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

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Acknowledgement

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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 **(±10 – ±30cm)**

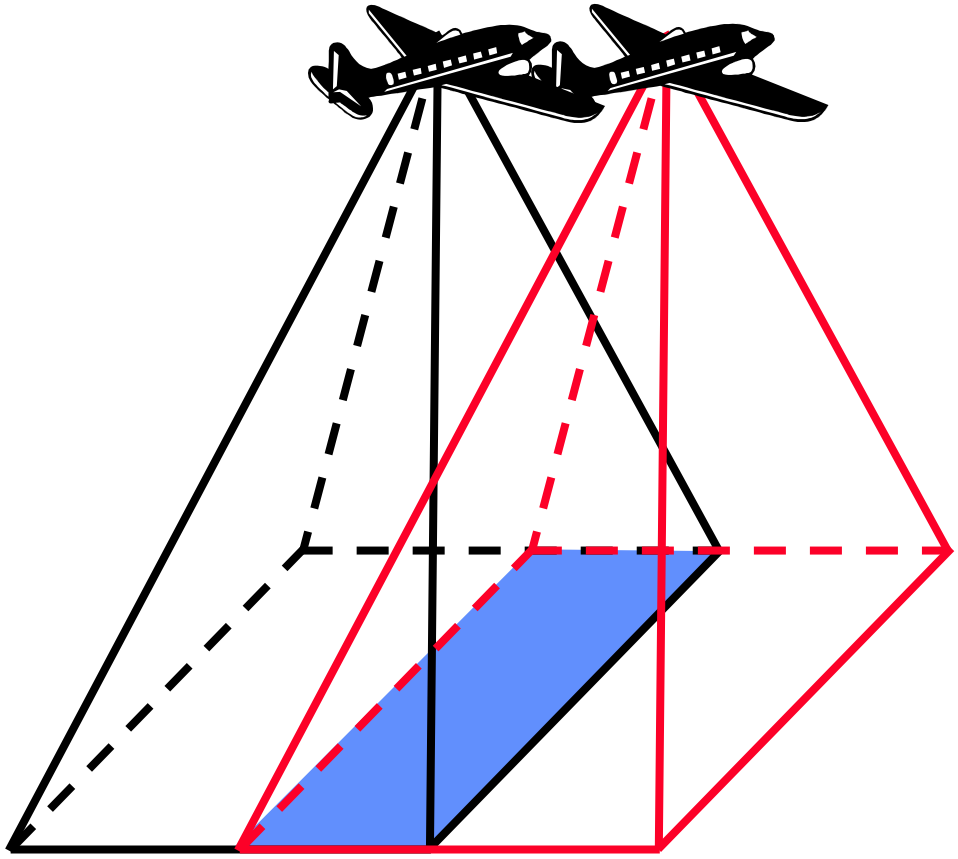
(R, G, B): 23, 136, 69

Accurate Enough for Engineering Applications

LiDAR + Photogrammetric Data: Why?

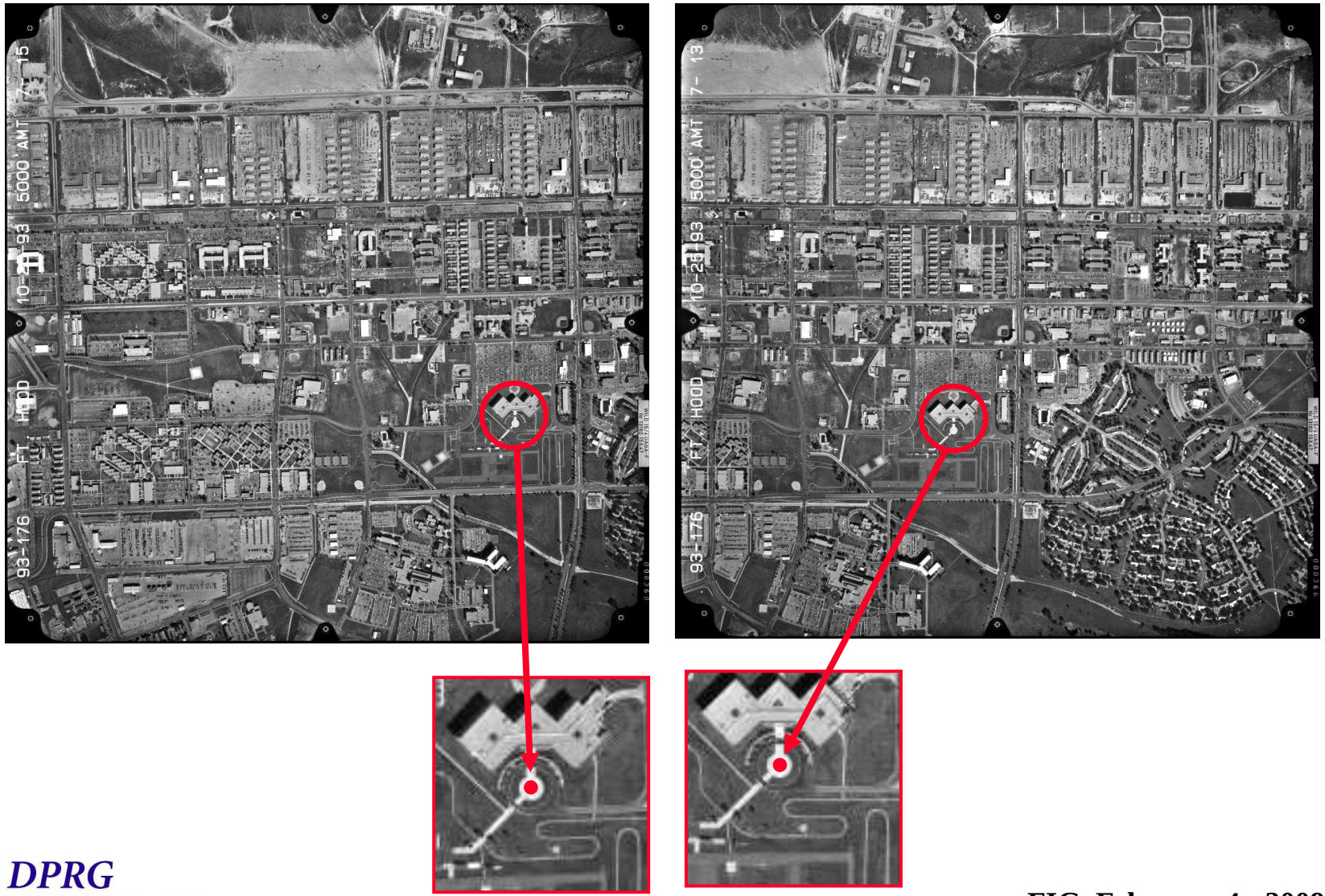
- There has been a recent increase in the volume and varying formats of remote sensing data (e.g., LiDAR data and imagery captured by digital cameras).
  - LiDAR provides a dense point cloud representing the object space surface, and thus offers a fast and accurate way of obtaining a Digital Surface 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

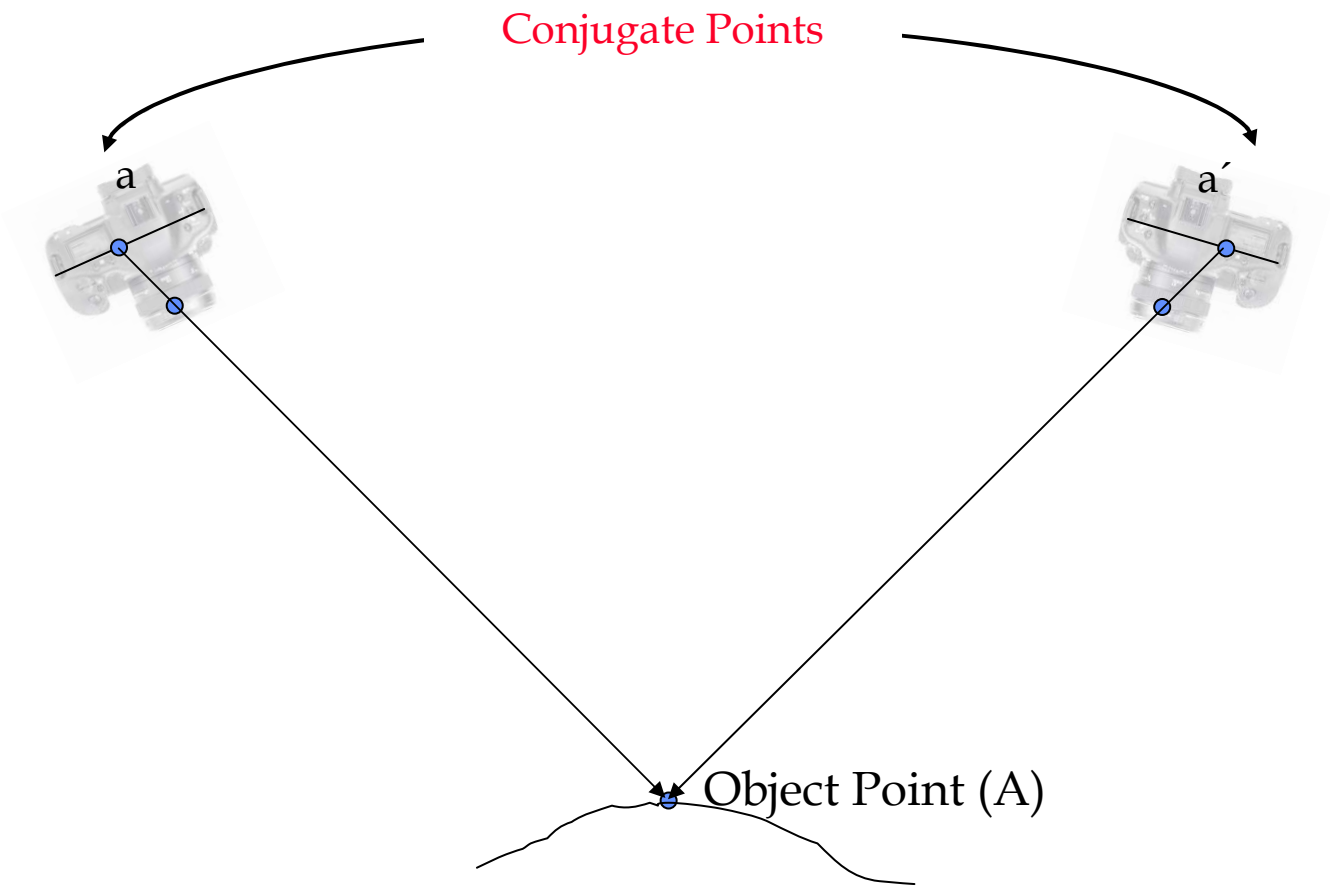


Overlap

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

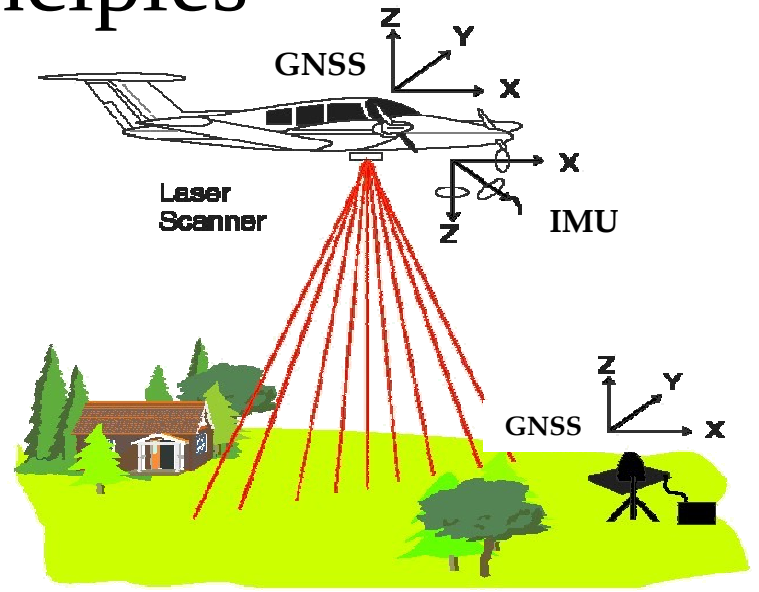
ADS 40

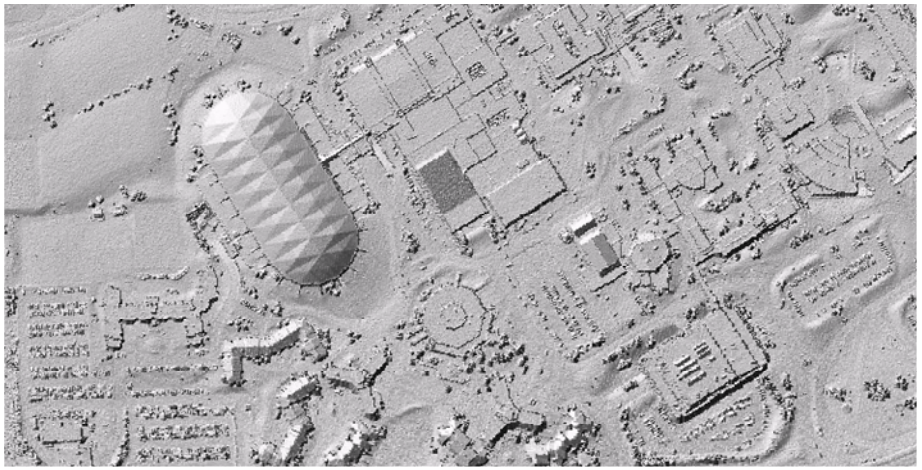
IKONOS/GeoEye

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 USA

Photogrammetric and LiDAR Data: Why?

LiDAR (Pros)	**Photogrammetry (Cons)**
Dense information from homogeneous surfaces	Almost no positional information along homogeneous surfaces
Day or night data collection	Day time data collection
Direct acquisition of 3D coordinates	Complicated and sometimes unreliable matching procedures
Vertical accuracy is better than its planimetric accuracy	Vertical accuracy is worse than the planimetric accuracy

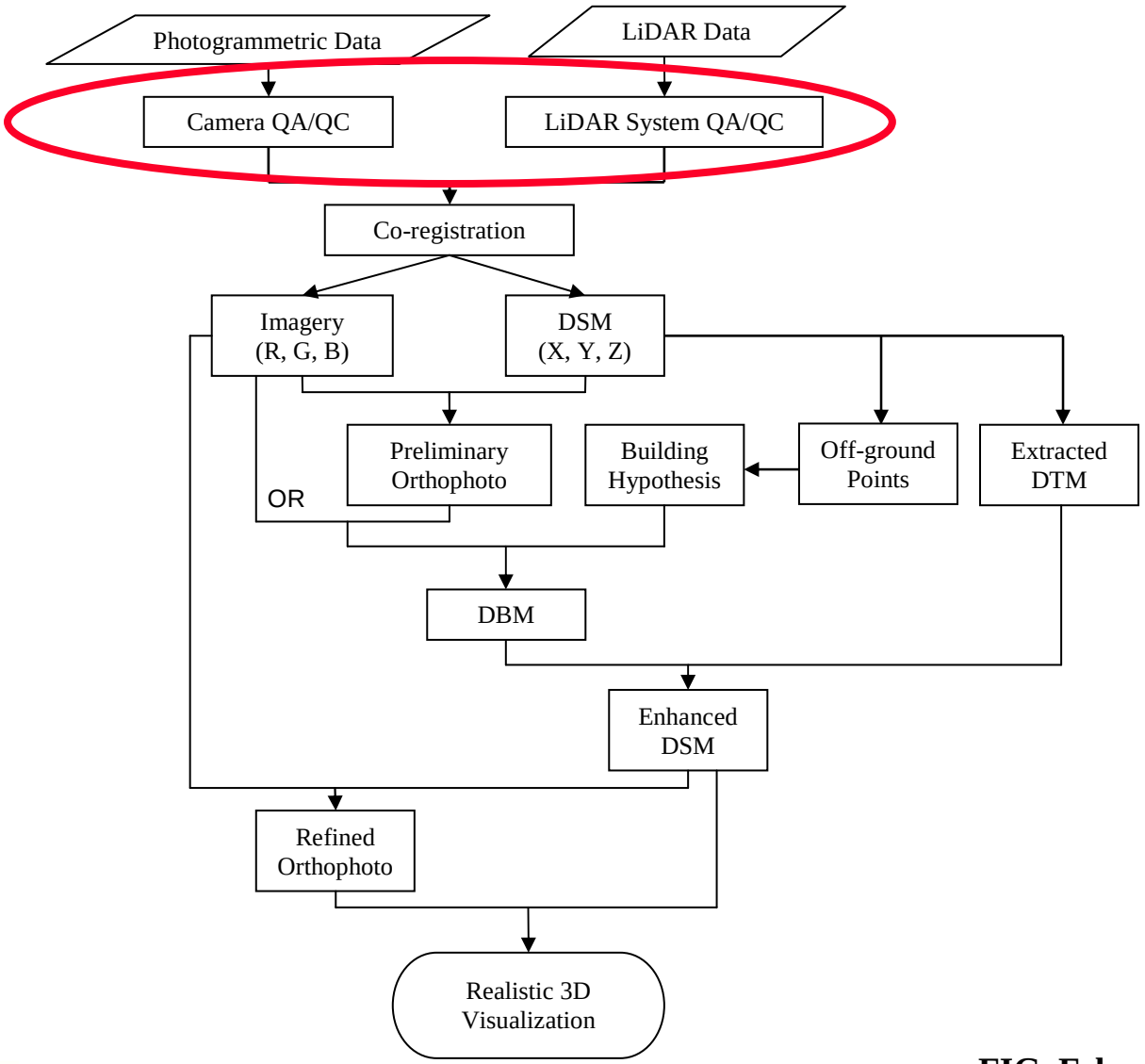
Photogrammetric and LiDAR Data: Why?

Photogrammetry (Pros)	**LiDAR (Cons)**
High redundancy	No inherent redundancy
Rich with semantic information	Positional; difficult to derive semantic information
Dense positional information along object space breaklines	Almost no information along breaklines
Planimetric accuracy is better than the vertical accuracy	Planimetric accuracy is worse than the vertical accuracy
Transparent Model	***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

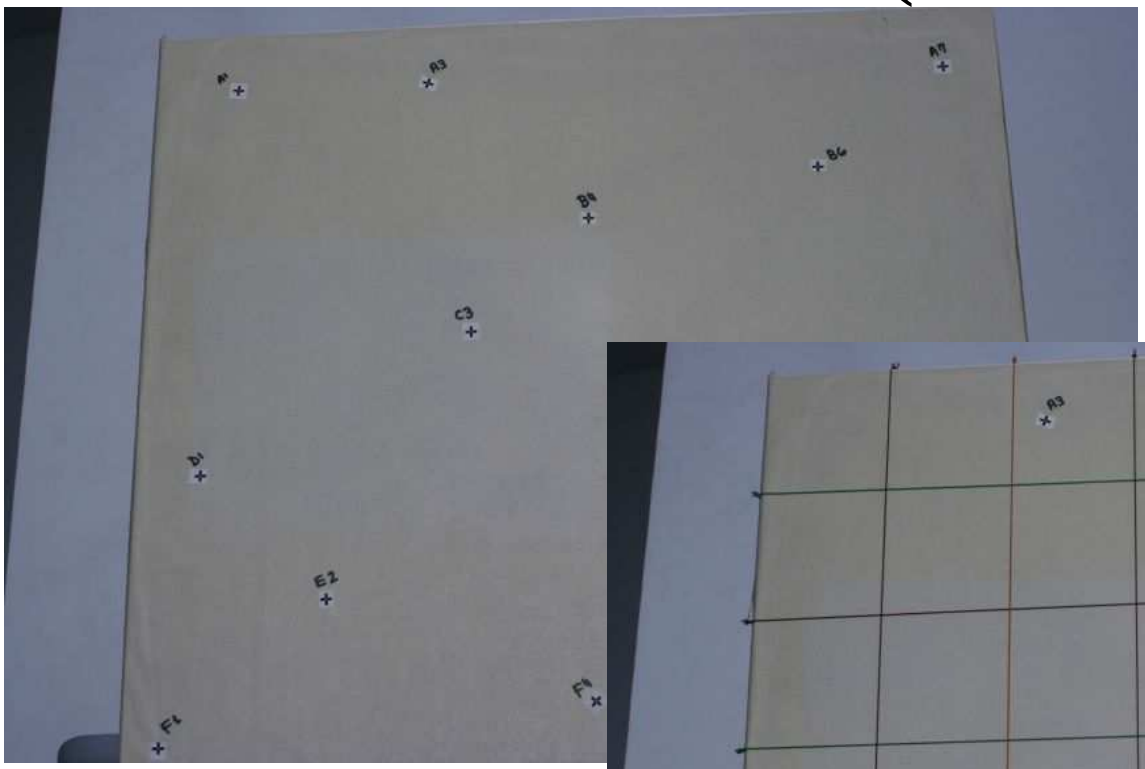
Kodak 14n

Canon EOS 1D

SONY 717

Camera calibration and stability analysis should be carefully addressed.

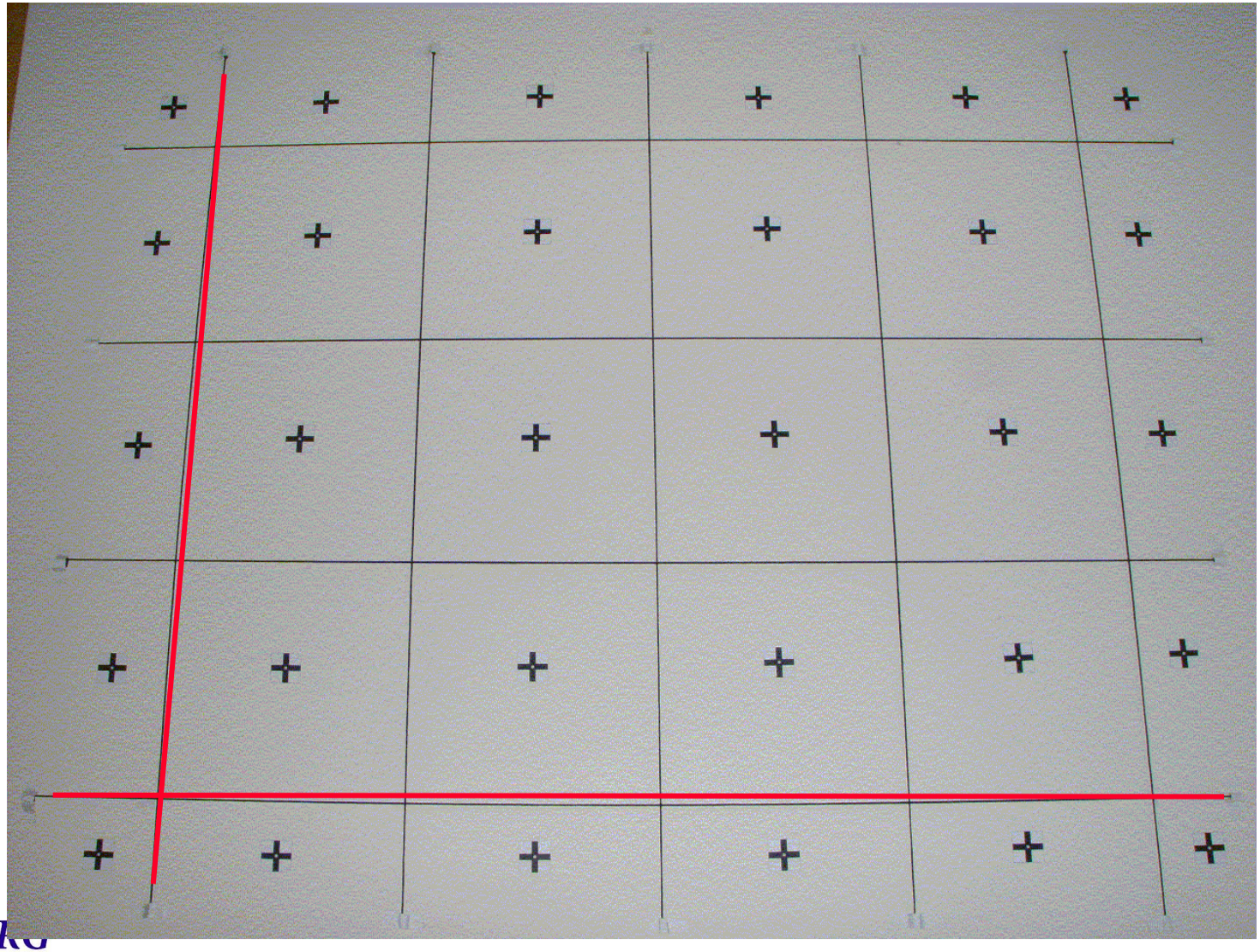
Camera Calibration (New Methodology)



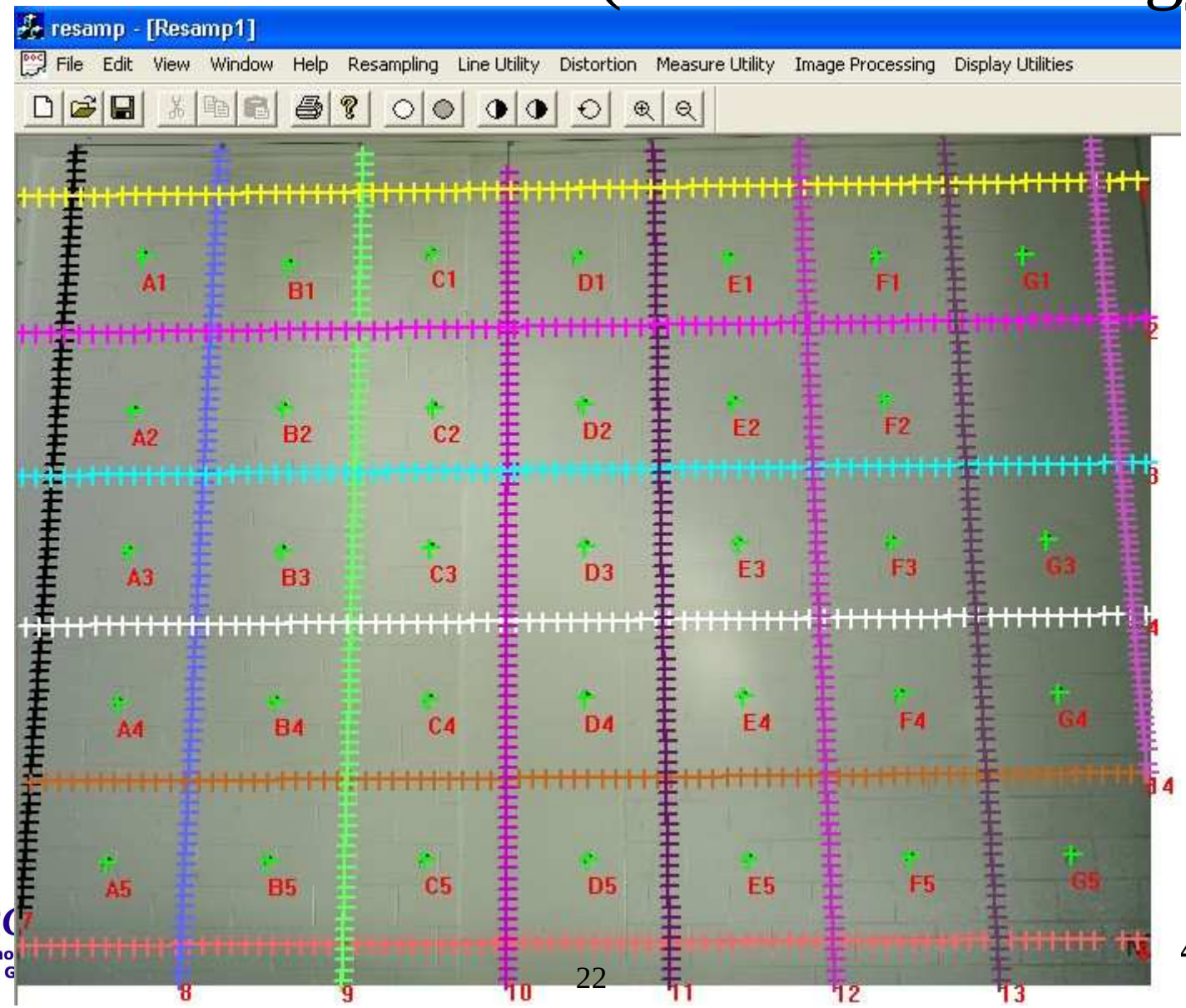
Traditional calibration test field

Proposed test field by the DPRG

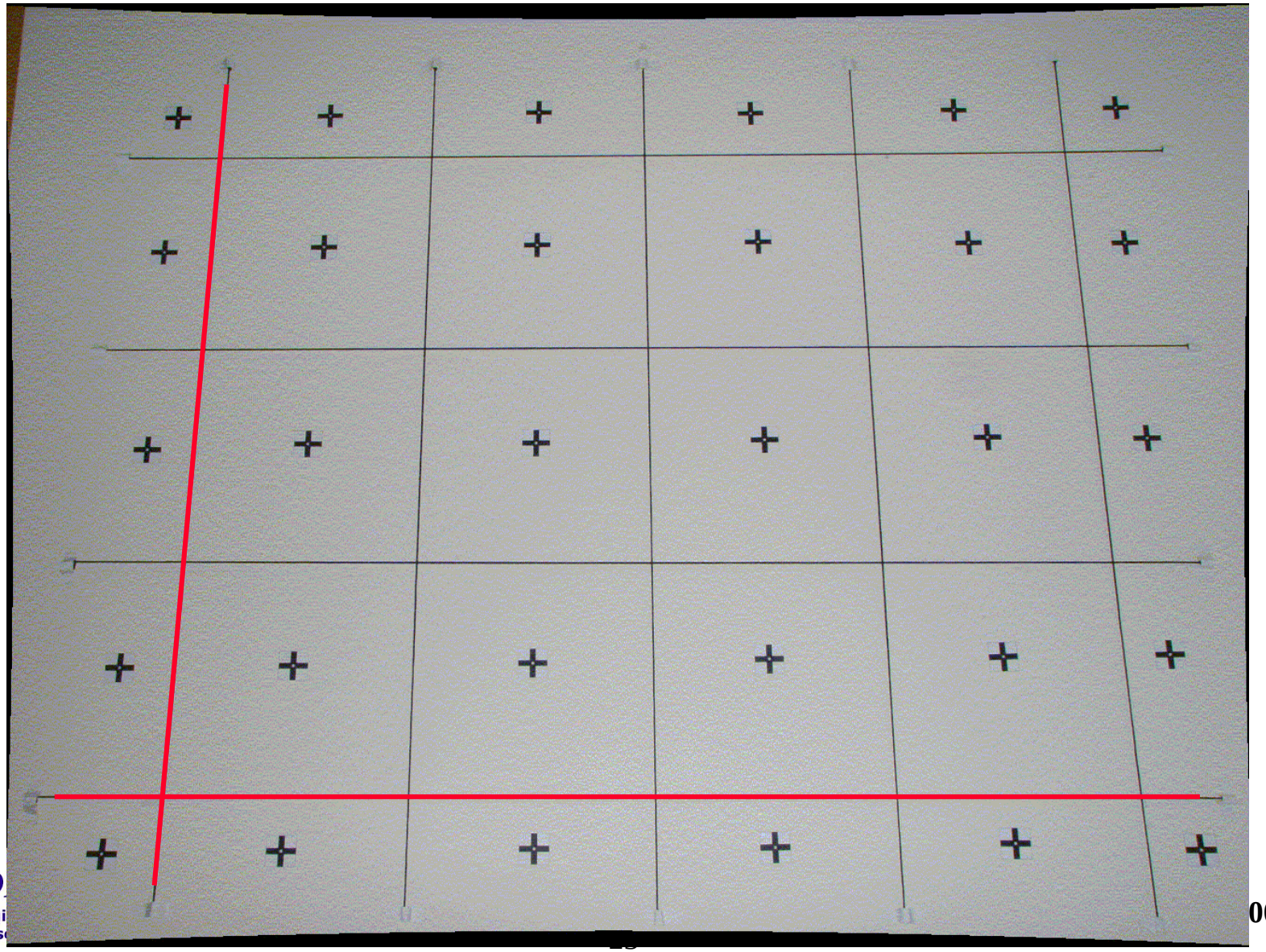
Camera Calibration (New Methodology)



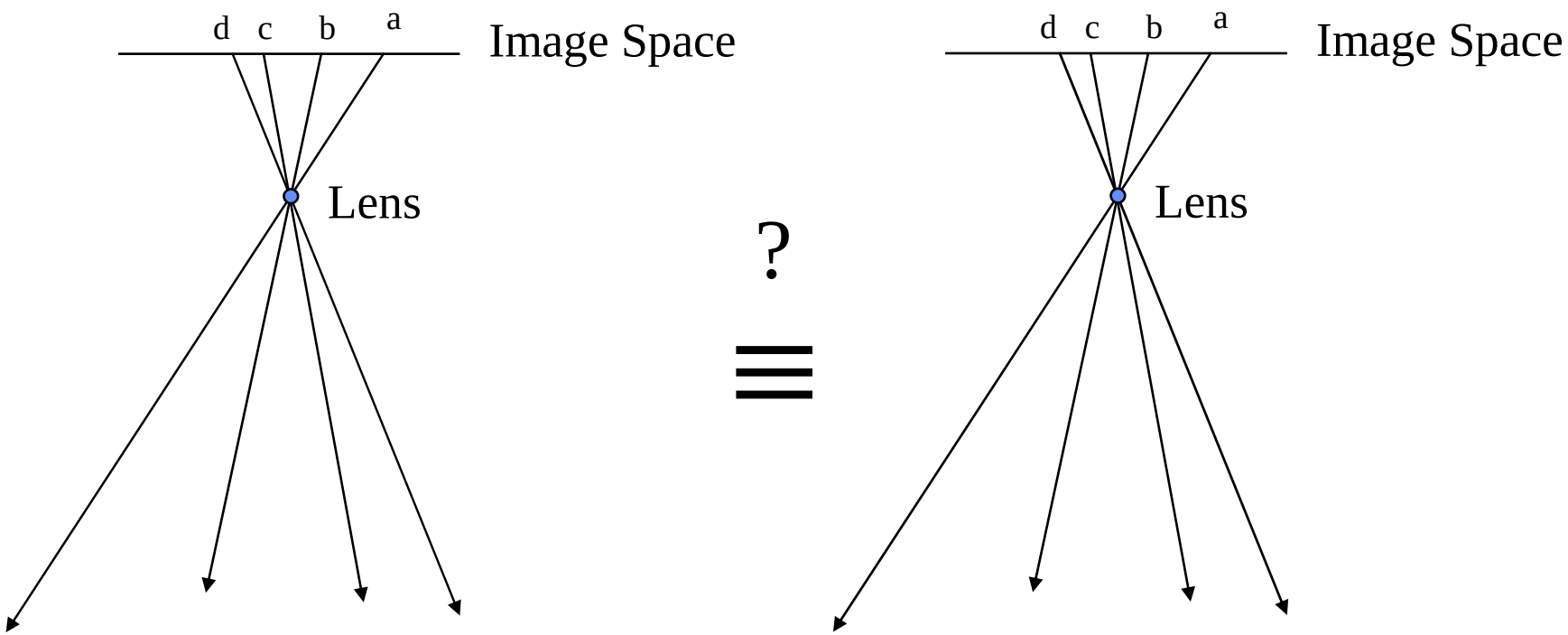
Camera Calibration (New Methodology)



QC: Camera Calibration



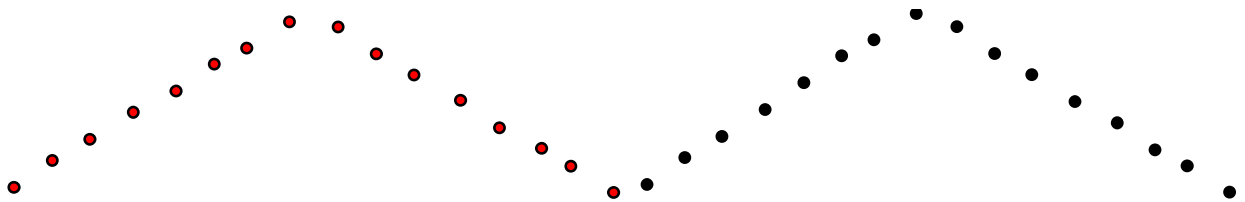
Stability Analysis (New Methodology)

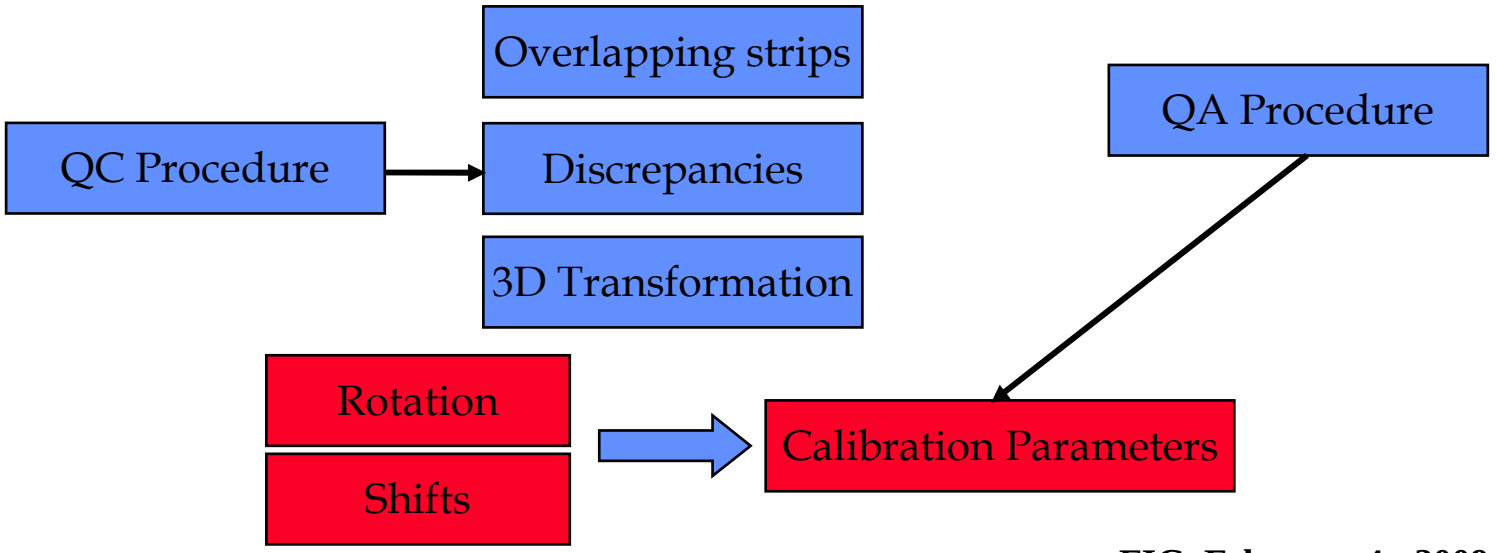


Reconstructed bundle using IOP_I Reconstructed bundle using IOP_{II}

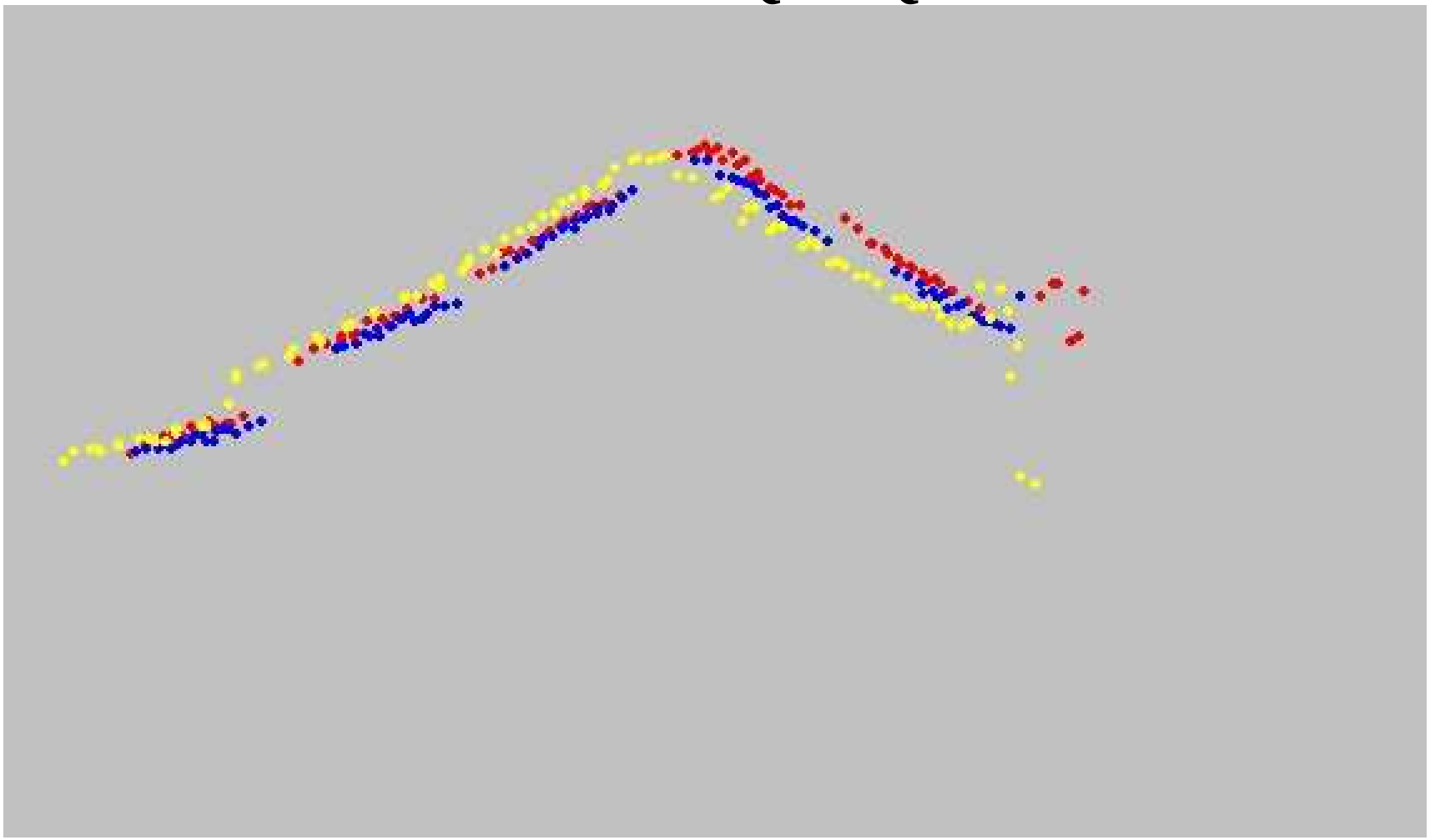
LiDAR QA/QC

- **LiDAR Data in Overlapping Strips**
  - ✓ **Point cloud coordinates**
  - ✓ **Raw measurements are not necessary available**



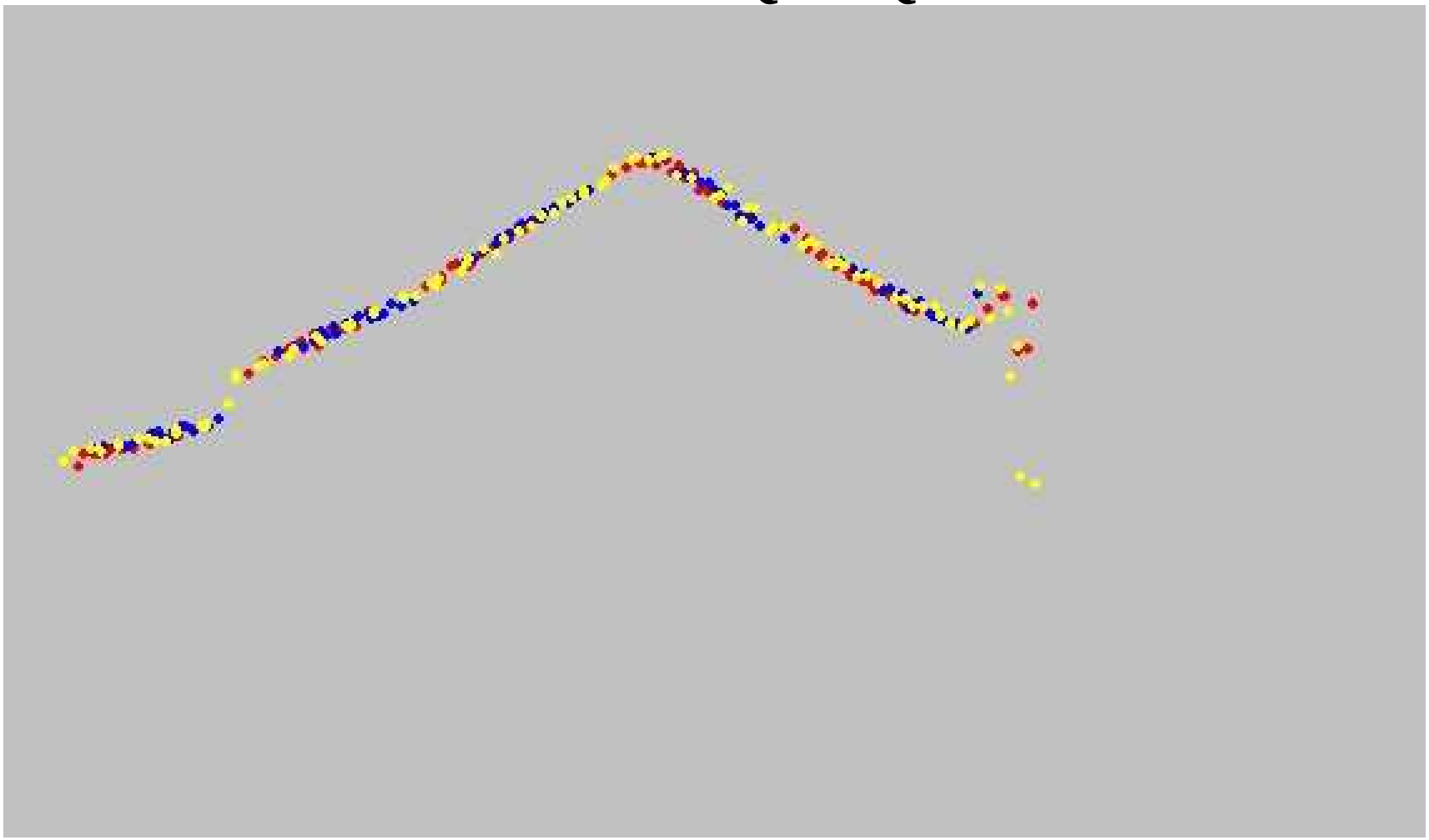


LiDAR QA/QC



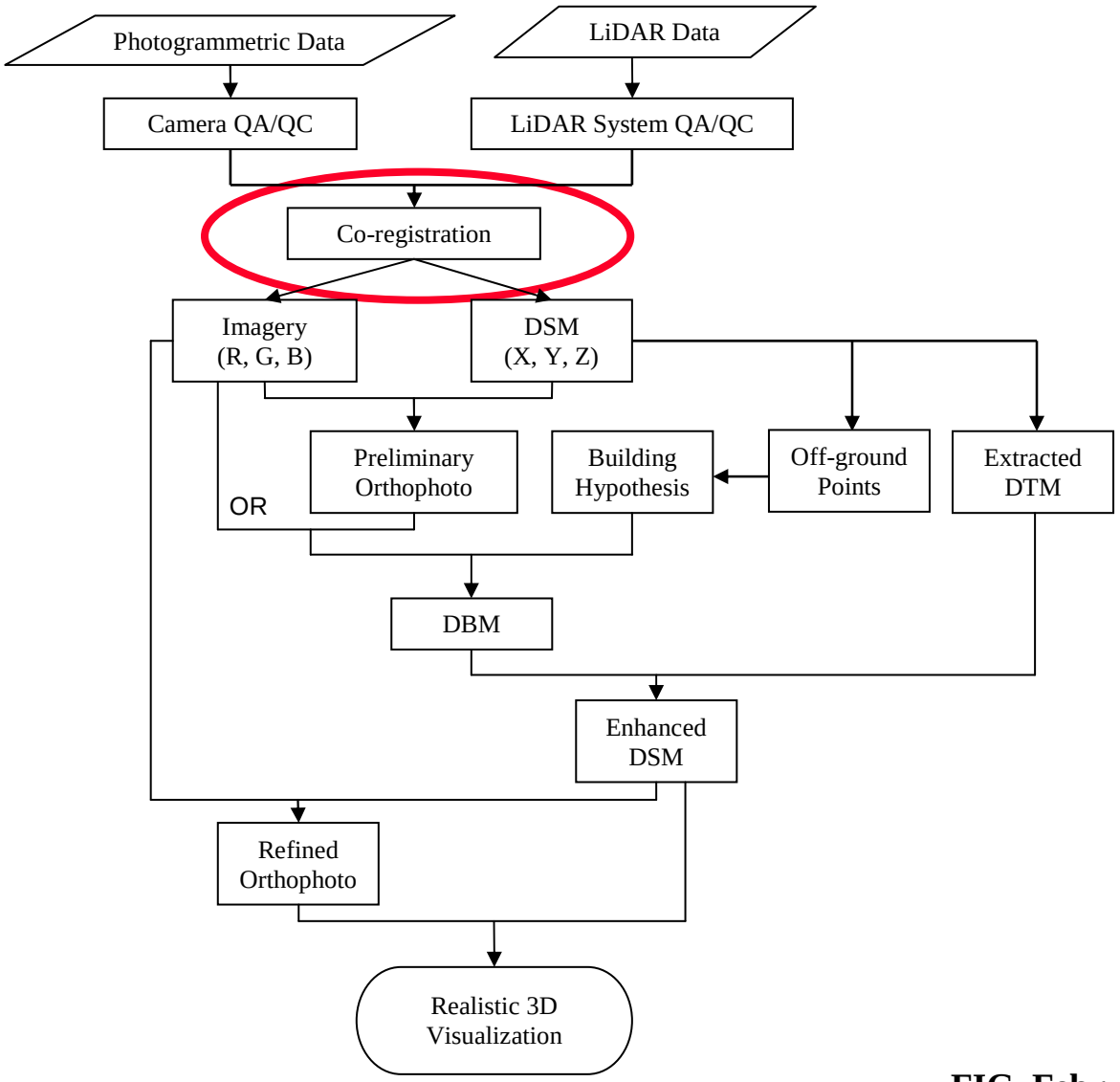
Check for the presence of biases

LiDAR QA/QC



Check the noise level in the point cloud after bias removal

Proposed Workflow

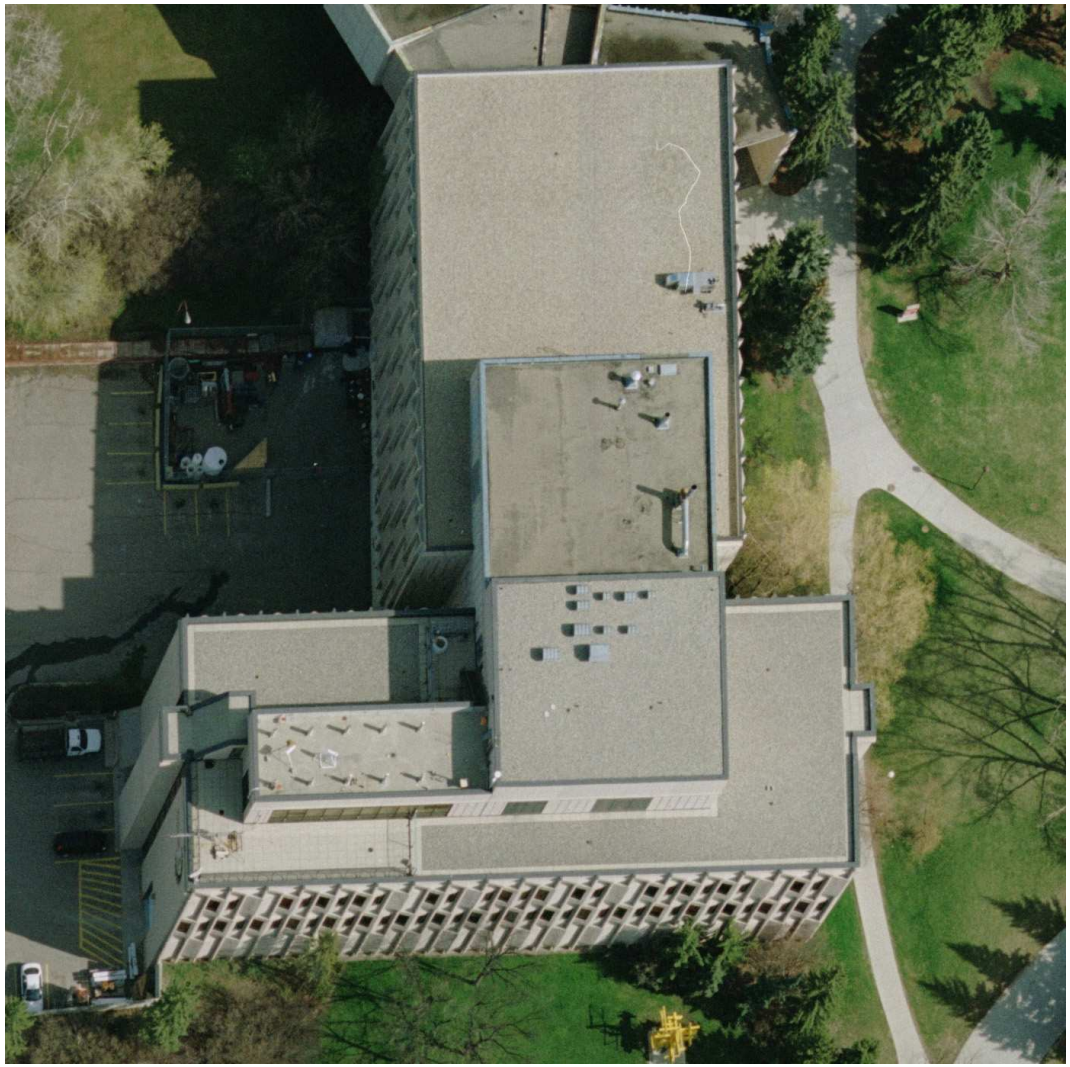


Data Registration

- 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.

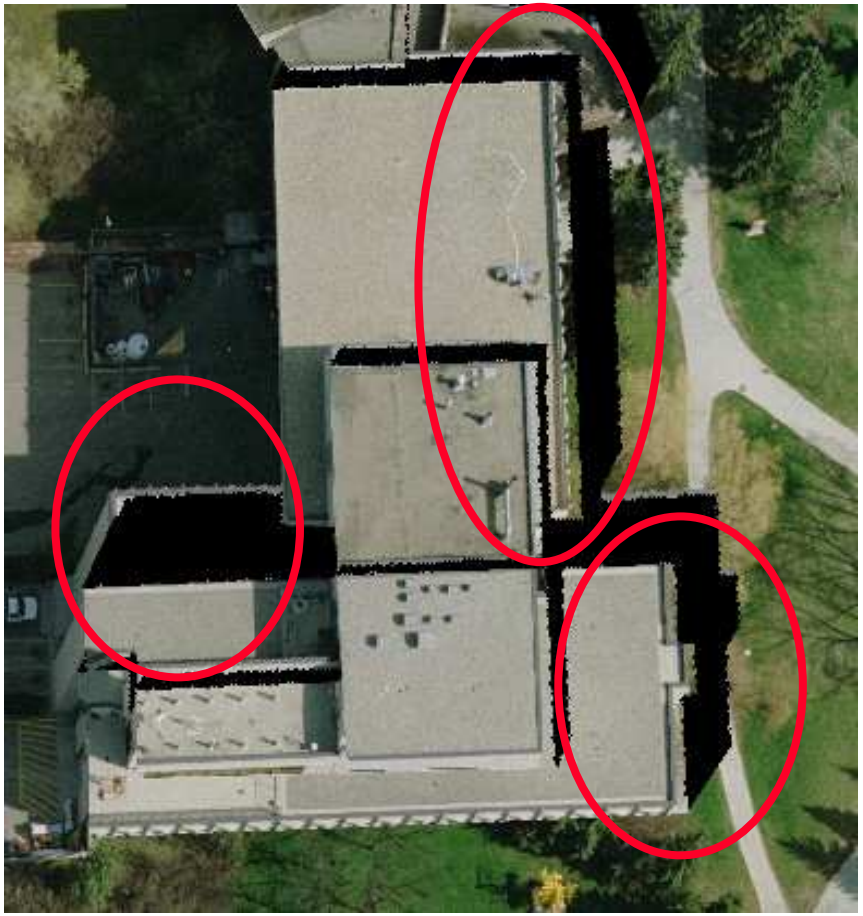
Data Registration

Input perspective imagery



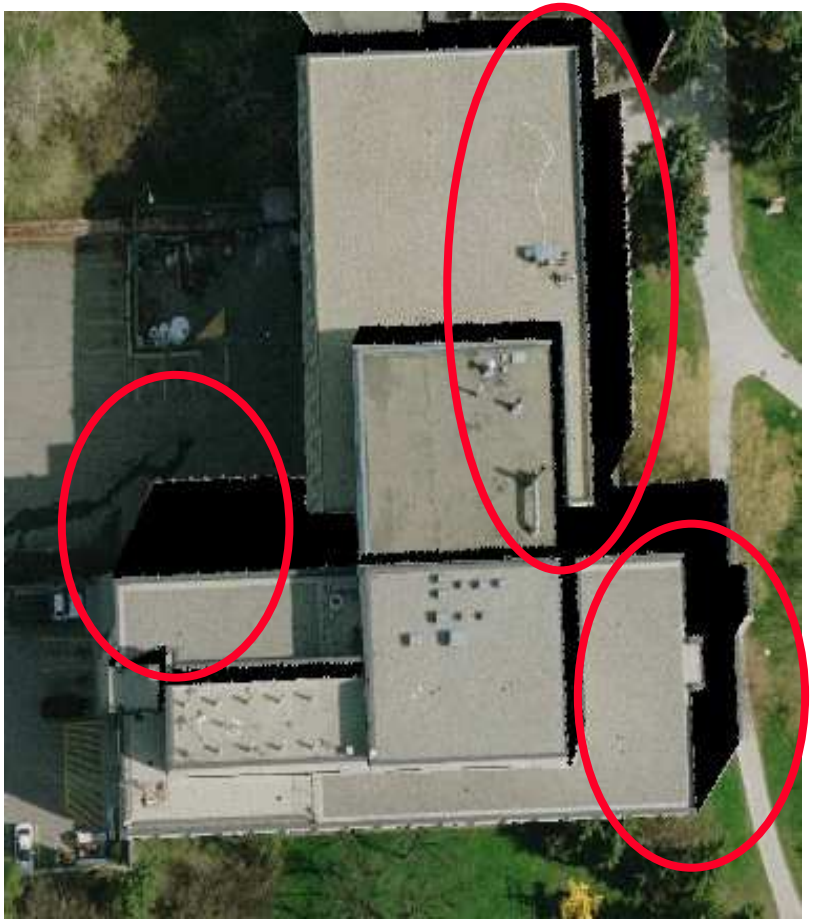
Data Registration

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



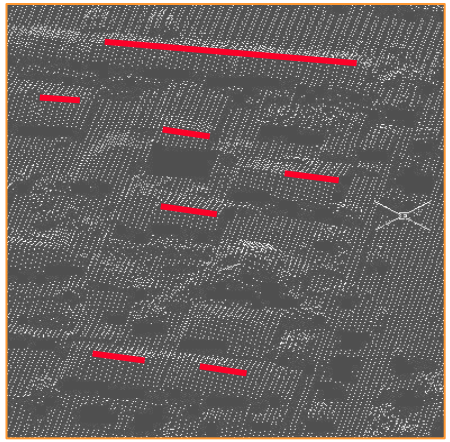
Data Registration

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



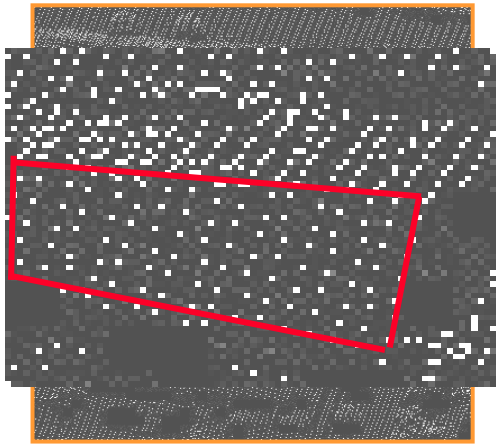
Data Registration

Potential Primitives



LiDAR cloud

Image patch



LiDAR cloud

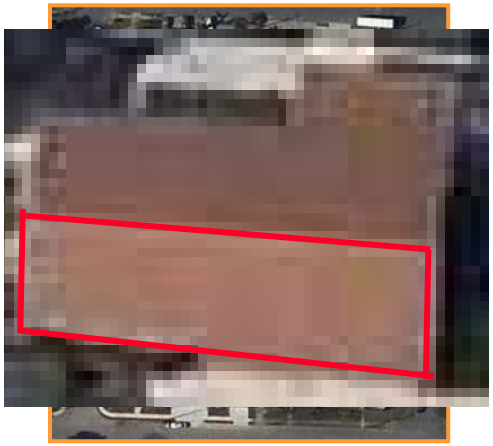
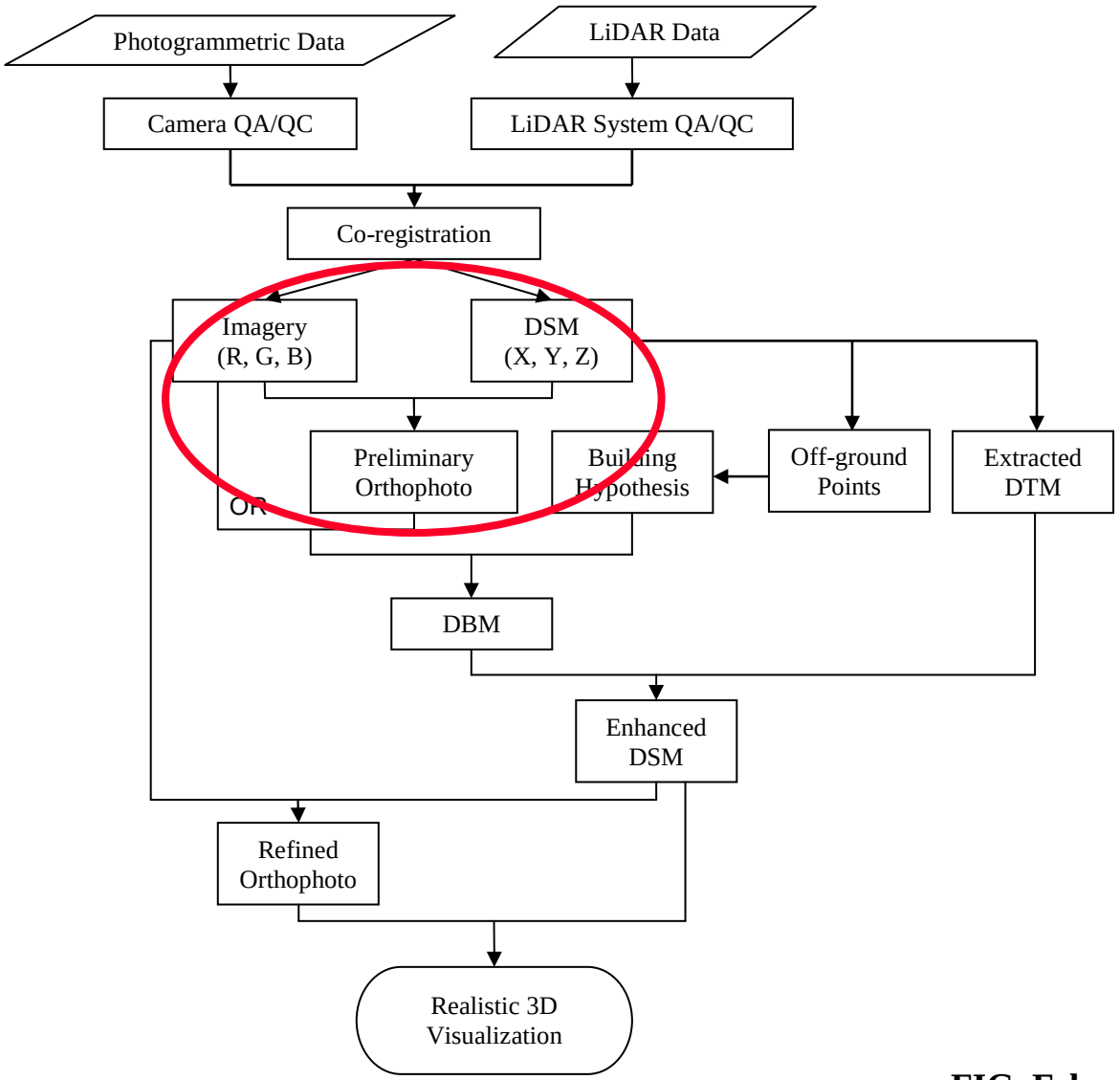


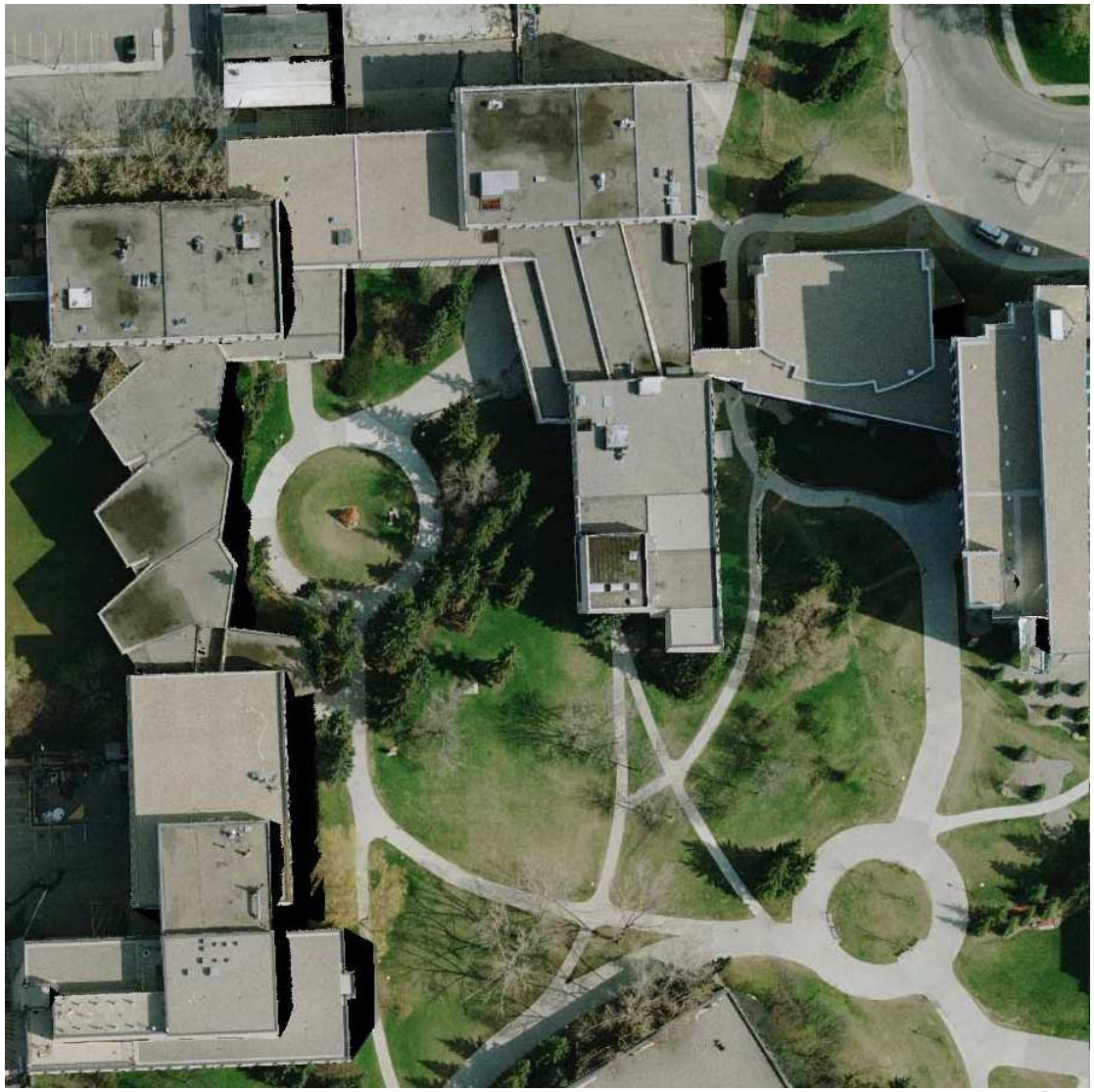
Image patch

Proposed Workflow

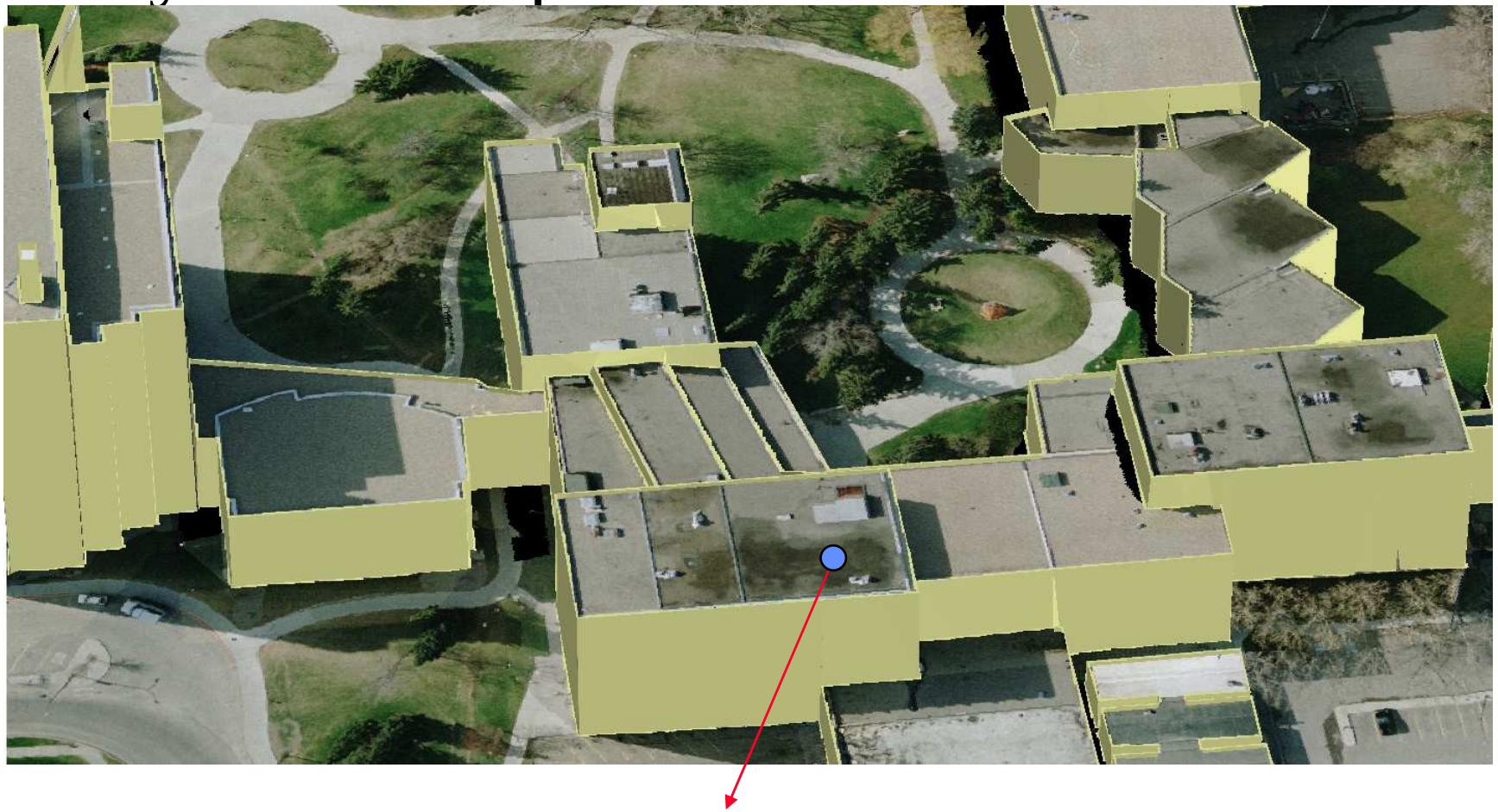


Perspective Image

Orthophoto



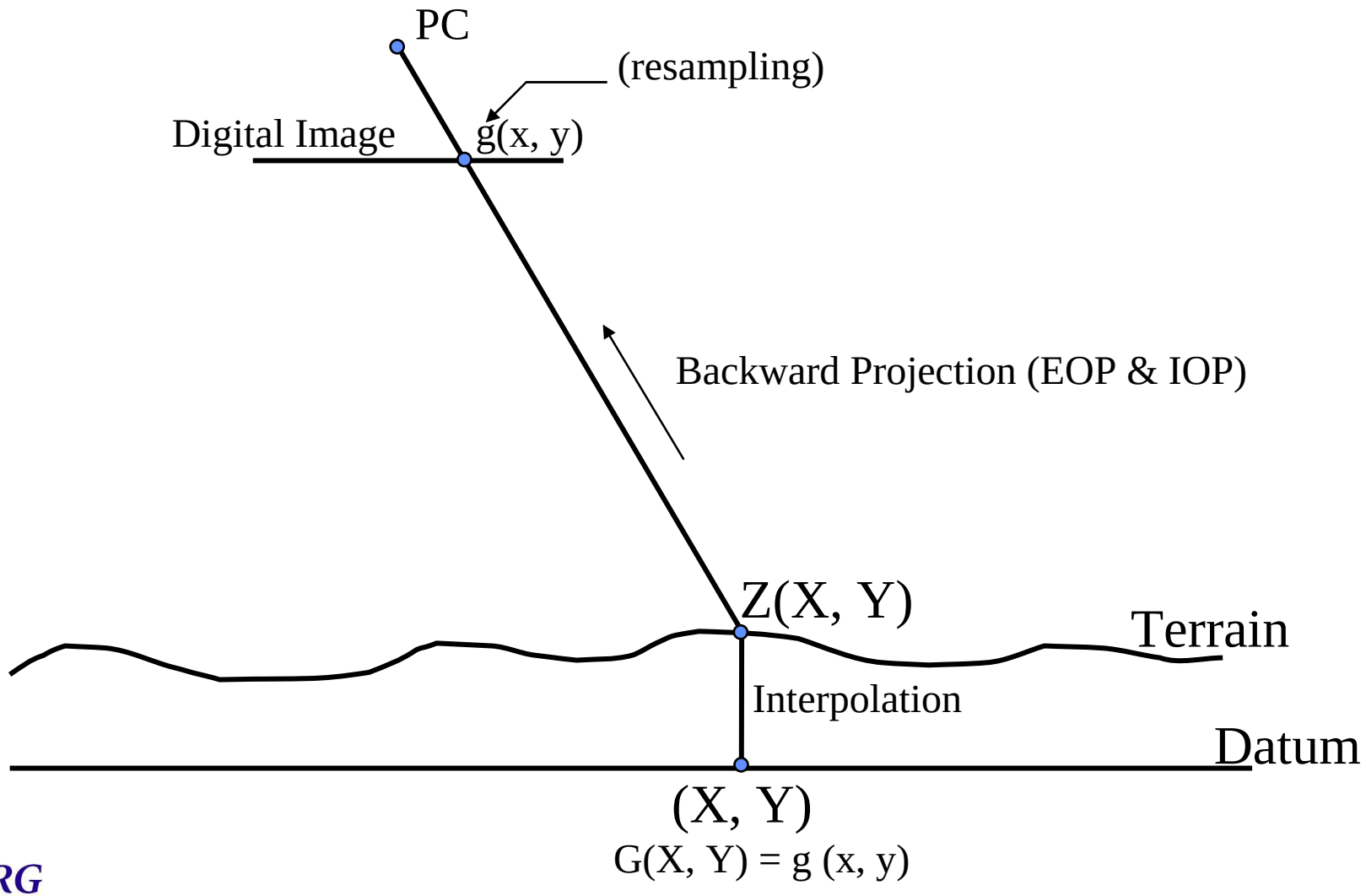
Beyond Orthophotos: 3D Realistic Views



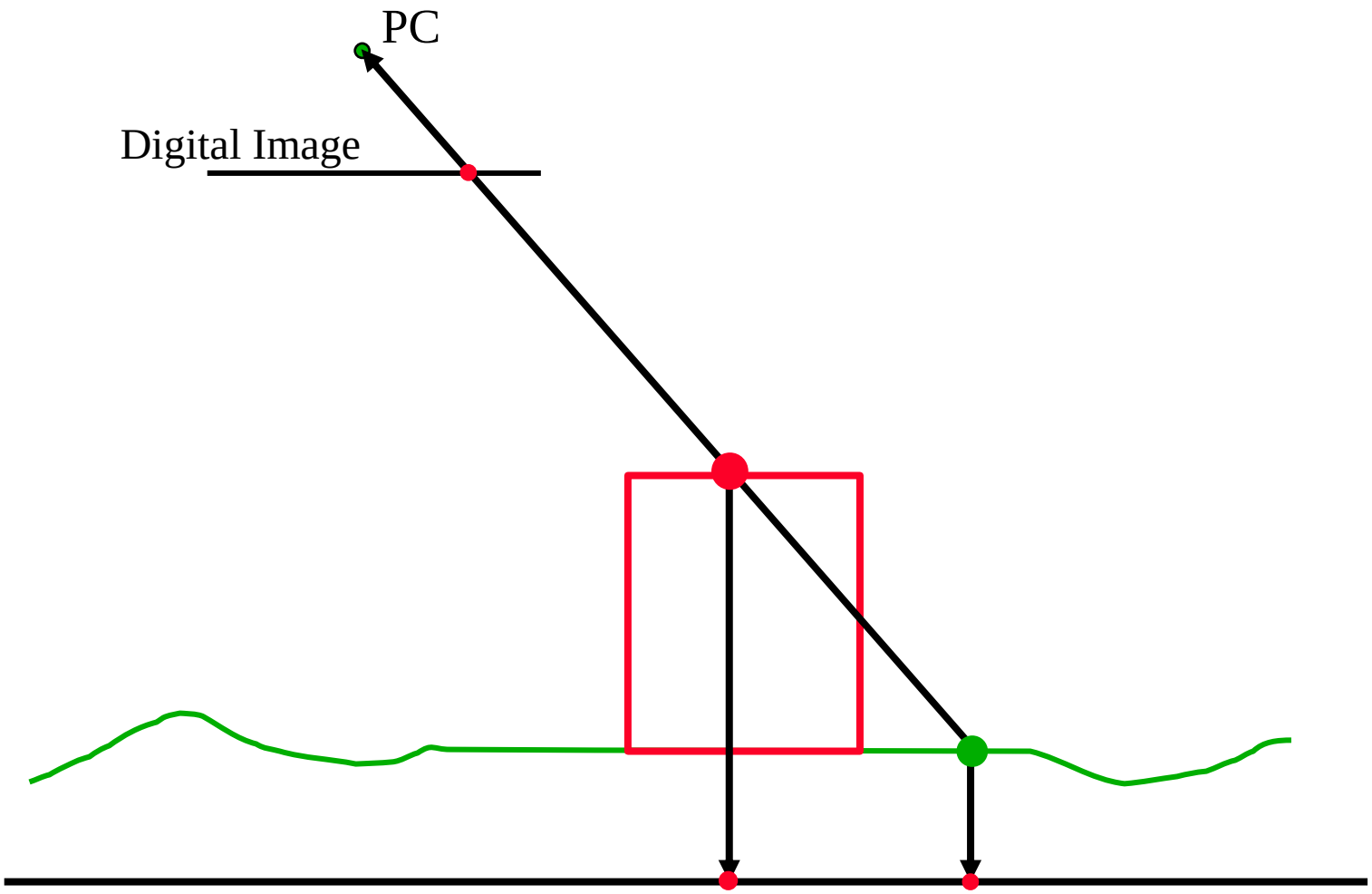
(X, Y, Z): 1122.23 m, 3251.53 m, 72.03 m

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

Differential Orthophoto Generation



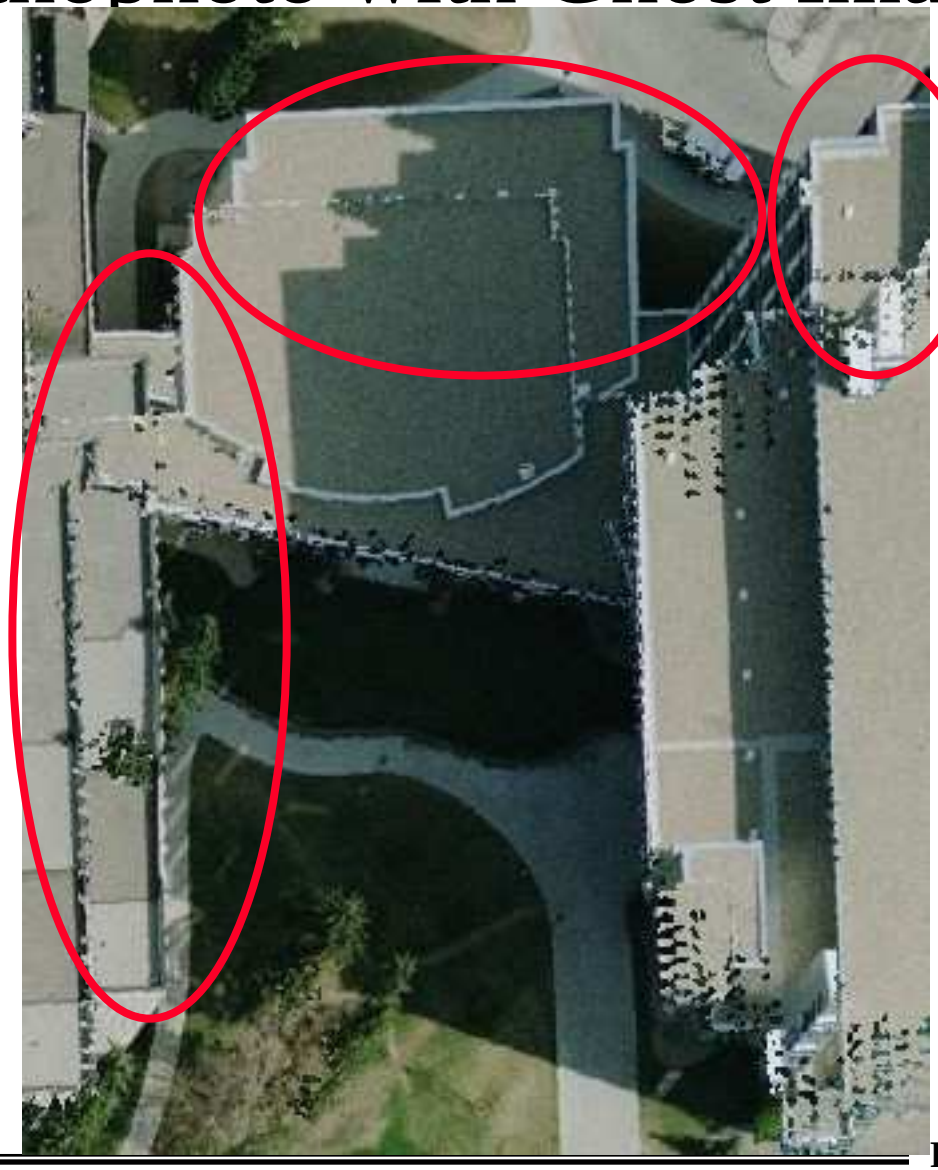
Differential Orthophoto Generation



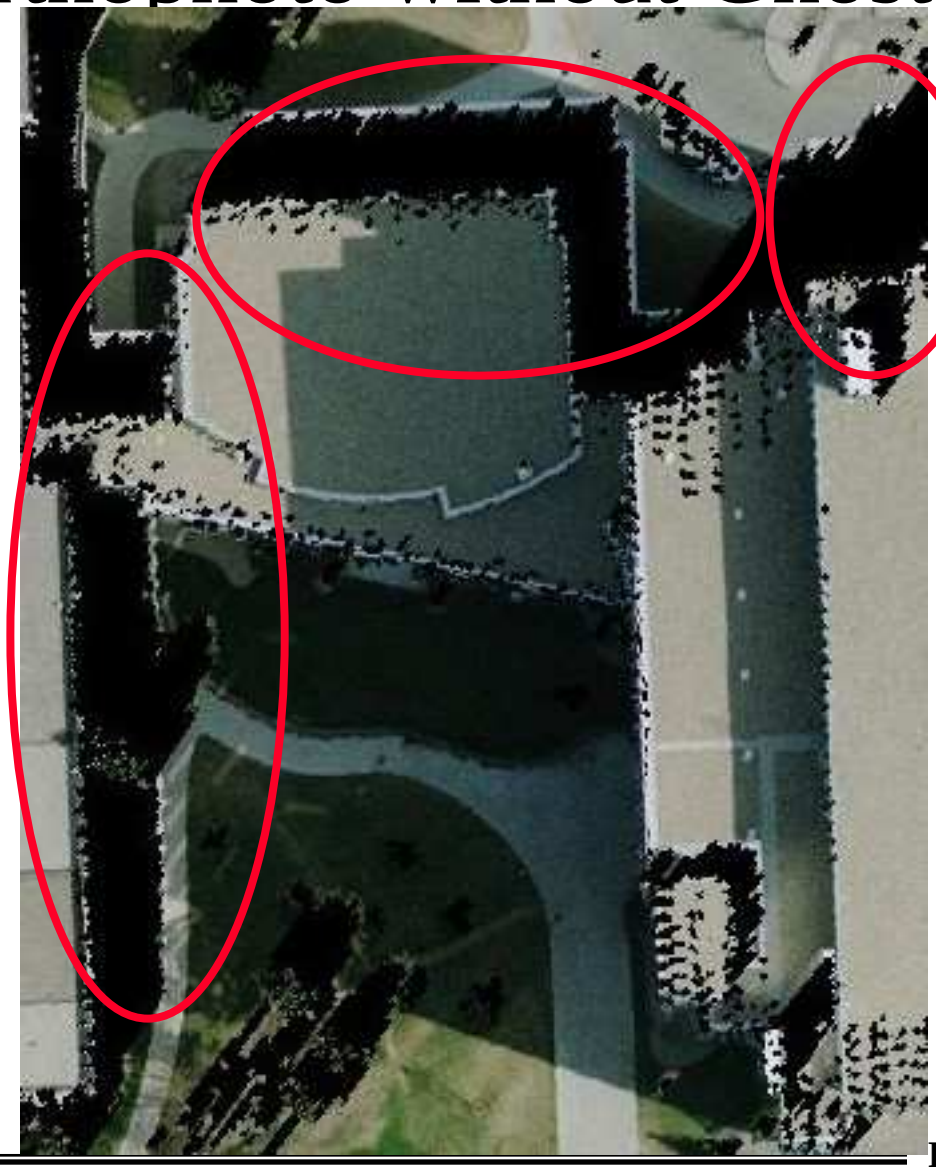
Double Mapping Problem (Ghost Images)

Perspective Image

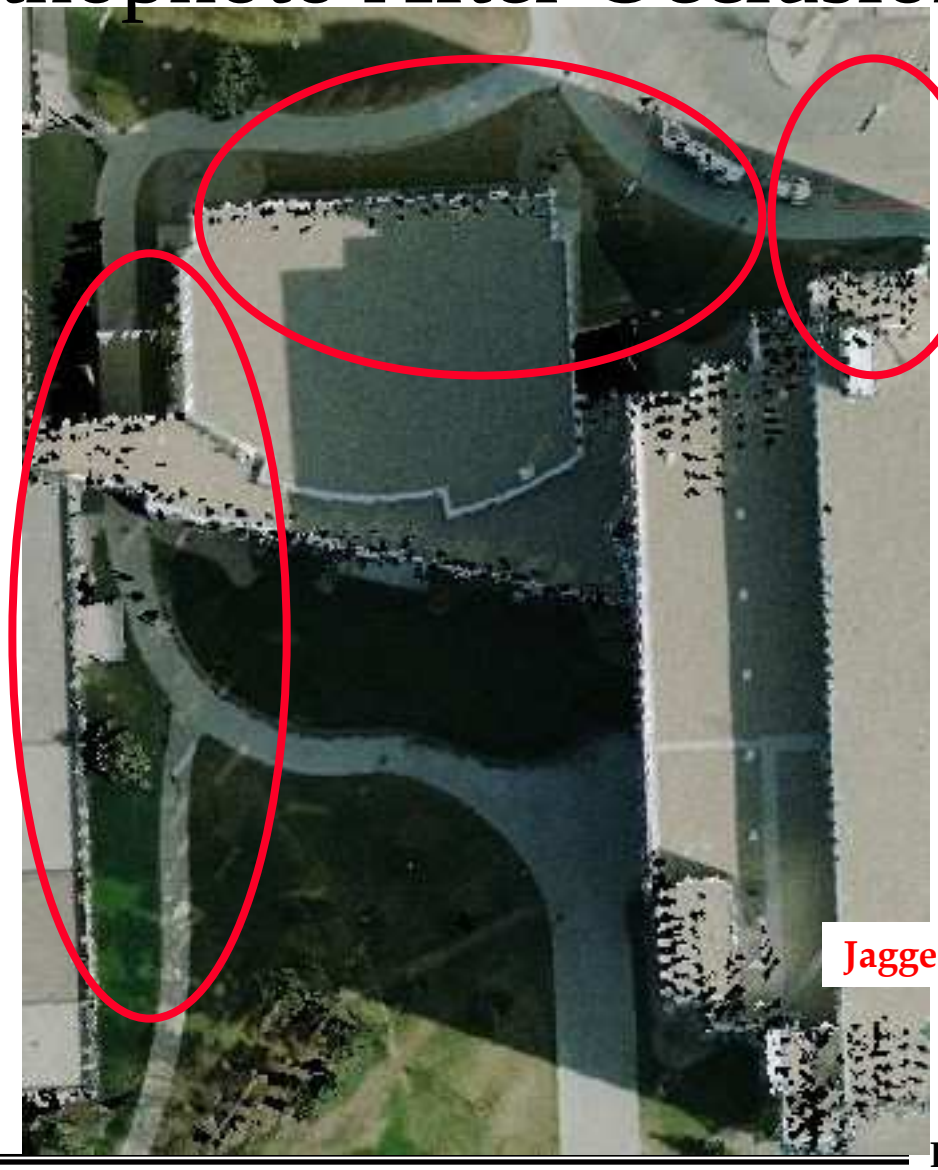
Orthophoto with Ghost Images



True Orthophoto without Ghost Images



True Orthophoto After Occlusion Filling

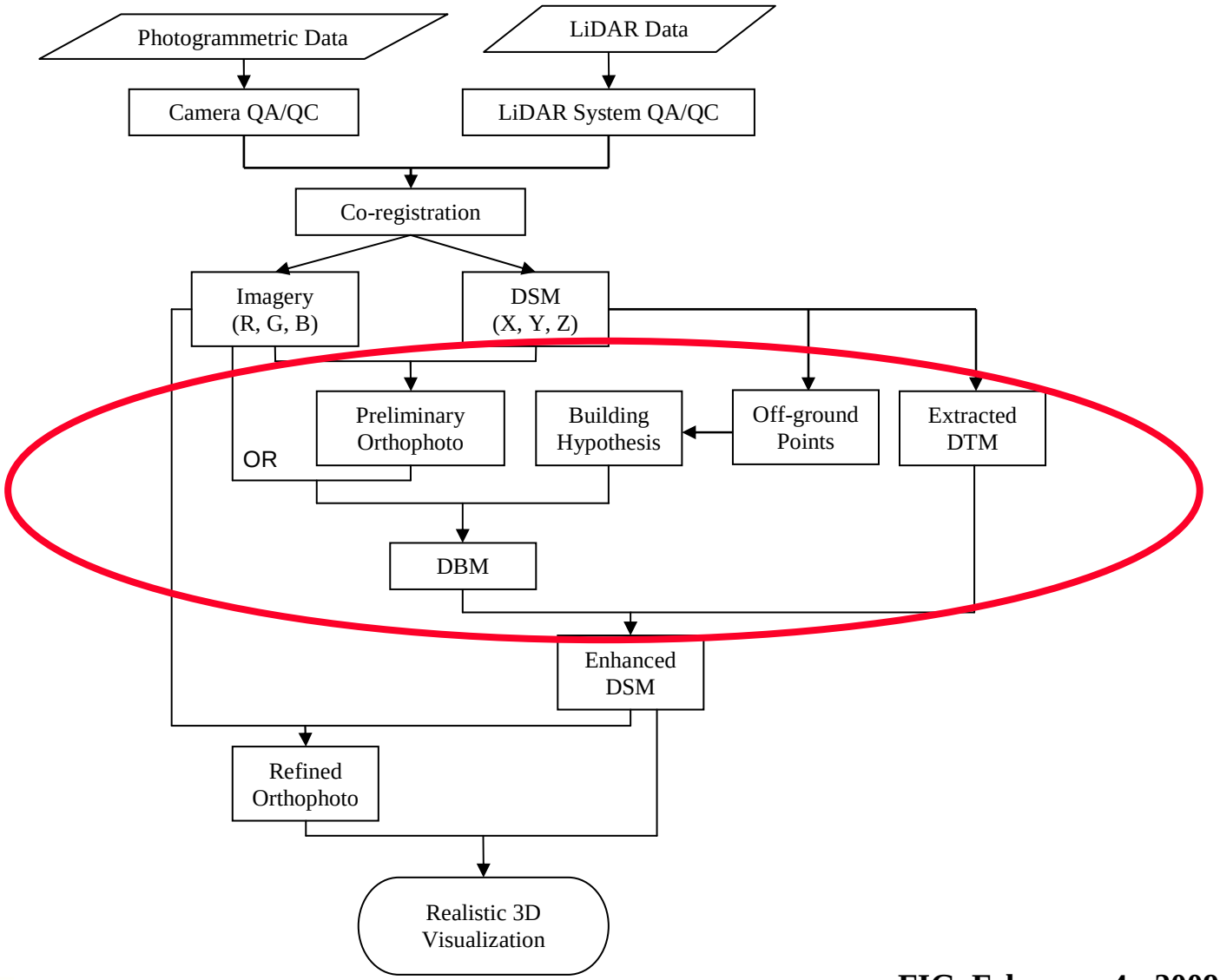


Jagged Building Boundaries

True Orthophoto After Boundary Enhancement

Utilized Surface: DSM + DBM

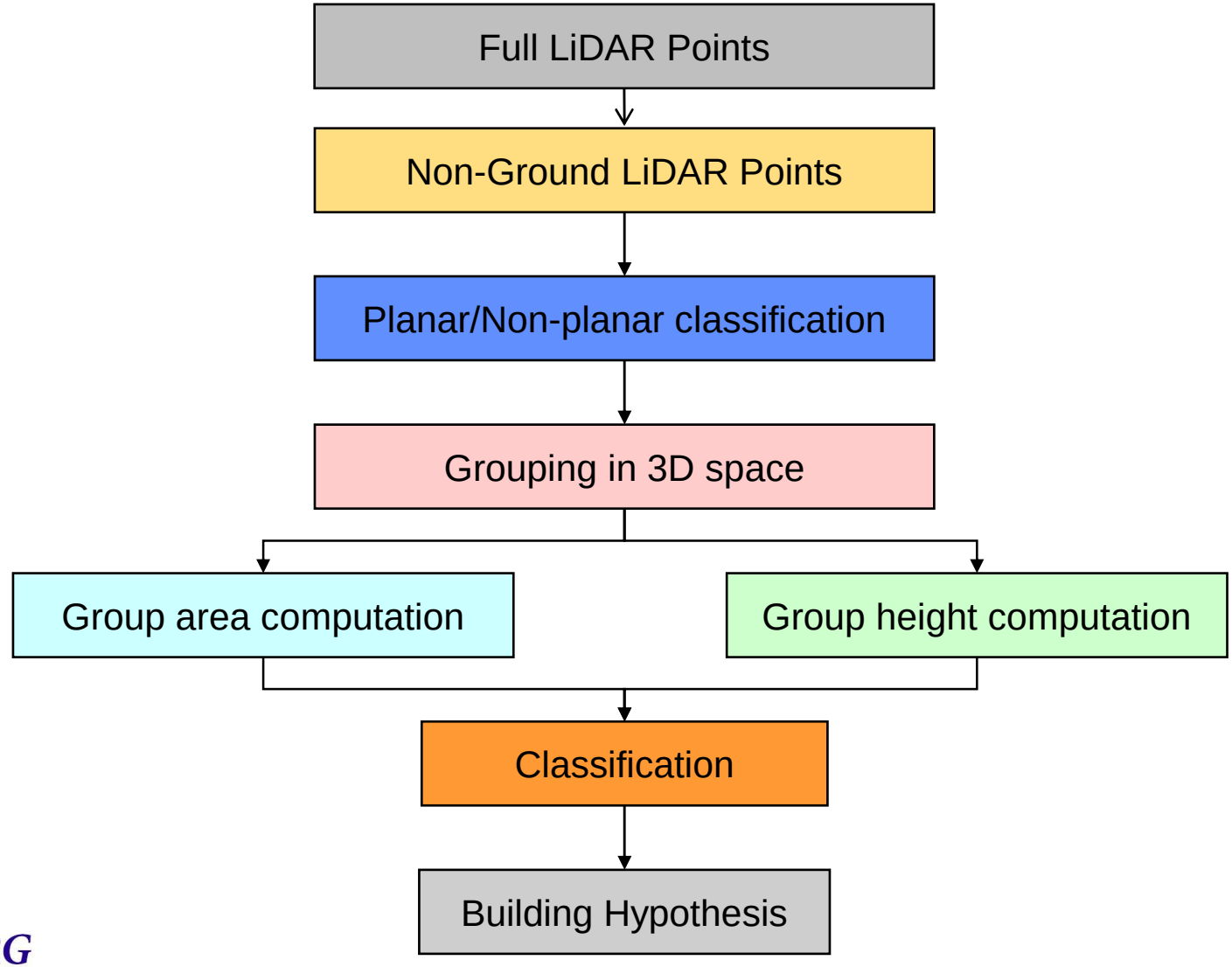
Proposed Workflow



DBM Generation

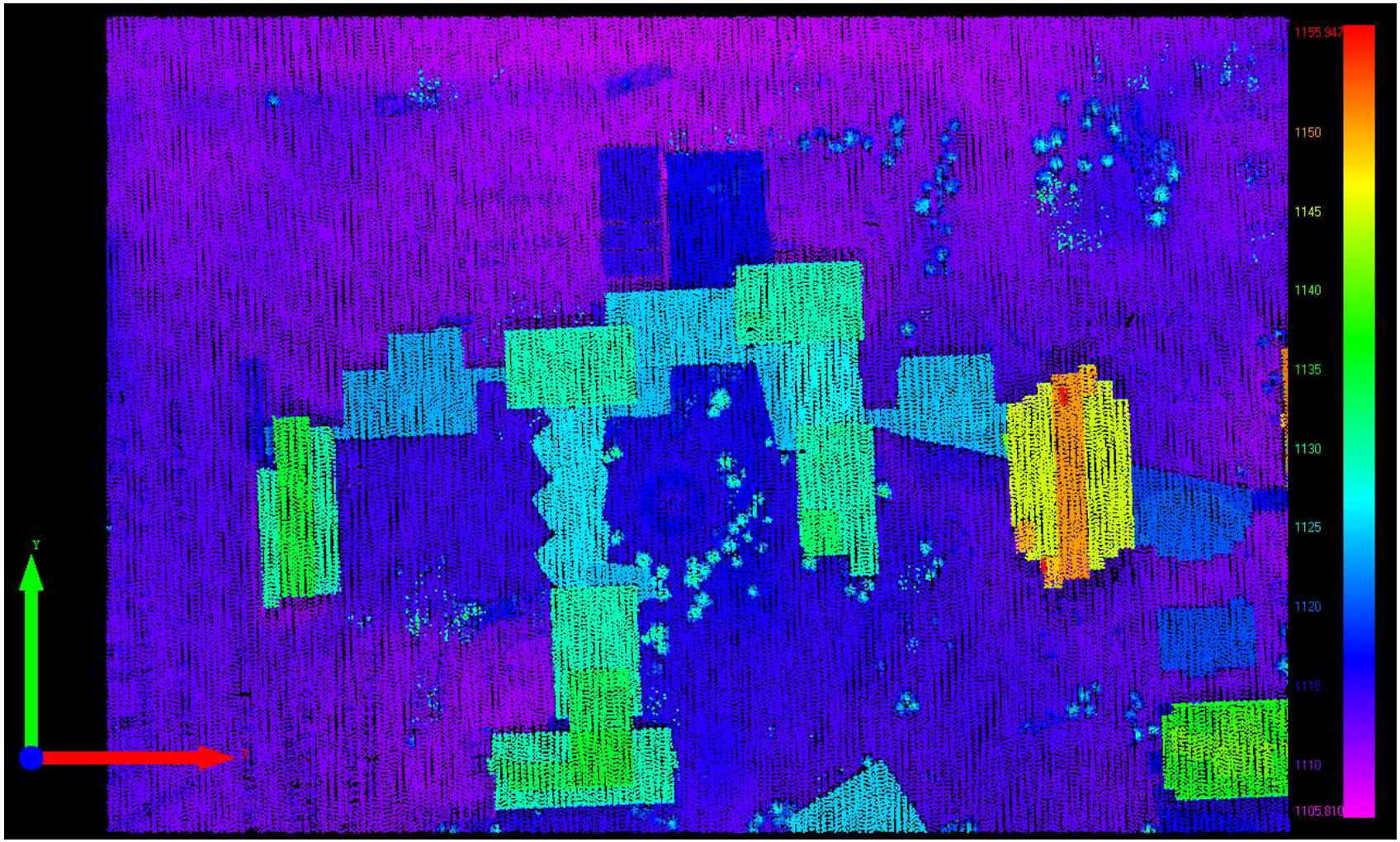
- DBM generation consists of two processes:
  - **Building Detection:** The process of generating building hypotheses by differentiating buildings from other objects within the data
  - **Building Reconstruction:** The process of utilizing the detected building regions in the data to derive the necessary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

Building Hypothesis Generation

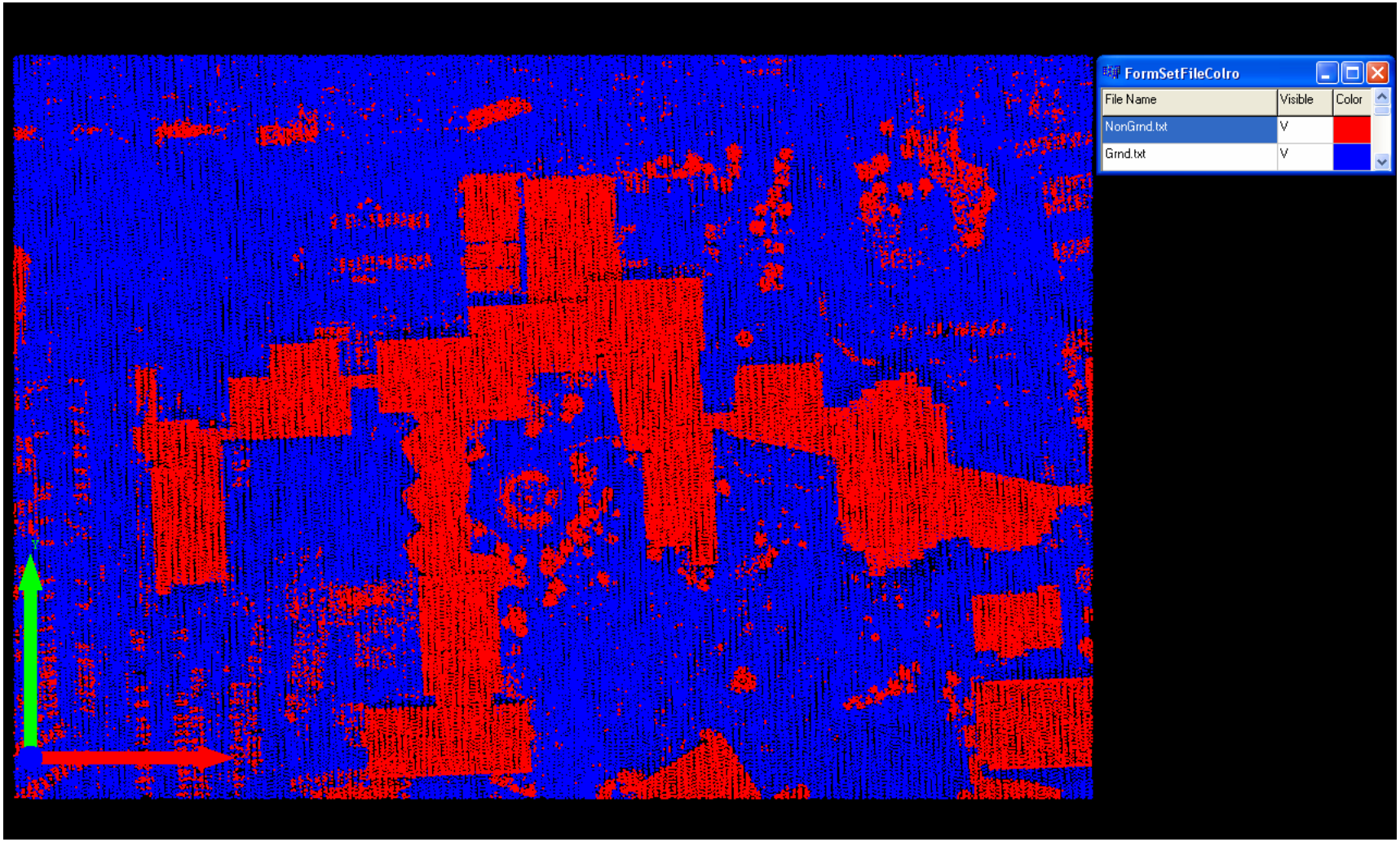


Aerial Photo over UofC

Original LiDAR Points over UofC

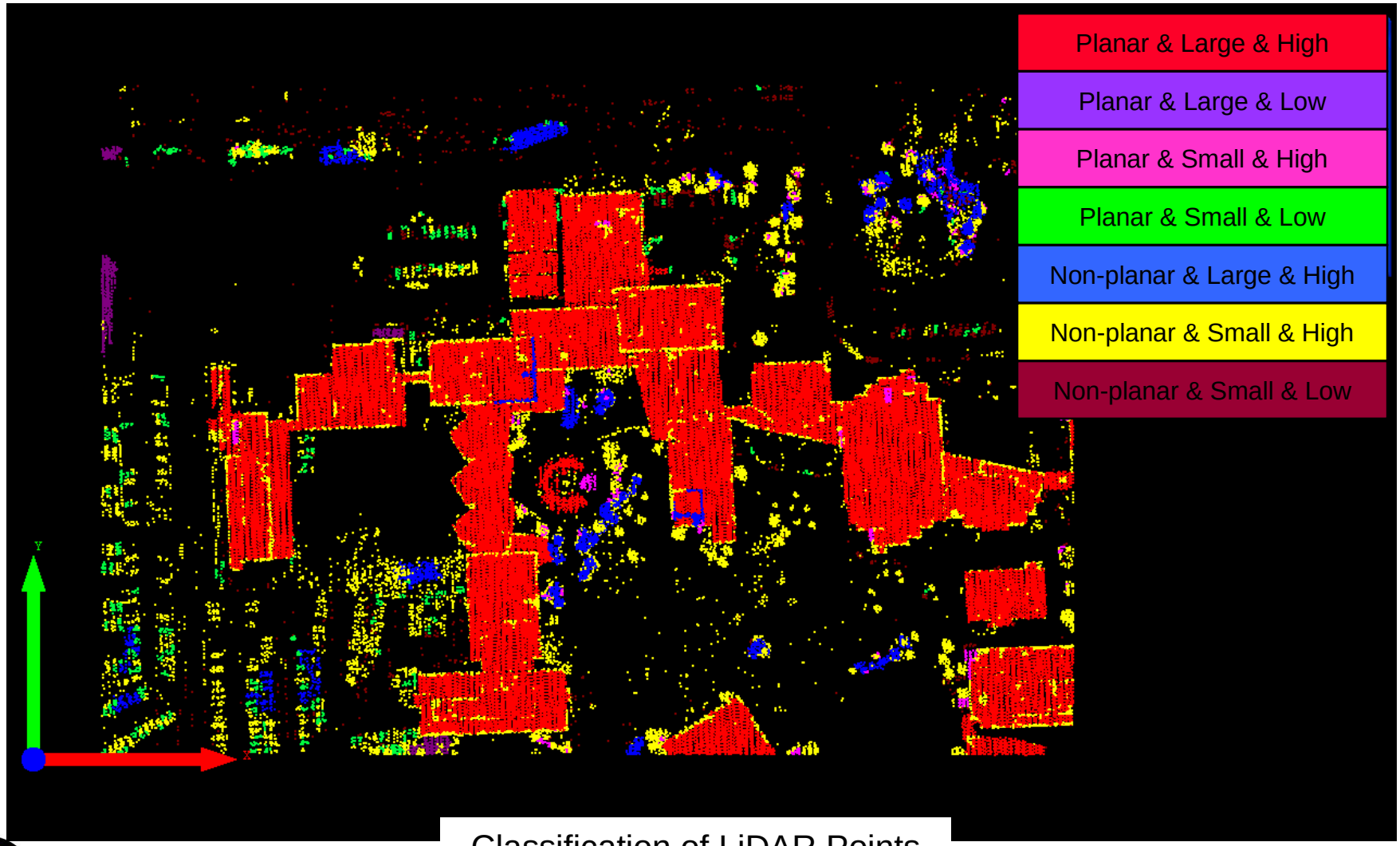


Ground/Non-Ground Classification



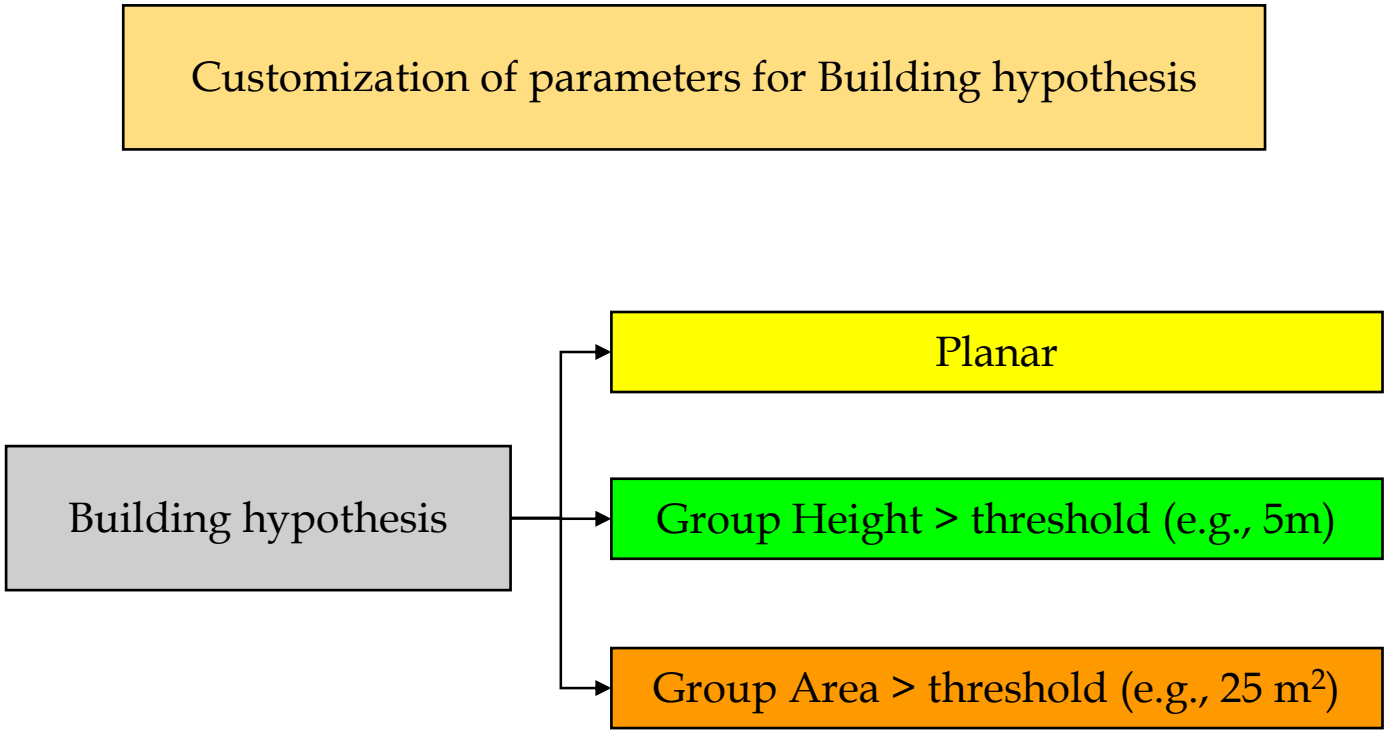
Ground/Non-Ground Points

Classifying Generated Groups

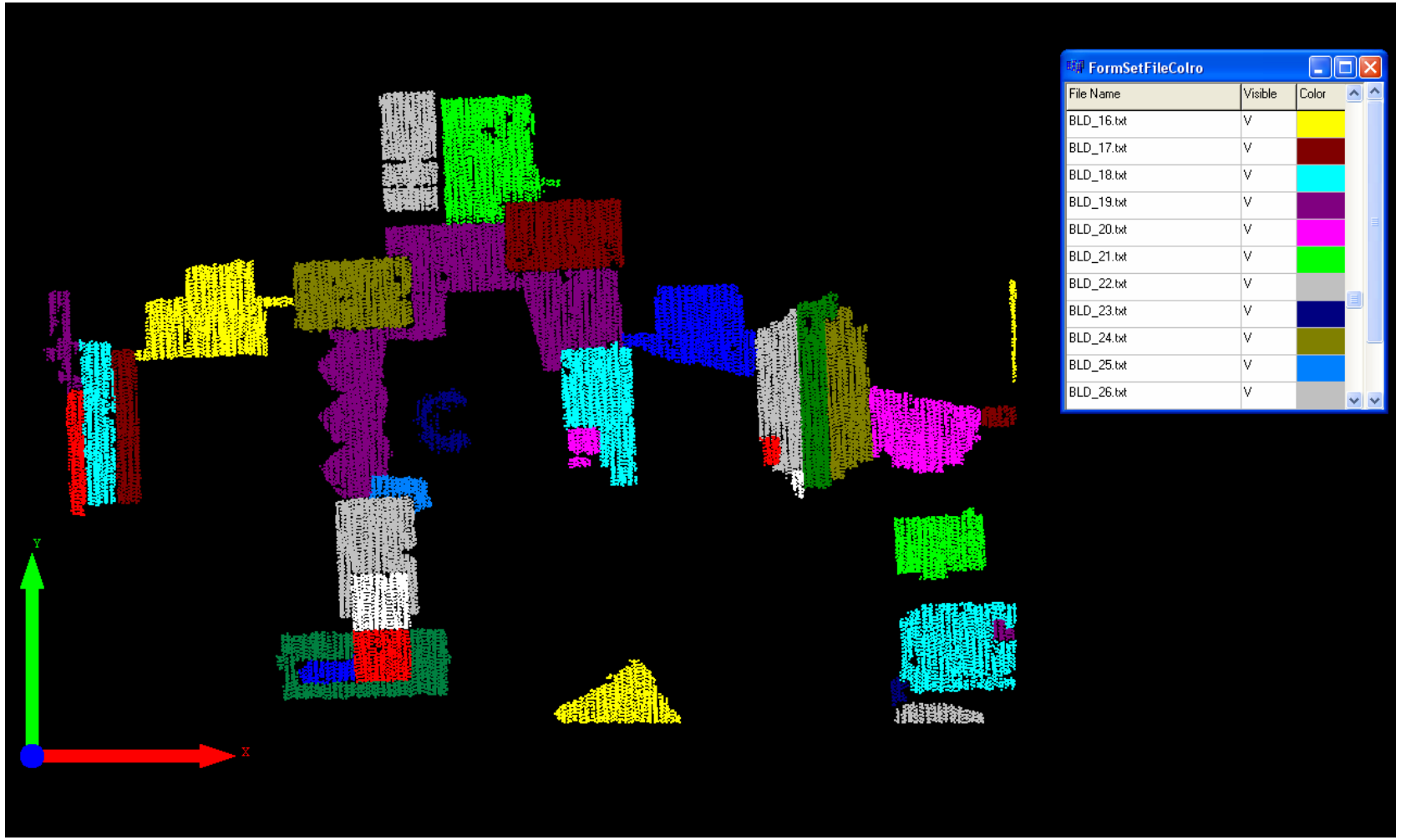


Classification of LiDAR Points

Building Hypothesis Generation

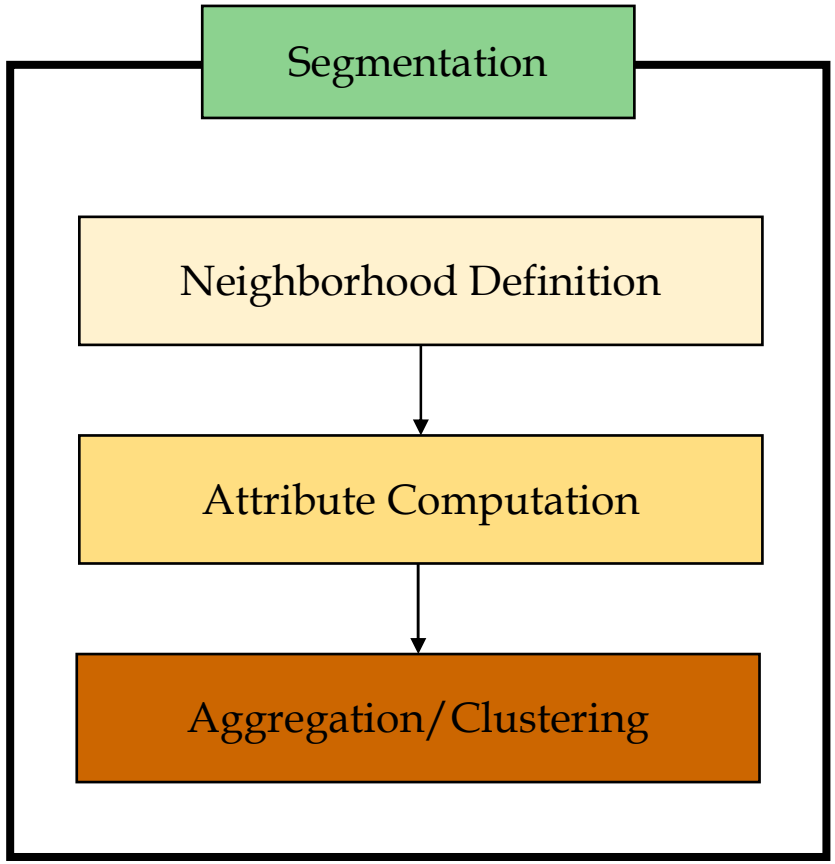


Building Hypothesis Generation



Generated Building Hypotheses

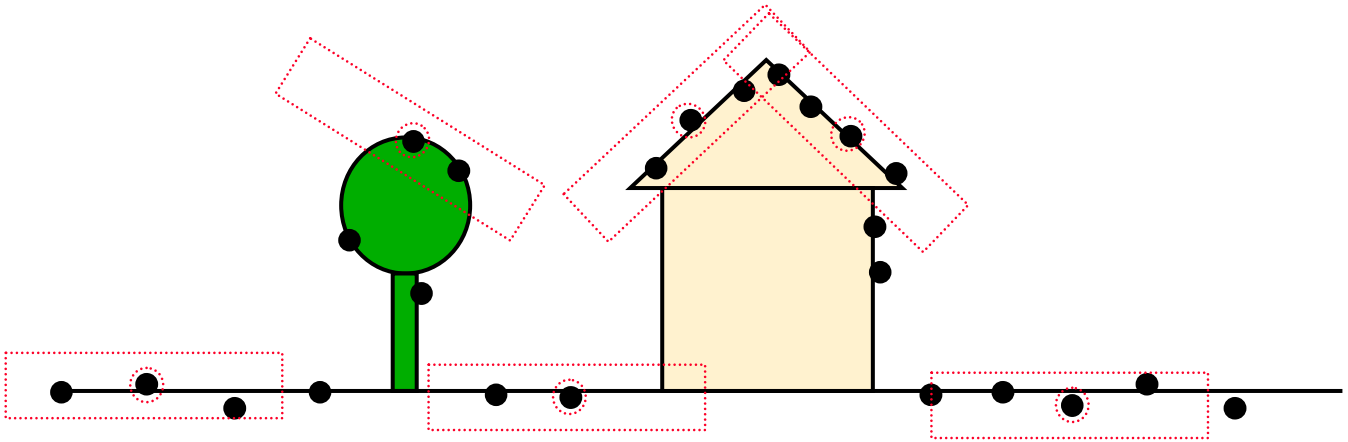
Segmentation of Building Primitives



Segmentation of Building Primitives

Neighborhood Definition

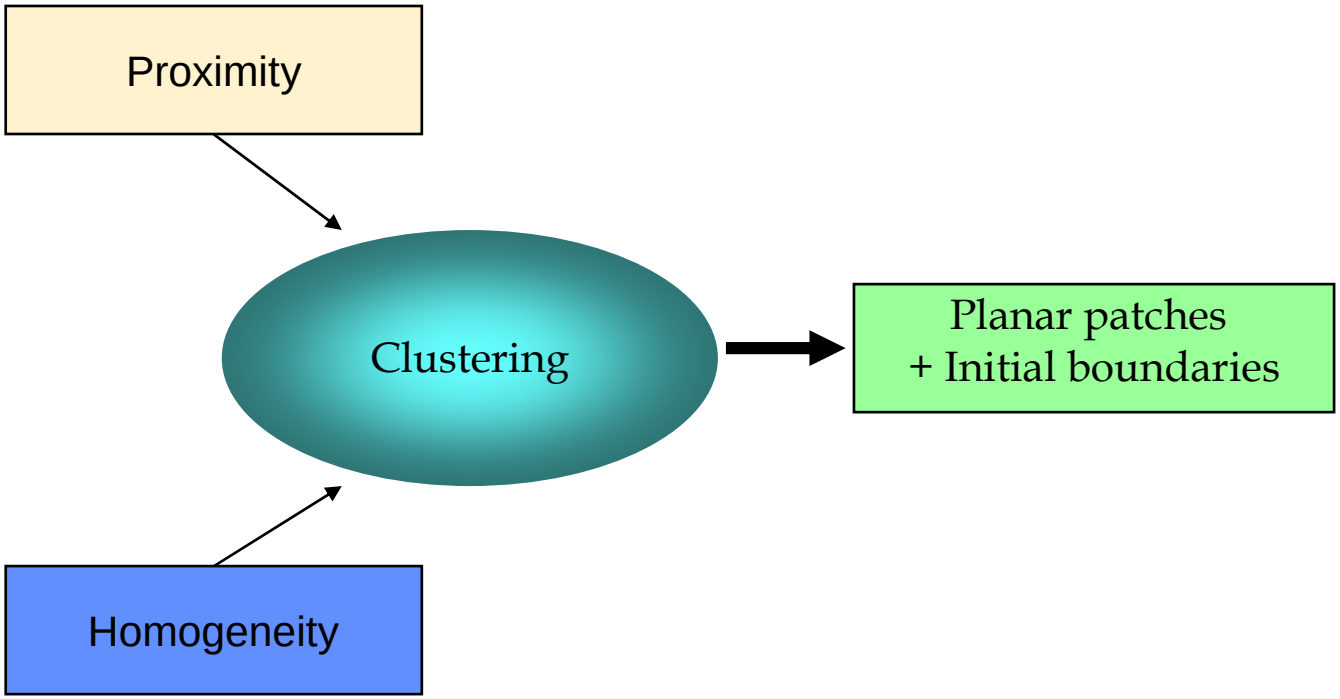
Neighboring points that belong to the same physical surface (adaptive cylinder).



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

Segmentation of Building Primitives

Clustering



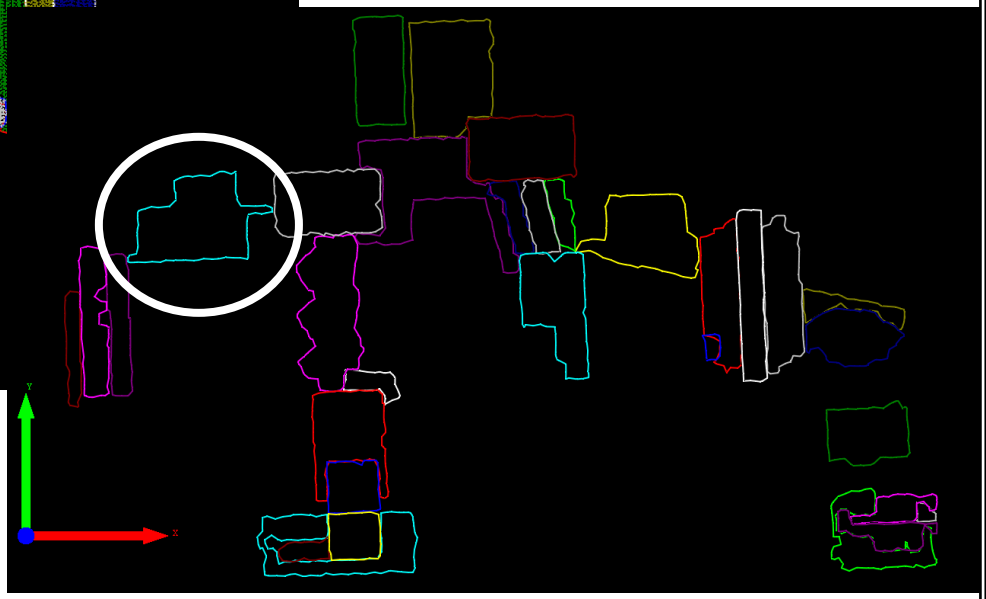
Simultaneously considering Homogeneity (globally) in the parameter space

+ Proximity (locally) in the object space → Accurate & Robust solution

Building Hypothesis → Building Primitives

Building Primitives

Segmentation + 3D initial boundaries



3D initial boundary Results

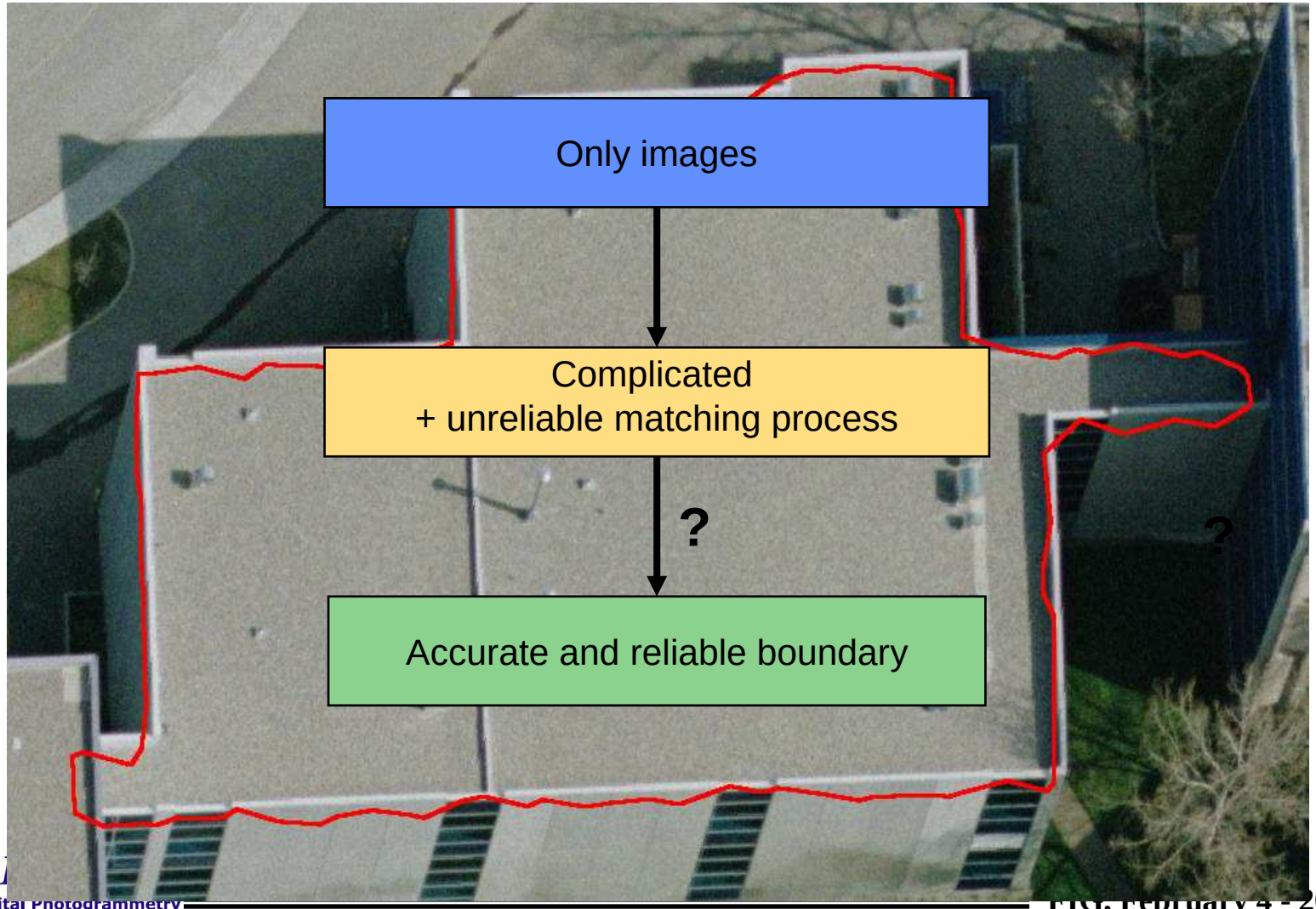
Rooftop Boundary Refinement

Using only LiDAR → Accurate planar patch + Not accurate boundary

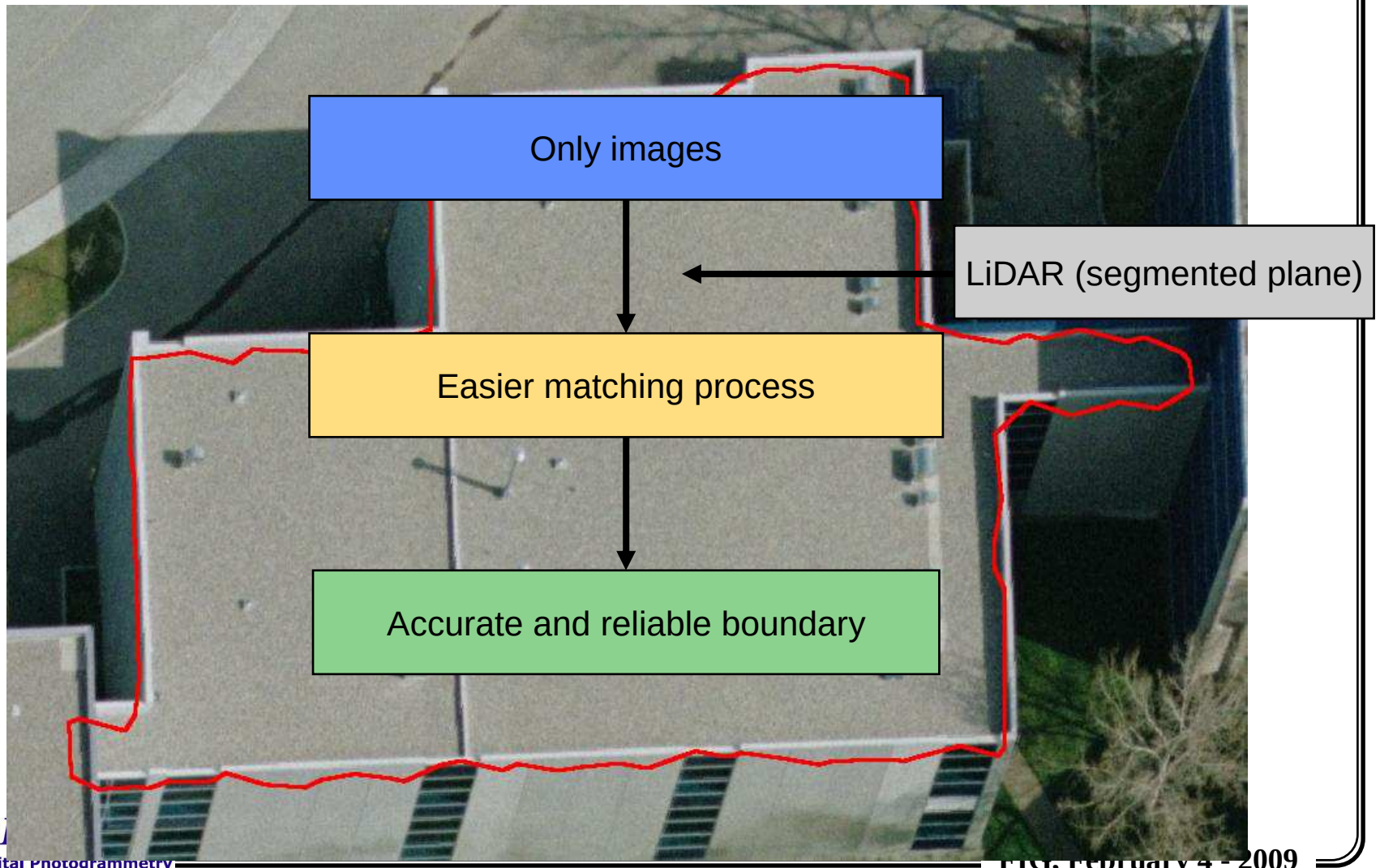
(Sampling Distance of LiDAR data (e.g., 80cm) → Limitation of produced 3D initial boundaries)

Projected 3D initial boundary on the aerial photo

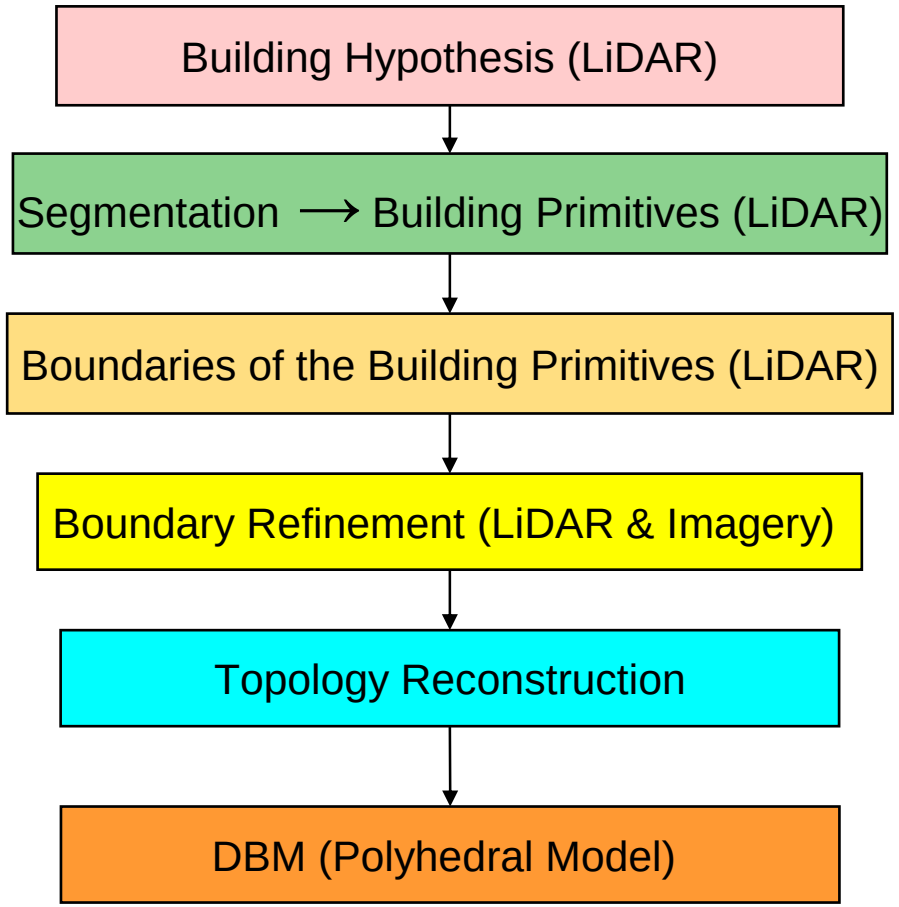
Rooftop Boundary Refinement



Rooftop Boundary Refinement

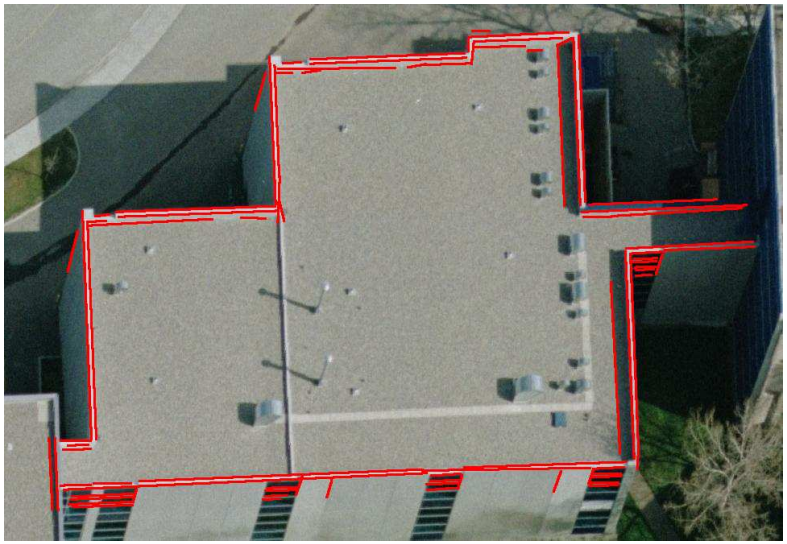


DBM Reconstruction (Polyhedral Model)



DBM Reconstruction (Polyhedral Model)

- Line Detection

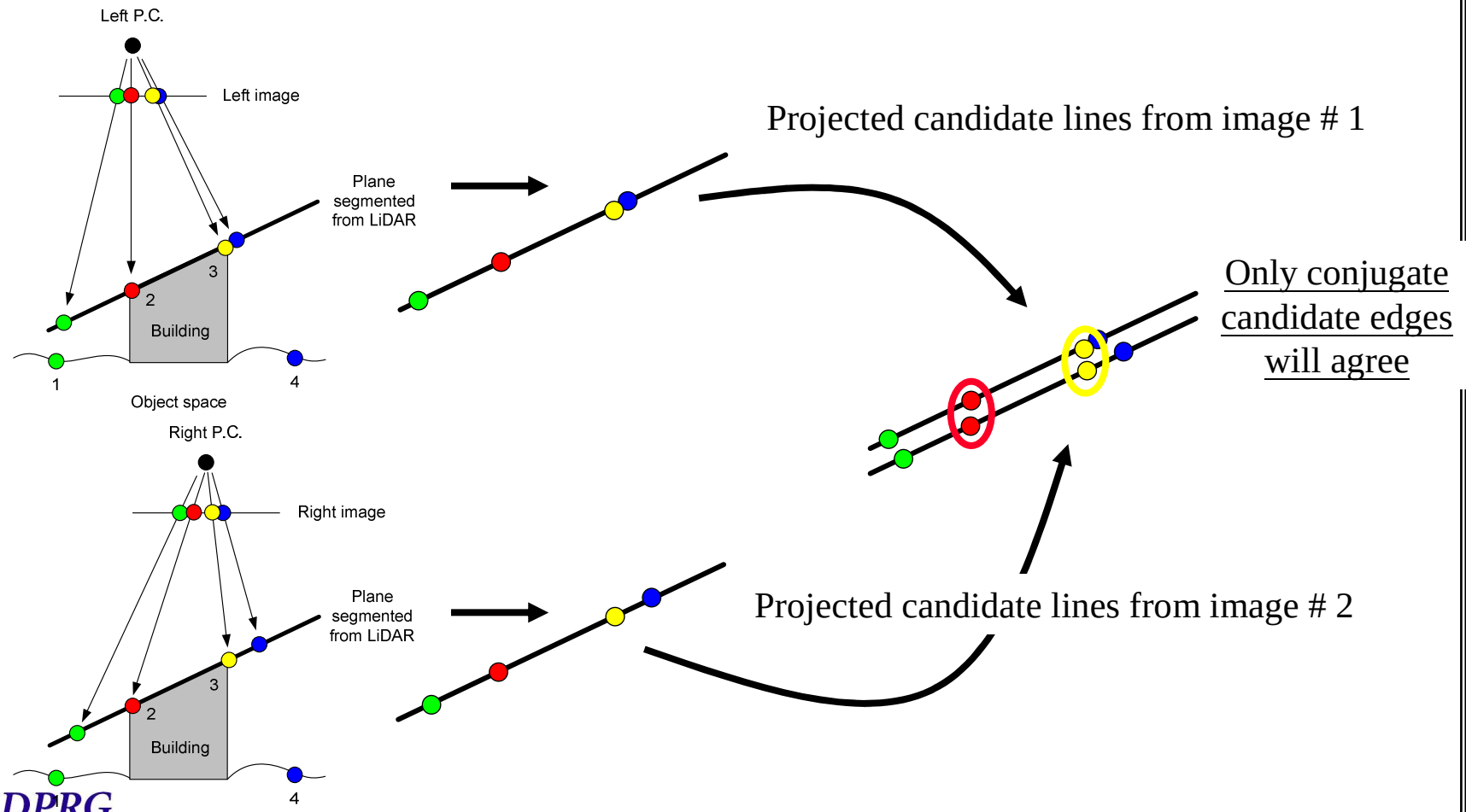


Edge lines on image #1

Edge lines on image #2

DBM Reconstruction (Polyhedral Model)

- Line Matching



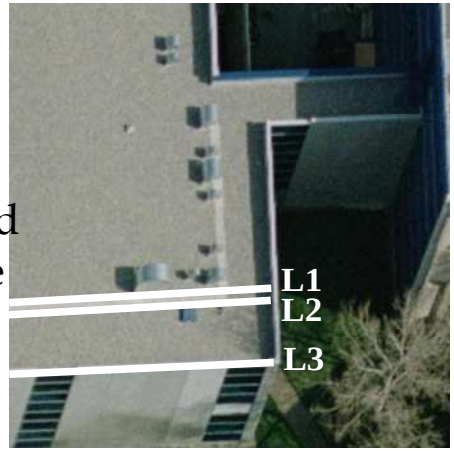
DBM Reconstruction (Polyhedral Model)

- Warped imagery comparison

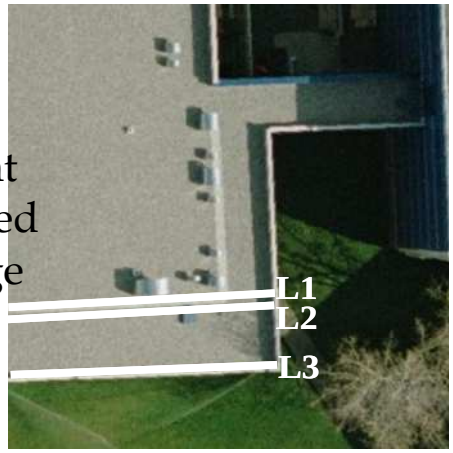
DBM Reconstruction (Polyhedral Model)

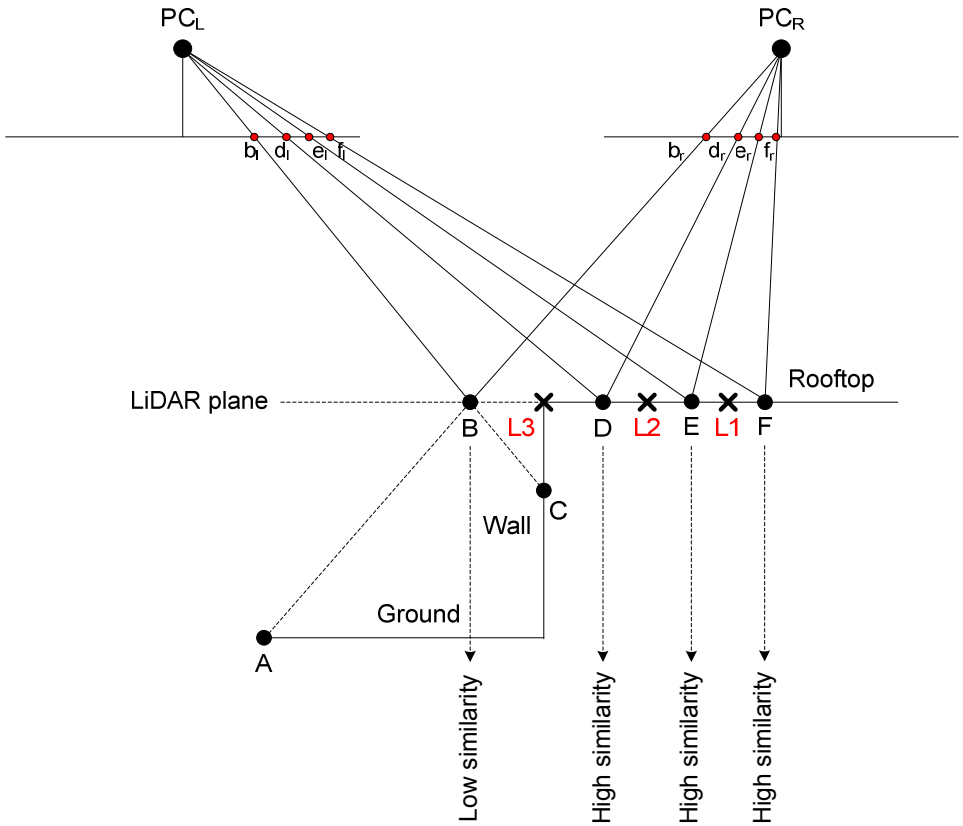
- Precise boundary segment selection

Left warped image

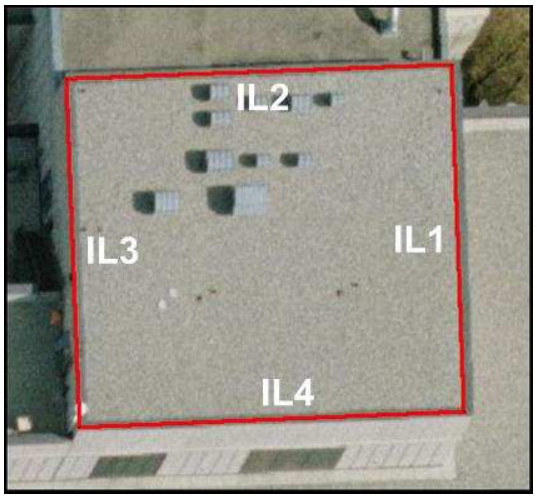


Right warped image

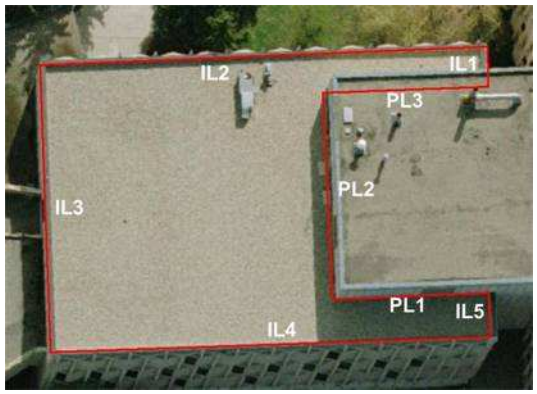




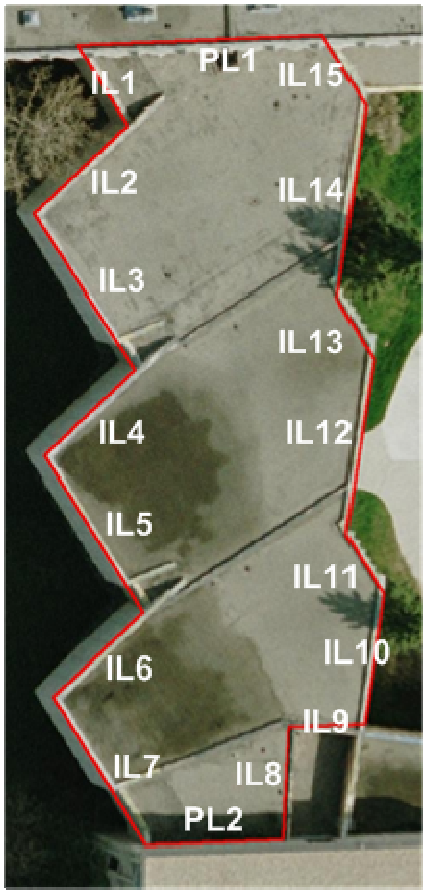
Extracted Rooftop Patches



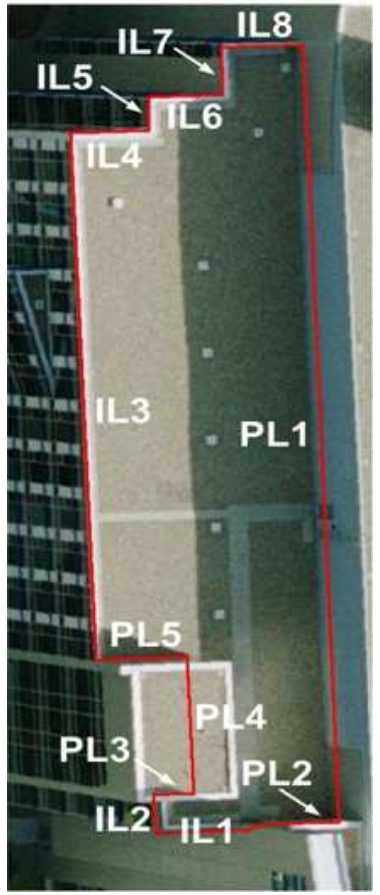
Simple building primitive



Building primitive with low complexity

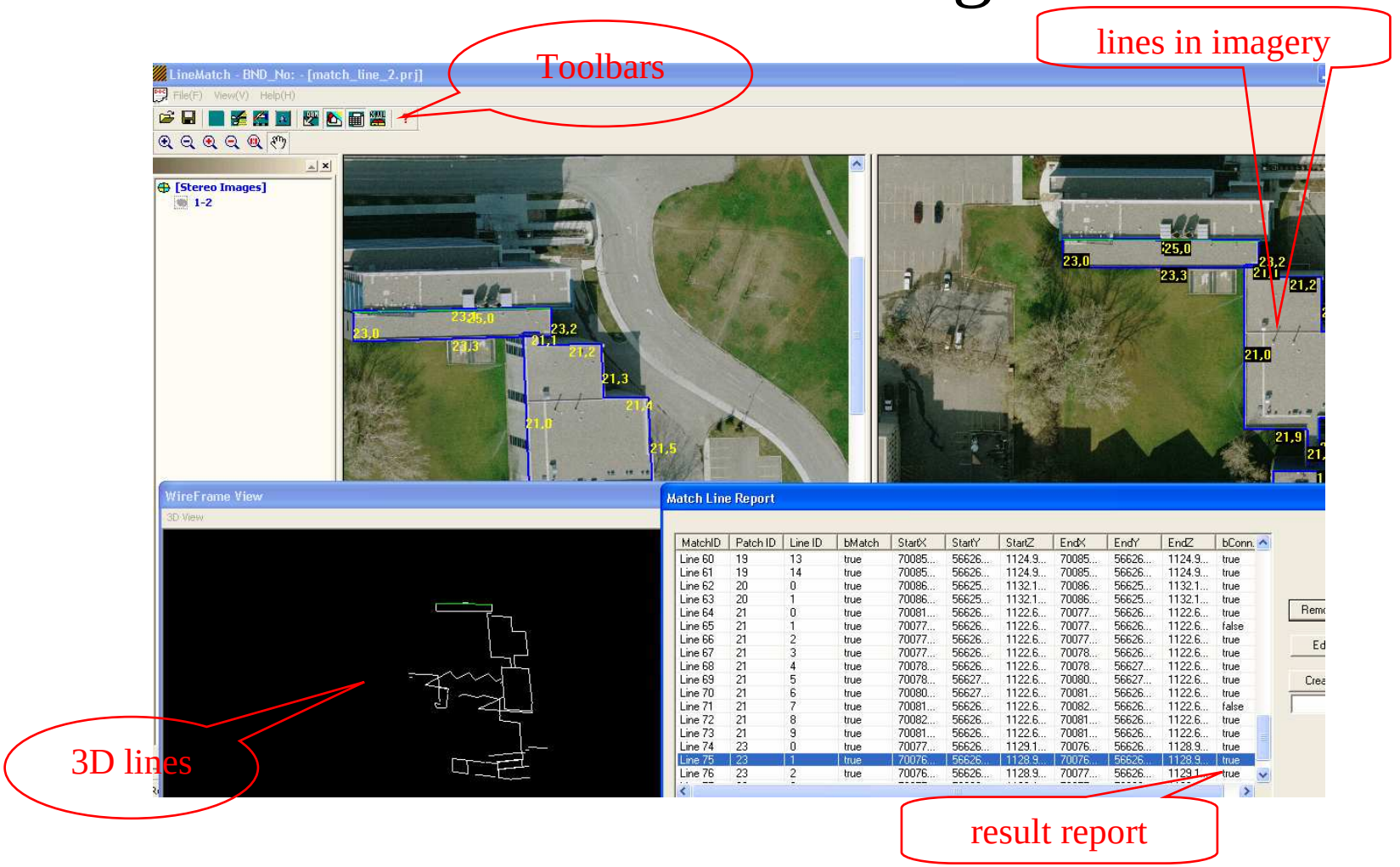


Building primitive with medium complexity



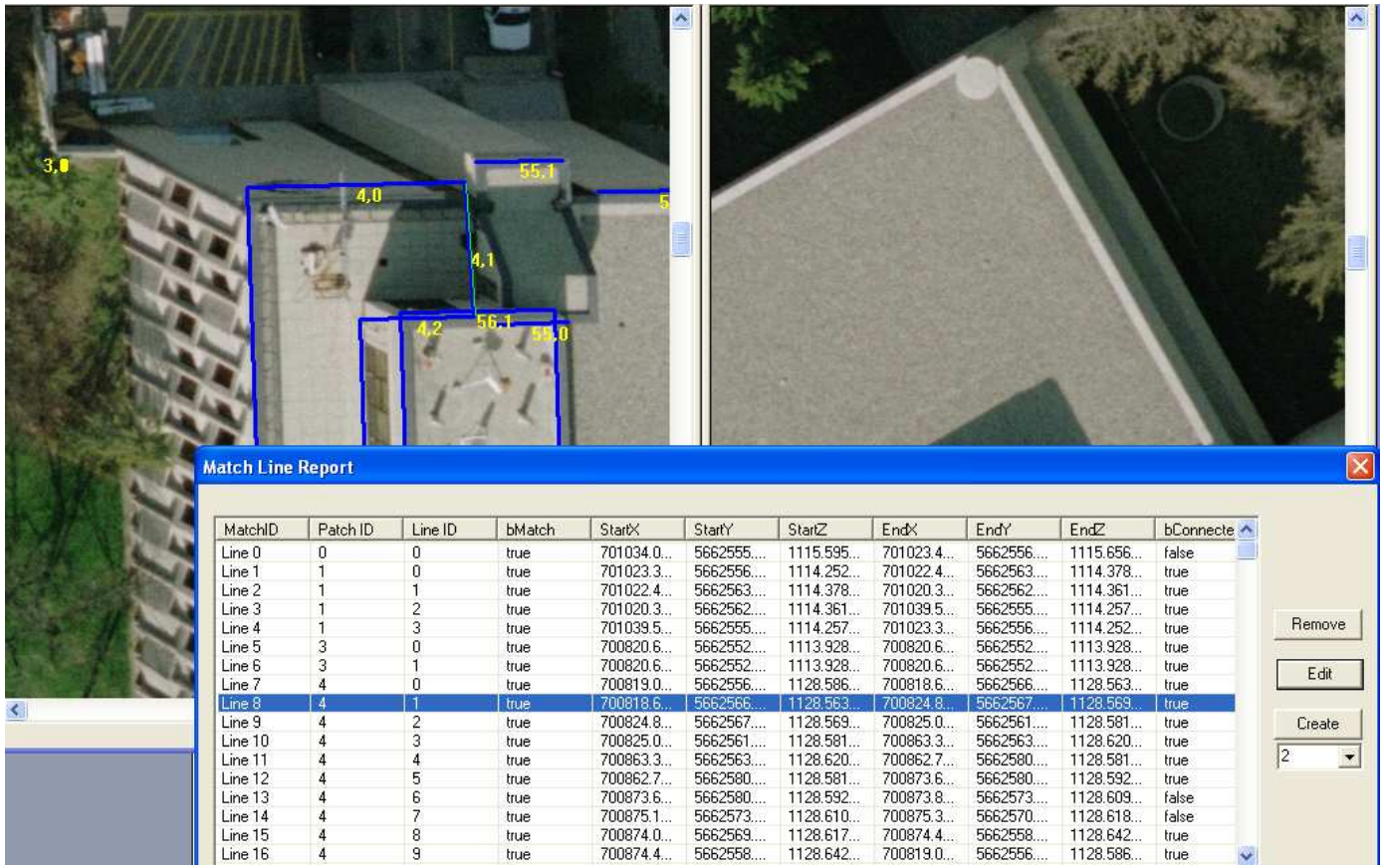
Building primitive with high complexity

Manual Editing



Software Interface

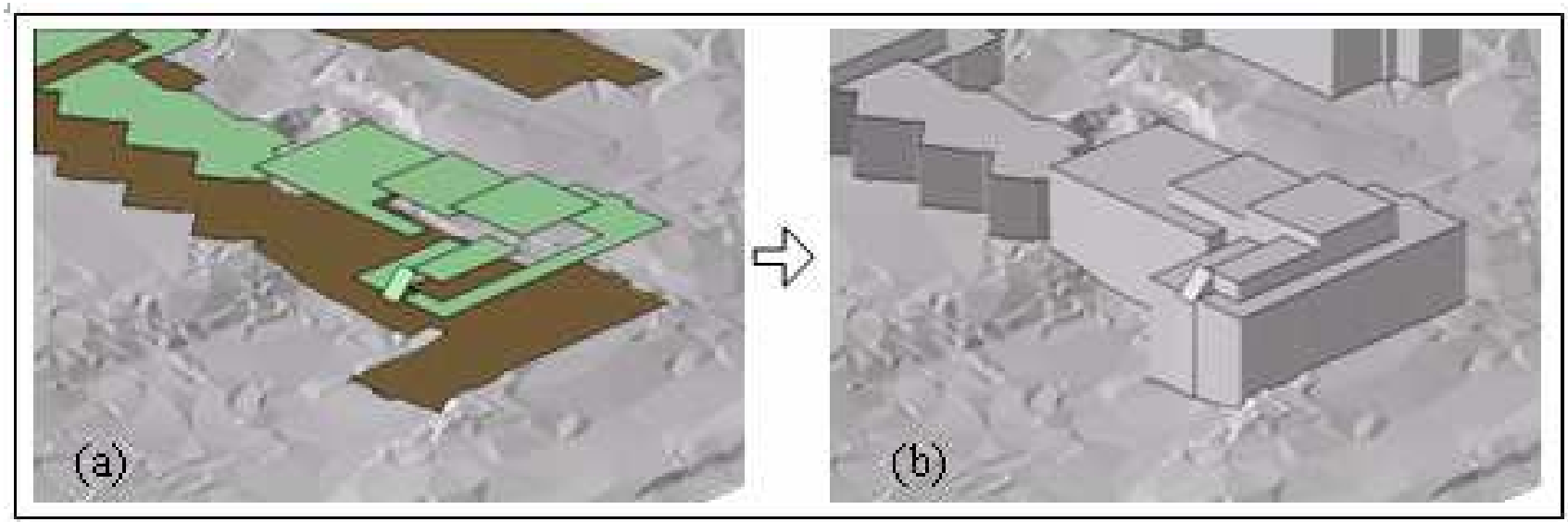
Manual Editing



Software Interface

Enhanced DSM

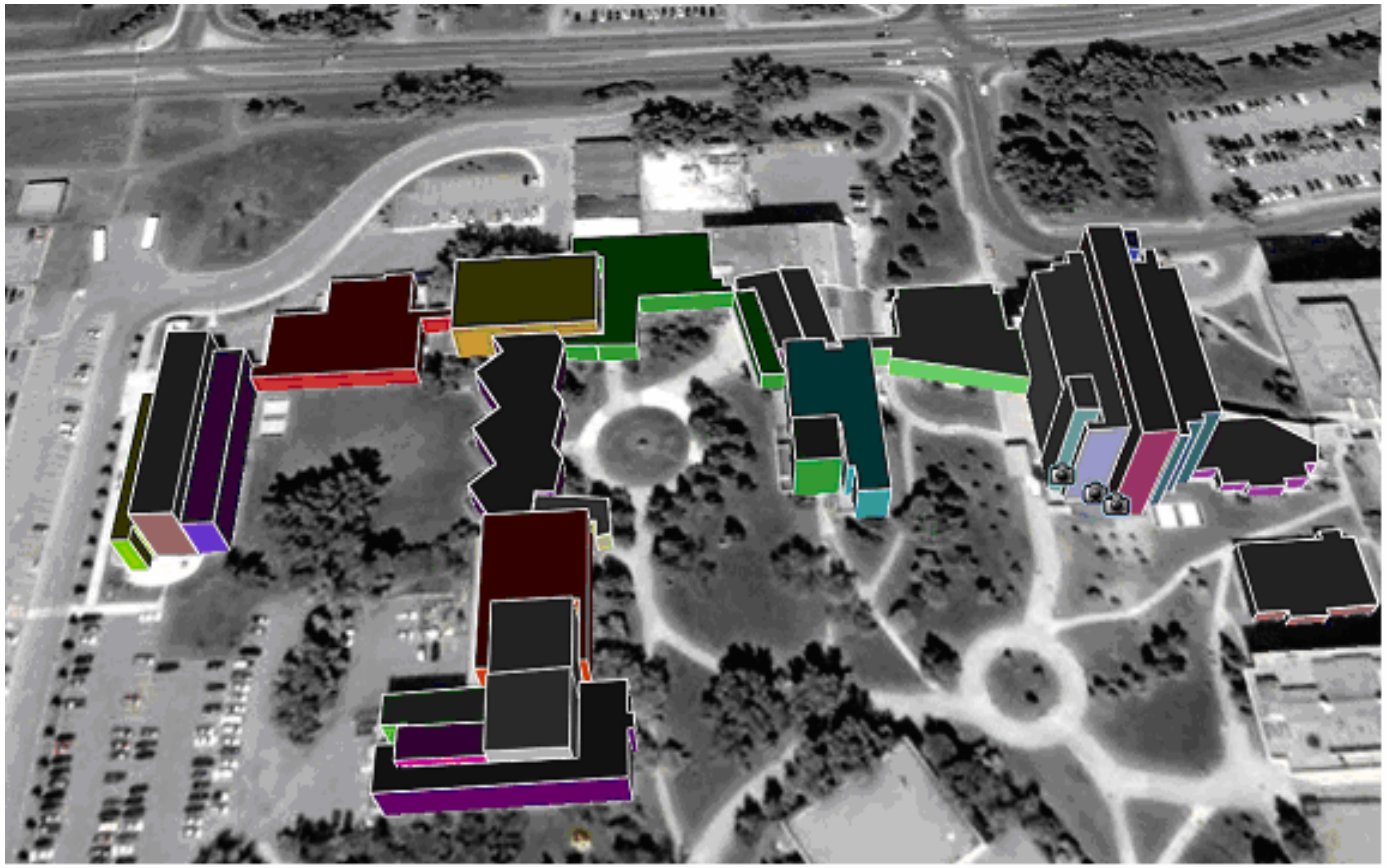
- The rooftop patches (and footprints) are added to the DTM, and an enhanced DSM is produced.



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%

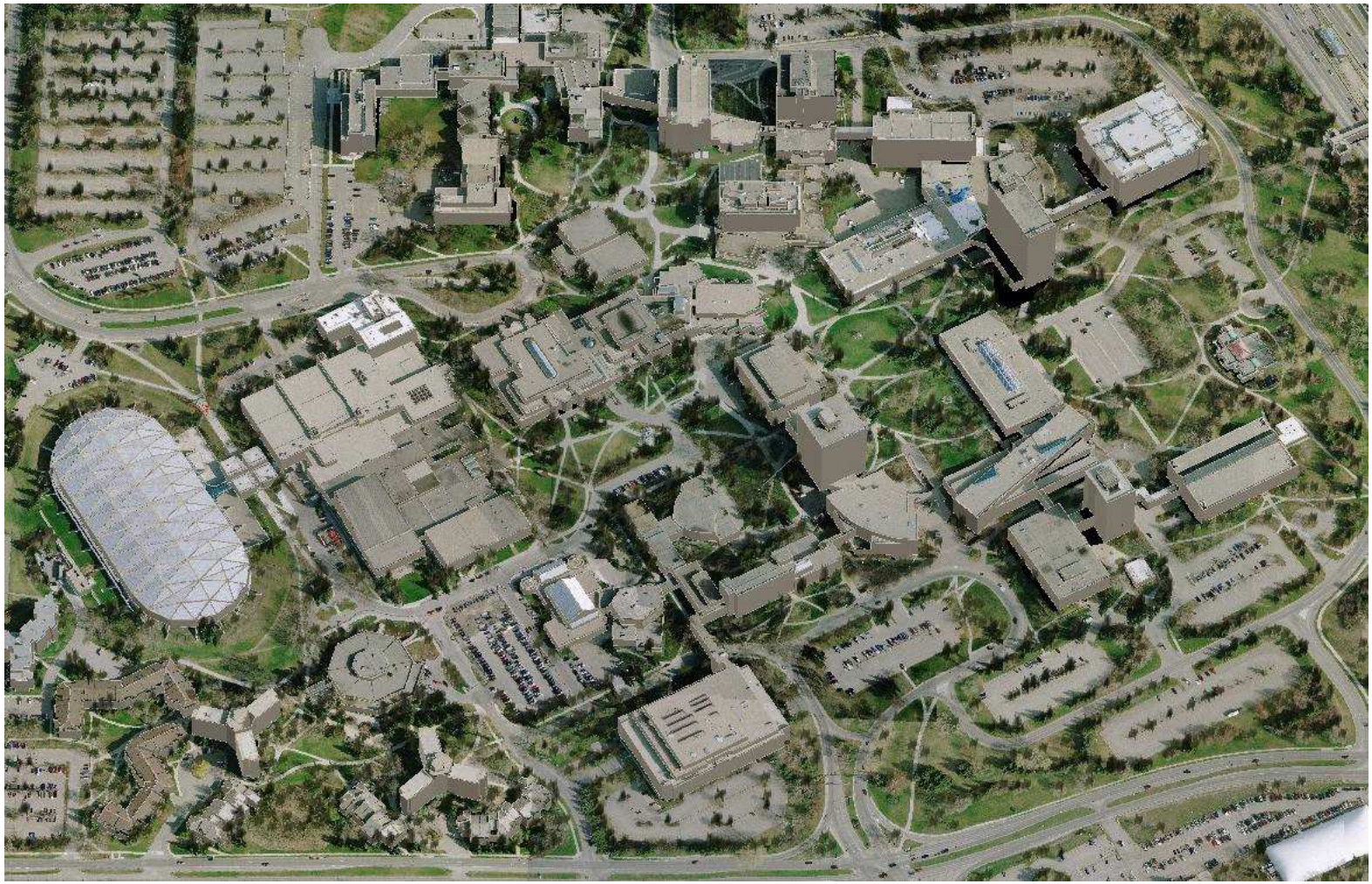
DBM: Quantitative Analysis

- 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

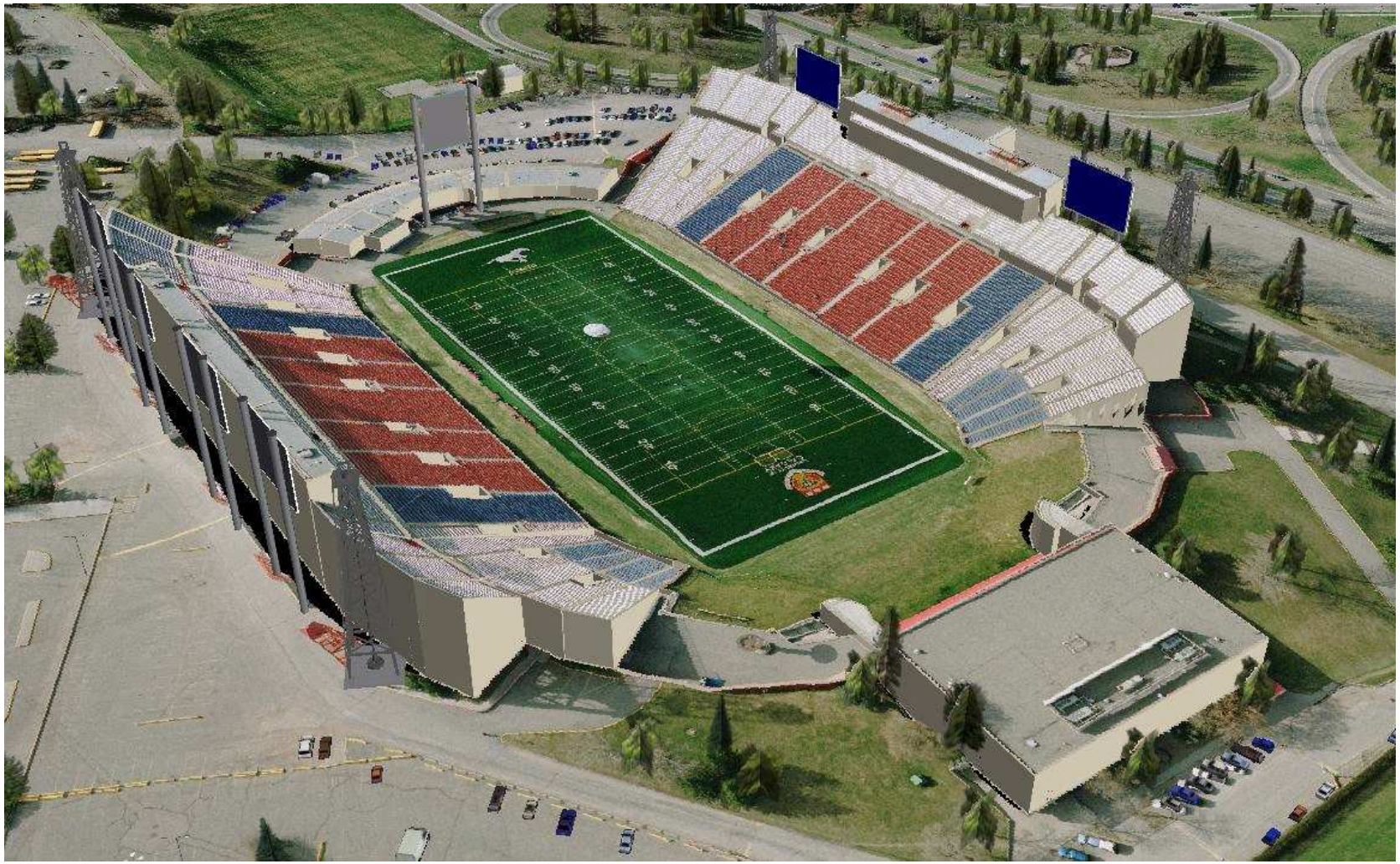


Main Campus Area

Final Product (Sample)

Engineering Building

Final Product (Sample)



McMahon Stadium

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?