



# Integration of Photogrammetric and LiDAR Data for Accurate Reconstruction & Realistic Visualization of Urban Environments

Ayman F. Habib

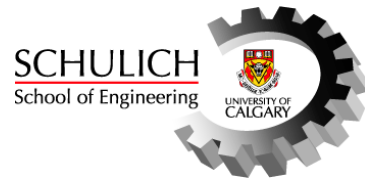
Digital Photogrammetry Research Group

<http://dprg.geomatics.ucalgary.ca>

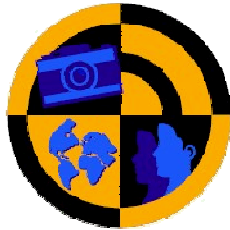
Department of Geomatics Engineering

University of Calgary, Canada





# Acknowledgement



**DPRG**  
Digital Photogrammetry  
Research Group



# Overview

- Need for accurate mapping of urban environments
- LiDAR and photogrammetric data: Why?
- Prerequisites and procedures for efficient photogrammetric and LiDAR data integration (emphasis: 3D reconstruction & visualization):
  - QA/QC procedures
  - Correspondence (orthophoto generation)
  - LiDAR data classification
  - DBM generation (hypothesis generation and reconstruction)
- Concluding remarks



# Urban Environments

- Globally: The number of dwellers in urban areas is expected to rise to almost 5 billion inhabitants by 2030 (62% of the global population at that time).
- Canada: Population living in metropolitan areas witnessed an increase of 45% (1971 – 2001).
  - In comparison, population living in rural areas only grew by 13%.
- To avoid social and environmental problems arising from this rapid urbanization, federal and local governments must have access to accurate and current **geo-spatial information** in a timely manner and at a reasonable cost.



# Existing Tools

- Current technology and tools (i.e., Google Earth, Microsoft's Virtual Earth, etc.) are good enough for navigation.
  - However, the level of accuracy is not high enough for design and engineering applications.

- Telecommunication,
- Architectural planning,
- Real-estate evaluation,
- Change detection applications,
- Security applications,
- Maintenance planning,
- Etc.



Courtesy of Google Earth



# Proposed Tool



(X, Y, Z): 1122.23 m, 3251.53 m, 72.03 m ( $\pm 10 - \pm 30$ cm)

(R, G, B): 23, 136, 69

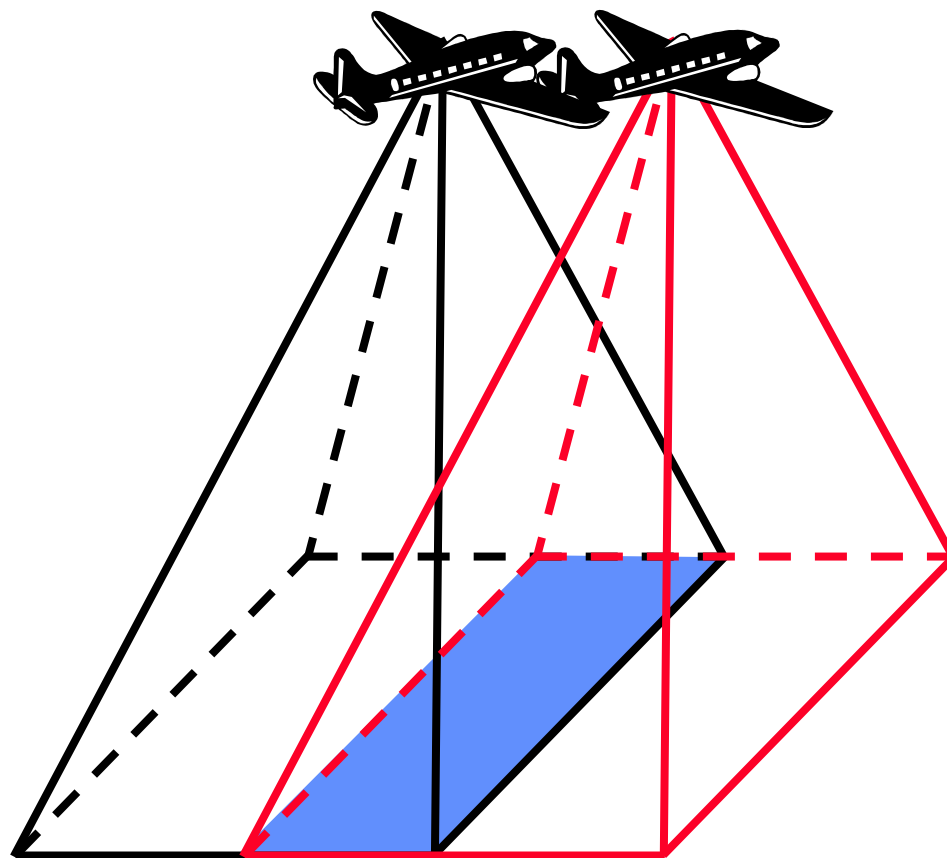


## LiDAR + Photogrammetric Data: Why?

- There has been a recent increase in the volume and varying formats of remote sensing data (e.g., LiDAR data and imagery captured by digital cameras).
  - LiDAR provides a dense point cloud representing the object space surface, and thus offers a fast and accurate way of obtaining a Digital Surface Model (DSM).
  - Digital cameras provide an alternative to the conventional large format analogue cameras, for rapid data collection.
- Through this work, the advantages of the integration of these two sources of data are investigated for the purpose of accurate reconstruction and realistic visualization of urban environments.



# Photogrammetric Principles

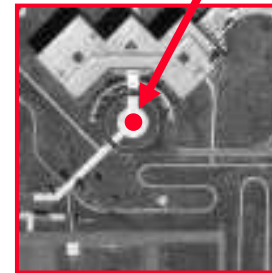
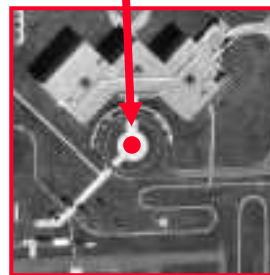
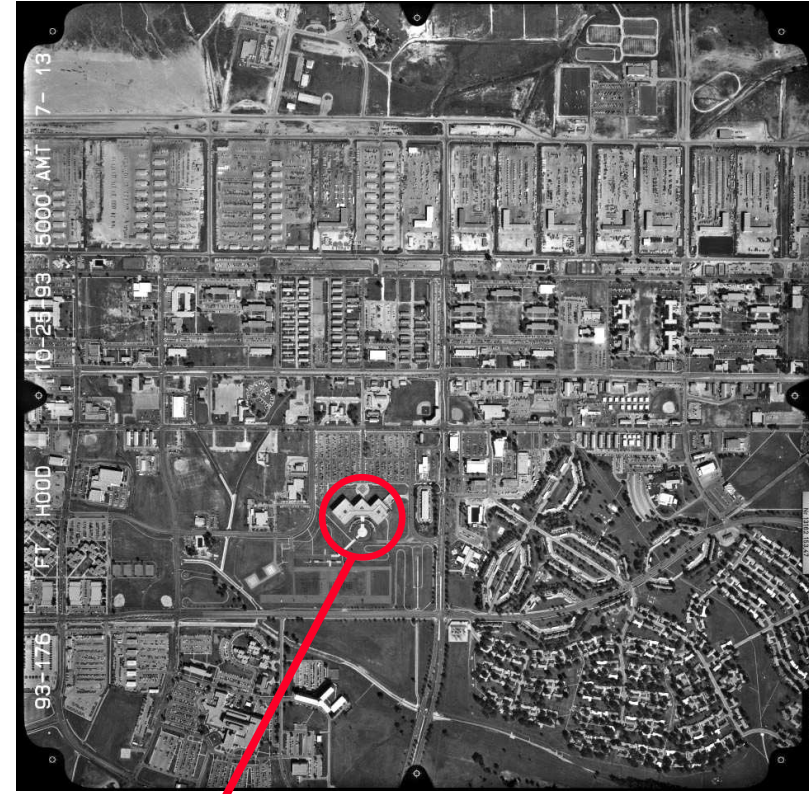
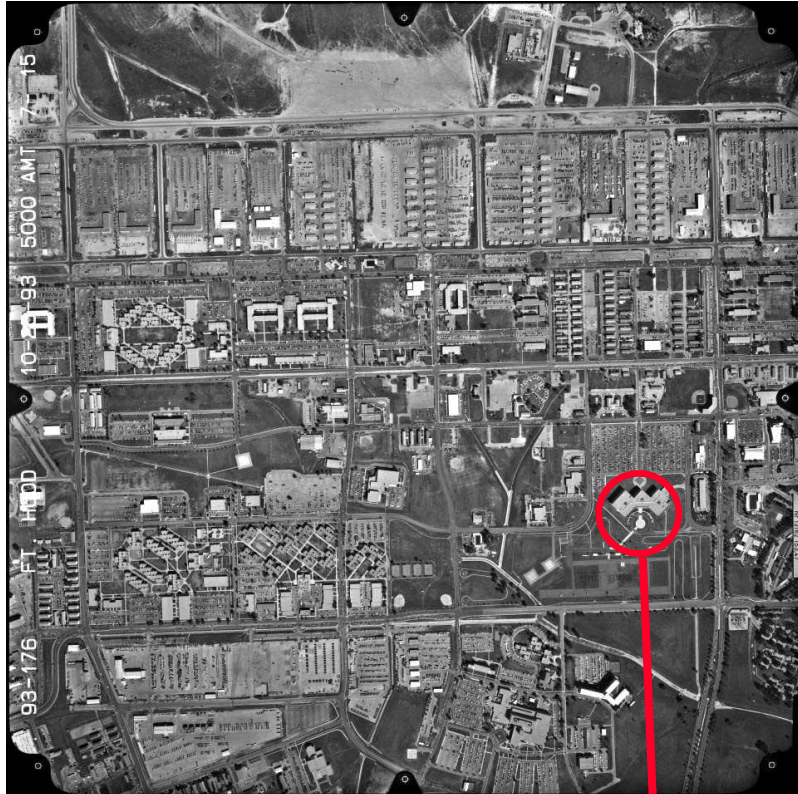


Overlap

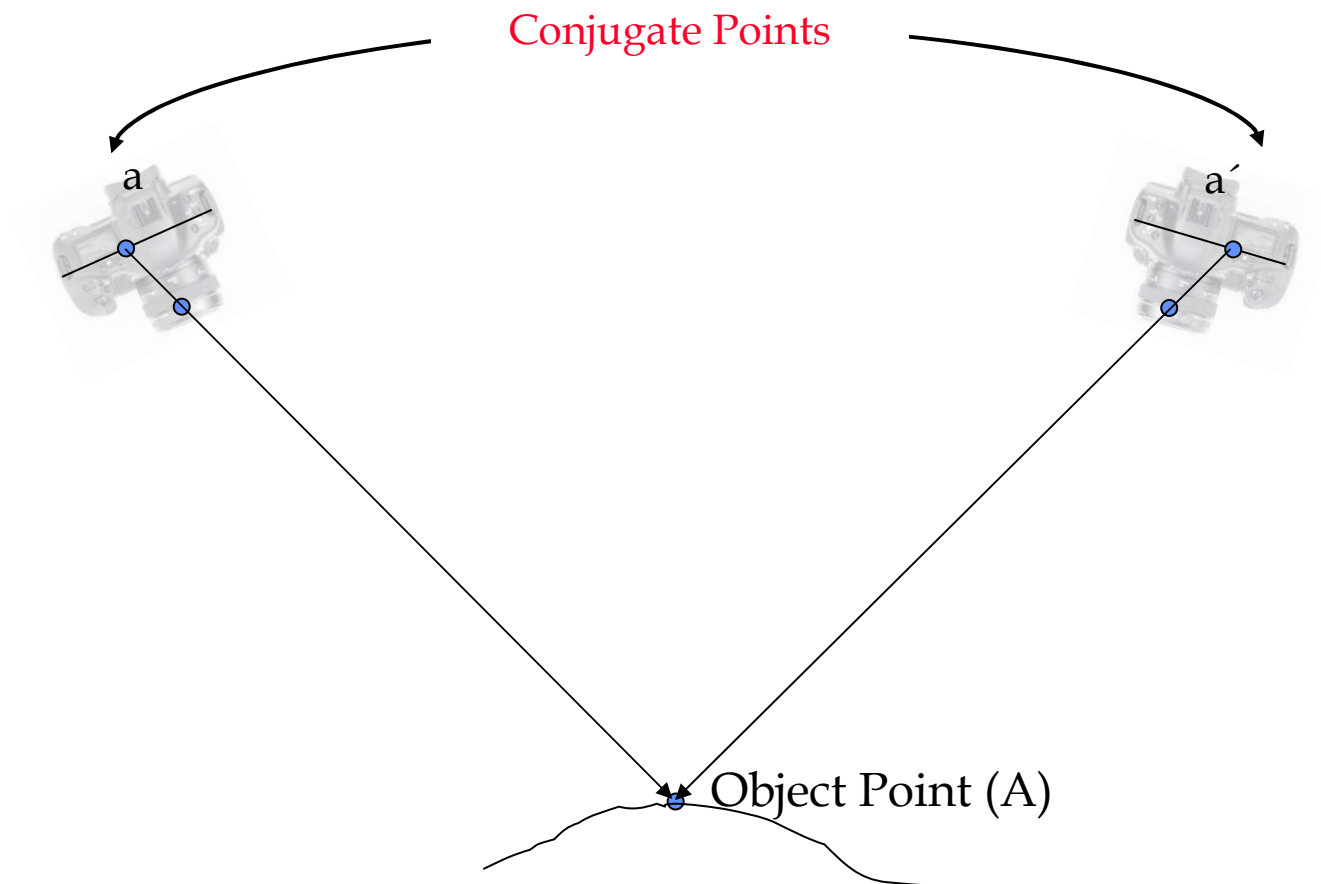




# Photogrammetric Principles



# Photogrammetric Principles



- The position and the orientation of the two camera stations have to be known (**geo-referencing problem**).



# Operational Photogrammetric Systems

## Frame Cameras



RC10



DMC



Applanix DSS



Kodak 14n



Canon EOS 1D



SONY 717

## Line Cameras



ADS 40



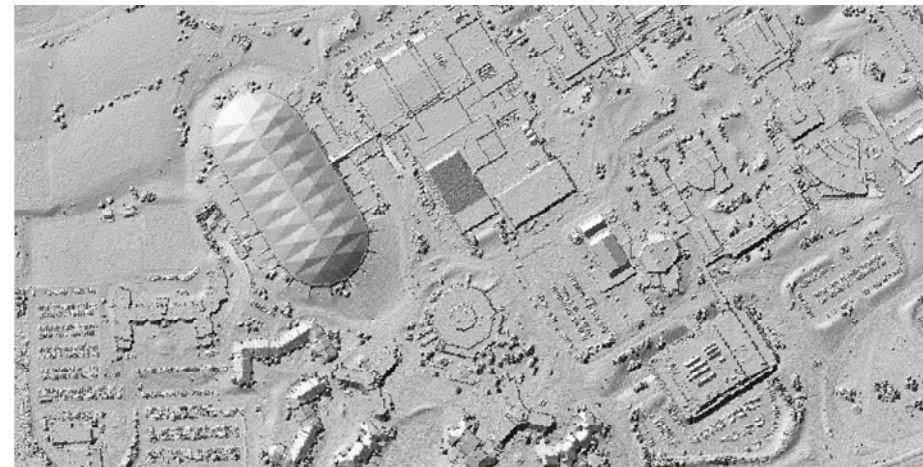
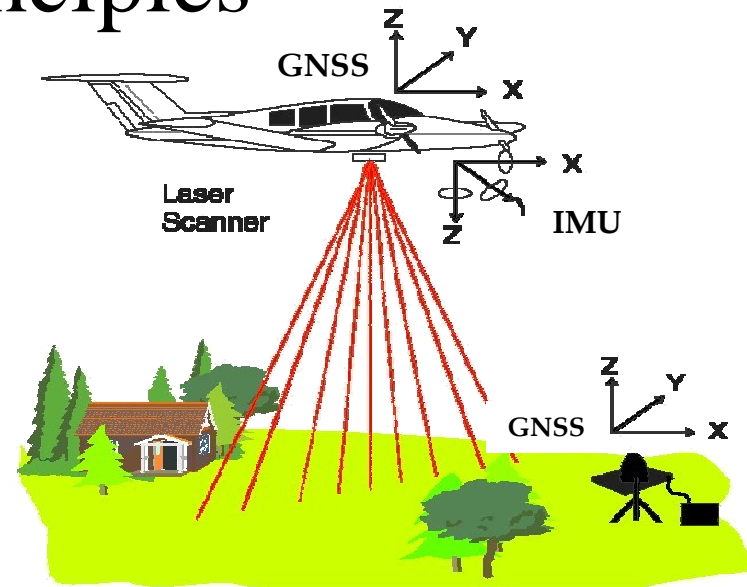
IKONOS/GeoEye



# LiDAR Principles

## Three Measurement Systems

1. GNSS
2. IMU
3. Laser scanner emits laser beams with high frequency and collects the reflections



Direct acquisition of  
high density and accurate  
topographic data



# Operational LiDAR Systems



ALS 40 (Leica Geosystems)

OPTECH ALTM 3100



TerraPoint<sup>TM</sup> USA



**DPRG**  
Digital Photogrammetry  
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# Photogrammetric and LiDAR Data: Why?

## LiDAR (Pros)

Dense information from homogeneous surfaces

Day or night data collection

Direct acquisition of 3D coordinates

Vertical accuracy is better than its planimetric accuracy

## Photogrammetry (Cons)

Almost no positional information along homogeneous surfaces

Day time data collection

Complicated and sometimes unreliable matching procedures

Vertical accuracy is worse than the planimetric accuracy



# Photogrammetric and LiDAR Data: Why?

## Photogrammetry (Pros)

High redundancy

Rich with semantic information

Dense positional information along object space breaklines

Planimetric accuracy is better than the vertical accuracy

***Transparent Model***

## LiDAR (Cons)

No inherent redundancy

Positional; difficult to derive semantic information

Almost no information along breaklines

Planimetric accuracy is worse than the vertical accuracy

***Non-transparent model***



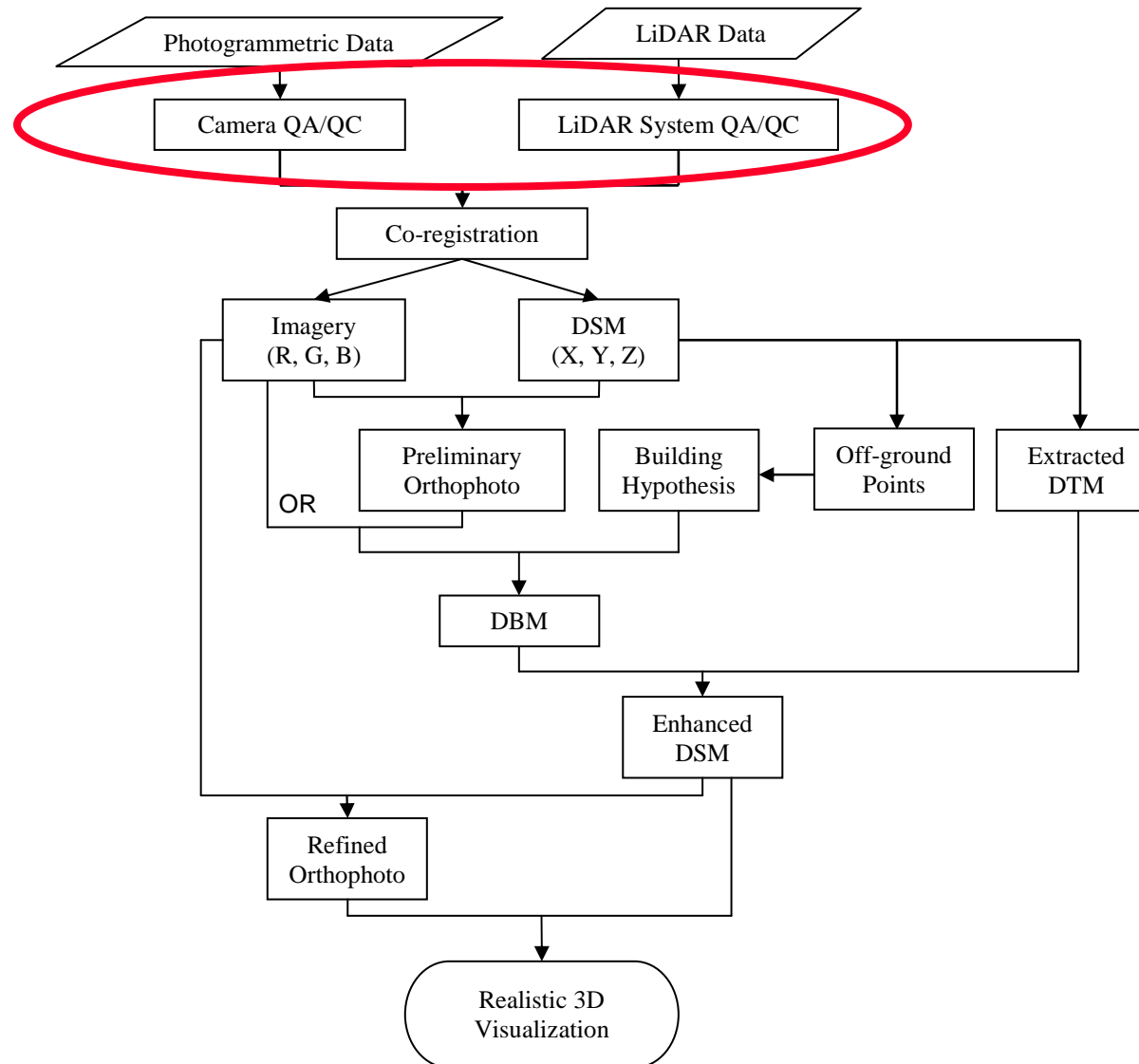
# LiDAR + Photogrammetric Data: How?

- There are several **prerequisites** for the integration of LiDAR and image data for the reconstruction and visualization of urban environments:
  - System Calibration (camera and LiDAR systems),
  - Quality Control (QC) of the photogrammetric and LiDAR data,
  - Registration of the photogrammetric and LiDAR data to a common reference frame, and
  - Relating the spectral and positional attributes in photogrammetric and LiDAR data.





# Proposed Workflow



# Quality Assurance & Quality Control

- Quality assurance (Pre-mission):
  - Management activities to ensure that a process, item, or service is of the quality needed by the user.
  - It deals with creating management controls that cover planning, implementation, and review of data collection activities.
  - Key activity in the quality assurance is the calibration procedure.
- Quality control (Post-mission):
  - Provide routines and consistent checks to ensure data integrity, correctness, and completeness.
  - Check whether the desired quality has been achieved.



# Low-Cost Imaging Systems



Kodak 14n



Canon EOS 1D

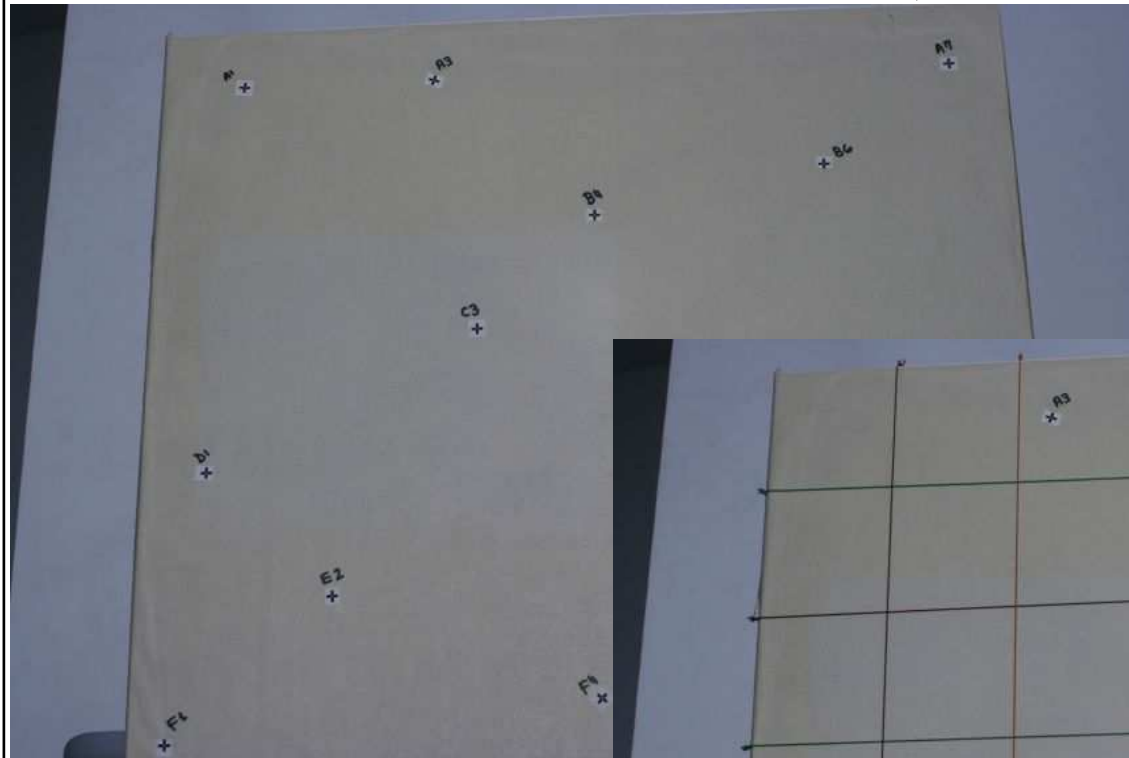


SONY 717

**Camera calibration and stability analysis** should be carefully addressed.



# Camera Calibration (New Methodology)



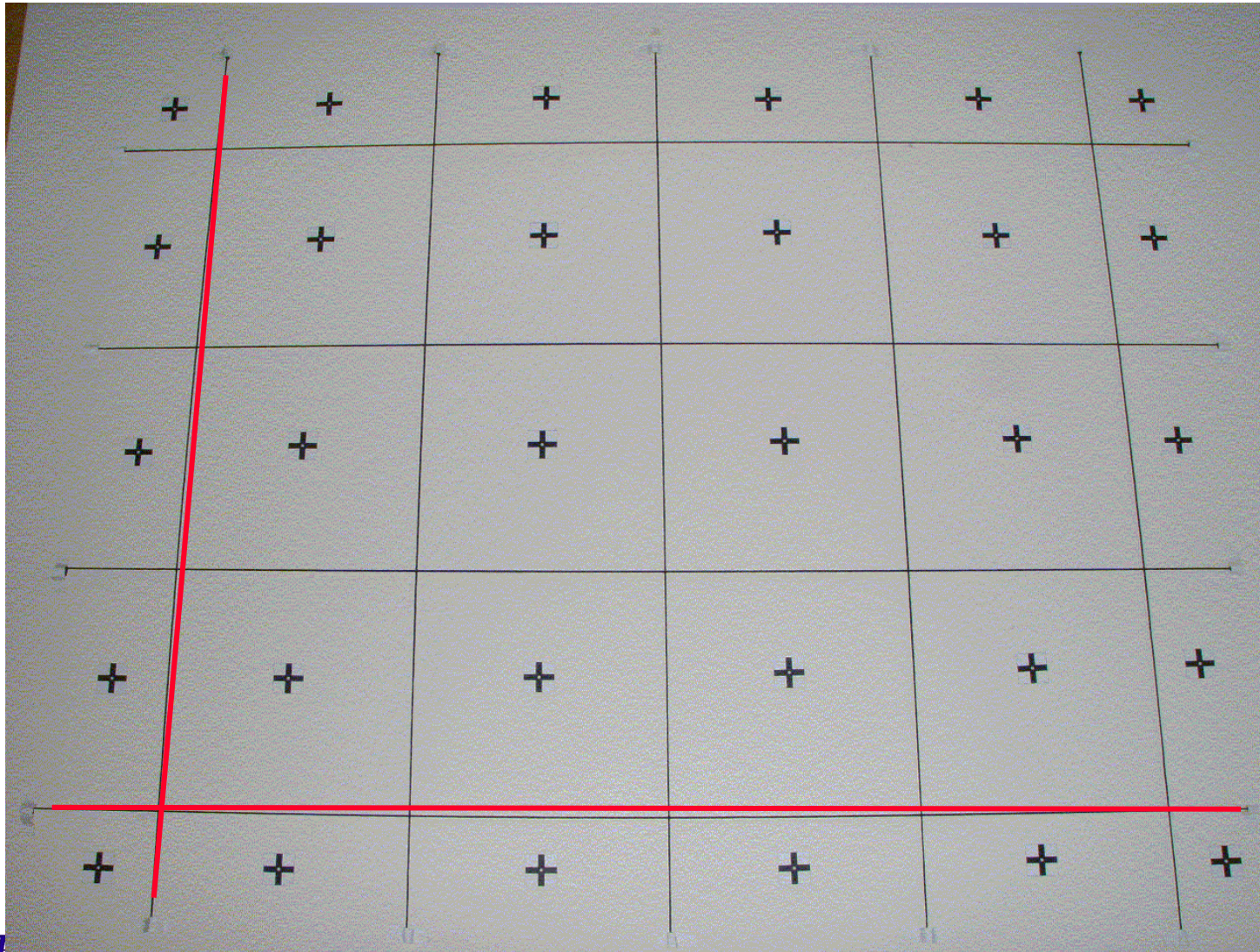
Traditional calibration  
test field



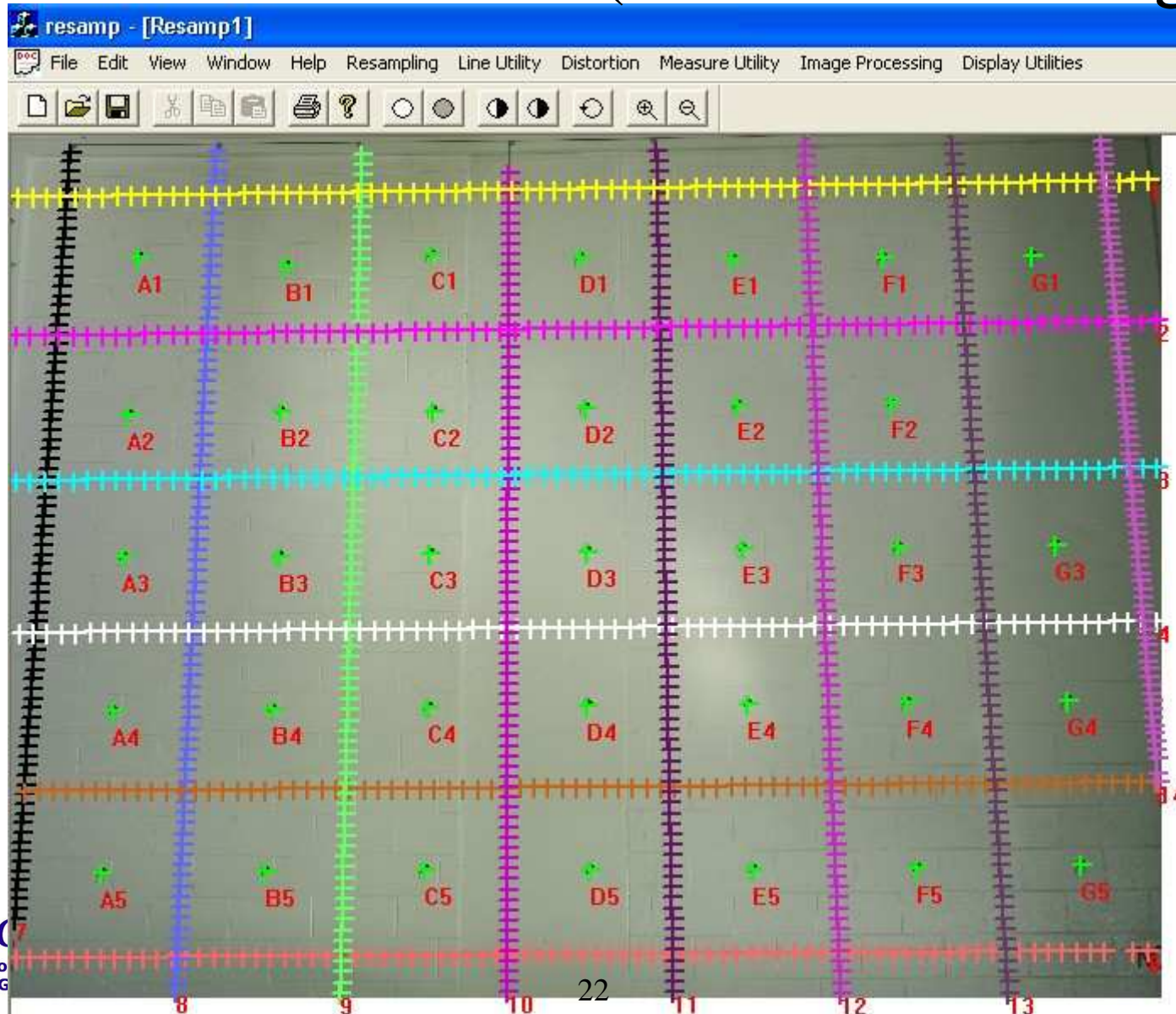
Proposed test field by the  
DPRG



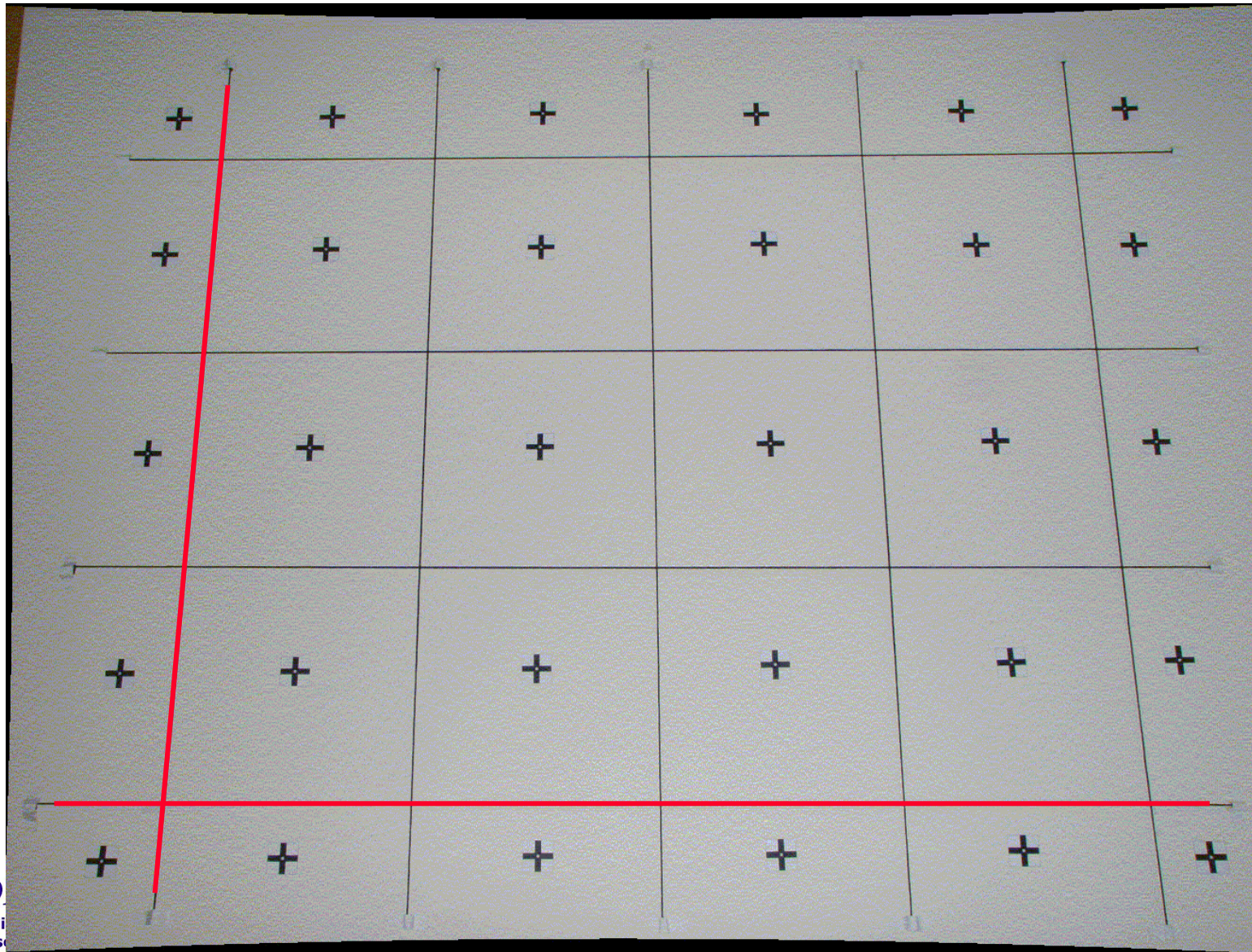
# Camera Calibration (New Methodology)



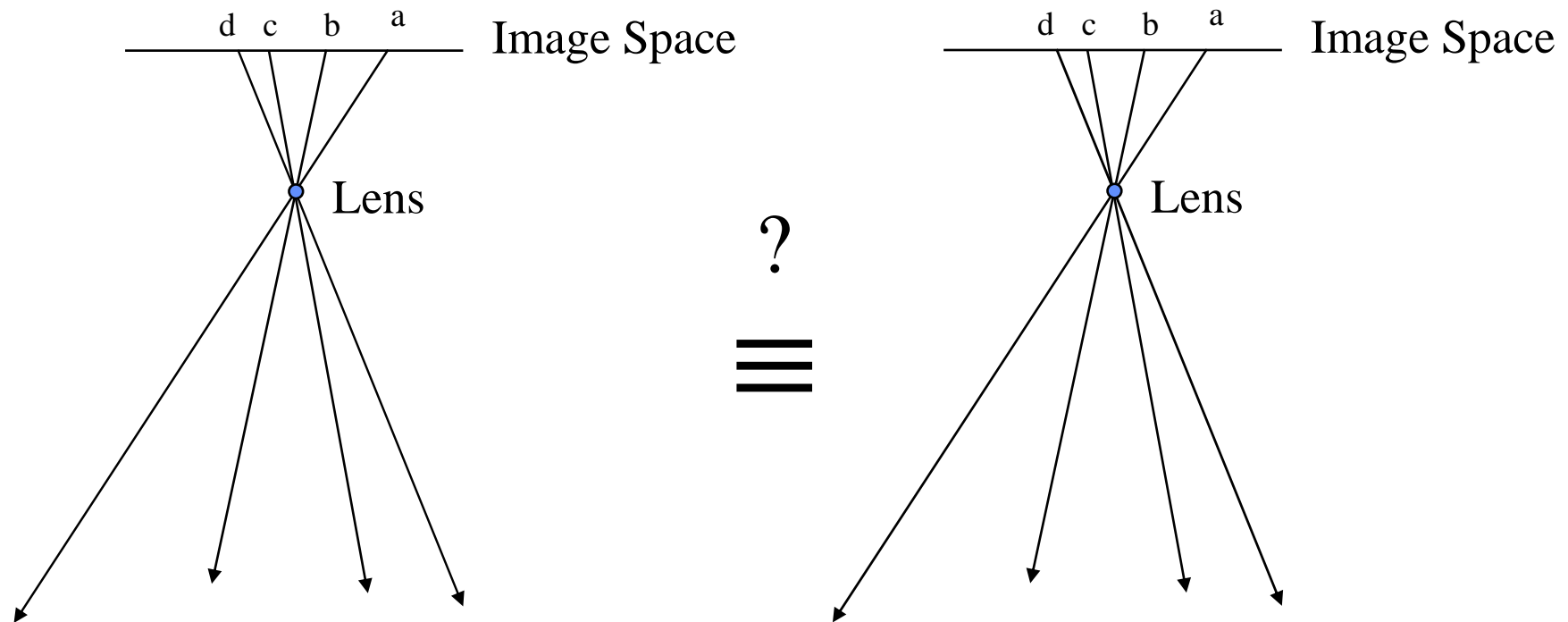
# Camera Calibration (New Methodology)



# QC: Camera Calibration



# Stability Analysis (New Methodology)



Reconstructed bundle using  $IOP_I$

Reconstructed bundle using  $IOP_{II}$

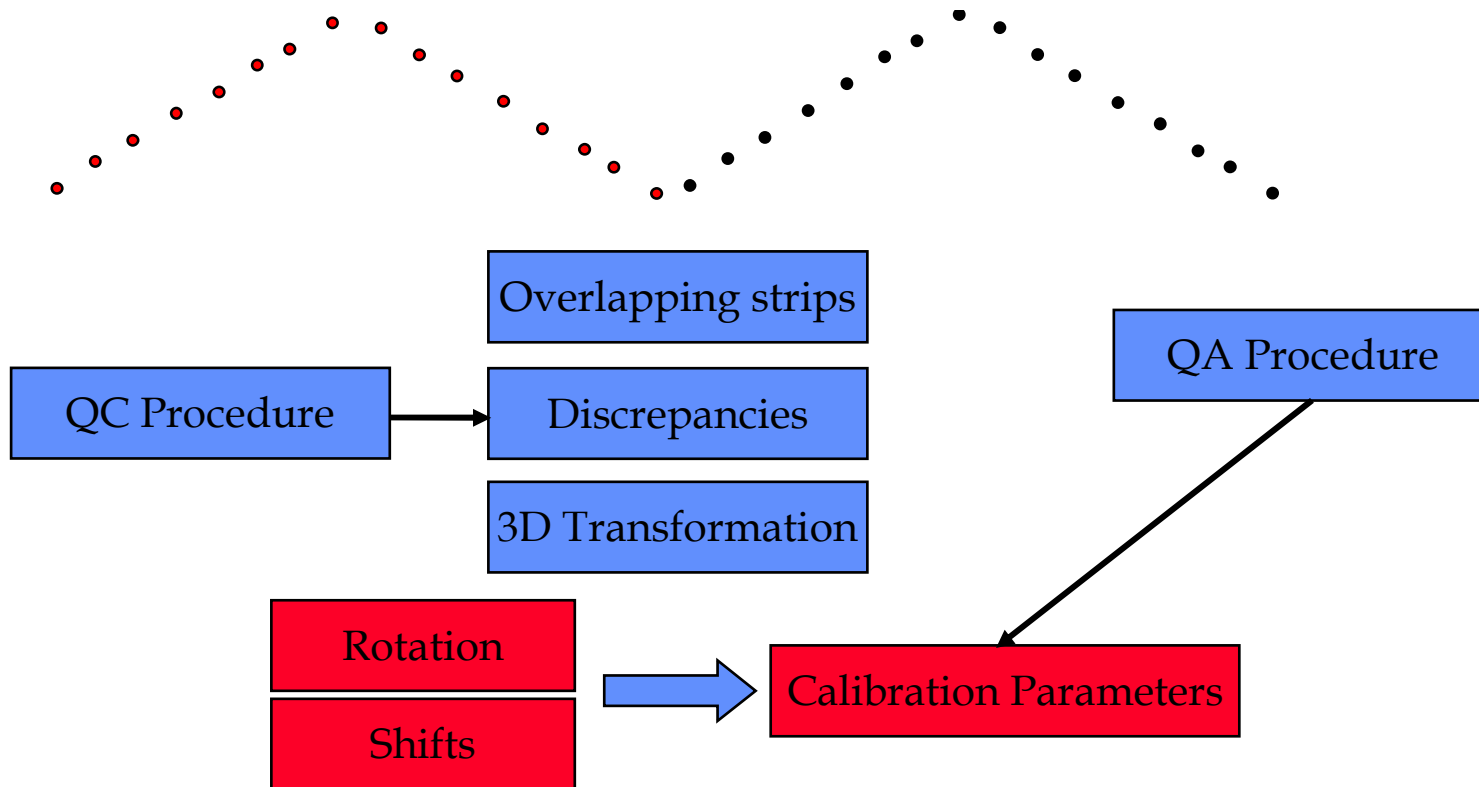




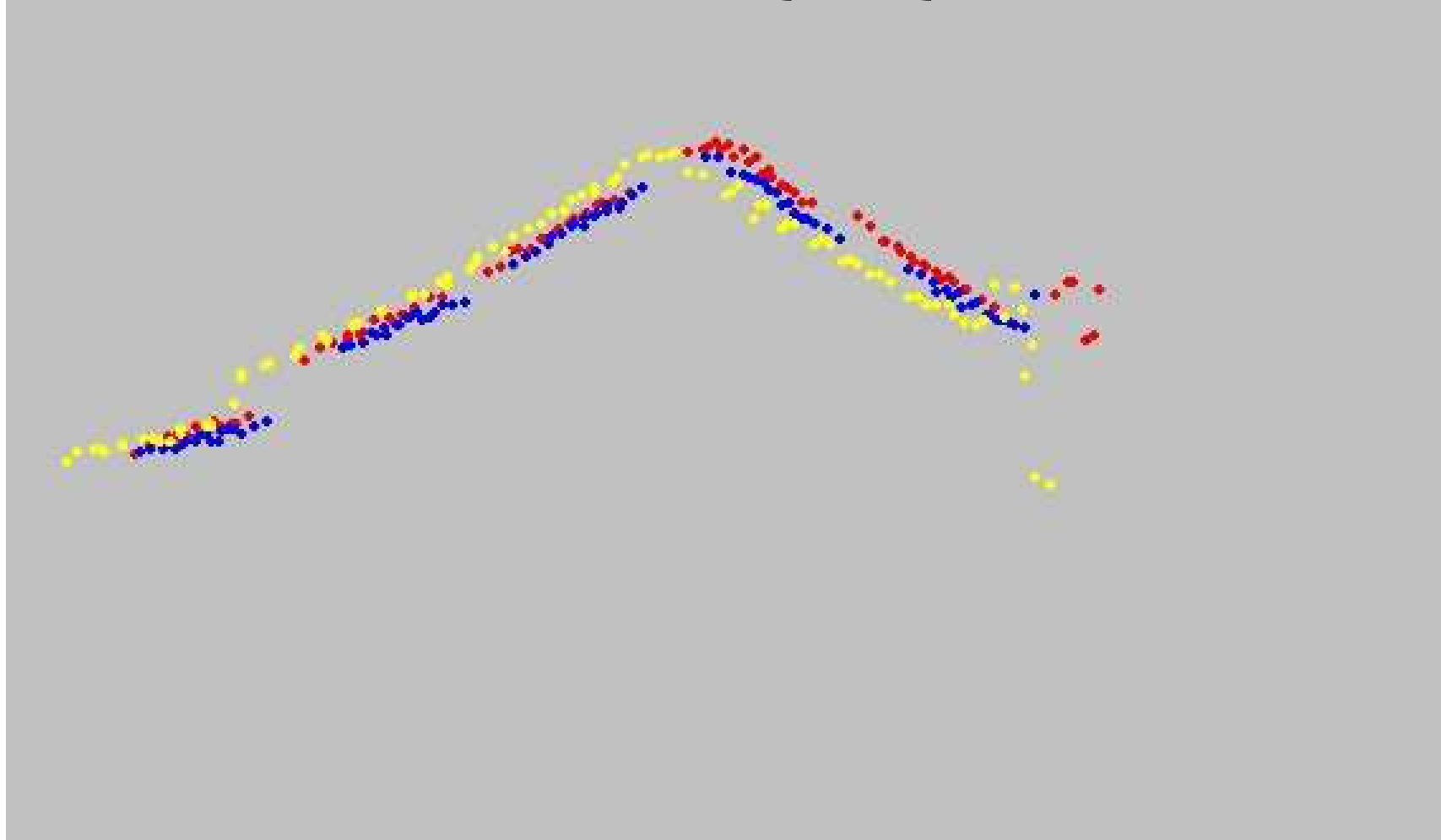
# LiDAR QA/QC

## • LiDAR Data in Overlapping Strips

- ✓ Point cloud coordinates
- ✓ Raw measurements are not necessary available



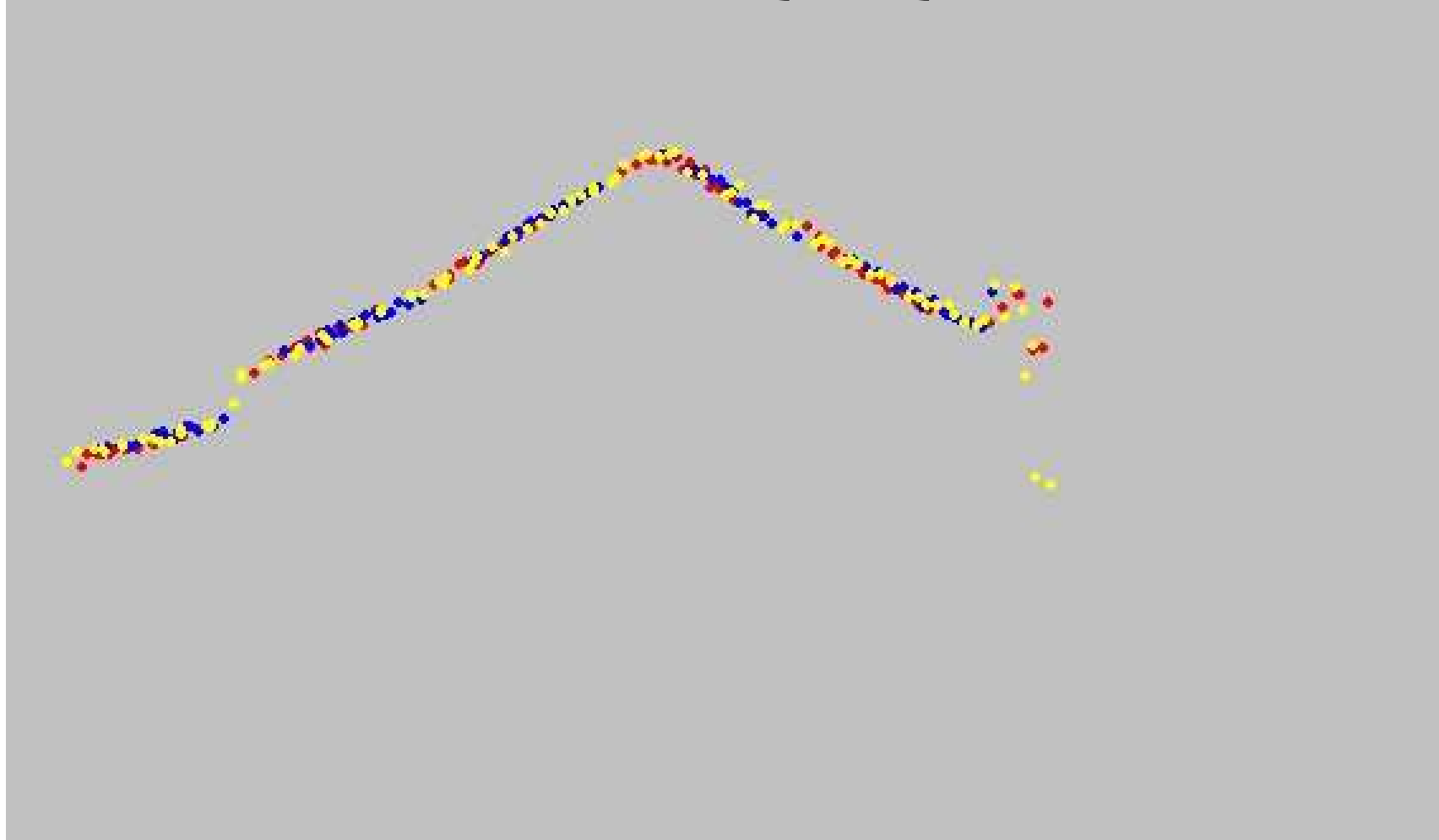
# LiDAR QA/QC



Check for the presence of biases



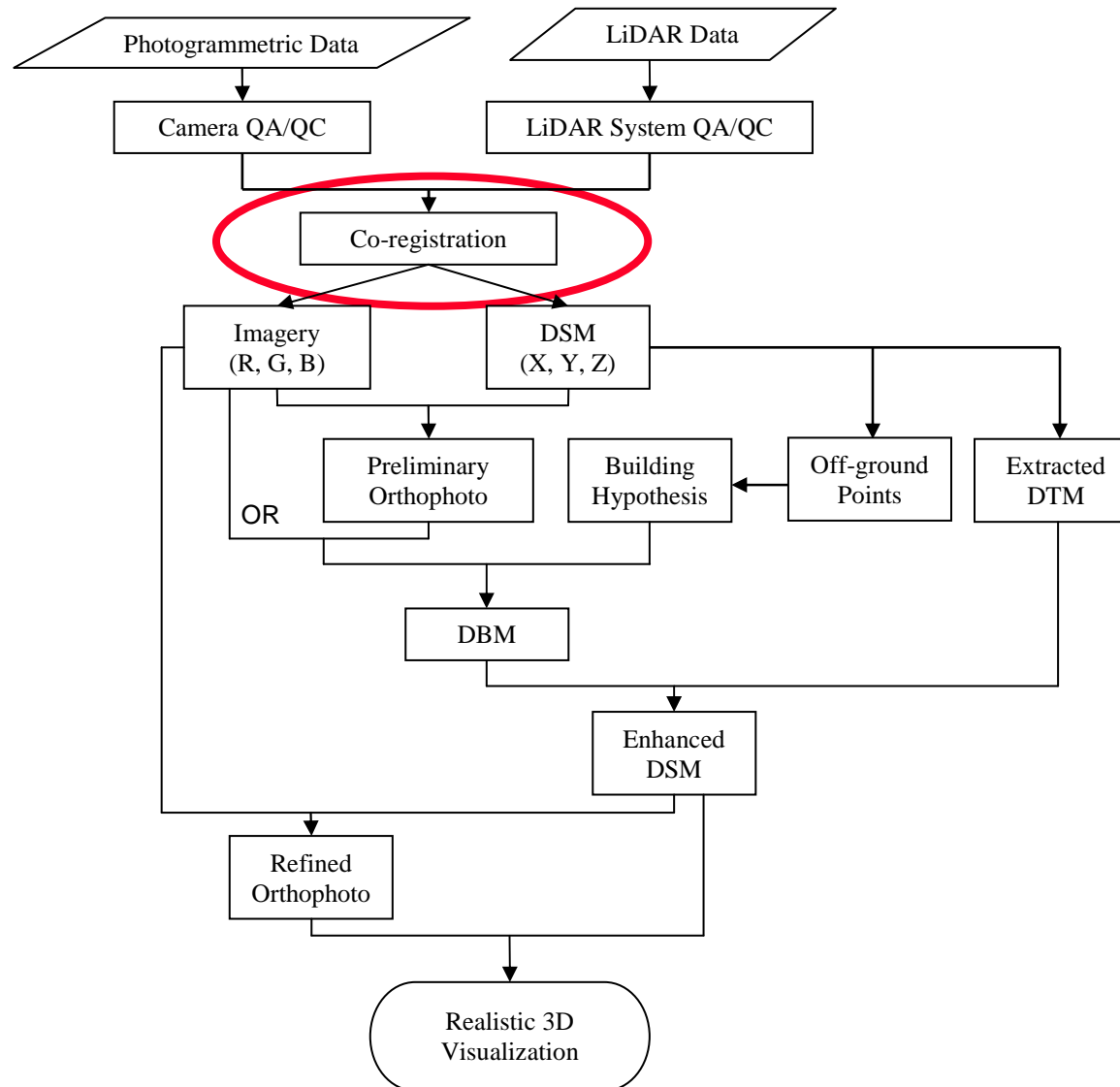
# LiDAR QA/QC



Check the noise level in the point cloud after bias removal



# Proposed Workflow



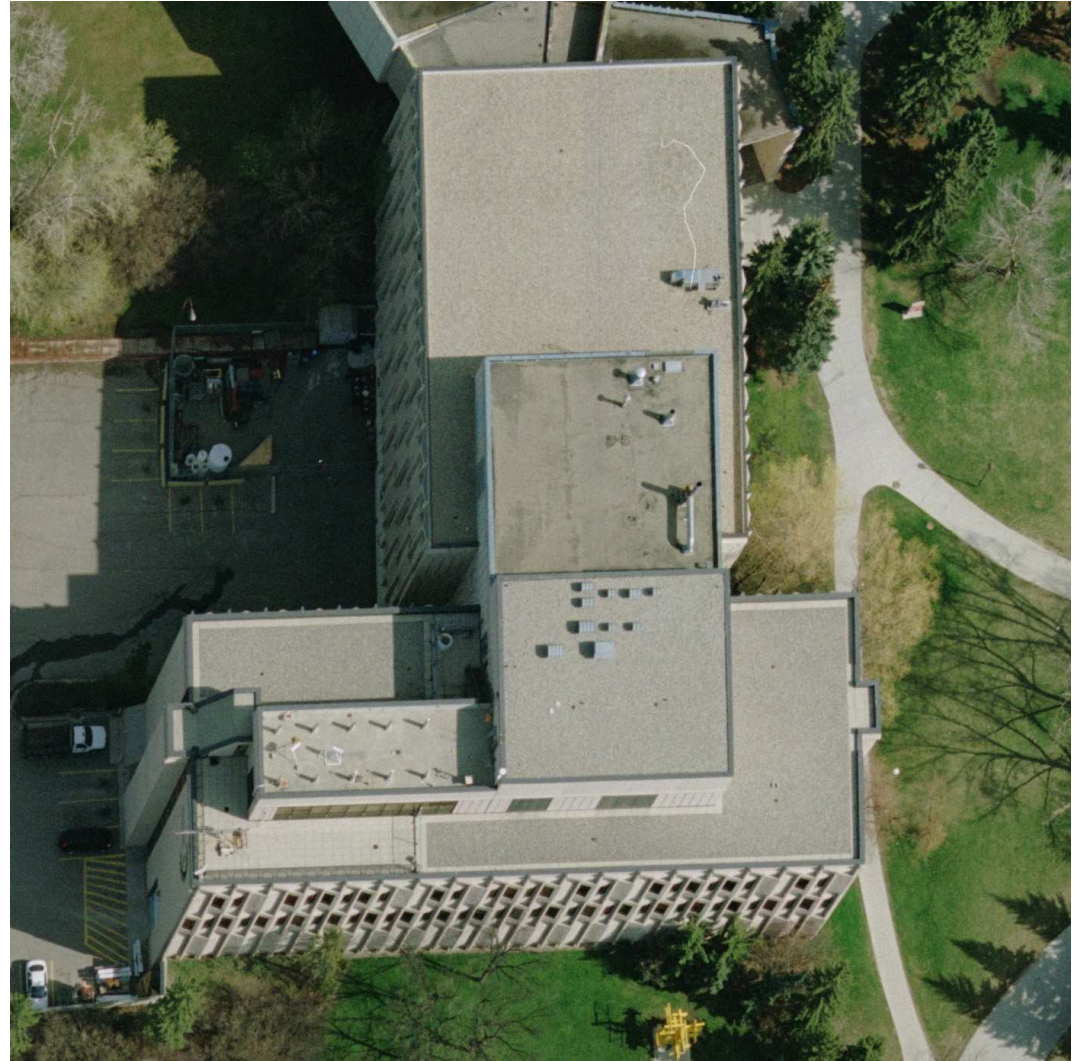
# Data Registration

- When integrating data from different sources, the datasets must be registered to a common reference frame.
- LiDAR geo-referencing is directly established through the GNSS/INS components of the LiDAR system.
- LiDAR can be used as the source of control data for image geo-referencing.



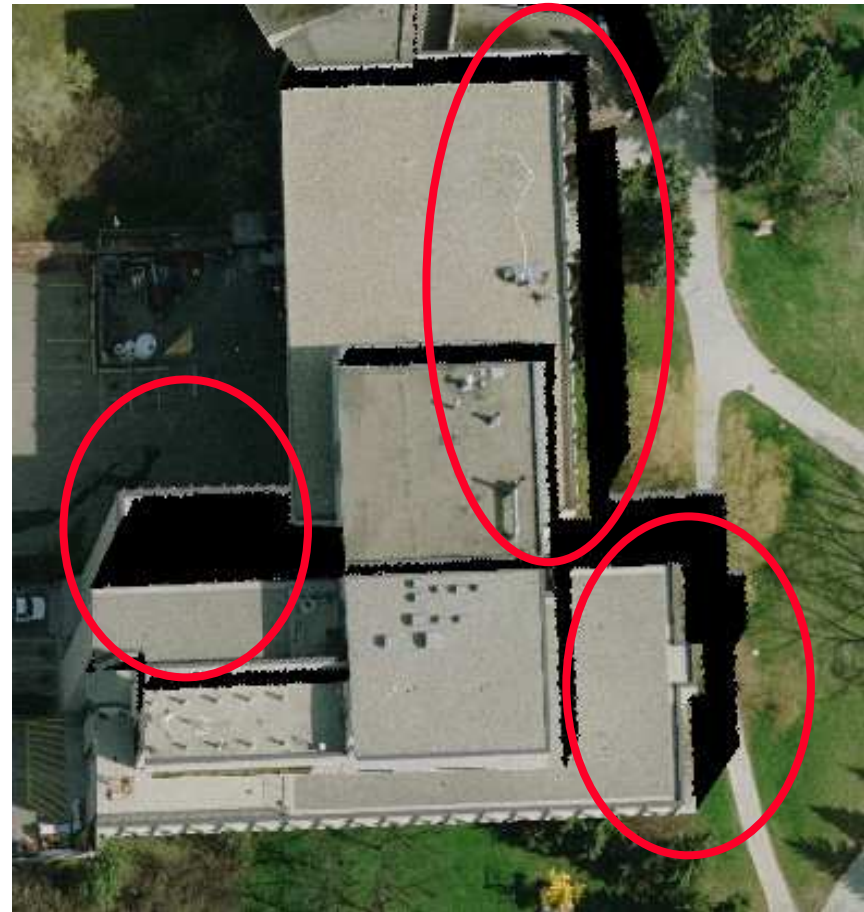
# Data Registration

Input perspective imagery



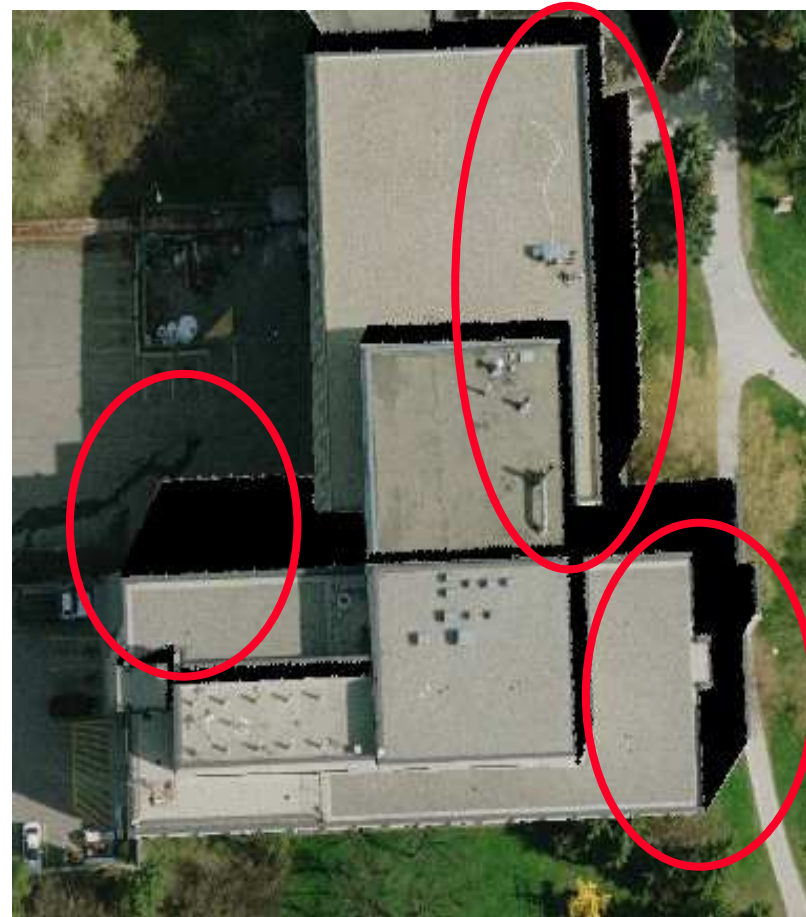
# Data Registration

- Impact of miss-registration
  - Produced orthophoto from optical imagery and LiDAR data using an independent source of control for photogrammetric geo-referencing.



# Data Registration

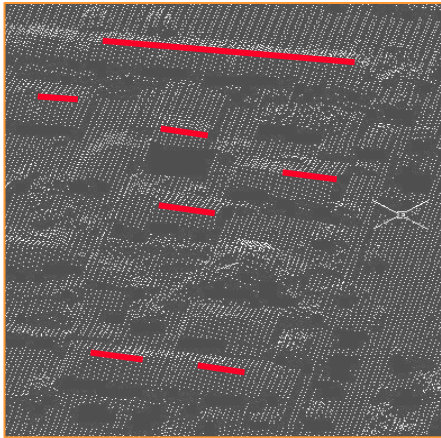
- Proper registration:
  - Produced orthophoto from optical imagery and LiDAR data using LiDAR as the source of control for photogrammetric geo-referencing.





# Data Registration

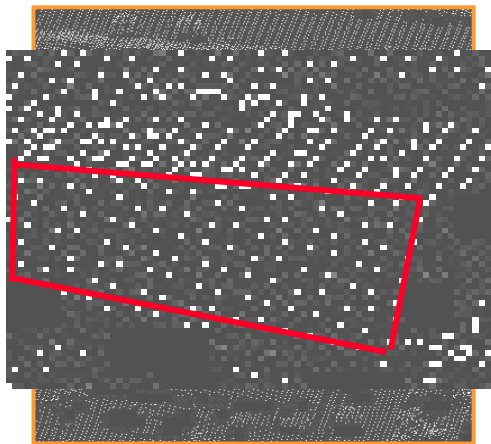
## Potential Primitives



LiDAR cloud



Image patch



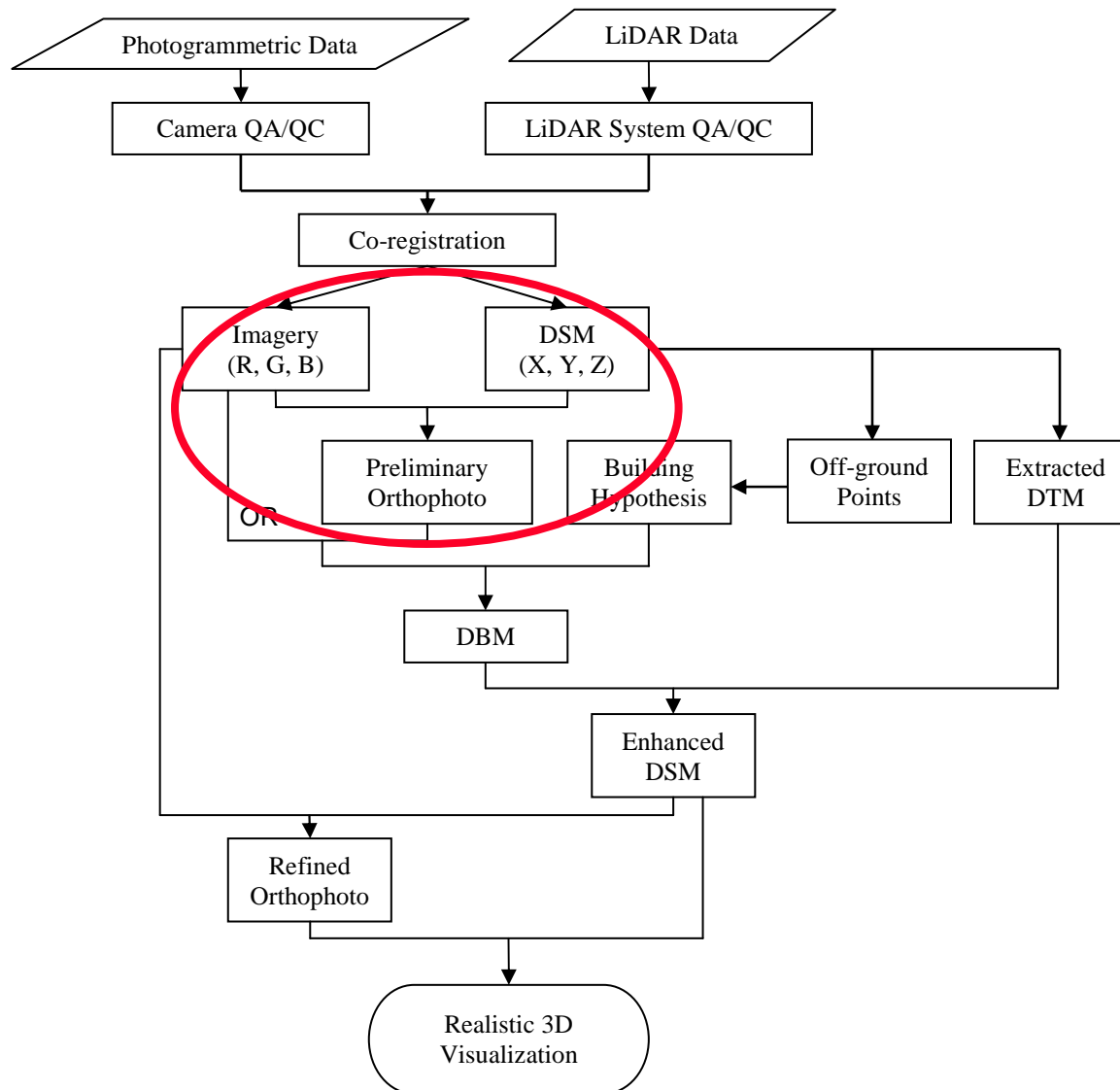
LiDAR cloud



Image patch



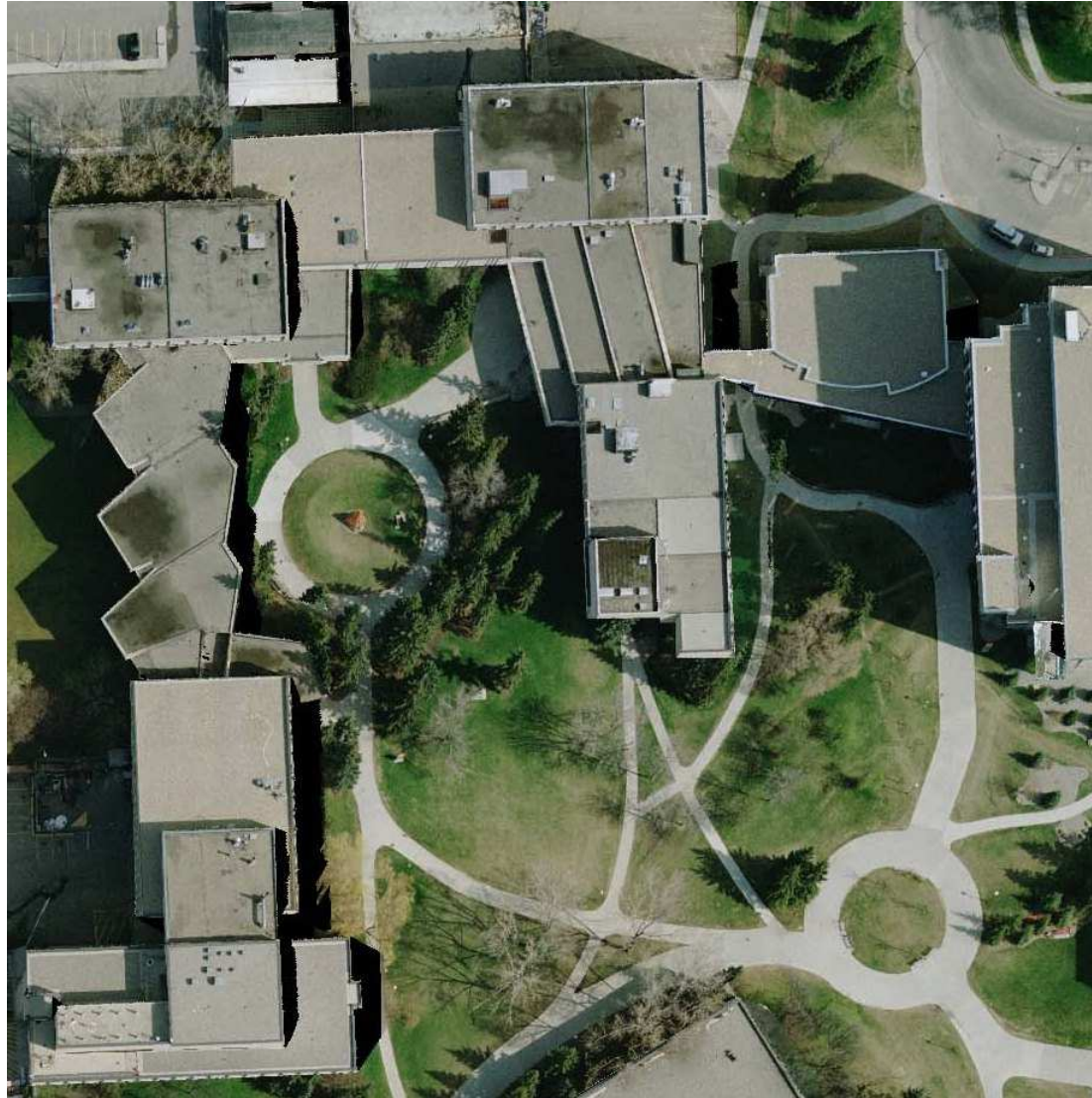
# Proposed Workflow



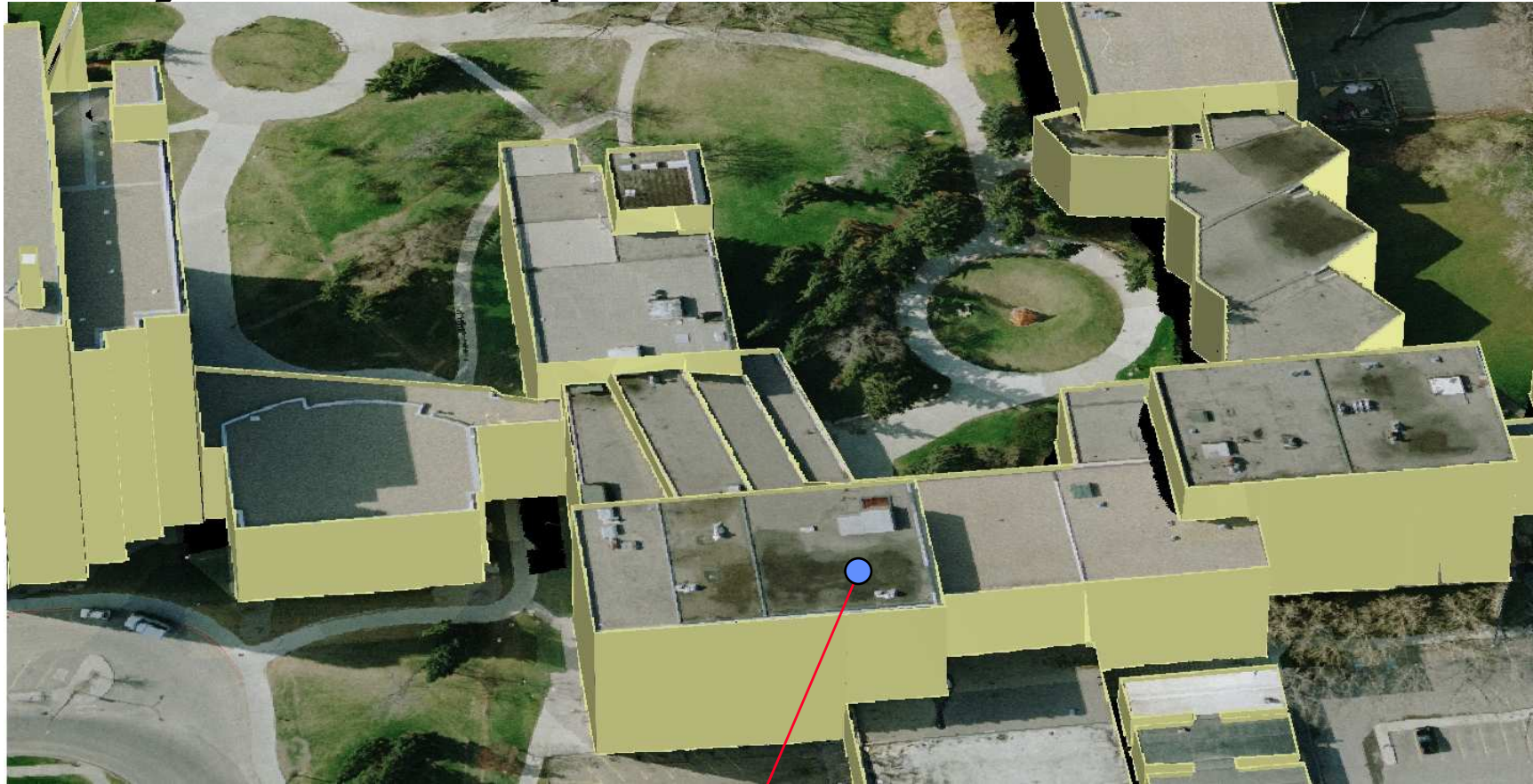
# Perspective Image



# Orthophoto



# Beyond Orthophotos: 3D Realistic Views

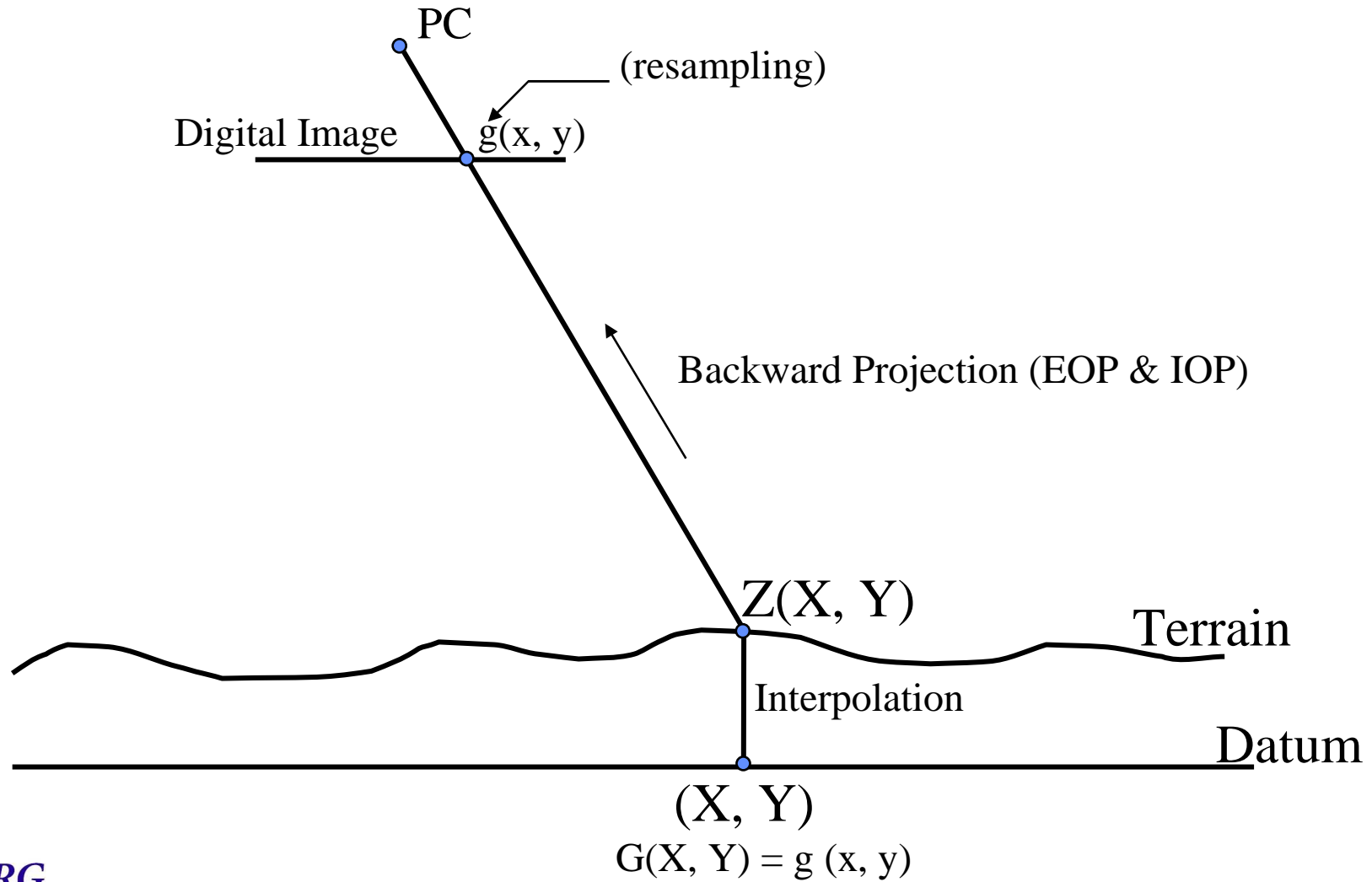


(X, Y, Z): 1122.23 m, 3251.53 m, 72.03 m

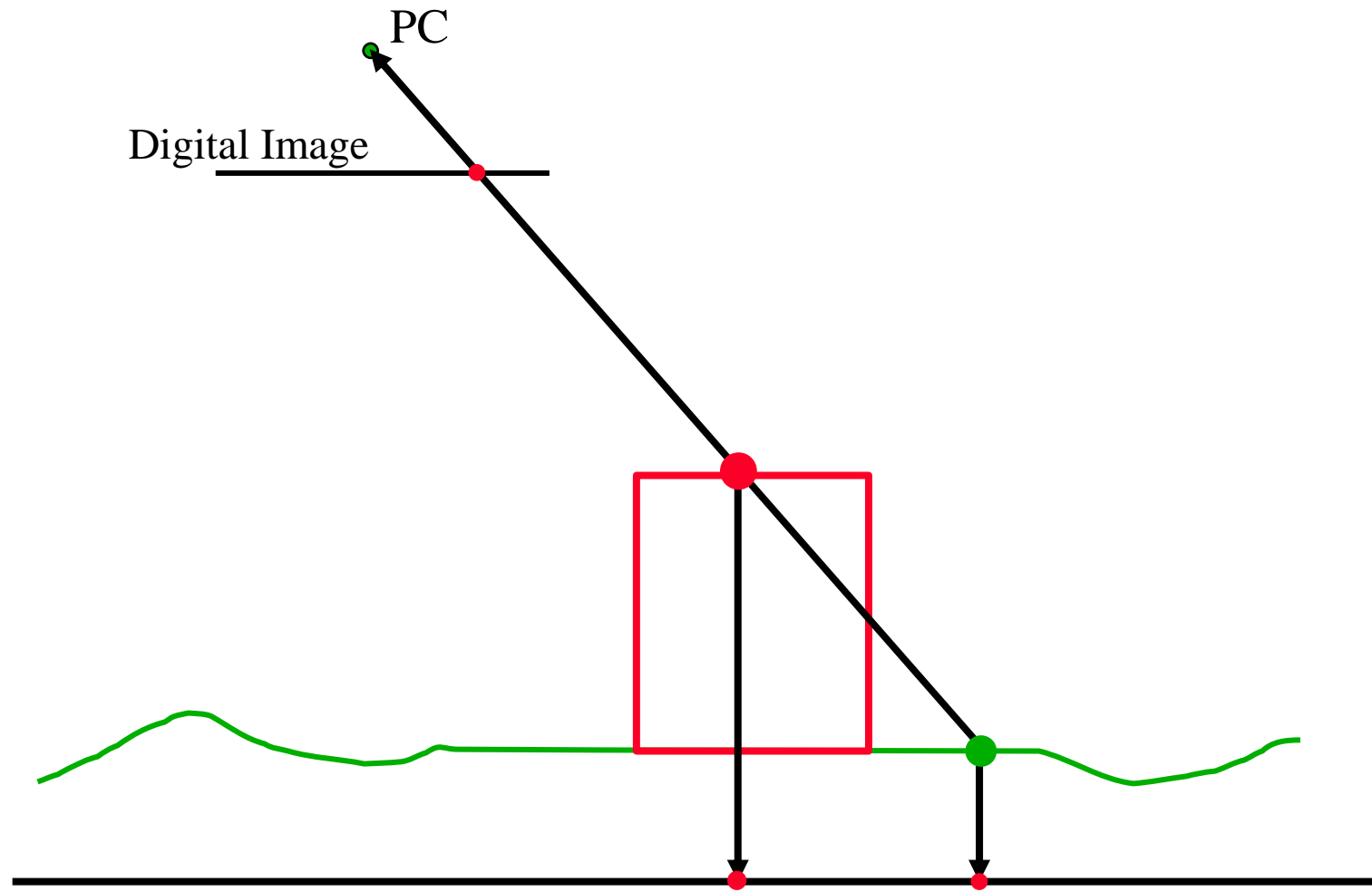
(R, G, B): 23, 136, 69



# Differential Orthophoto Generation



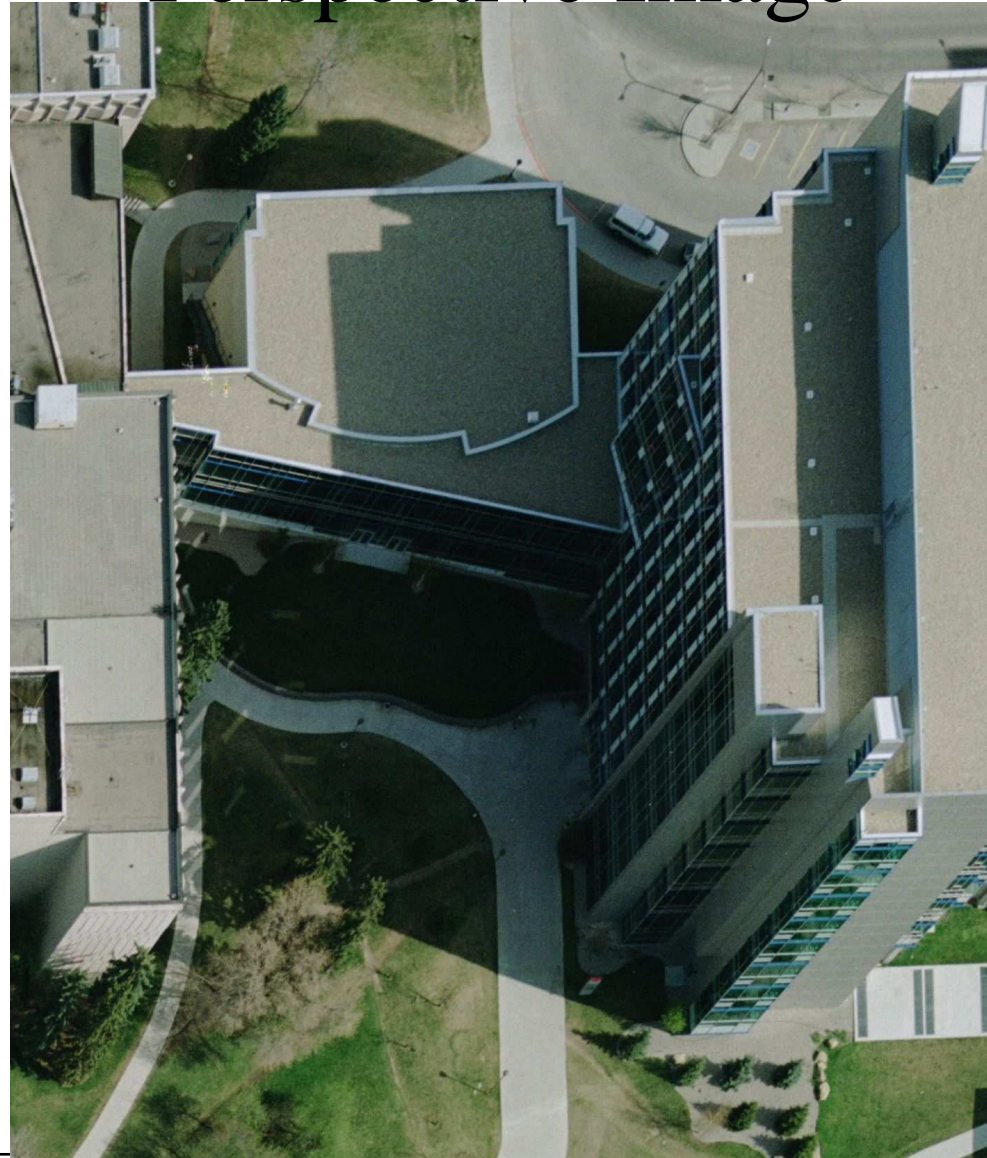
# Differential Orthophoto Generation



Double Mapping Problem (Ghost Images)



# Perspective Image

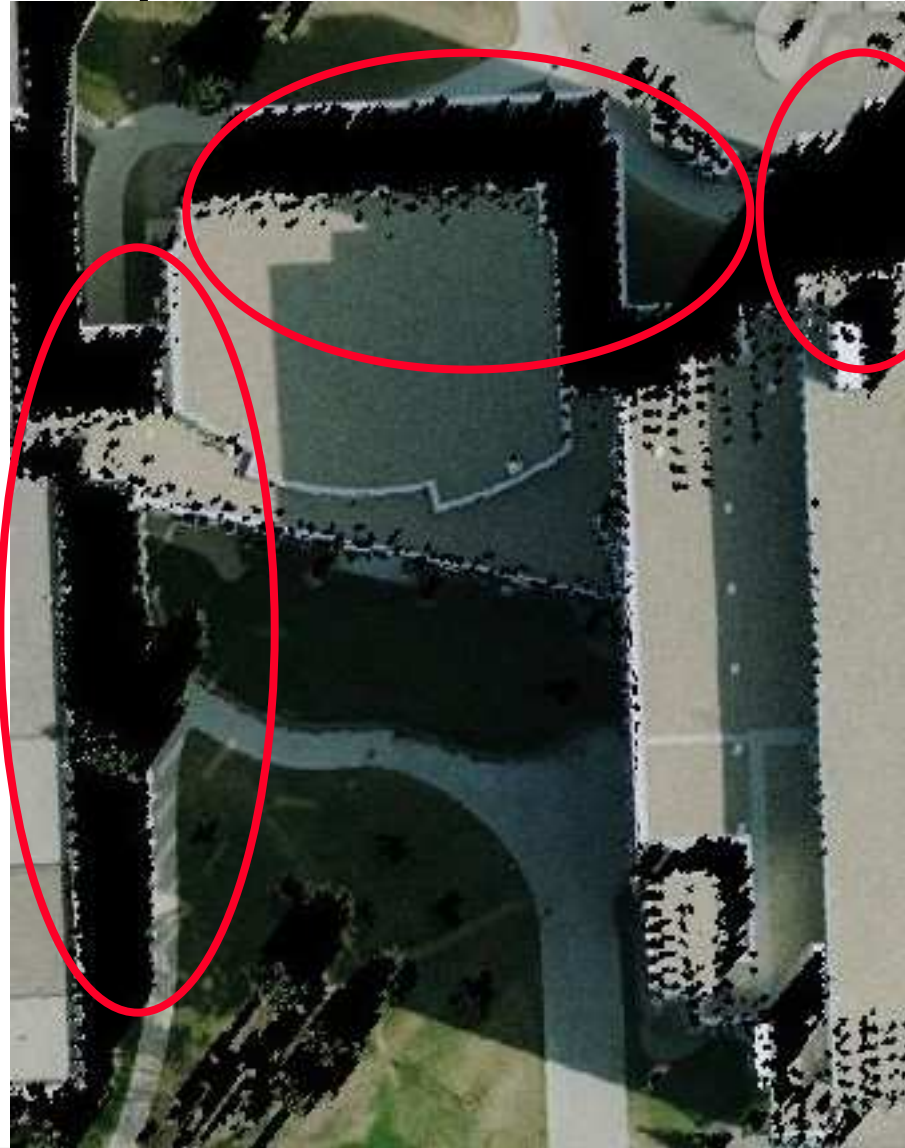




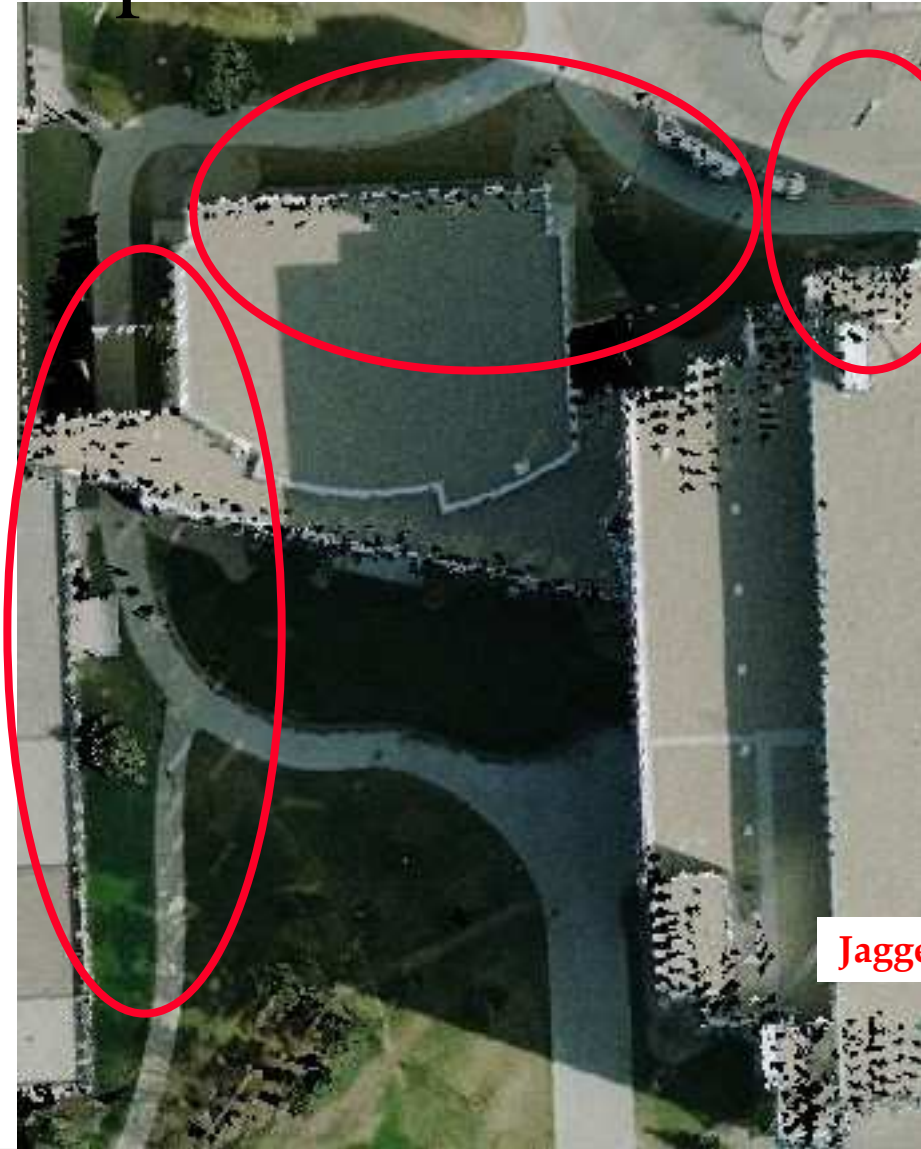
# Orthophoto with Ghost Images



# True Orthophoto without Ghost Images



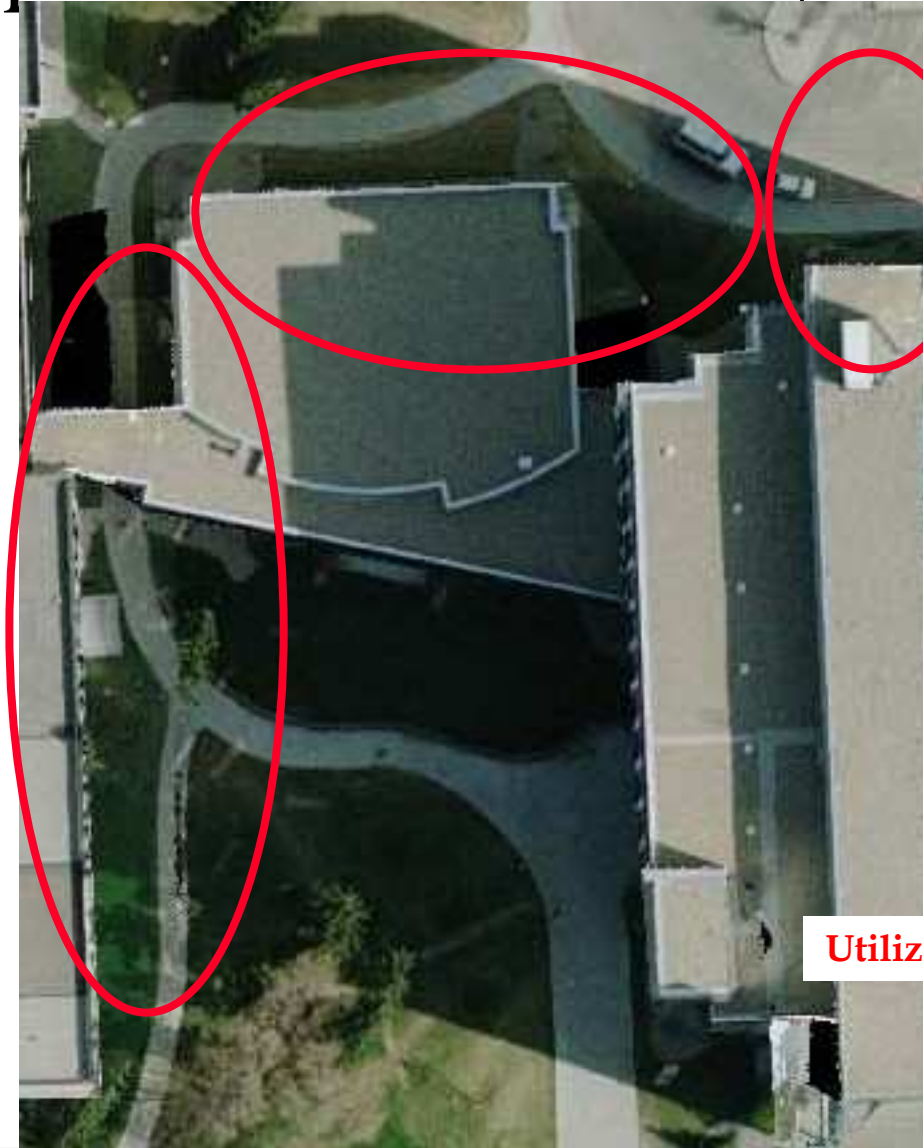
# True Orthophoto After Occlusion Filling



Jagged Building Boundaries



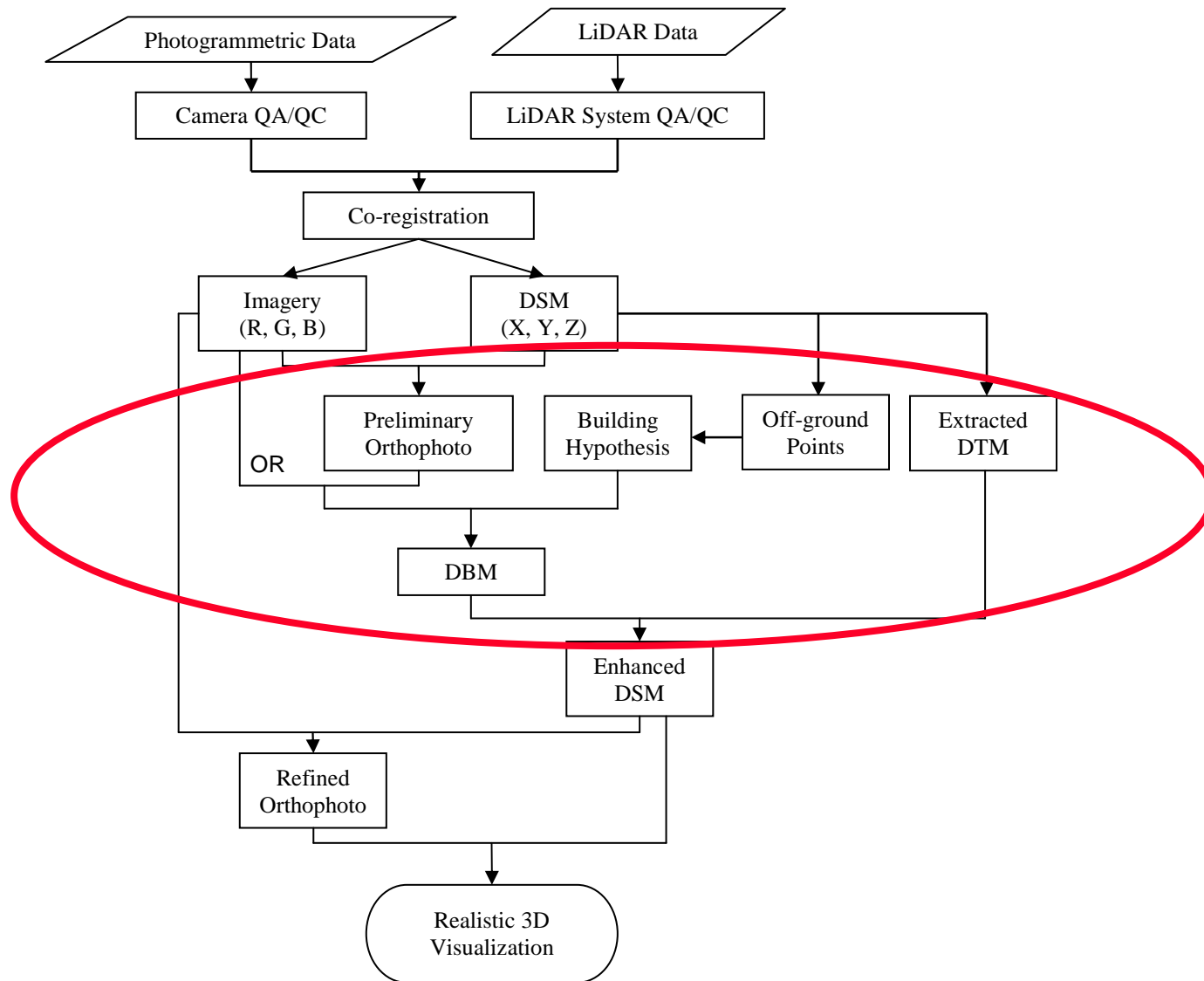
# True Orthophoto After Boundary Enhancement



Utilized Surface: DSM + DBM



# Proposed Workflow

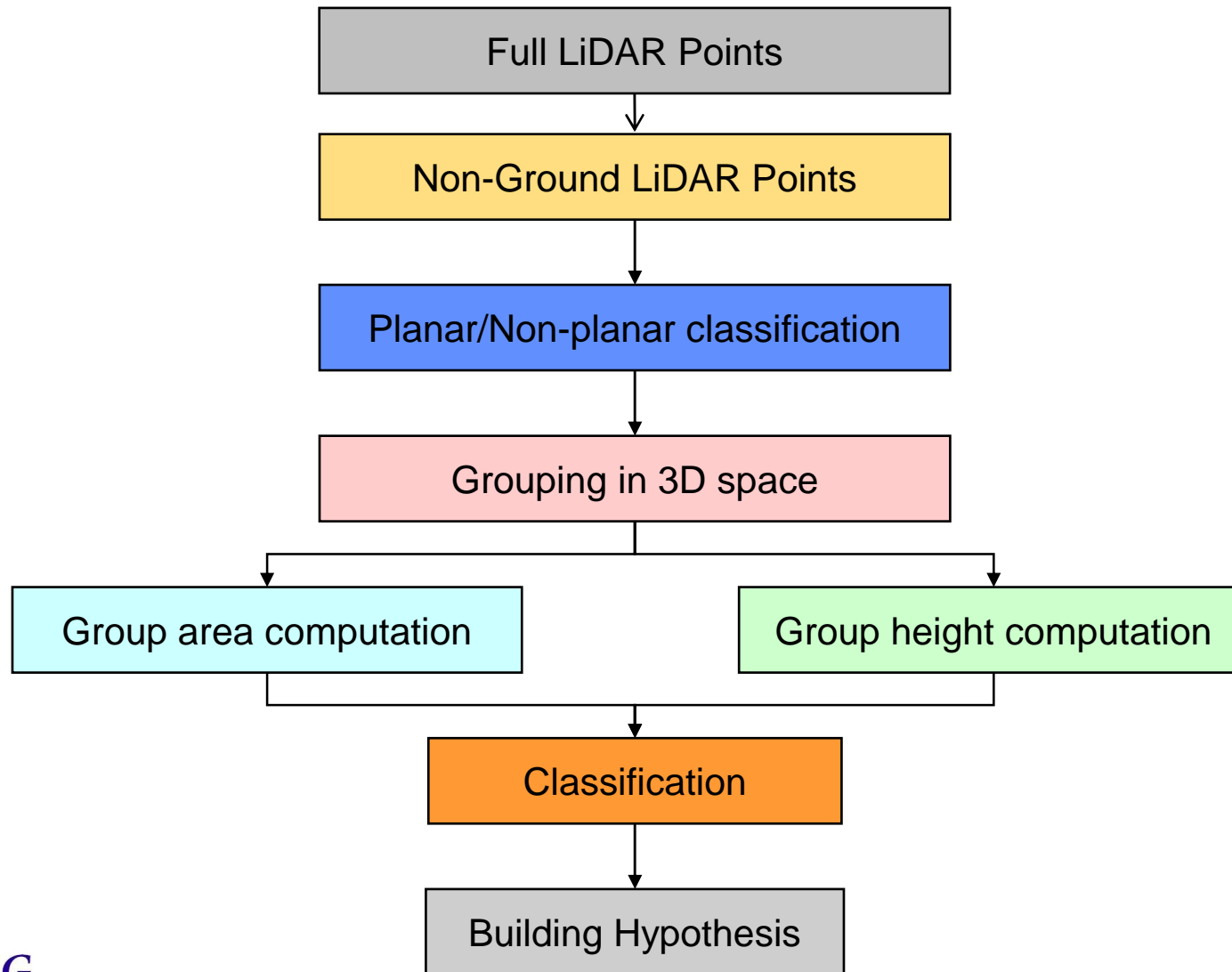


# DBM Generation

- DBM generation consists of two processes:
  - **Building Detection**: The process of generating building hypotheses by differentiating buildings from other objects within the data
  - **Building Reconstruction**: The process of utilizing the detected building regions in the data to derive the necessary building model parameters/primitives for its 3-D representation



# Building Hypothesis Generation

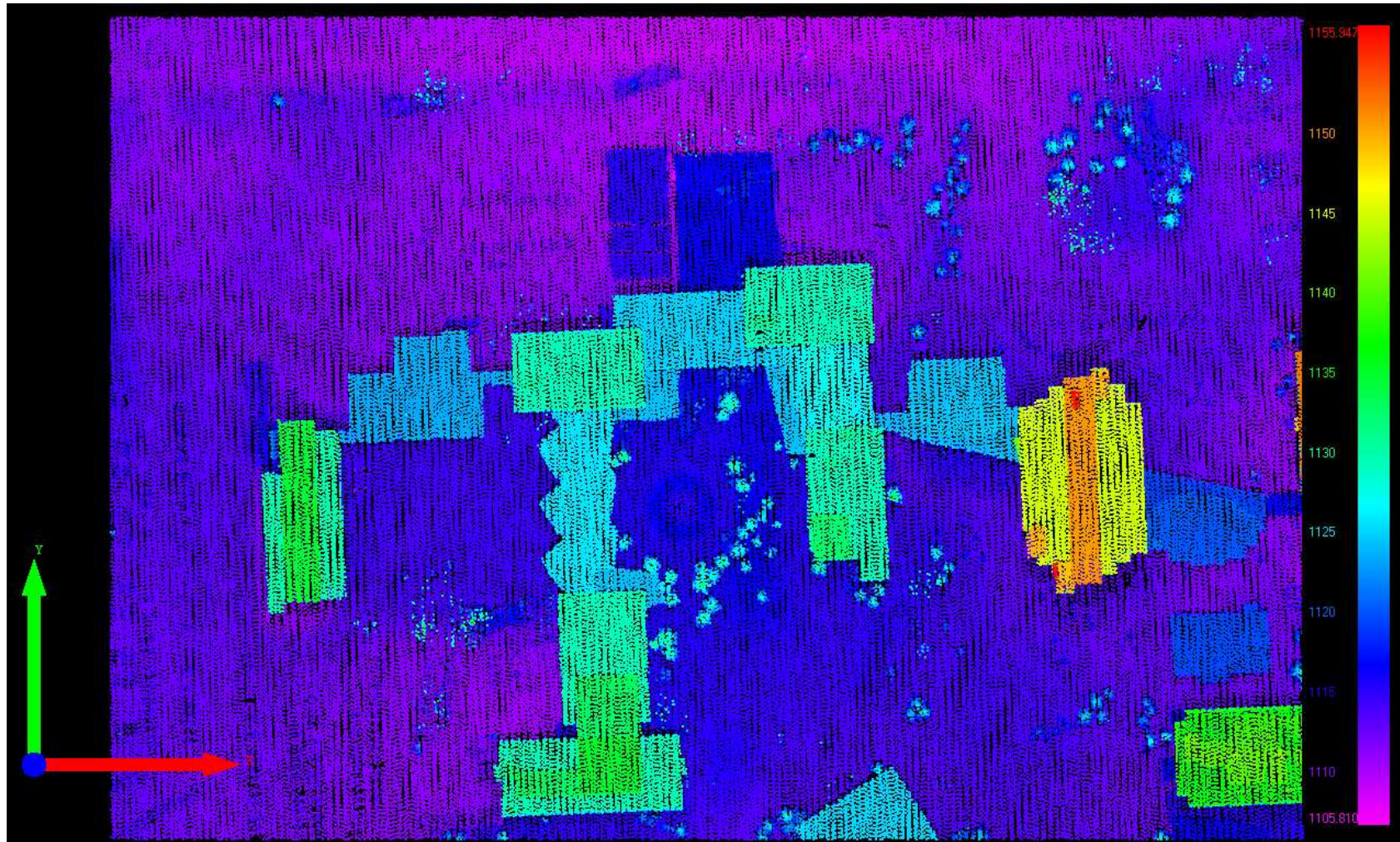


# Aerial Photo over UofC

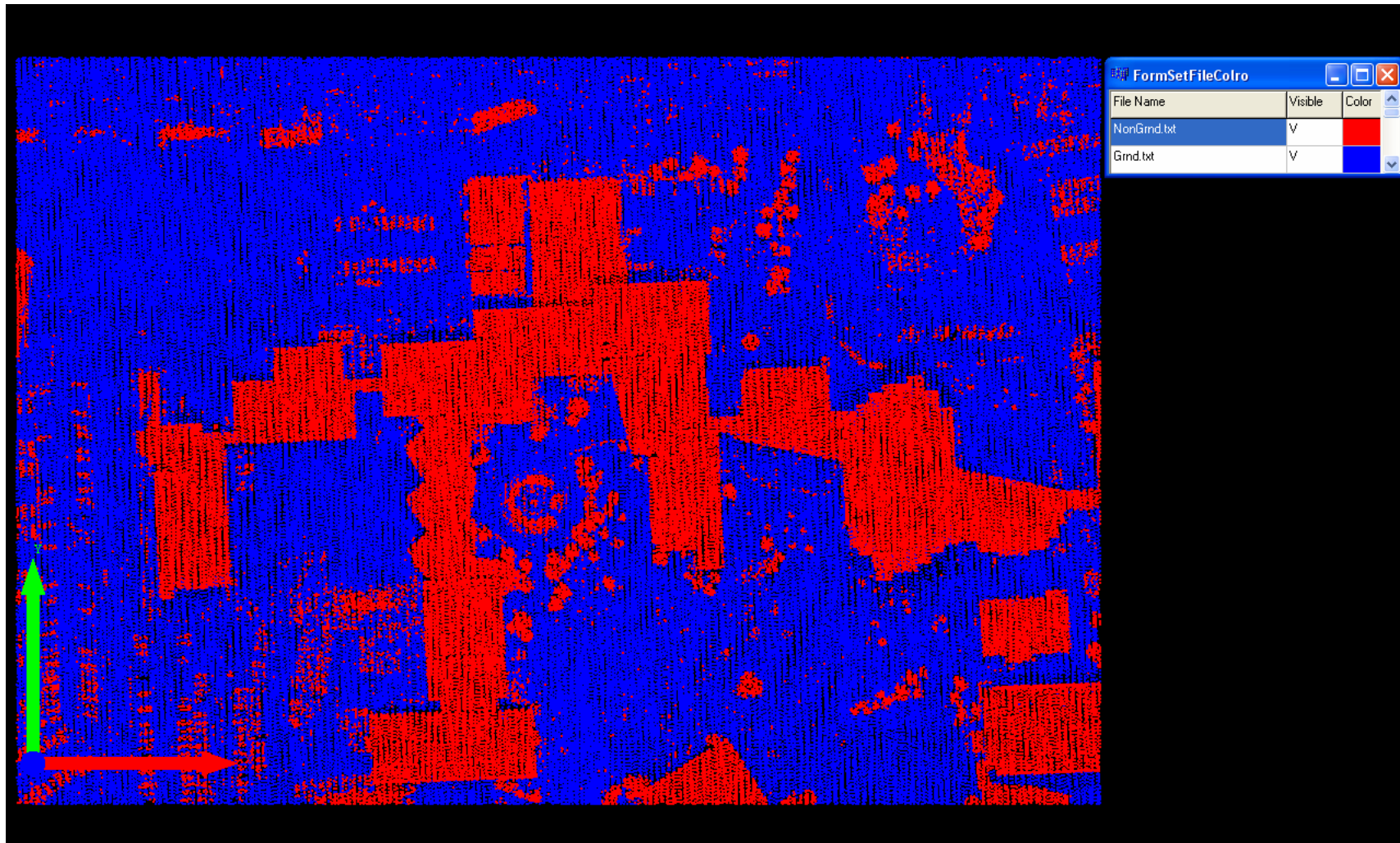




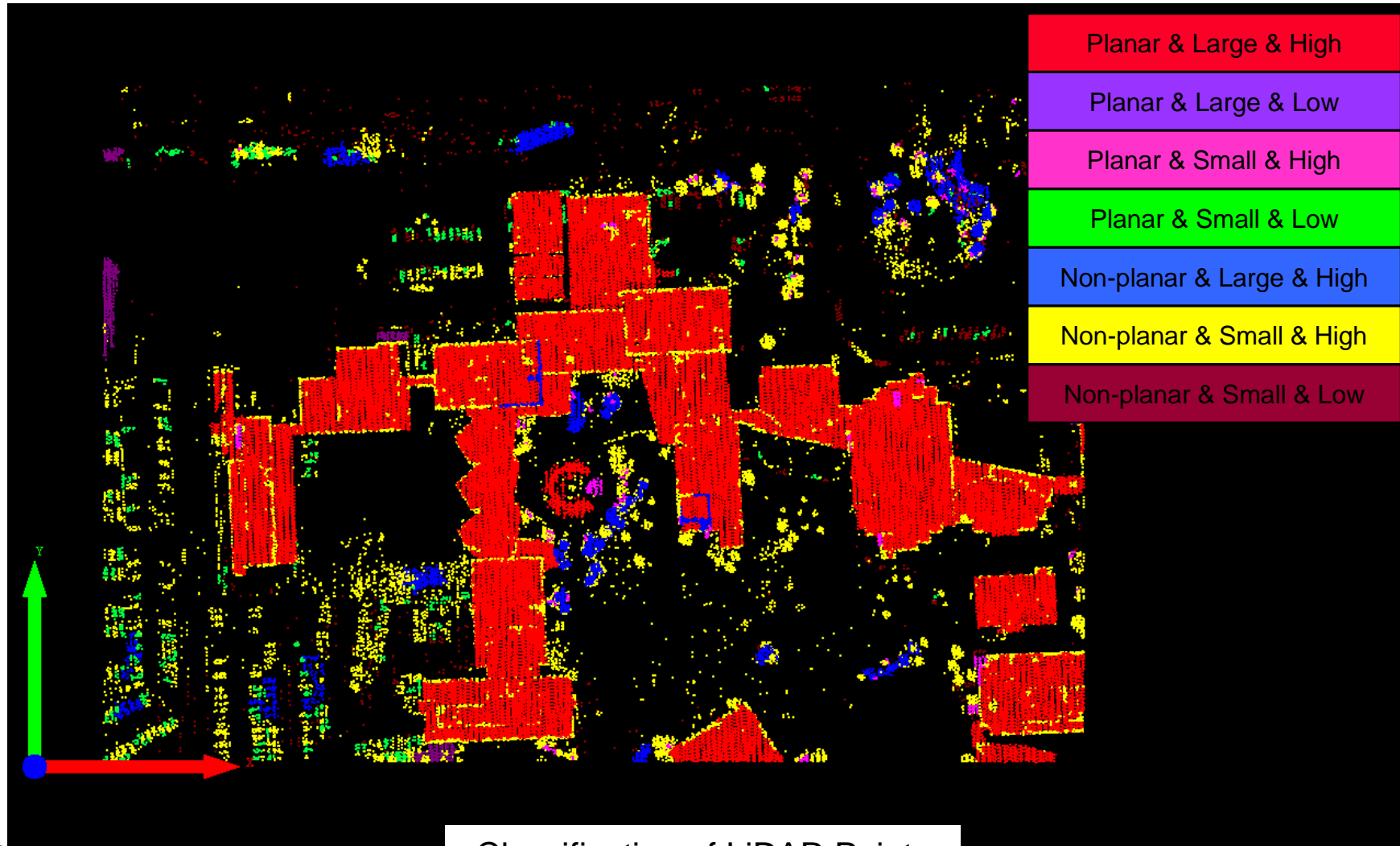
# Original LiDAR Points over UofC



# Ground/Non-Ground Classification



# Classifying Generated Groups

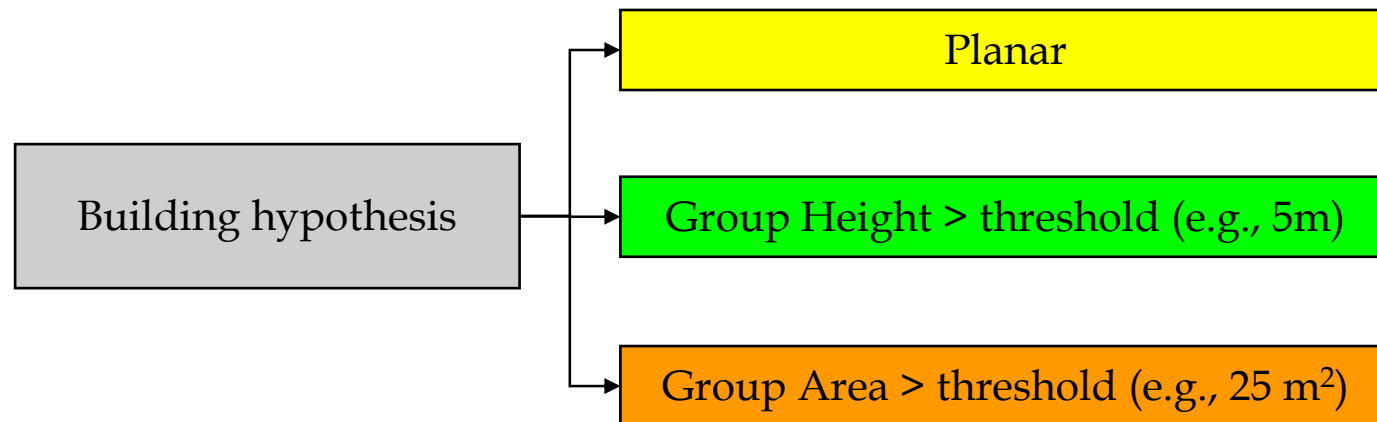


Classification of LiDAR Points

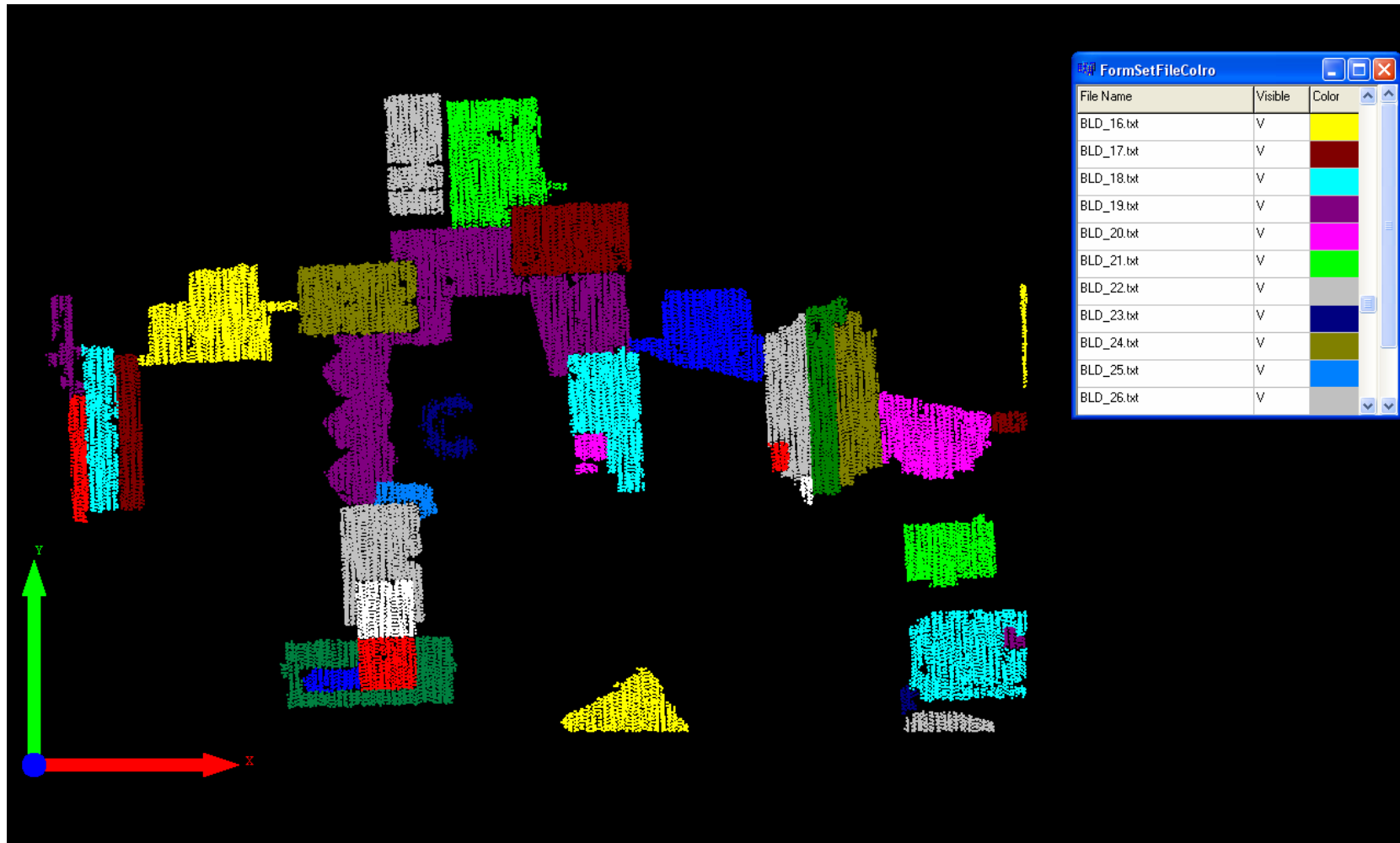


# Building Hypothesis Generation

Customization of parameters for Building hypothesis



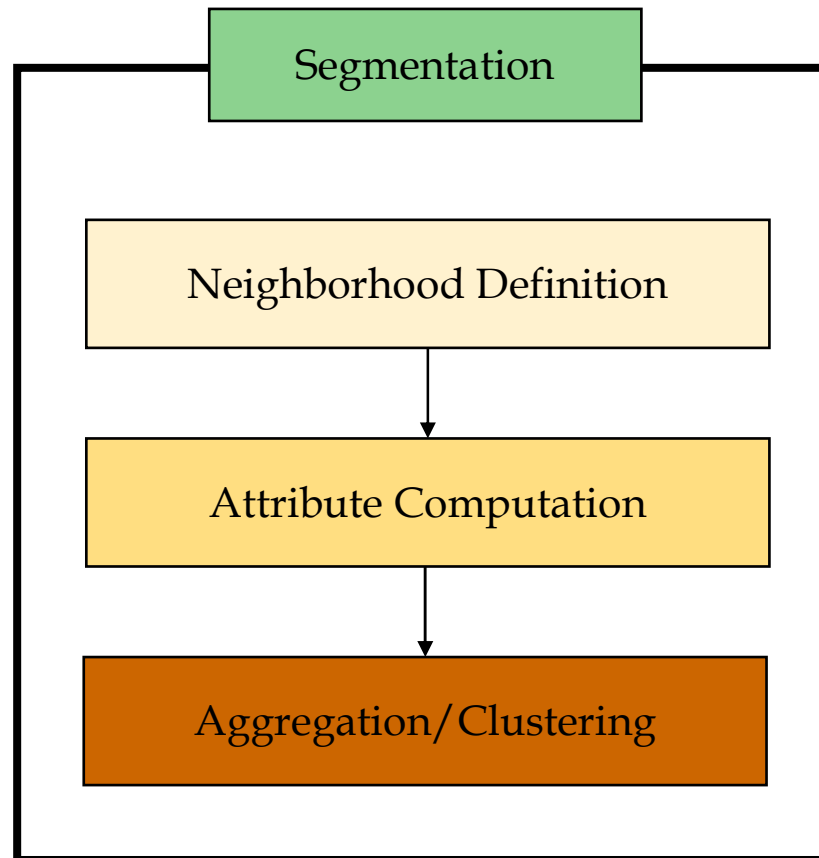
# Building Hypothesis Generation



Generated Building Hypotheses



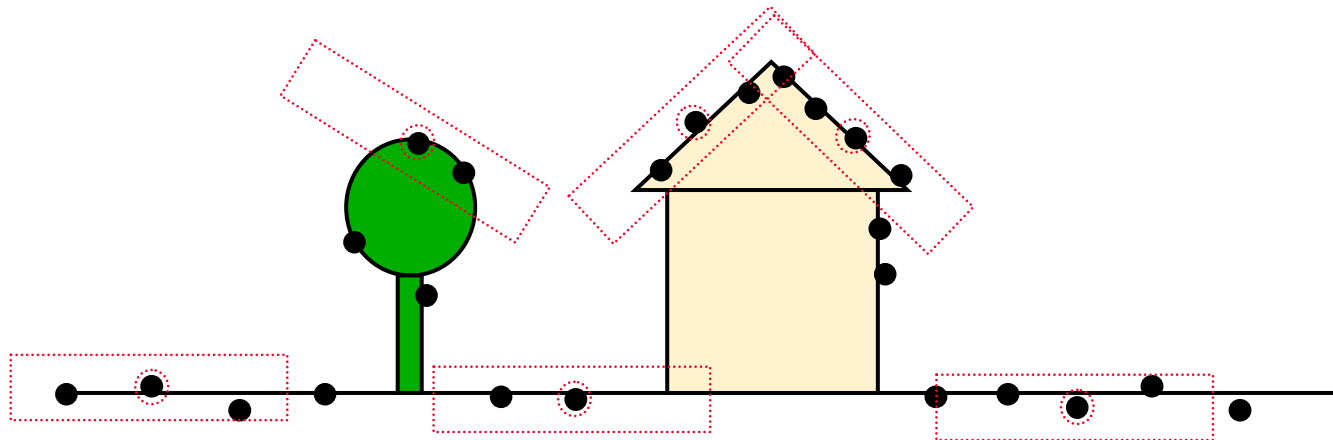
# Segmentation of Building Primitives



# Segmentation of Building Primitives

## Neighborhood Definition

Neighboring points that belong to the same physical surface (adaptive cylinder).

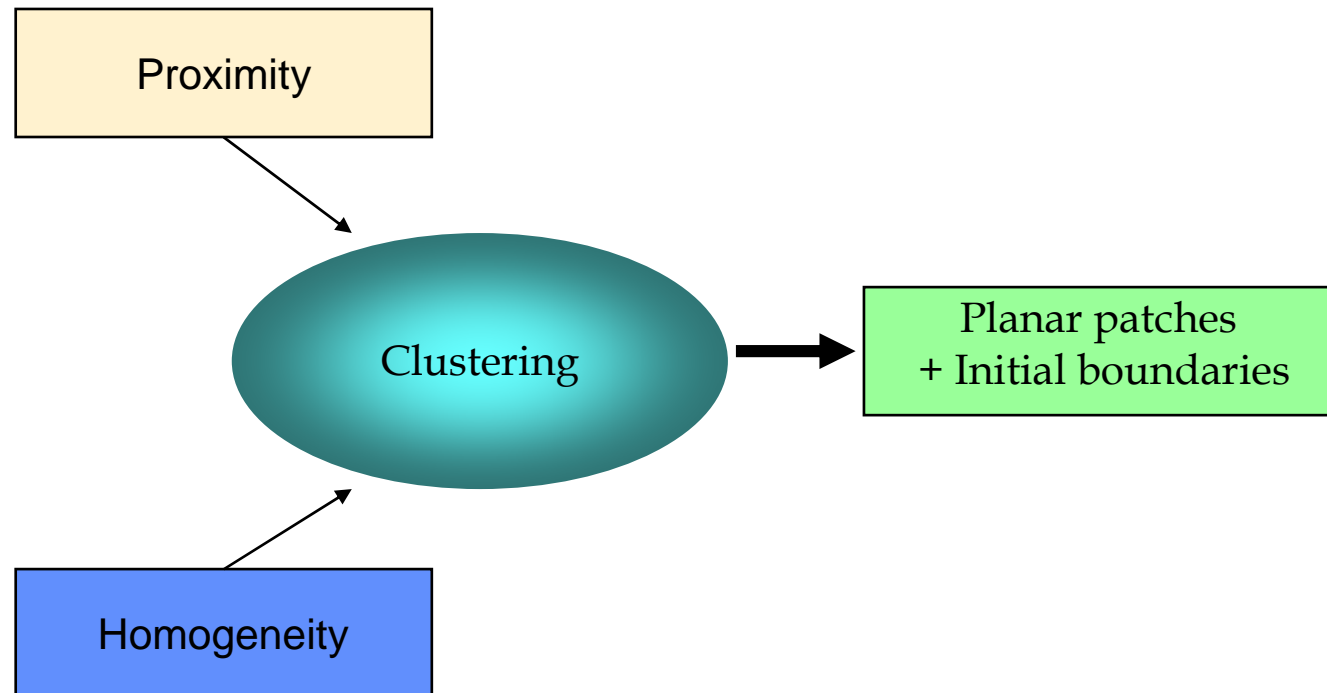


Attributes: Parameters of the plane through the defined neighborhood for a given point



# Segmentation of Building Primitives

## Clustering



Simultaneously considering Homogeneity (globally) in the parameter space  
+ Proximity (locally) in the object space → Accurate & Robust solution

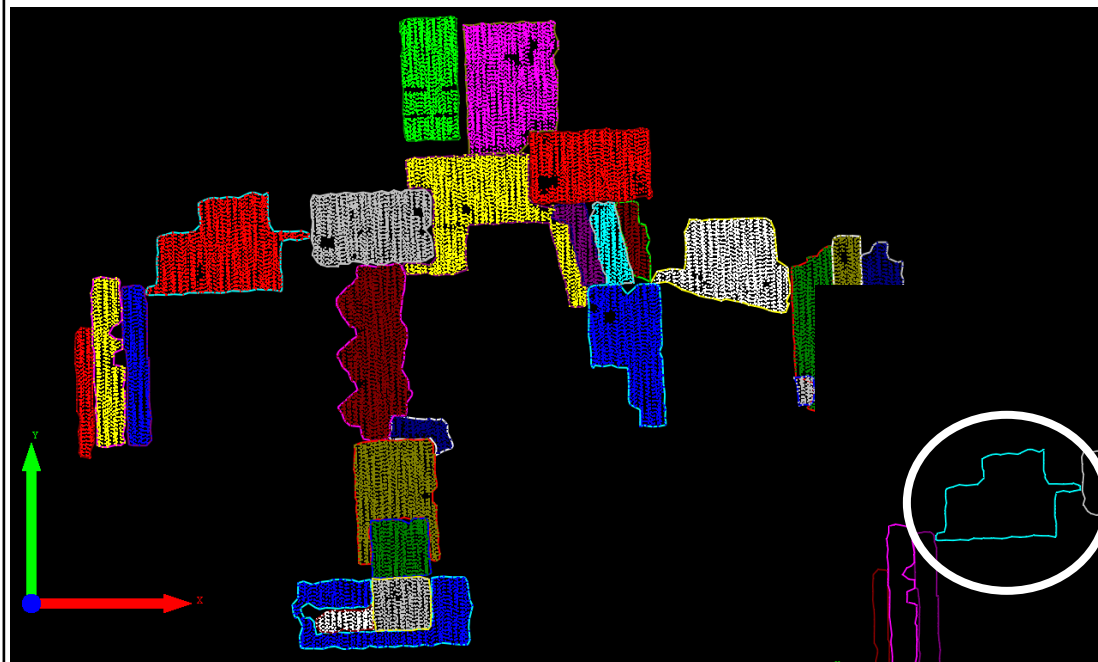




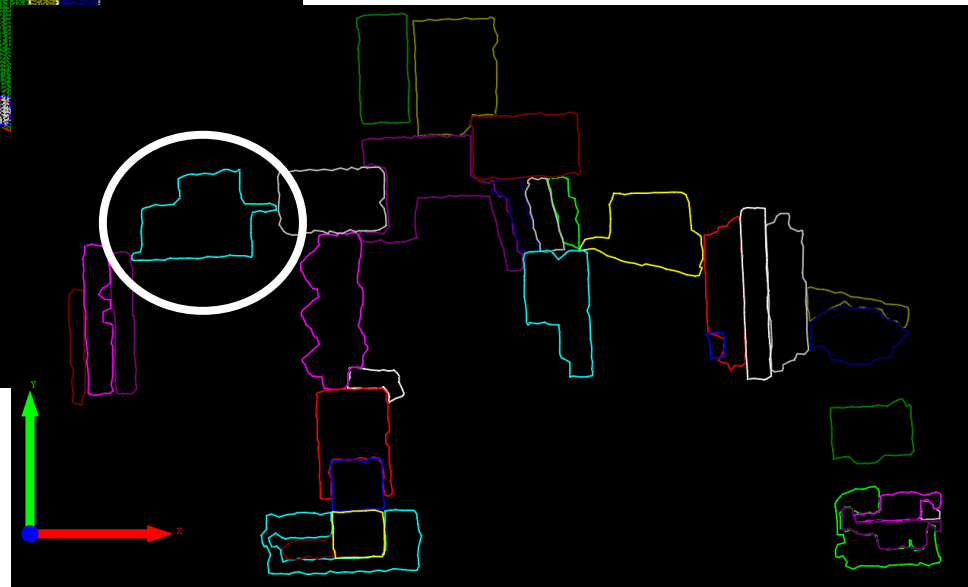
# Building Hypothesis $\rightarrow$ Building Primitives



# Building Primitives



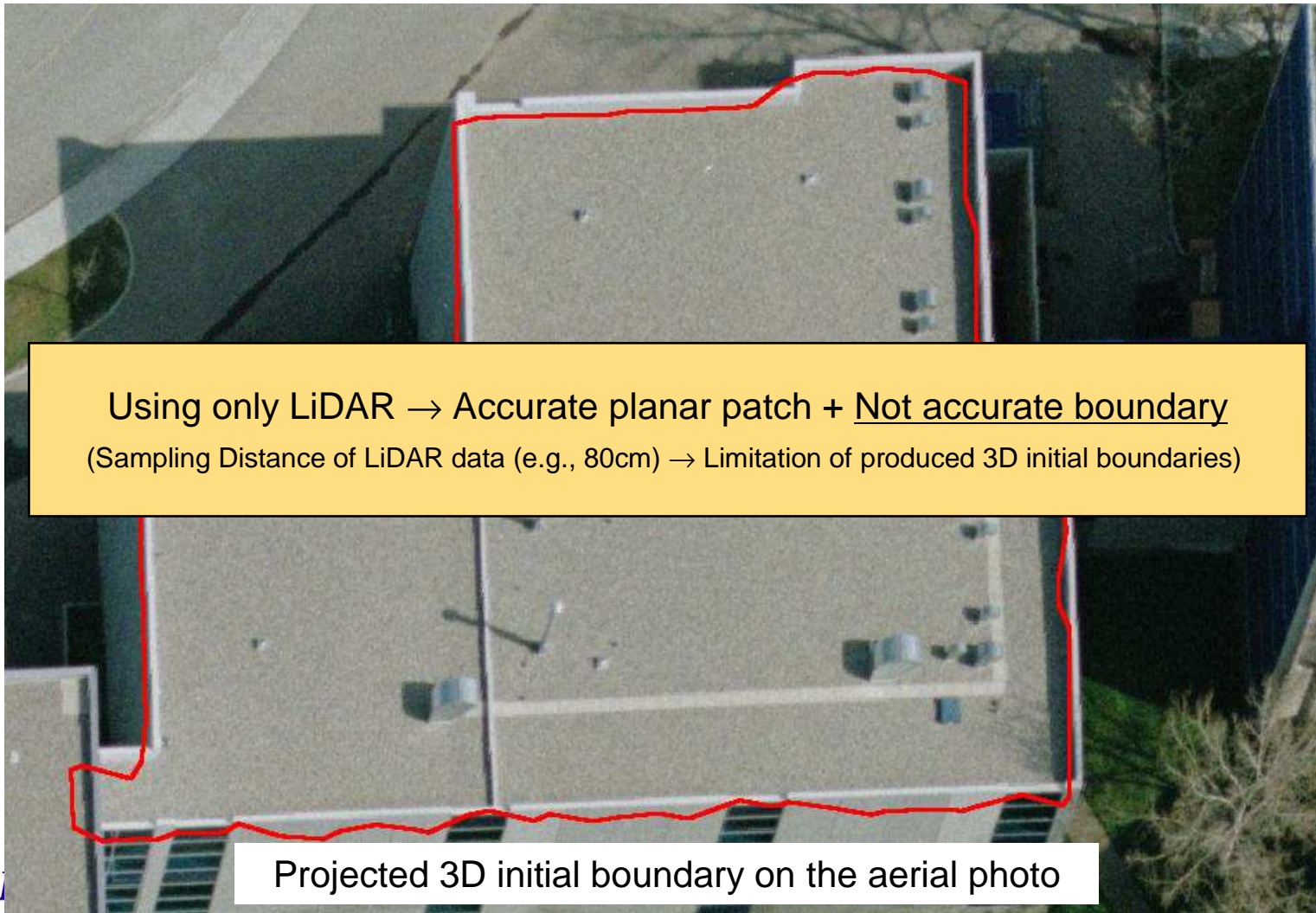
Segmentation + 3D initial boundaries



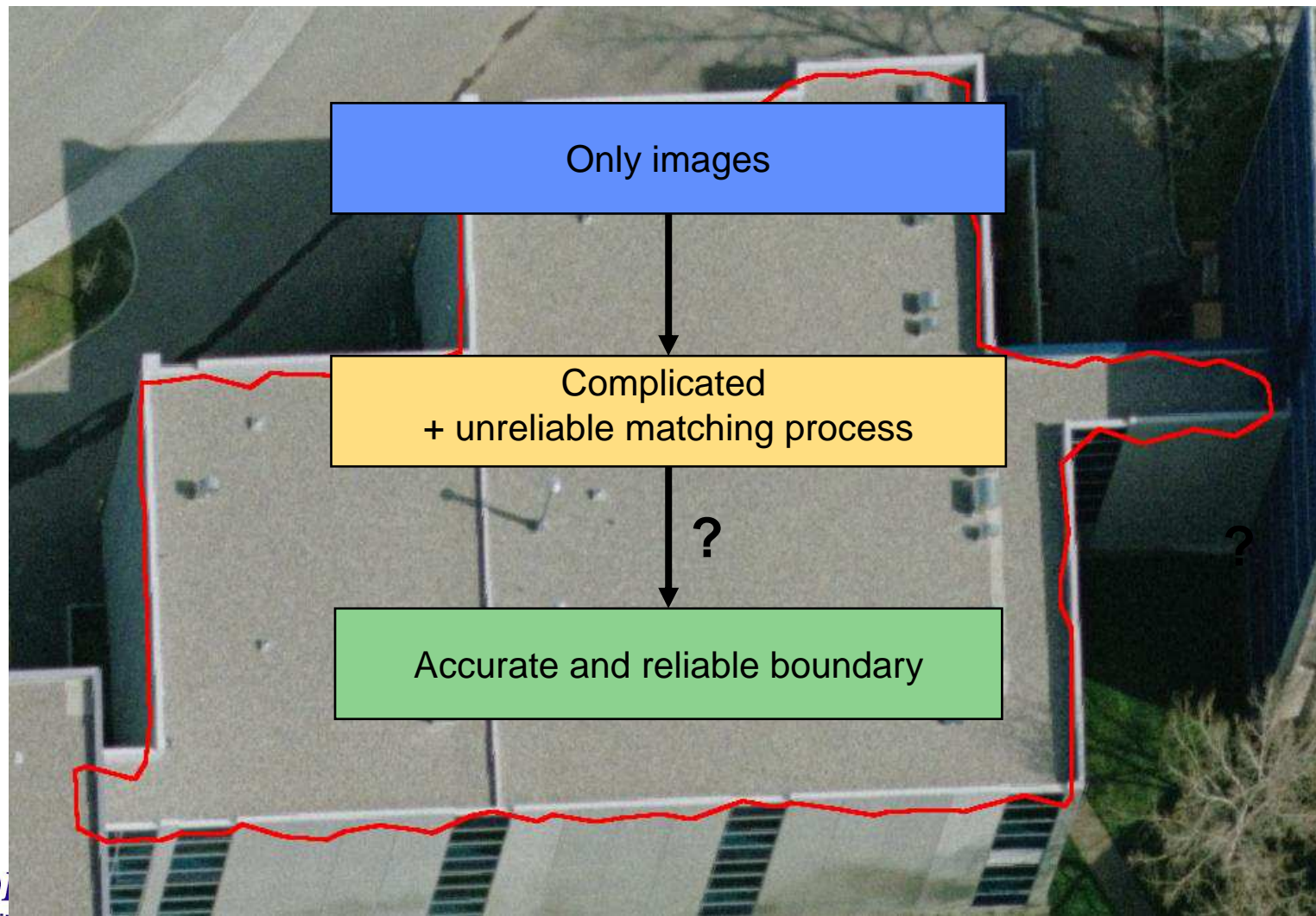
3D initial boundary Results



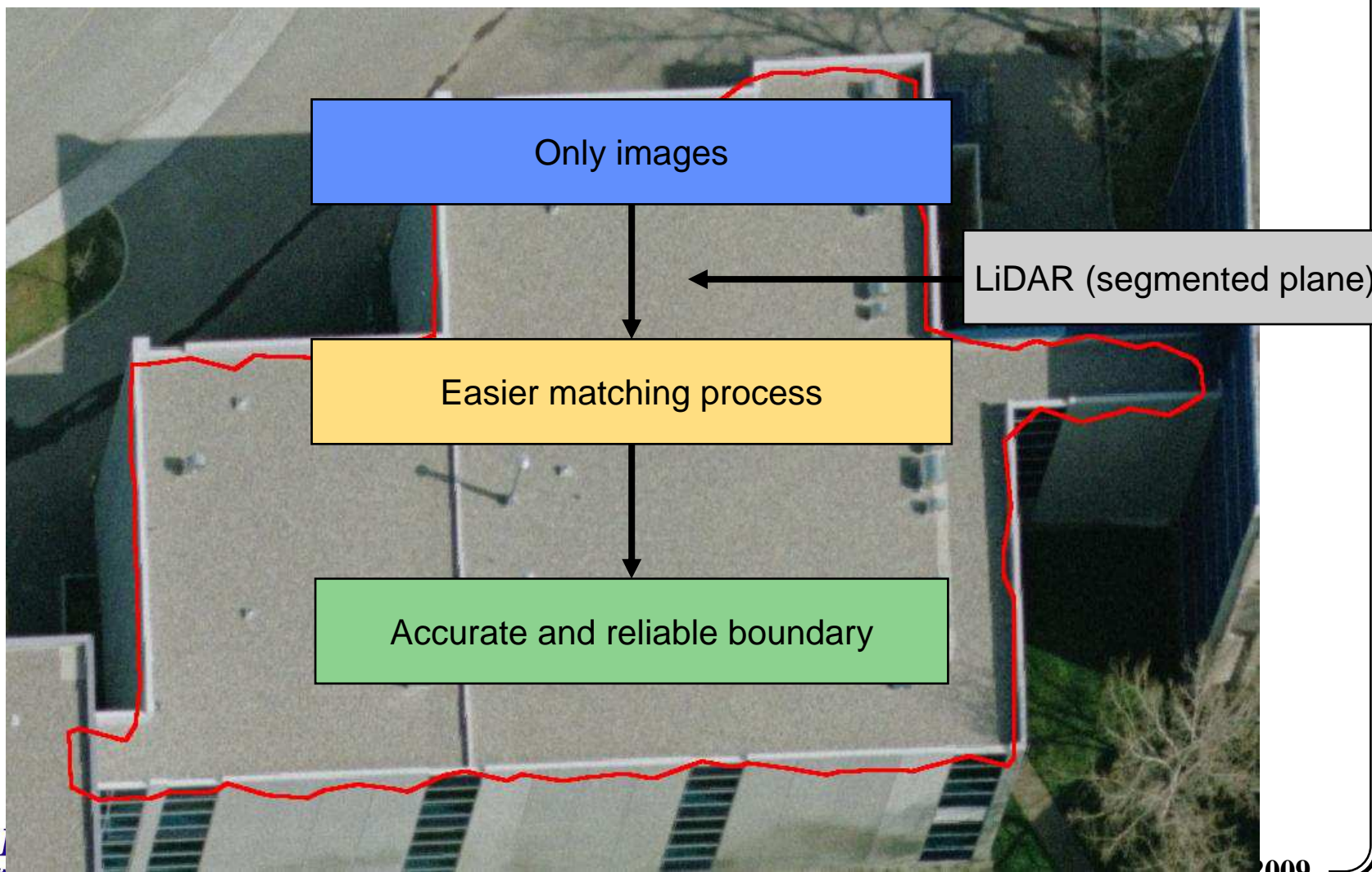
# Rooftop Boundary Refinement



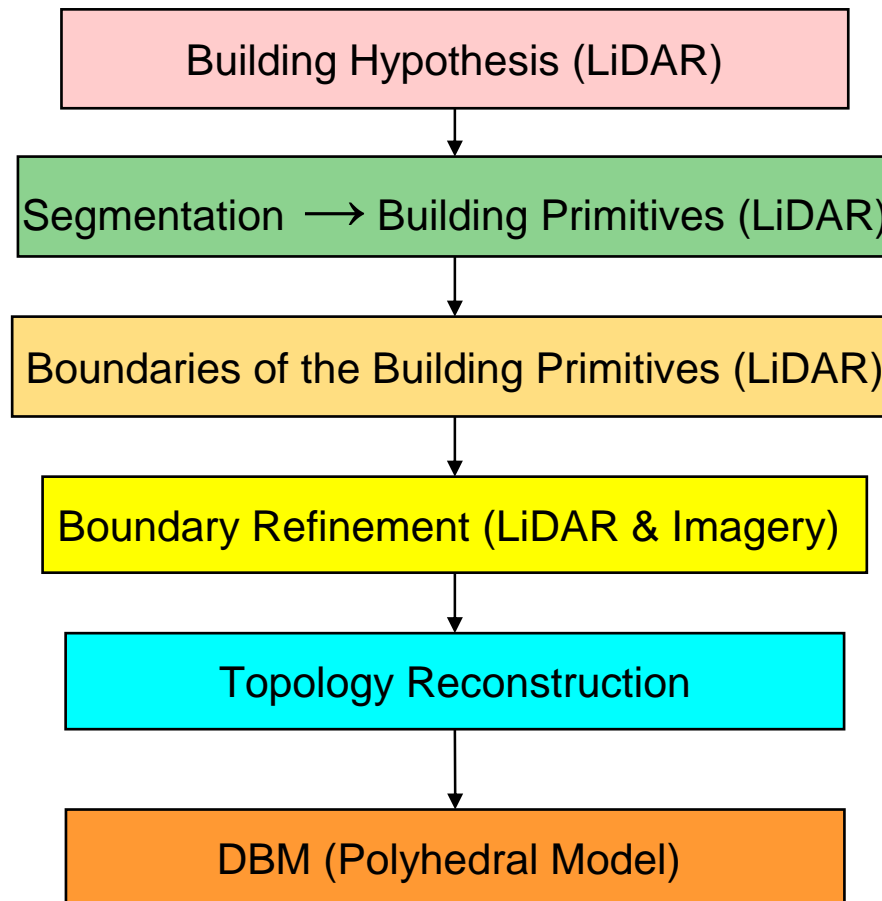
# Rooftop Boundary Refinement



# Rooftop Boundary Refinement



# DBM Reconstruction (Polyhedral Model)



# DBM Reconstruction (Polyhedral Model)

- Line Detection



Edge lines on image #1

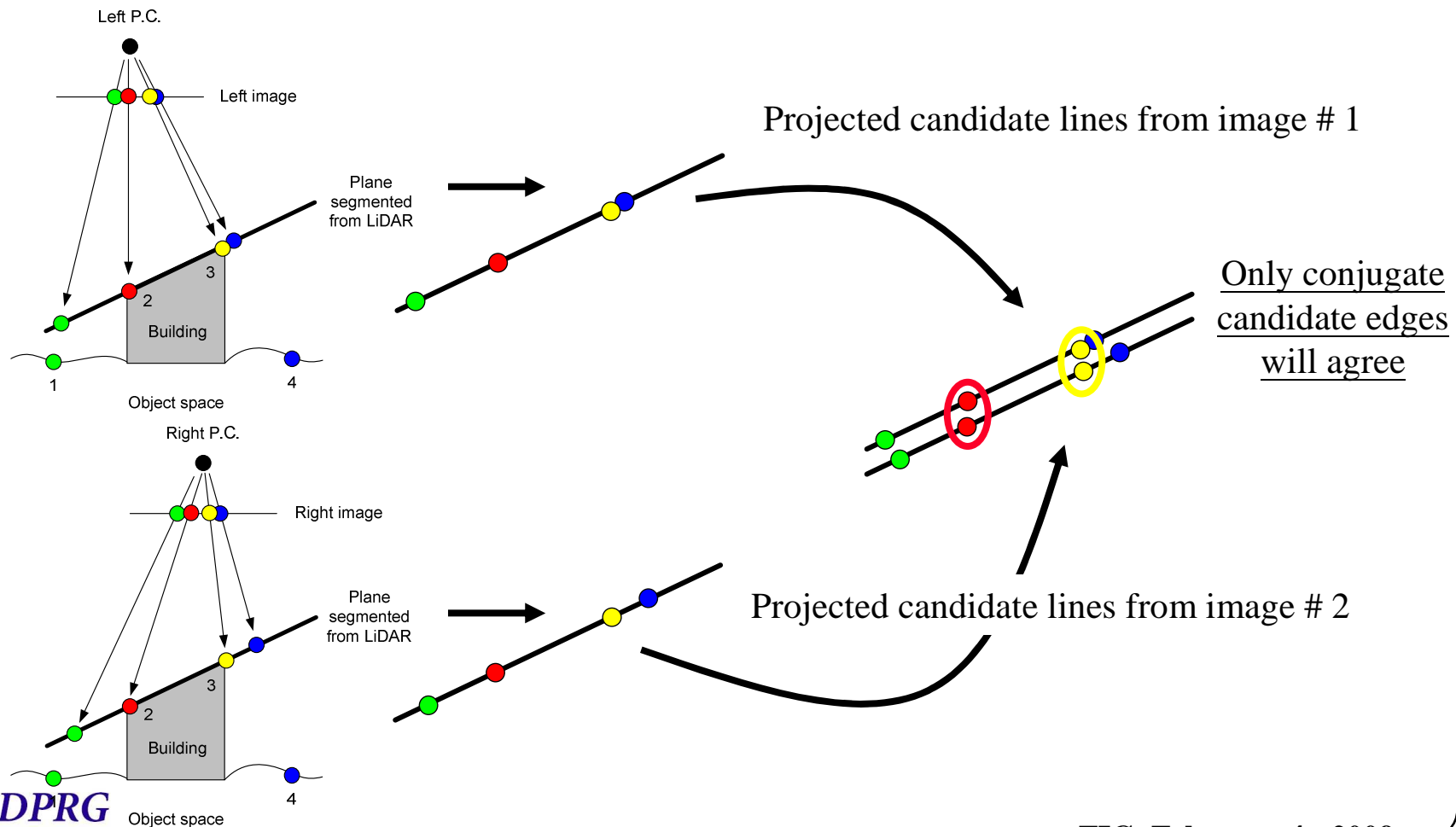


Edge lines on image #2



# DBM Reconstruction (Polyhedral Model)

- Line Matching





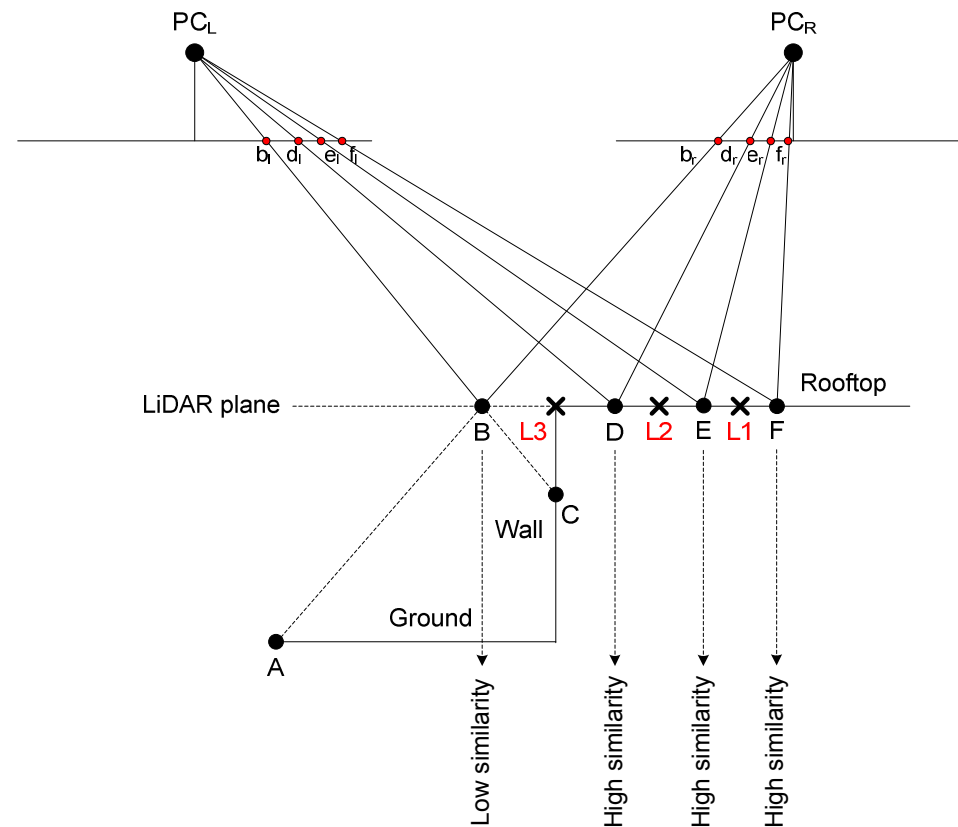
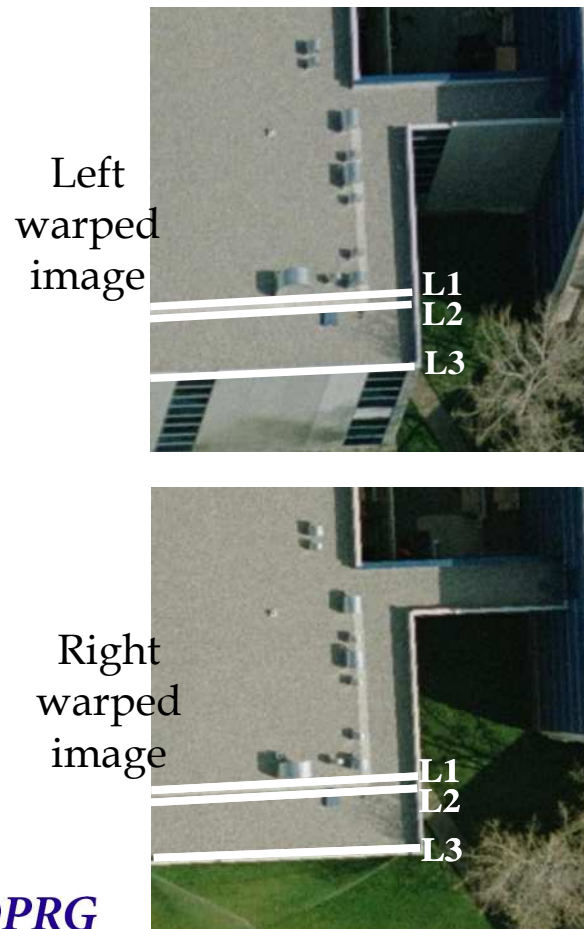
# DBM Reconstruction (Polyhedral Model)

- Warped imagery comparison

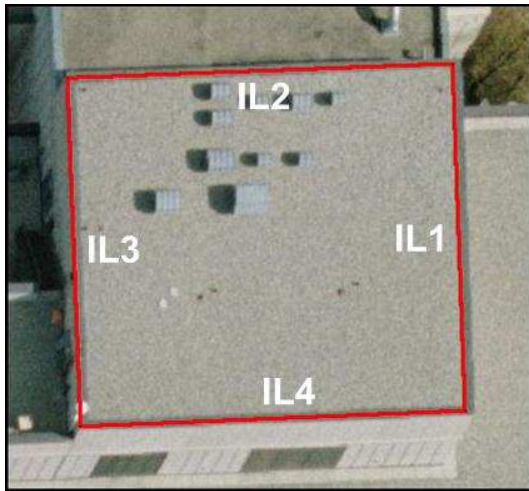


# DBM Reconstruction (Polyhedral Model)

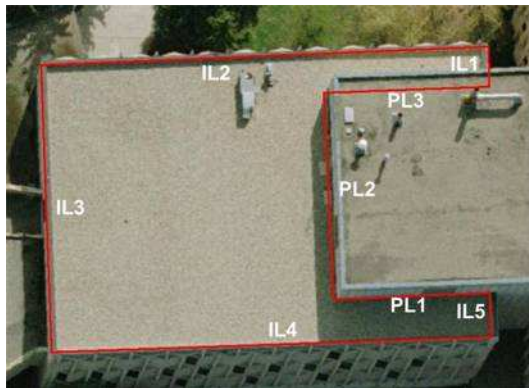
- Precise boundary segment selection



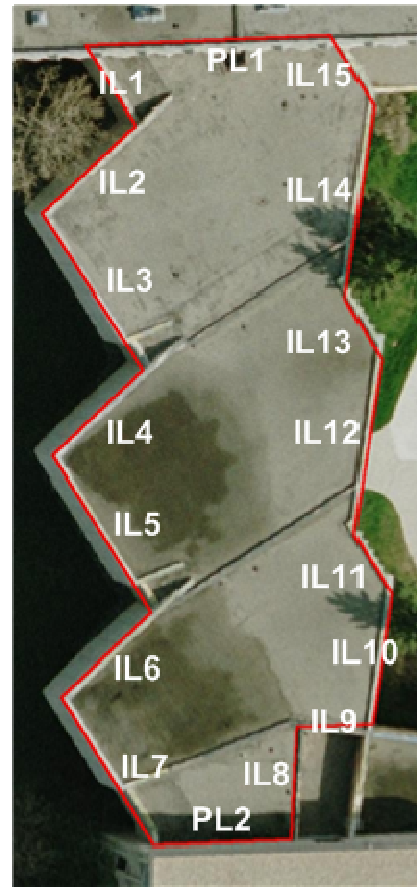
# Extracted Rooftop Patches



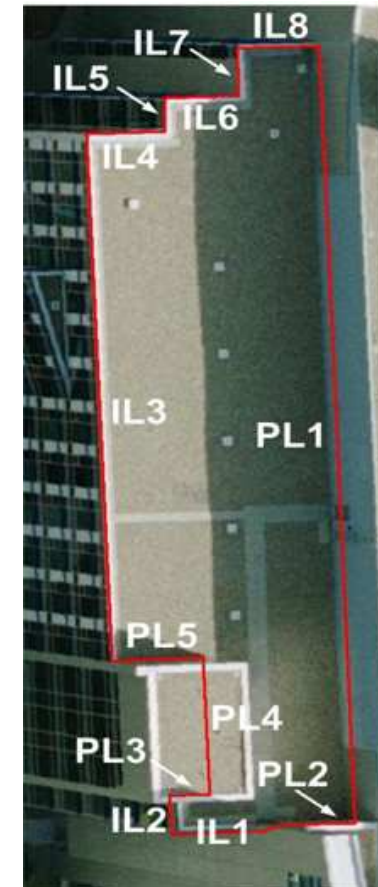
Simple building primitive



Building primitive with low complexity



Building primitive with medium complexity



Building primitive with high complexity

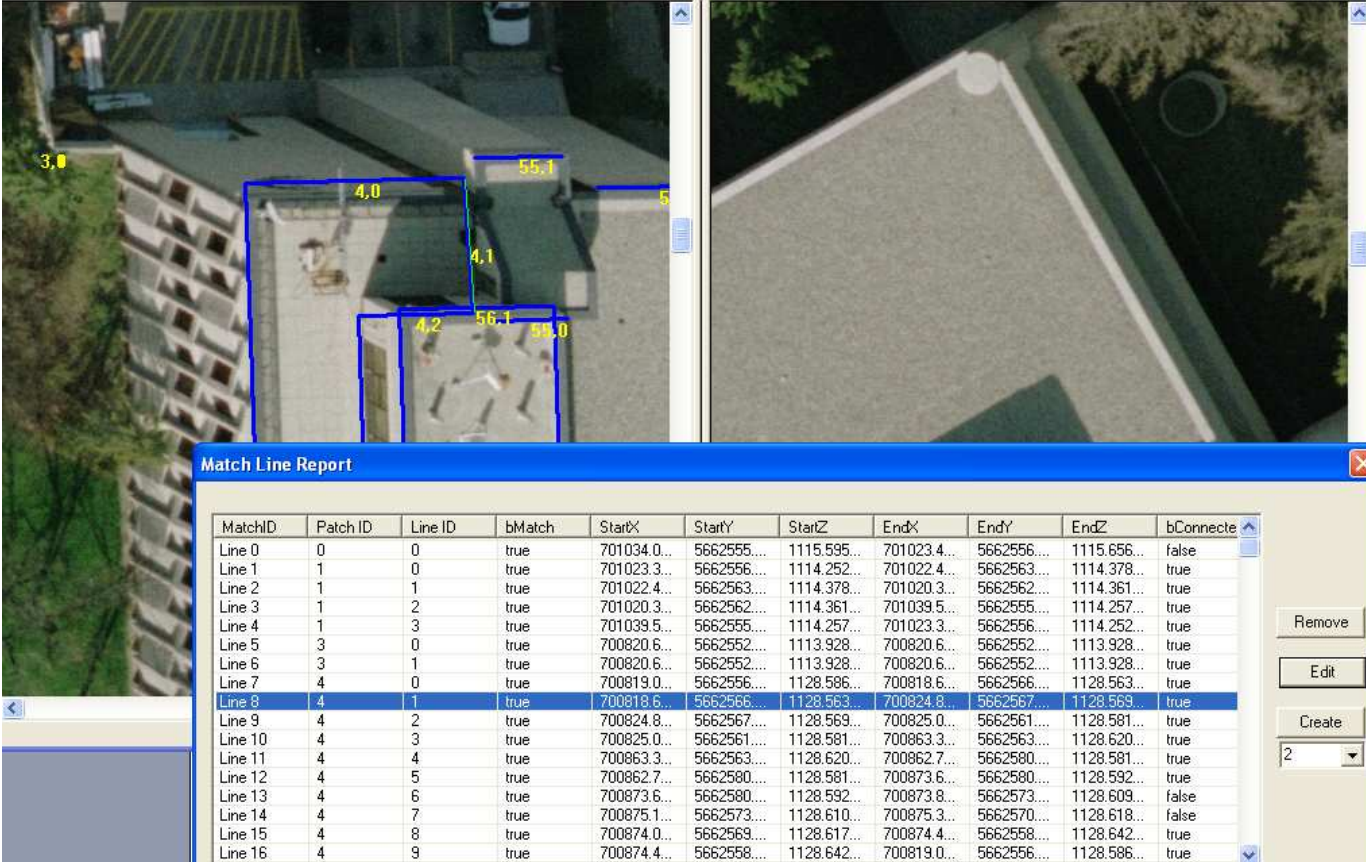
# Manual Editing

The screenshot displays the LineMatch software interface. At the top, a menu bar includes File(F), View(V), and Help(H). Below it is a toolbar with various icons. The main workspace is split into two stereo image windows, each showing an aerial view of a building with blue lines overlaid on its roof and walls. Red callouts point to these lines, labeling them as 'lines in imagery'. Below the stereo images are two panels: 'WireFrame View' on the left, which shows a 3D wireframe model of the building, and 'Match Line Report' on the right, which contains a table of match data. A red callout points to the table, labeling it as 'result report'. Another red callout points to the 3D wireframe, labeling it as '3D lines'. The title bar of the software window reads 'LineMatch - BND\_No: - [match\_line\_2.prj]'.

MatchID	Patch ID	Line ID	bMatch	StartX	StartY	StartZ	EndX	EndY	EndZ	bConn.
Line 60	19	13	true	70085...	56626...	1124.9...	70085...	56626...	1124.9...	true
Line 61	19	14	true	70085...	56626...	1124.9...	70085...	56626...	1124.9...	true
Line 62	20	0	true	70086...	56625...	1132.1...	70086...	56625...	1132.1...	true
Line 63	20	1	true	70086...	56625...	1132.1...	70086...	56625...	1132.1...	true
Line 64	21	0	true	70081...	56626...	1122.6...	70077...	56626...	1122.6...	true
Line 65	21	1	true	70077...	56626...	1122.6...	70077...	56626...	1122.6...	false
Line 66	21	2	true	70077...	56626...	1122.6...	70077...	56626...	1122.6...	true
Line 67	21	3	true	70077...	56626...	1122.6...	70078...	56626...	1122.6...	true
Line 68	21	4	true	70078...	56626...	1122.6...	70078...	56627...	1122.6...	true
Line 69	21	5	true	70078...	56627...	1122.6...	70080...	56627...	1122.6...	true
Line 70	21	6	true	70080...	56627...	1122.6...	70081...	56626...	1122.6...	true
Line 71	21	7	true	70081...	56626...	1122.6...	70082...	56626...	1122.6...	false
Line 72	21	8	true	70082...	56626...	1122.6...	70081...	56626...	1122.6...	true
Line 73	21	9	true	70081...	56626...	1122.6...	70081...	56626...	1122.6...	true
Line 74	23	0	true	70077...	56626...	1129.1...	70076...	56626...	1128.9...	true
Line 75	23	1	true	70076...	56626...	1128.9...	70076...	56626...	1128.9...	true
Line 76	23	2	true	70076...	56626...	1128.9...	70077...	56626...	1129.1...	true

## Software Interface

# Manual Editing



The screenshot displays a 3D model of a building with several match lines highlighted in blue. The match lines are labeled with IDs such as 3.0, 4.0, 4.1, 4.2, 55.1, 56.1, and 58.0. Below the model is a 'Match Line Report' dialog box with a table of match line data. The table has columns for MatchID, PatchID, LineID, bMatch, StartX, StartY, StartZ, EndX, EndY, EndZ, and bConnecte. The data is as follows:

MatchID	PatchID	LineID	bMatch	StartX	StartY	StartZ	EndX	EndY	EndZ	bConnecte
Line 0	0	0	true	701034.0...	5662555...	1115.595...	701023.4...	5662556...	1115.656...	false
Line 1	1	0	true	701023.3...	5662556...	1114.252...	701022.4...	5662563...	1114.378...	true
Line 2	1	1	true	701022.4...	5662563...	1114.378...	701020.3...	5662562...	1114.361...	true
Line 3	1	2	true	701020.3...	5662562...	1114.361...	701039.5...	5662555...	1114.257...	true
Line 4	1	3	true	701039.5...	5662555...	1114.257...	701023.3...	5662556...	1114.252...	true
Line 5	3	0	true	700820.6...	5662552...	1113.928...	700820.6...	5662552...	1113.928...	true
Line 6	3	1	true	700820.6...	5662552...	1113.928...	700820.6...	5662552...	1113.928...	true
Line 7	4	0	true	700819.0...	5662556...	1128.586...	700818.6...	5662566...	1128.563...	true
Line 8	4	1	true	700818.6...	5662556...	1128.583...	700824.8...	5662567...	1128.569...	true
Line 9	4	2	true	700824.8...	5662567...	1128.569...	700825.0...	5662561...	1128.581...	true
Line 10	4	3	true	700825.0...	5662561...	1128.581...	700863.3...	5662563...	1128.620...	true
Line 11	4	4	true	700863.3...	5662563...	1128.620...	700862.7...	5662580...	1128.581...	true
Line 12	4	5	true	700862.7...	5662580...	1128.581...	700873.6...	5662580...	1128.592...	true
Line 13	4	6	true	700873.6...	5662580...	1128.592...	700873.8...	5662573...	1128.609...	false
Line 14	4	7	true	700873.8...	5662573...	1128.610...	700875.3...	5662570...	1128.618...	false
Line 15	4	8	true	700874.0...	5662569...	1128.617...	700874.4...	5662558...	1128.642...	true
Line 16	4	9	true	700874.4...	5662558...	1128.642...	700819.0...	5662556...	1128.586...	true

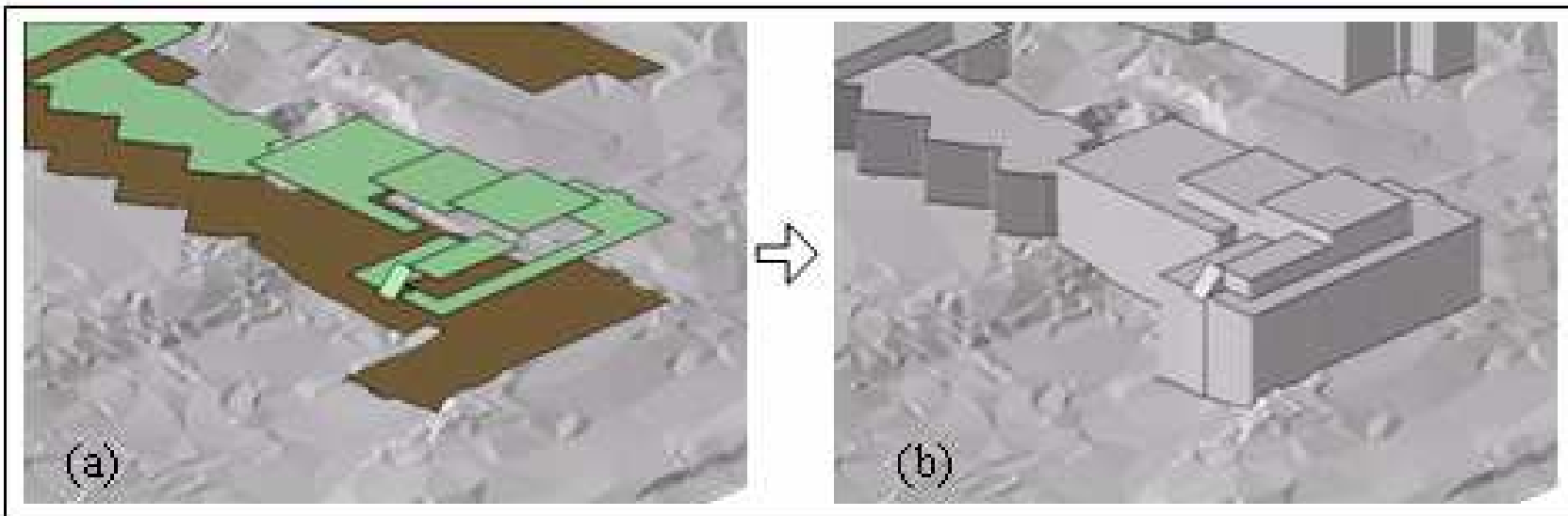
On the right side of the dialog box, there are buttons for 'Remove', 'Edit', and 'Create', along with a dropdown menu showing the number '2'.

## Software Interface



# Enhanced DSM

- The rooftop patches (and footprints) are added to the DTM, and an enhanced DSM is produced.



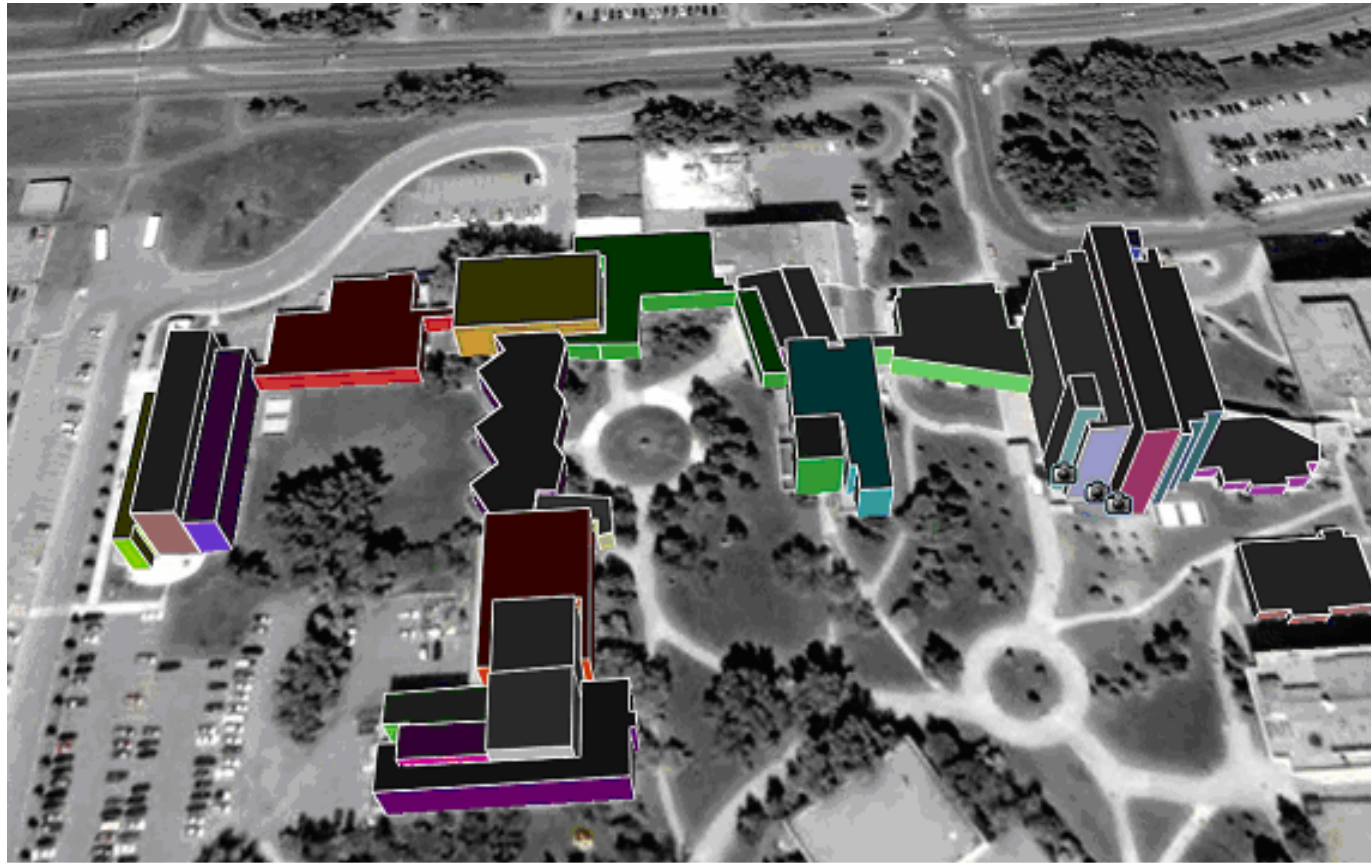
DTM, roof patches, and footprint

Enhanced DSM (DBM+DTM)



# Generated DBM

- DBM Visualization: Link to Google Earth by KML



# Orthophotos: Qualitative Analysis



2D visualization before DSM enhancement

2D visualization after DSM enhancement





# 3D Visualization: Qualitative Analysis



3D visualization before DSM enhancement



3D visualization after DSM enhancement



# DBM: Quantitative Analysis

- 40 building primitives with 291 boundary segments
- **Quantitative analysis using only the automatically established boundary segments**
- Established segments: 311
- Correctly determined segment: 276
- **Correctness** = % of correctly determined segments among the established ones =  $276/311 = 89\%$
- **Completeness** = % of correctly determined segments among total actual boundary segments =  $276/291 = 95\%$



# DBM: Quantitative Analysis

- Accuracy of the established DBM: RMSE computation using the DBM corner points

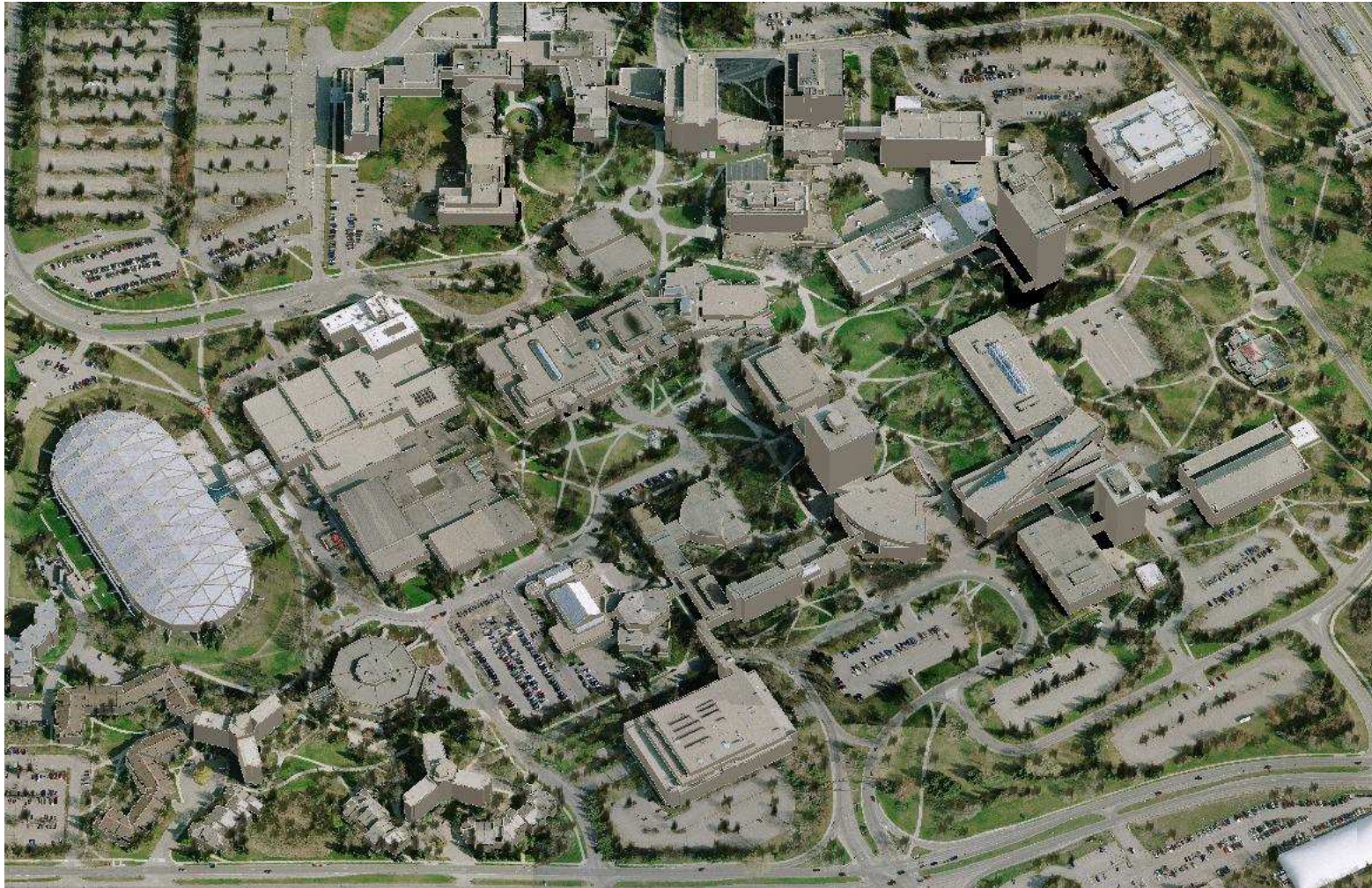
	Manual DBM	Automated DBM
No. of vertices	116	78
Mean (X), m	-0.086	-0.040
Mean (Y), m	-0.008	0.003
Mean (Z), m	-0.091	0.553
Std_dev (X), m	±0.349	±0.392
Std_dev (Y), m	±0.364	±0.407
Std_dev (Z), m	±0.239	±0.237
RMSE (X), m	0.357	0.392
RMSE (Y), m	0.362	0.405
RMSE (Z), m	0.255	0.601



Heights of the fences range from 0.5m to 1.0m



# Final Product



Main Campus Area



**DPRG**  
Digital Photogrammetry  
Research Group

# Final Product (Sample)



Engineering Building



# Final Product (Sample)



# Final Product (Sample)



## Concluding Remarks

- There is a wide range of data acquisition systems, which provide data with complementary information content.
  - Integration is necessary for complete description of 3D environments.
- Successful integration depends on:
  - Validity of the sensor model and parameters,
  - Quality of the data (practical QC procedures),
  - Registration/geo-referencing of the multi sensory data,
  - Correspondence between conjugate elements in the multi-sensory data, and
  - Quality of the reconstruction & visualization techniques.





# Comments and Questions?

