U.S. DEPARTMENT OF ENERGY

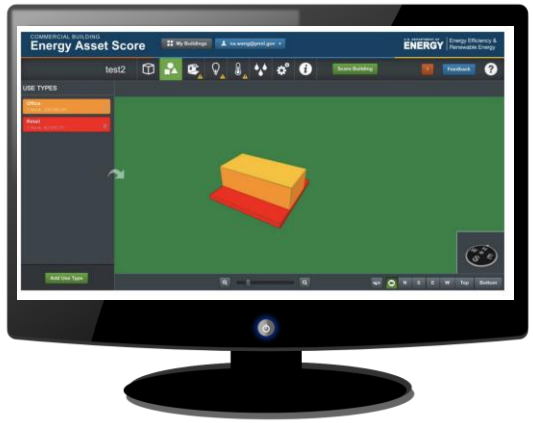
Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Working With Unstructured Data: Using Machine Learning for Improved Efficiency Analysis

J. Granderson, Berkeley Lab

November 16, 2020

Today's Remote Analytics: Simulation-based



COMMERCIAL BUILDING 2

ENERGY ASSET SCORE

UPGRADE OPPORTUNITIES

Building ID #: XXXXX — Gross Floor Area: 100,000 ft²

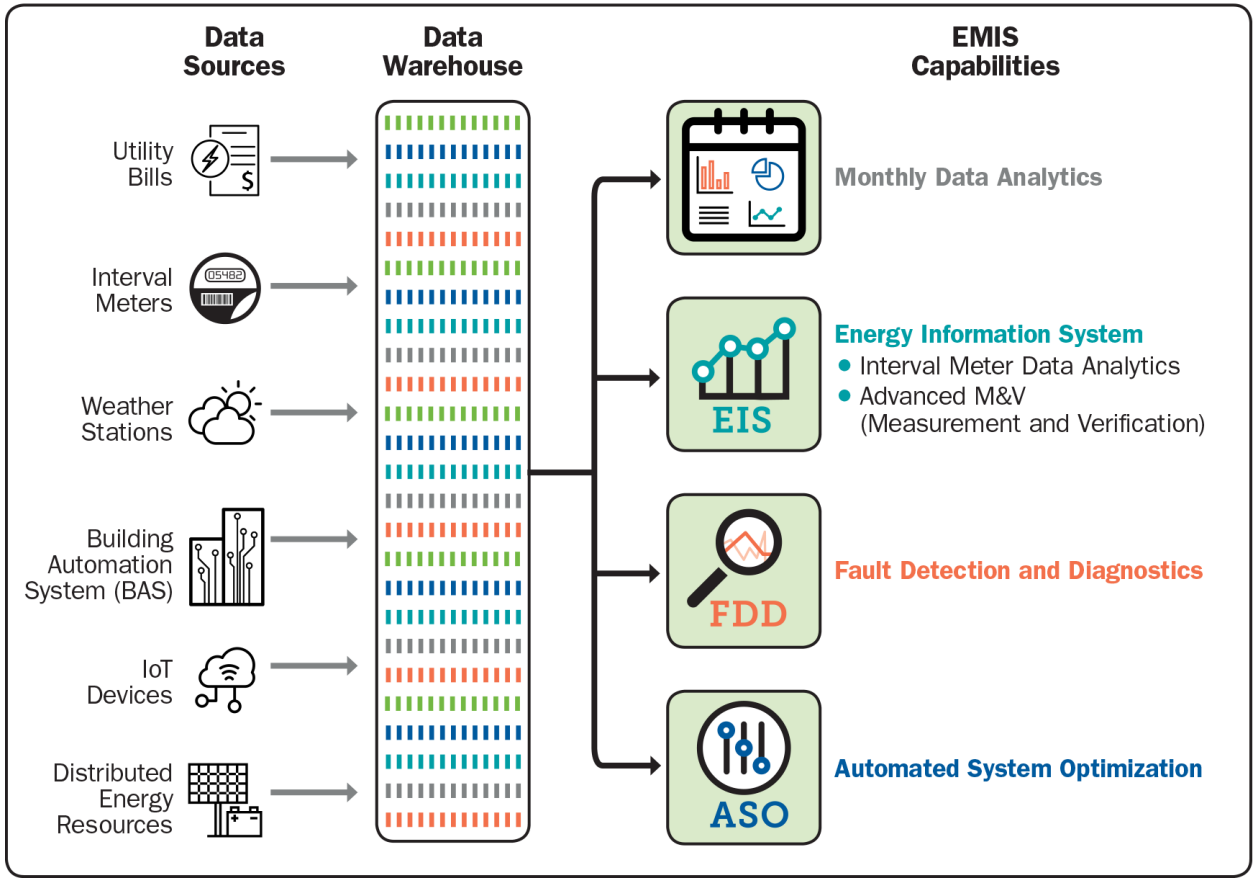
COST EFFECTIVE UPGRADE OPPORTUNITIES

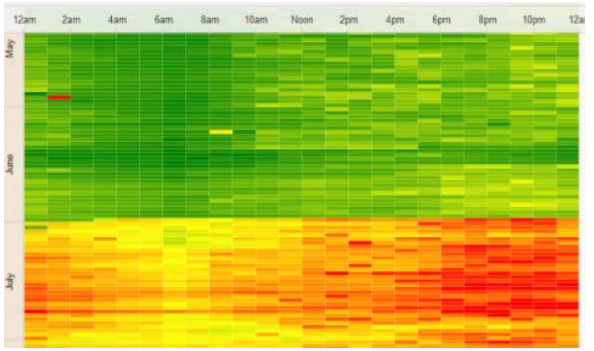
	Energy Savings[a]	Cost[b]
Building Envelope		
• Add roof insulation in Office *Learn More*	Medium	$$
• Upgrade windows in Office with high performance double pane windows *Learn More*	Medium	$$
Interior Lighting		
• Upgrade Fluorescent T8 lighting system in Office to compact fluorescent lighting system *Learn More*	High	$
HVAC Systems		
• Upgrade cooling system in Office with high efficiency electric DX cooling system *Learn More*	High	$$$
• Add supply air temperature reset to HVAC system in Office *Learn More*	Low	$
Hot Water Systems		
• Upgrade service hot water system in Office with electric heat pump water heater *Learn More*	Medium	$$

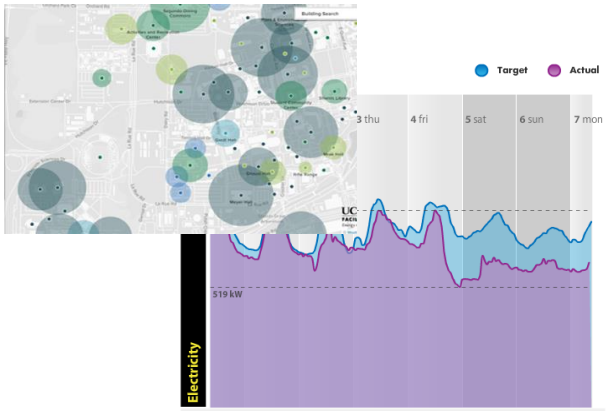
User Inputs

- Floors, footprint, orientation
- Envelope
- Windows
- Lighting
- Mechanical
- Utilities info

Today's Remote Analytics: Continuous, Data-driven







Remote ID of Capital and Operational Measures

Operational insights

- HVAC scheduling
- Space temperature setpoints
- Economizer use
- Reset strategies
- Under/over ventilation

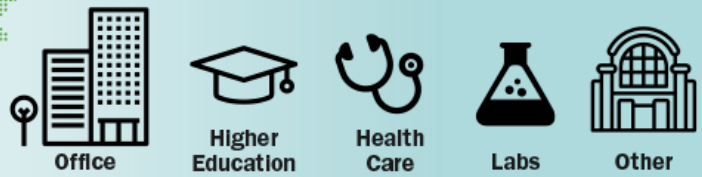
‘New normal’ relevance

- Ventilation, outside air intake
- Pre/post occupancy flush
- Disabling demand controlled ventilation
- Low occupancy turn-down, setbacks

Continuous Analytics Enable Deep, Cost Effective Savings

Largest Dataset Documents the Costs and Benefits of EMIS

104 ORGANIZATIONS



6,500 BUILDINGS

567 MILLION SQUARE FEET

EMIS SOFTWARE REPRESENTING **40** DIFFERENT EMIS VENDORS HAVE BEEN INSTALLED

ANNUAL ENERGY SAVINGS FOR ORGANIZATIONS WITH EMIS:

3% EIS

9% FDD

$3 million ANNUAL SAVINGS *for the median portfolio (15 million sq ft)*

$95 million PROJECTED ANNUAL SAVINGS *for all organizations*

FIRST-YEAR INSTALLATION AND SOFTWARE COSTS:

EIS $0.02/sq ft

FDD $0.08/sq ft

INVESTMENT PAYBACK:

2 years

Advancing the State of the Art

Partners

ADVISORY

nyserda
Energy. Innovation. Solutions.

PERFORMERS

BERKELEY LAB

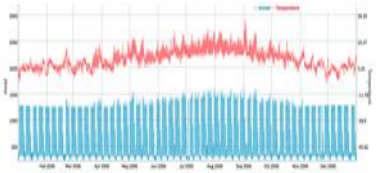
Signetron

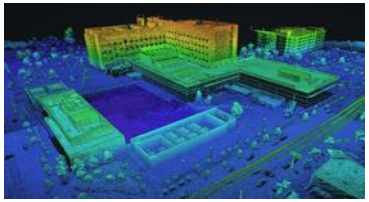
TRC
Results you can rely on

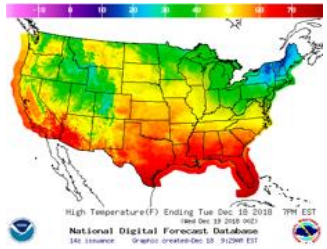
Opportunity

- Recent advances in public data availability (disclosures and permit data), sensor technology, and falling costs
- Increasing number of data collectors for buildings
- These novel data + feature extraction hold promise to ID
  - Building characteristics and assets
  - Building-specific EE measures

Types of Data







RGB & Thermal Images

Street View

Aerial / Satellite Images

LIDAR

Features Extraction Tools:

- Machine Learning
- Image processing
- Energy Analytics
- Natural Language Processing

Public Data

Meter Data

Weather Data

Data Fusion

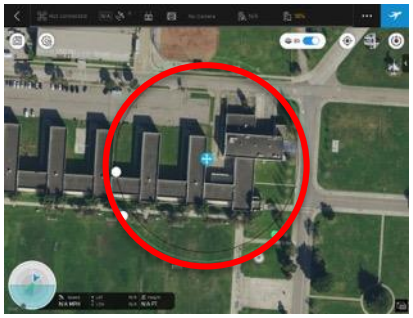
Building Characteristics

Efficiency Opportunities

Drone-based Thermal and RBG Images

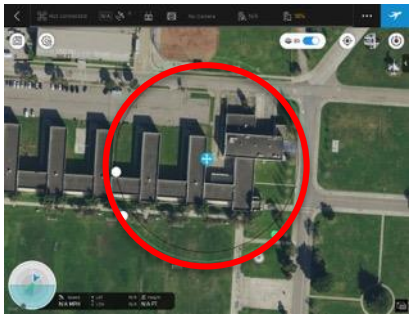
- Inexpensive camera and drone hardware
- Advances in photogrammetry software, machine learning, computer vision
- Adapted to
  - Auto-generate 3D geometry
  - Extract exterior features (e.g., windows, PV, packaged units)
  - Identify thermal anomalies

Drone-based Generation of 3D Geometry, RGB Images



Planned flights

Drone-based Generation of 3D Geometry, RGB Images



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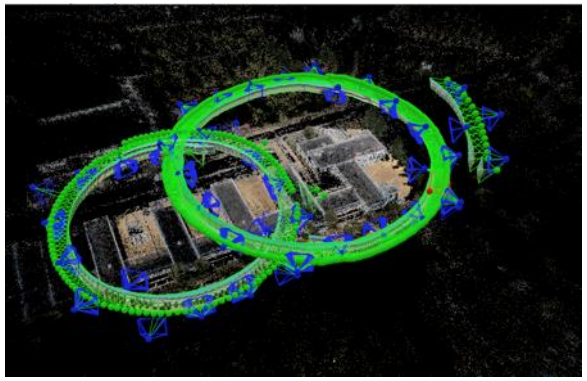
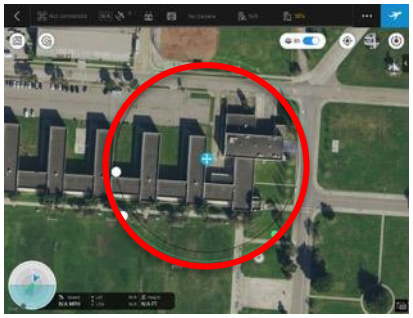


Position of the drone during the data capture

Collected imagery (2D)

Drone-based Generation of 3D Geometry, RGB Images



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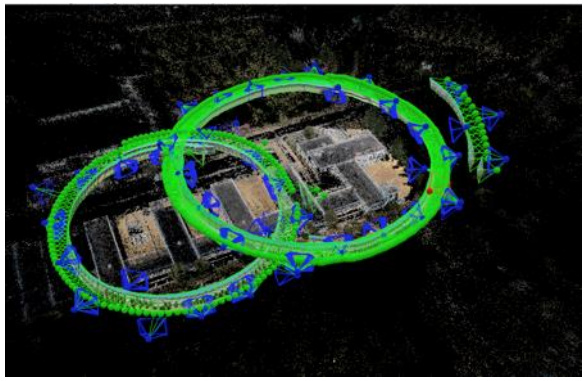

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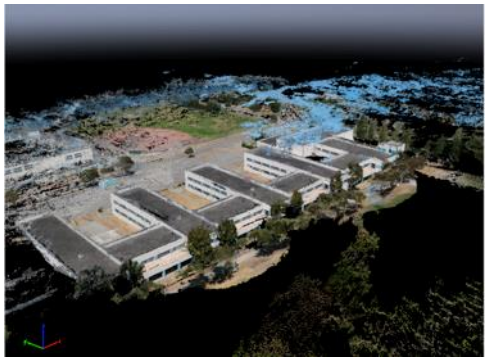
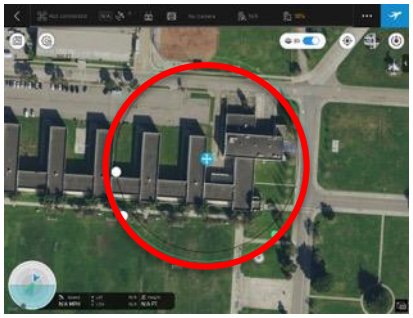


3D Reconstruction
(Photogrammetry)

Drone-based Generation of 3D Geometry, RGB Images



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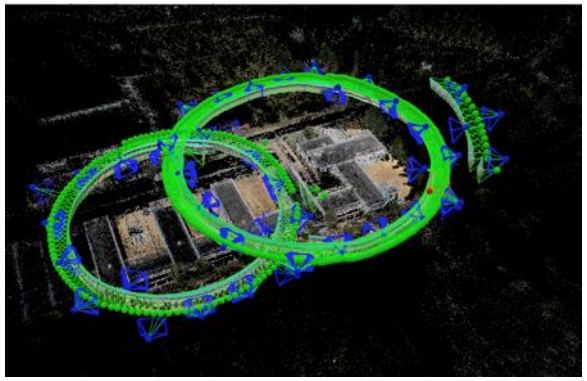

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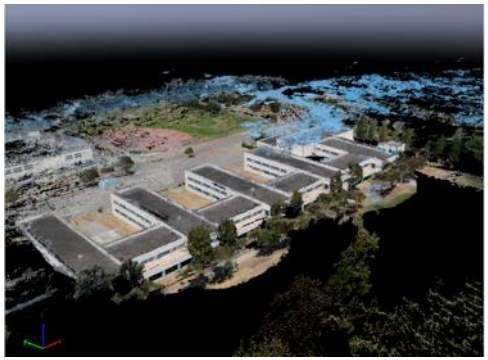

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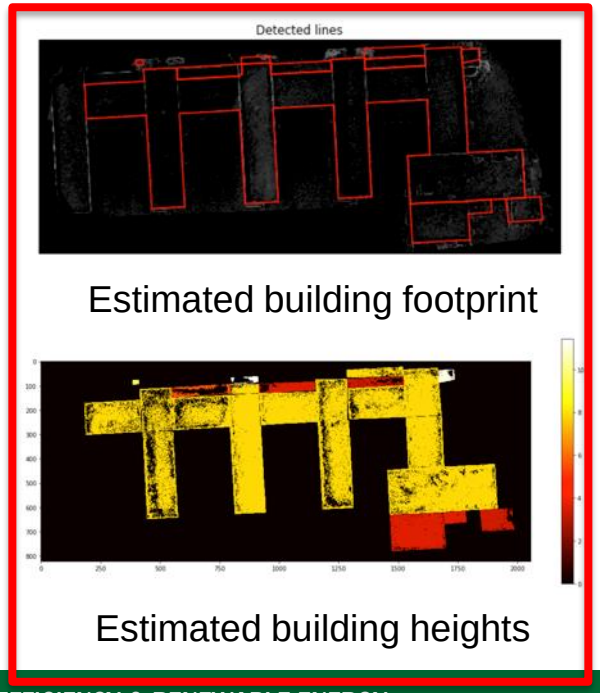
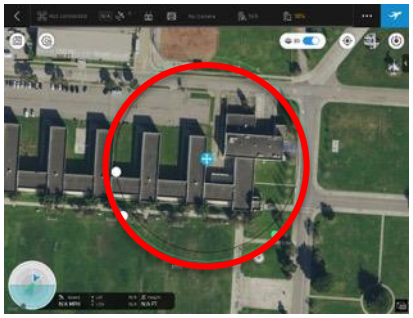


Estimated building footprint

Estimated building heights

Drone-based Generation of 3D Geometry, RGB Images



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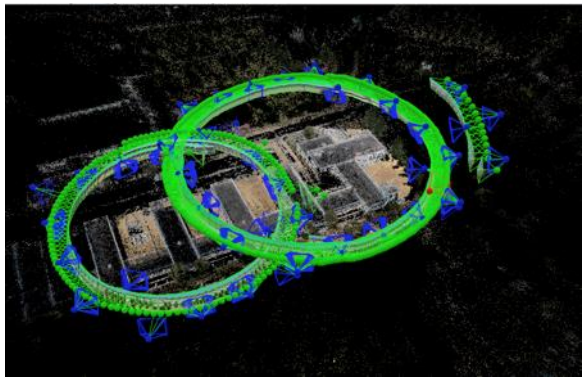

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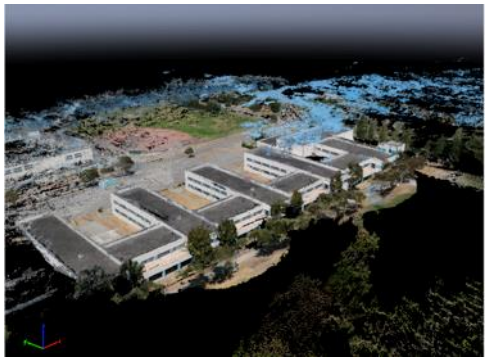

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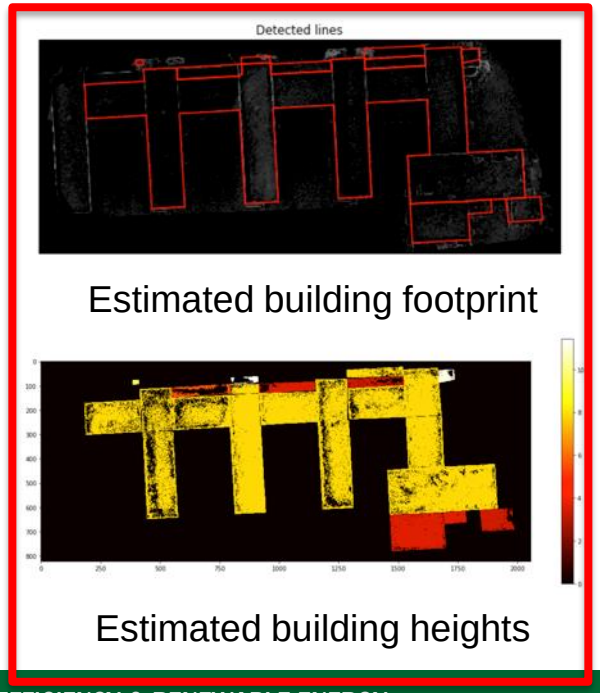

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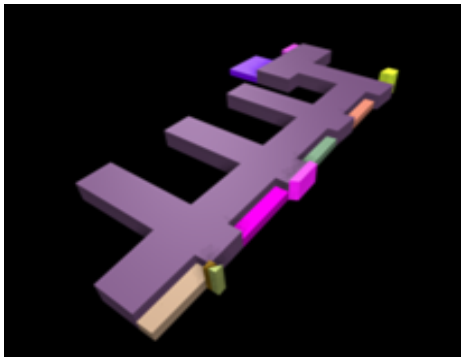
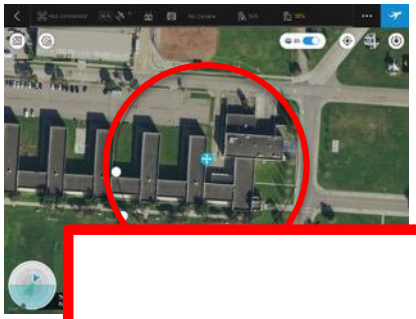
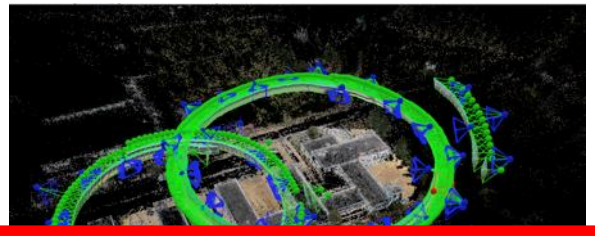


Building 3-D model
(GeoJSON format)

Drone-based Generation of 3D Geometry, RGB Images





Medium size building: ~2 hours to acquire images, ~1 day to process data (photogrammetry) and generate GeoJSON 3D model

WuDunn, M., Zakhor, A., Touzani, S. and Granderson, J., 2020, June. Aerial 3D building reconstruction from RGB drone imagery. In *Geospatial Informatics X* (Vol. 11398, p. 1139803). International Society for Optics and Photonics.

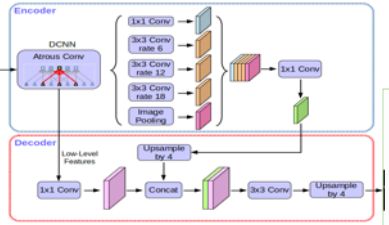
Estimated building heights

Window-to-Wall Ratio Estimation

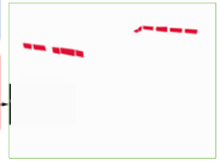
Windows deep learning semantic segmentation

Drone collected RGB images

Neural Network Architecture: DeepLab V3+



Predicted Windows masks



Predict windows masks from RGB drone images using a trained DeeplabV3+* model

* Chen et al., 2018. Encoder-decoder with atrous separable convolution for semantic image segmentation. In *Proceedings of the European conference on computer vision (ECCV)* (pp. 801-818).

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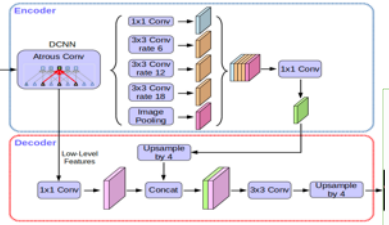

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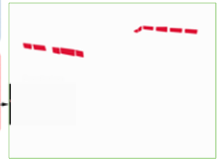

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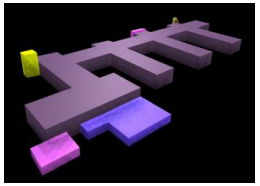
Façades detection in the drone RGB images



3D building model

Projected façades (and roofs) onto the RGB images

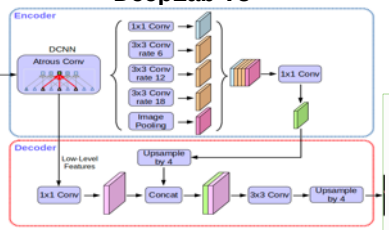
Project the façades corners from the extracted 3D model onto the RGB images using photogrammetry metadata, matching each 2D pixel to 3D pixel

Window-to-Wall Ratio Estimation

Windows deep learning semantic segmentation

Drone collected RGB images

Neural Network Architecture: DeepLab V3+



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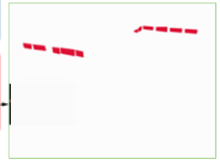

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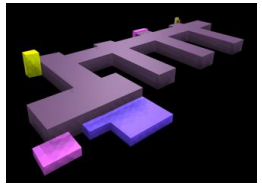
Façades detection in the drone RGB images



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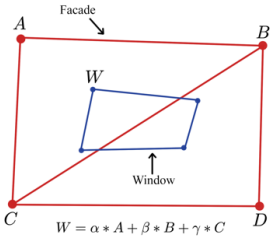
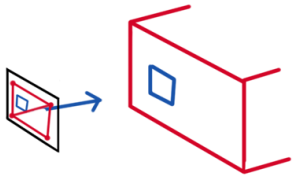
Estimate windows-to-wall ratio

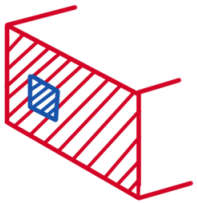
Using windows mask and projected facades detect windows on each façade



Delaunay triangulation to position window points relative to façade corners

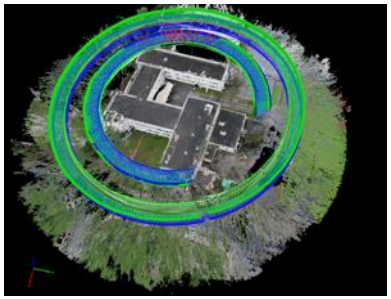


Project Window into 3D



Compute Window-to-Wall ratio

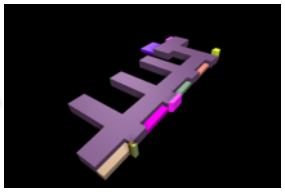
Thermal Imaging and Anomaly Detection



Data capture

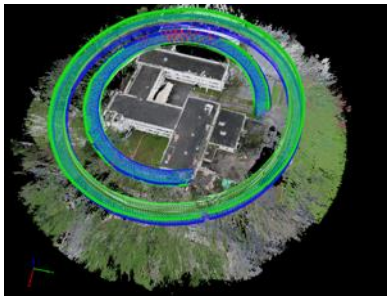
2D imagery (RGB and Thermal)

3D Reconstruction using Photogrammetry (Visual and Thermal)



3D building model

Thermal Imaging and Anomaly Detection



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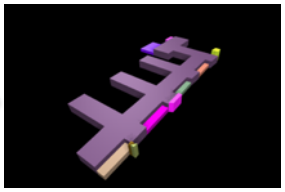
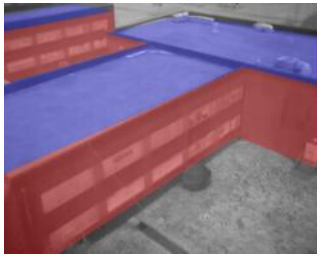


3D building model

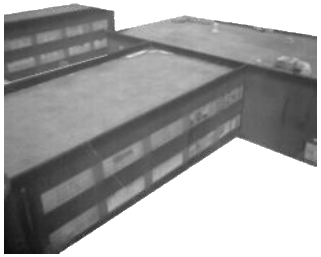
Thermal images

Thermal images metadata

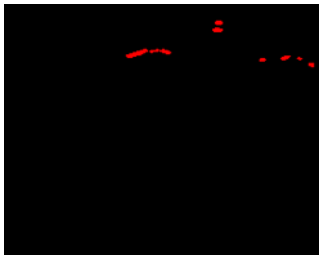
Thermal anomaly detection workflow



Project 3D model onto 2D thermal image



Extract building's pixels from 2D thermal image



Extract contours of detected anomalies - kmeans clustering, morphological ops

Superpose anomalous regions onto thermal image

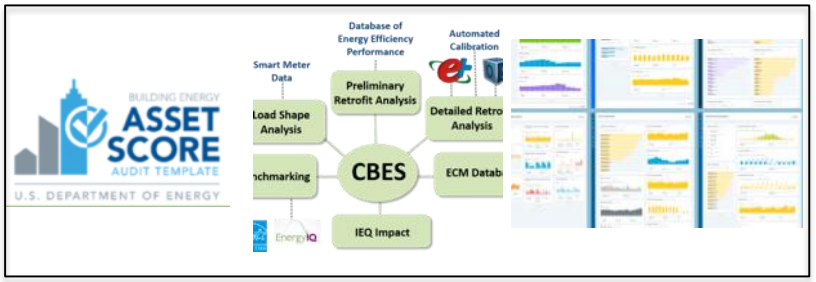
Additional Work

- **Satellite/aerial images for building footprint extraction**
  - Fusion w LIDAR for 3D geometries without drones
- **Field testing with EE program implementer to assess value of new information obtained**
- **Open source release of code, training data sets to enable adoption, further extensions**

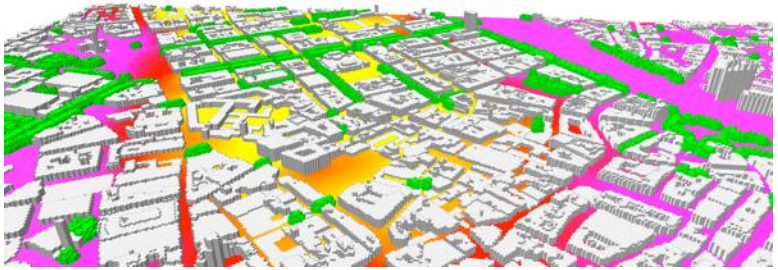
https://github.com/LBNL-ETA/AutoBFE

Takeaways

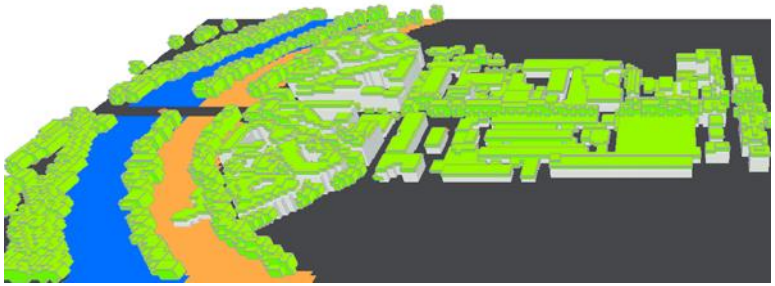
- **Remote analytics technologies are available and enabling cost effective savings today**
  - Capital and operational, benefits under normal and ”new normal” conditions



- **New data sources, extraction and fusion techniques hold promise to further advance technology capabilities**



- **Additional benefits beyond EEM ID**
  - Outdoor asset identification, classification
  - Site and track distributed energy resources
  - Plan the hardscape: vegetation ratio, cool surfaces, water bodies
  - Inventory localized building typologies for program planning, targeting



Thank you

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Reshma Singh

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