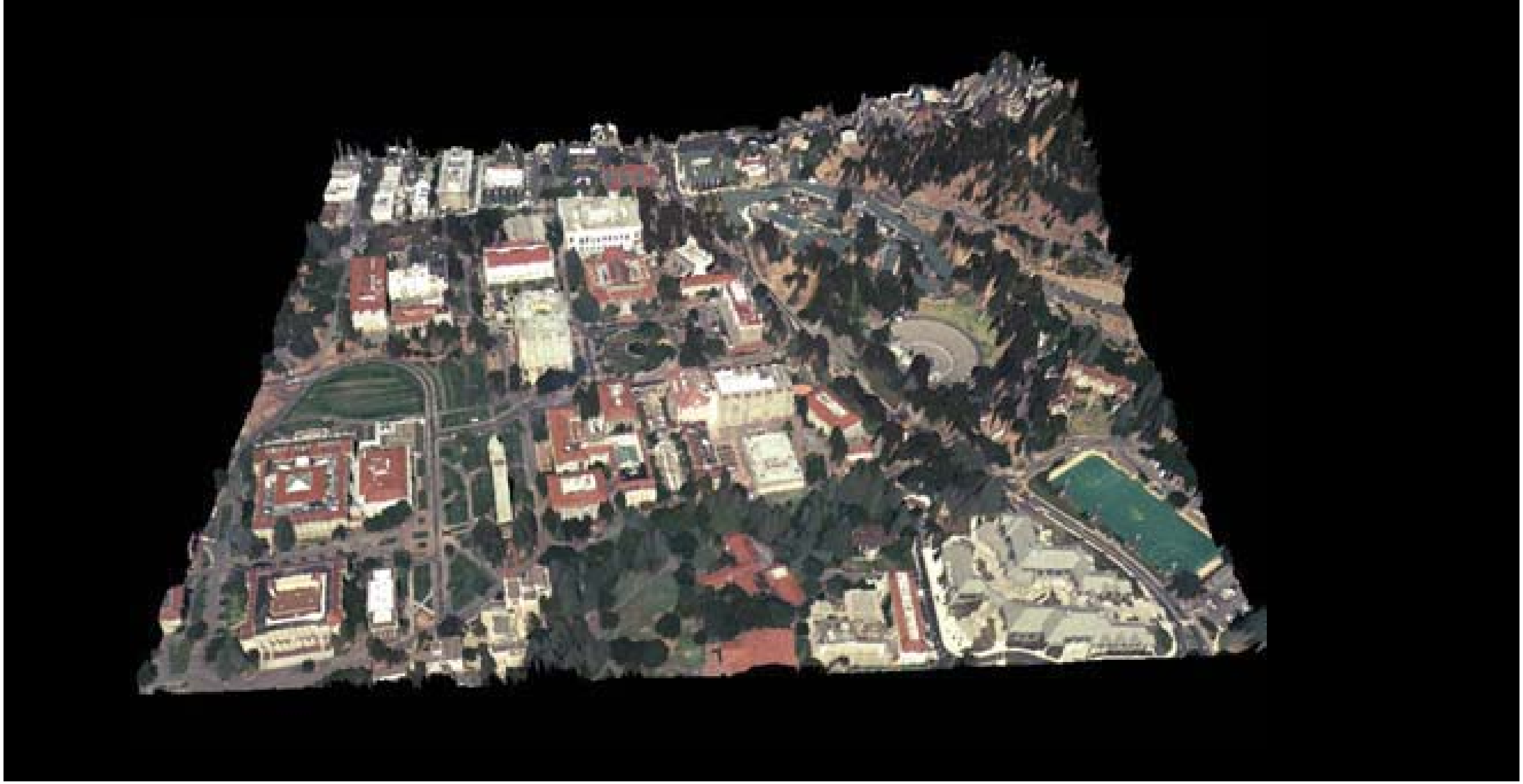


façade
(ground-based)
blend mesh
ground
(airborne)





Results



Texture Mapped Model of the East Side of Berkeley Campus

Results