AutoBEM: Automatic Detection and Creation of Individual Building Energy Models for Each Building in an Area of Interest

II International Energy & Environment Summit - 2017

Theme: The Future of Energy & Emerging Technologies

Presented by:

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Oak Ridge National Laboratory
Oak Ridge, Tennessee, USA

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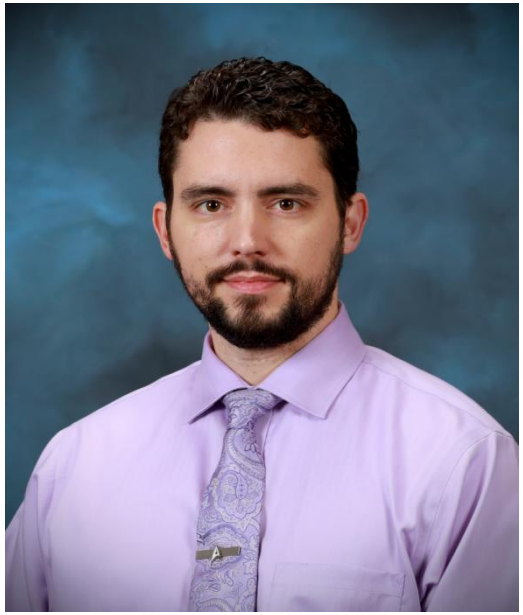
for the US Department of Energy

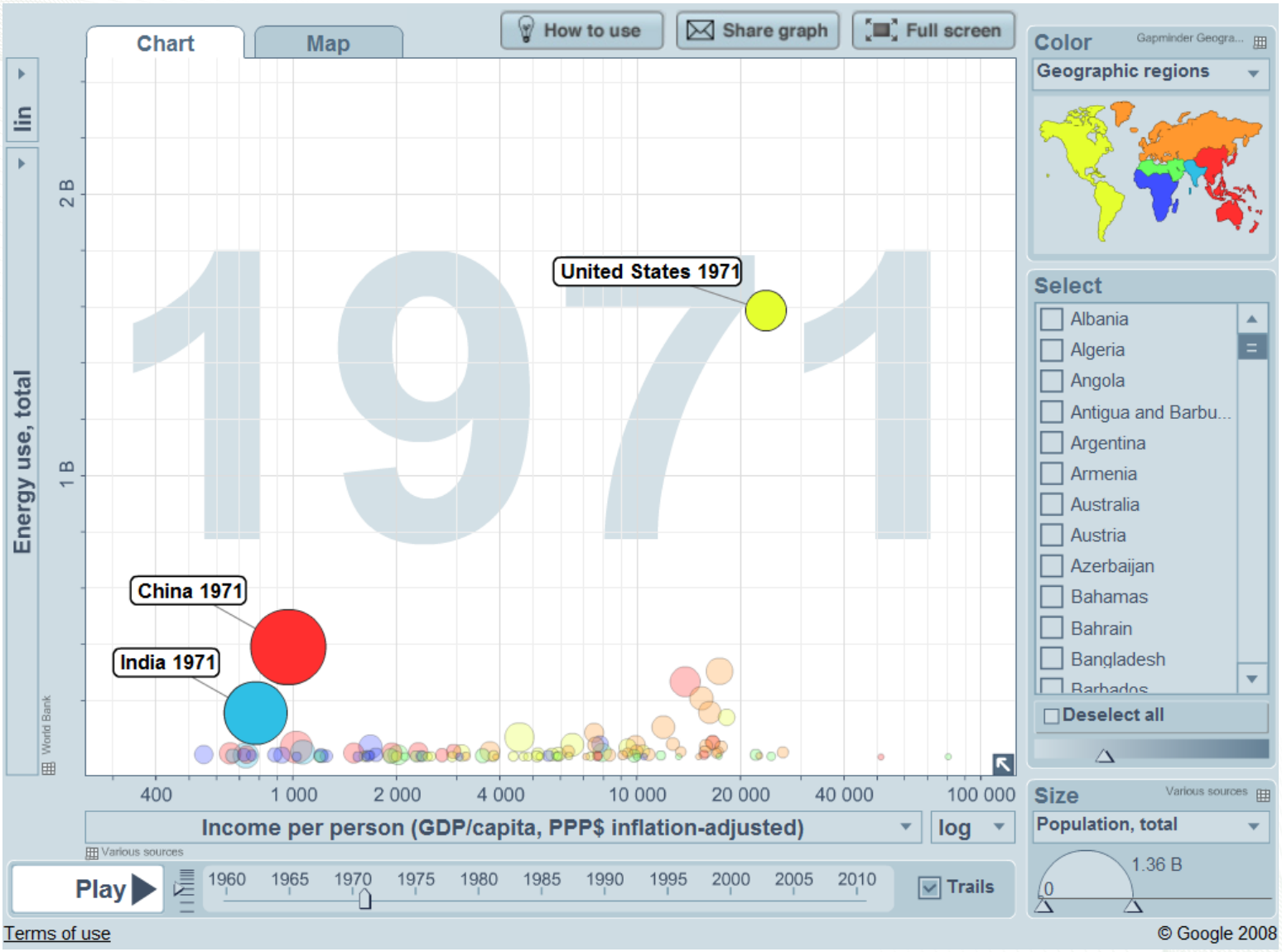
OAK RIDGE National Laboratory | BUILDING TECHNOLOGIES RESEARCH AND INTEGRATION CENTER

Joshua New, Ph.D., C.E.M.

- **Career**
  - 2009+ Oak Ridge National Laboratory, R&D staff
    - ETSD, Building Technology Research & Integration Center (BTRIC), Building Envelope & Urban Systems Research Group (BEUSR)
  - 2012+ The University of Tennessee, Joint Faculty
- **Education**
  - The University of TN, (2004-2009), Knoxville; Ph.D. Comp. Sci.
  - Jacksonville State University, AL (1997-2001, 2001-2004) M.S. Systems&Software Design, double-B.S. Computer Science and Mathematics, Physics minor.
- **Professional Involvement**
  - IEEE, Senior Member
  - ASHRAE, defines international building codes
    - TC1.5, Computer Applications, Voting member and officer
    - TC4.7, Energy Calculations, Voting member and officer
    - TC4.2, Climatic Information, Voting member and officer
    - SSPC169, Weather Data for Building Design Standards (24% of page count of building code), Voting member
    - SSPC140 and ASHRAE Guideline 14 involvement



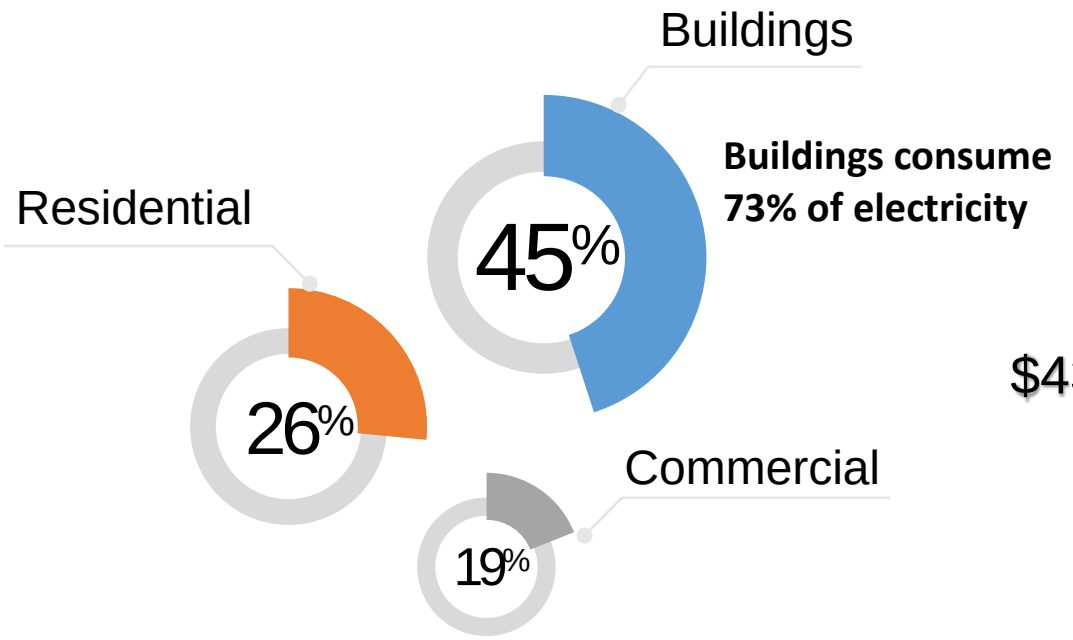
40 Years: Energy and Quality of Life



Energy Consumption

- China, India, United States, and United Kingdom consume 39-45% of each nation's primary energy
- China and India are on-track to triple 2010 building floor space by 2030
- Such fast-growing countries are projected to have buildings that use 76% of their primary energy by 2040
- UAE buildings currently consume 80% of UAE's energy
  - Dubai :70% of energy used by buildings
- Buildings (residential and commercial) are the largest energy-consuming sector in the world
- 20% savings, low-cost energy conservation measures
- 30-80% savings with return-on-investment (ROI) can be assessed with building energy models

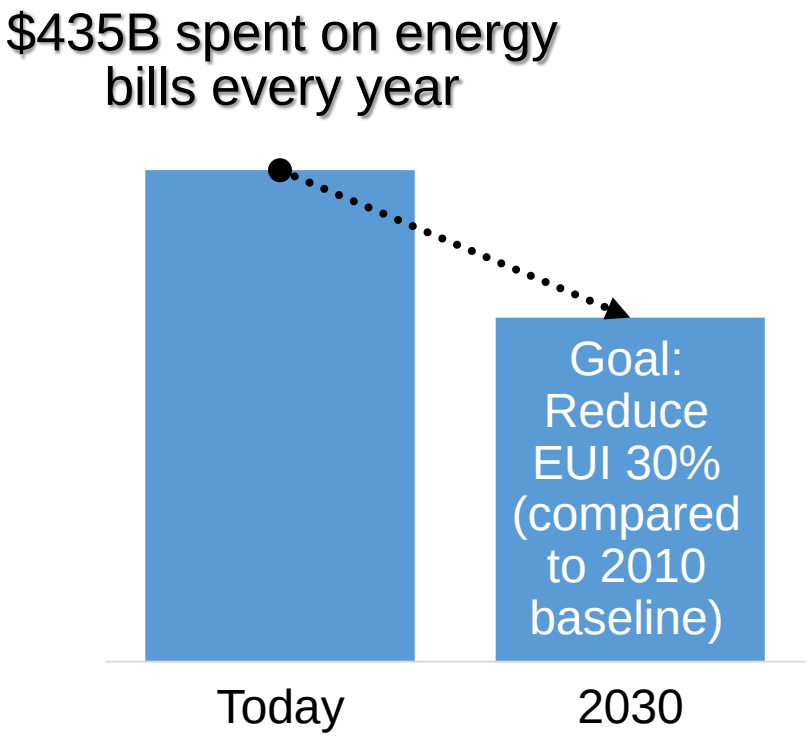
U.S. Building Energy Consumption



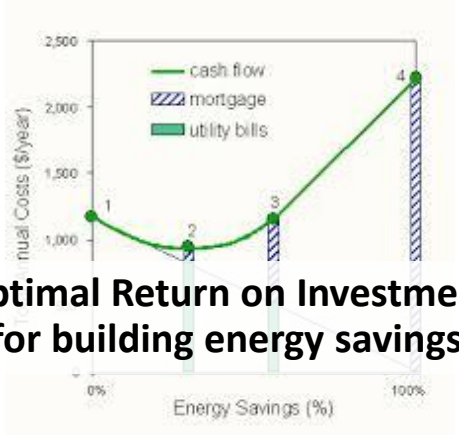
Buildings consume 73% of electricity

130 million U.S. Buildings
Building Energy Modeling – building descriptions + weather = estimated building energy consumption

$9B/yr – ESCO; $7B/yr – utility EE
$14B/yr – DR management systems
0.3% modified, BEM < 10% of those



Building Energy Modeling Overview



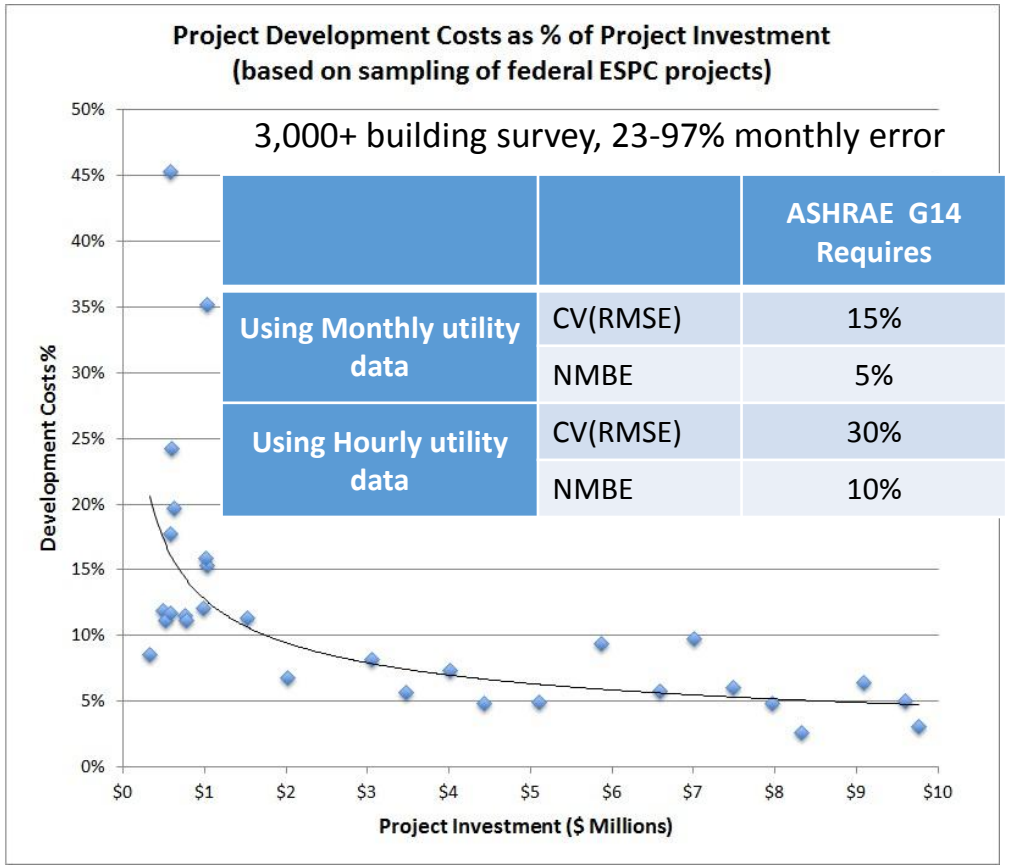
Optimal Return on Investment (for building energy savings)

Simulation Engine and Analysis Platform

DOE–$85M (1995–?)

EnergyPlus

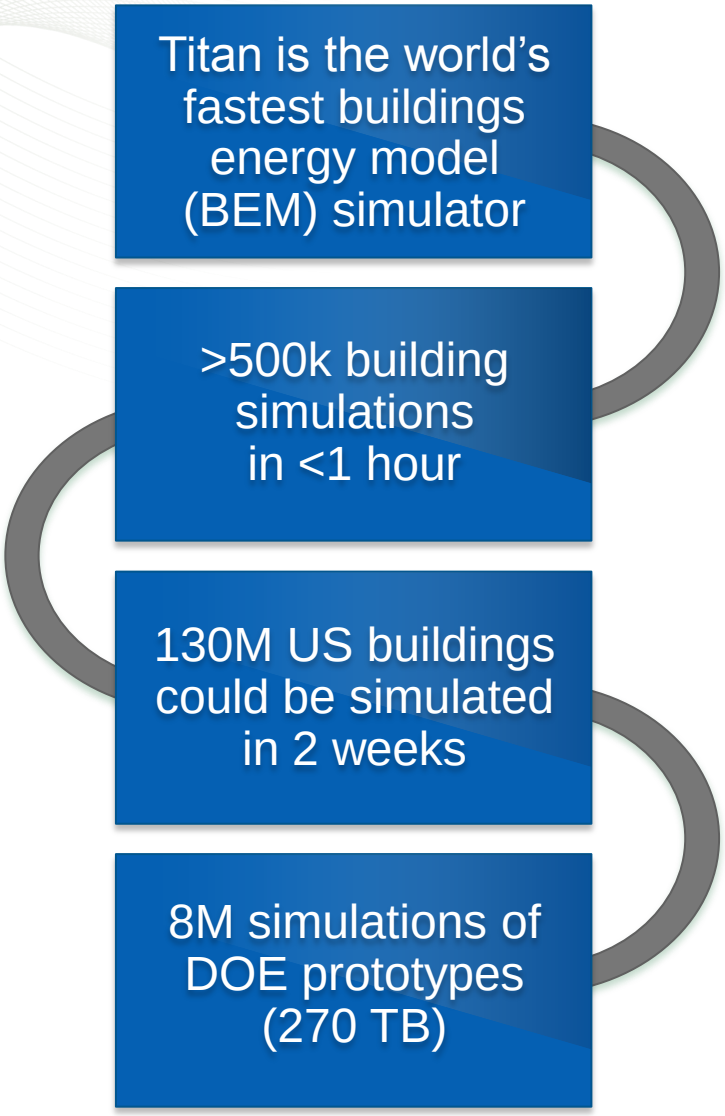
OpenStudio



		ASHRAE G14 Requires
Using Monthly utility data	CV(RMSE)	15%
	NMBE	5%
Using Hourly utility data	CV(RMSE)	30%
	NMBE	10%

Automatic calibration of software to data

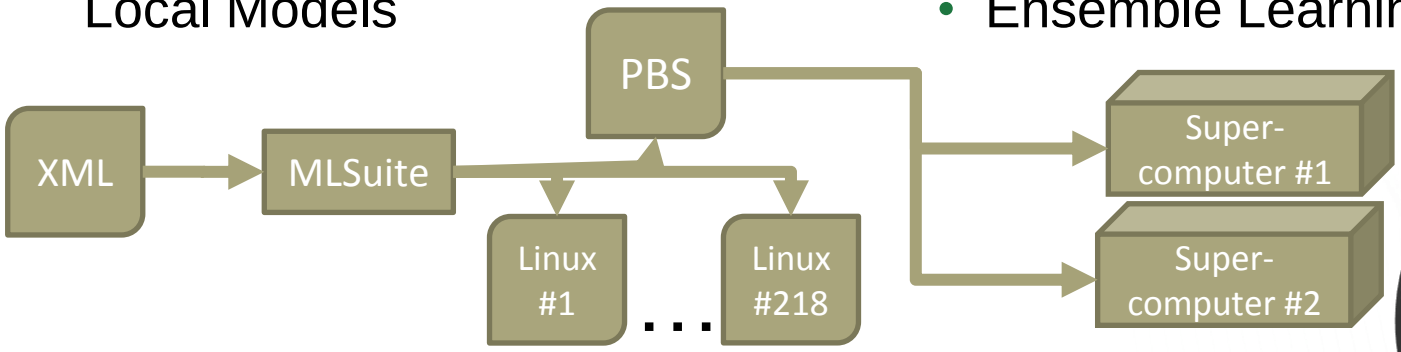
HPC scalability for desktop software



CPU Cores	Wall-clock Time (mm:ss)	Data Size	EnergyPlus Simulations
16	18:14	5 GB	64
32	18:19	11 GB	128
64	18:34	22 GB	256
128	18:22	44 GB	512
256	20:30	88 GB	1,024
512	20:43	176 GB	2,048
1,024	21:03	351 GB	4,096
2,048	21:11	703 GB	8,192
4,096	20:00	1.4 TB	16,384
8,192	26:14	2.8 TB	32,768
16,384	26:11	5.6 TB	65,536
32,768	31:29	11.5 TB	131,072
65,536	44:52	23 TB	262,144
131,072	68:08	45 TB	524,288

MLSuite: HPC-enabled suite of Artificial Intel.

- Linear Regression
- Feedforward Neural Network
- Support Vector Machine Regression
- Non-Linear Regression
- K-Means with Local Models
- Gaussian Mixture Model with Local Models
- Self-Organizing Map with Local Models
- Regression Tree (using Information Gain)
- Time Modeling with Local Models
- Recurrent Neural Networks
- Genetic Algorithms
- Ensemble Learning



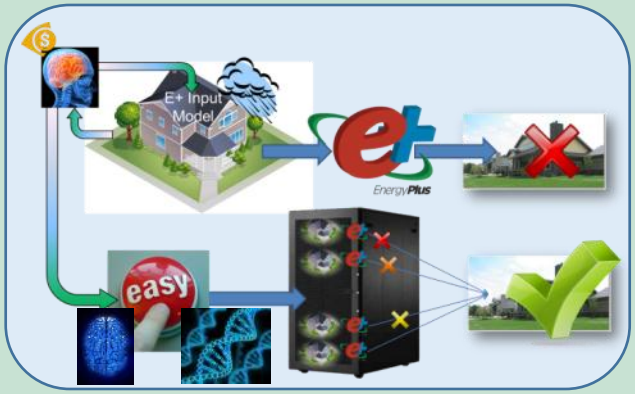
Acknowledgment: Dr. Lynne Parker (NSF Div. Dir. Info. and Intel. Systems); Dr. Richard Edwards (doctoral student, now Amazon's ad analytics)

Calibration Performance – automated M&V

National HPC Resources → **Applied Research** → **Industry and building owners**

High Performance Computing

- Different calibration algorithms
- Machine learning – big data mining
- Large-scale calibration tests



Features

- Calibrate any model to data
- Calibrates to the data you have (monthly utility bills to submetering)
- Runs on a laptop and in the cloud

- 35 Publications: `http://bit.ly/autotune_science`
- Open source (GitHub): `http://bit.ly/autotune_code`

Results

		ASHRAE G14 Requires
Monthly utility data	CVR	15%
	NMBE	5%
Hourly utility data	CVR	30%
	NMBE	10%

Results of 20,000+ Autotune calibrations
(15 types, 47-282 tuned inputs each)

Other error metrics

Residential home	Tuned input avg. error
Within 30¢/day (actual use $4.97/day)	Hourly – 8% Monthly – 15% 3 bldgs, 8-79 inputs

Leveraging HPC resources to calibrate models for optimized building efficiency decisions

Energy I-Corps/Lab-Corps

- Multiple organizations and countries using Autotune
- 6-week training program, commercialization of calibration software
  - Scientific method applied to the "business model canvas"
  - 115 interviews, evolve business model
  - Customer Segments: ESCOs and Utilities
    - Key technical gap:
      Utilities need a building energy model for every building in their service area

NTNU

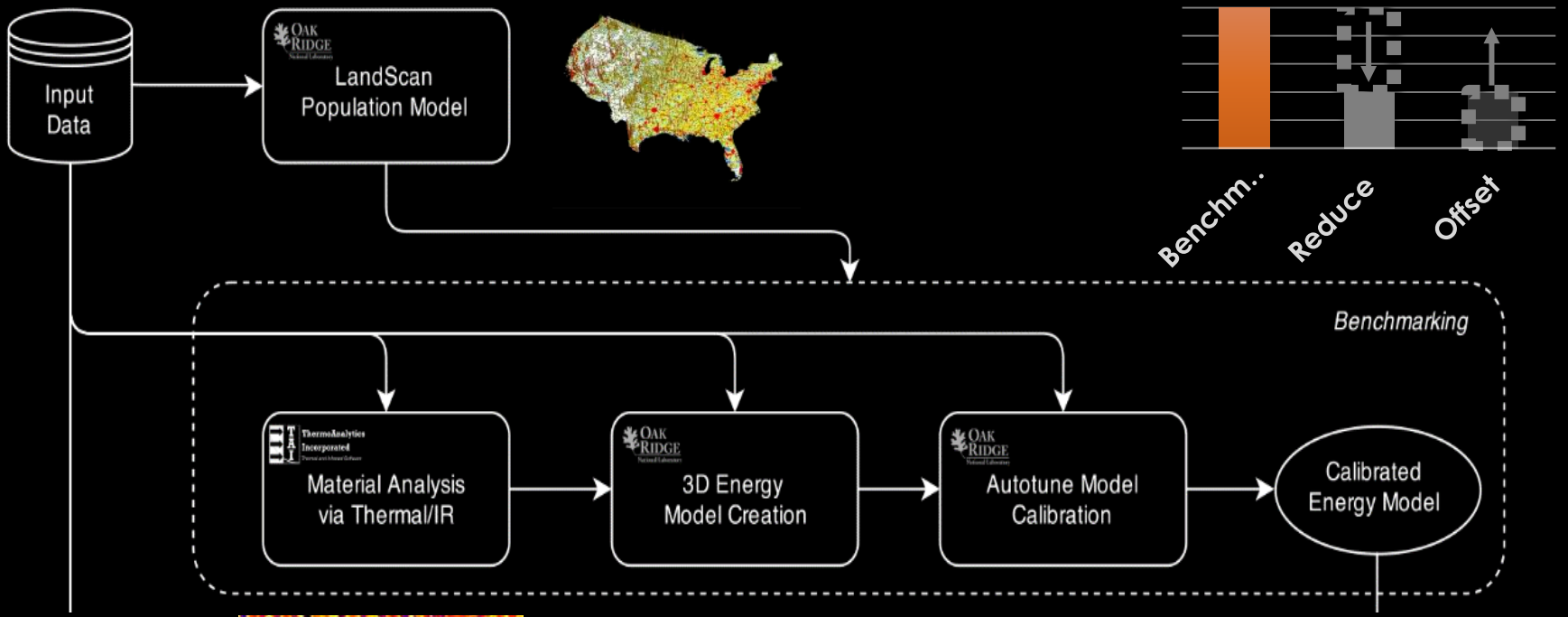
NASA

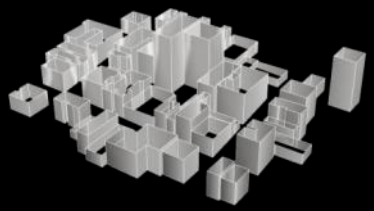
ICF INTERNATIONAL

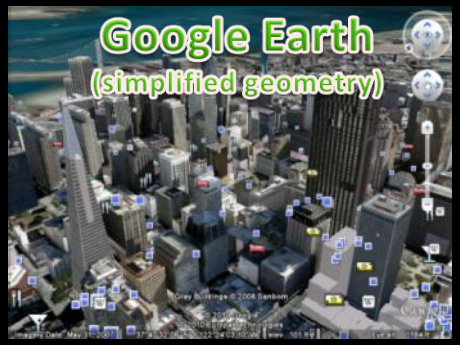
parallel.works

organic think

Model America - calibrated model for every US building

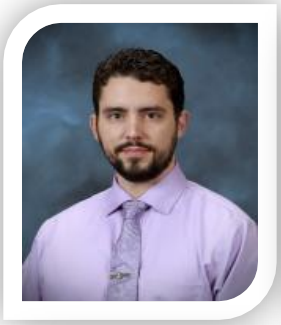






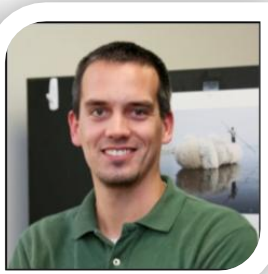
Acknowledgements

- U.S. Department of Energy
- National Nuclear Security Administration
- Oak Ridge National Laboratory
- Building Technologies Office
- Office of Electricity











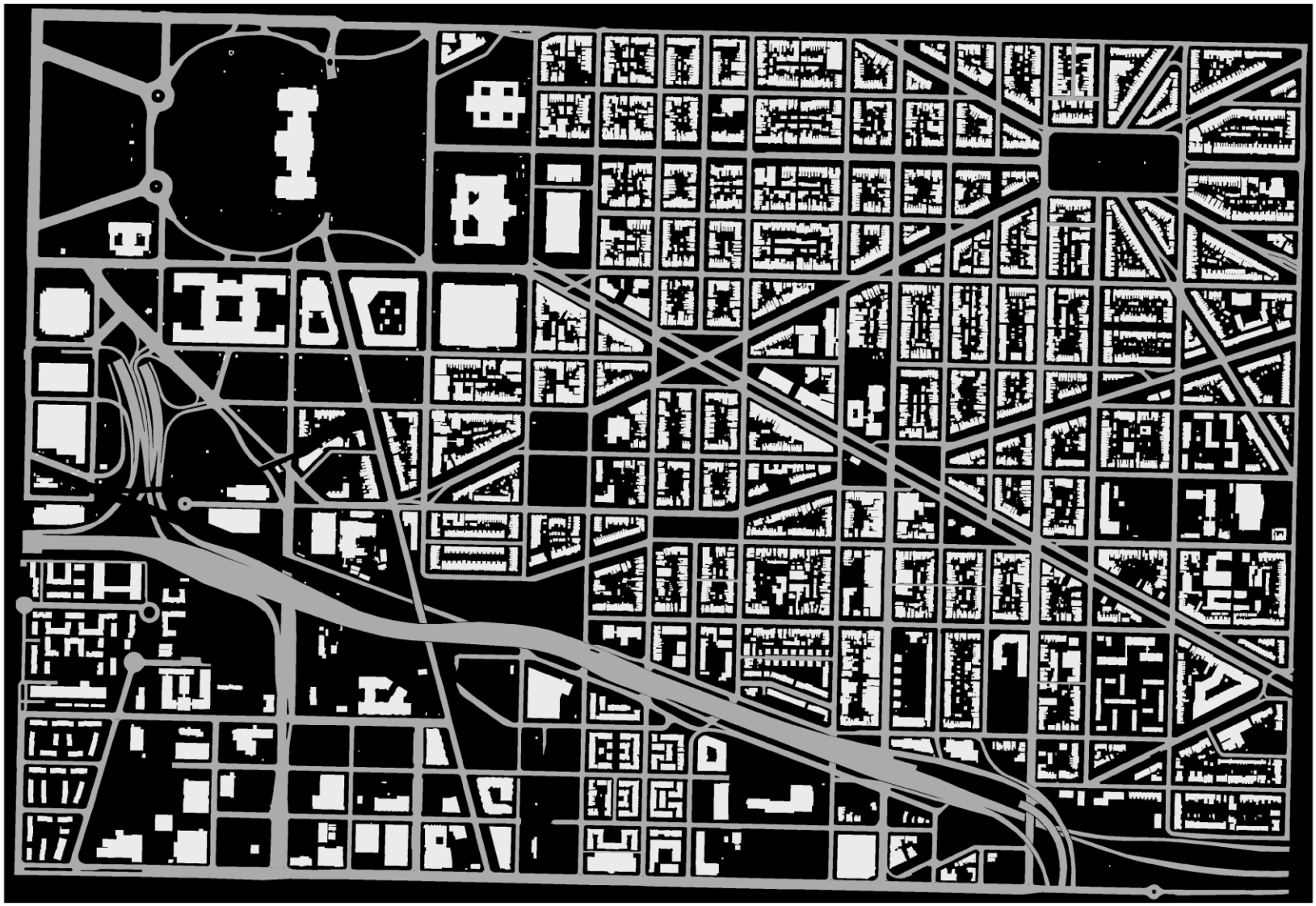



Data Sources

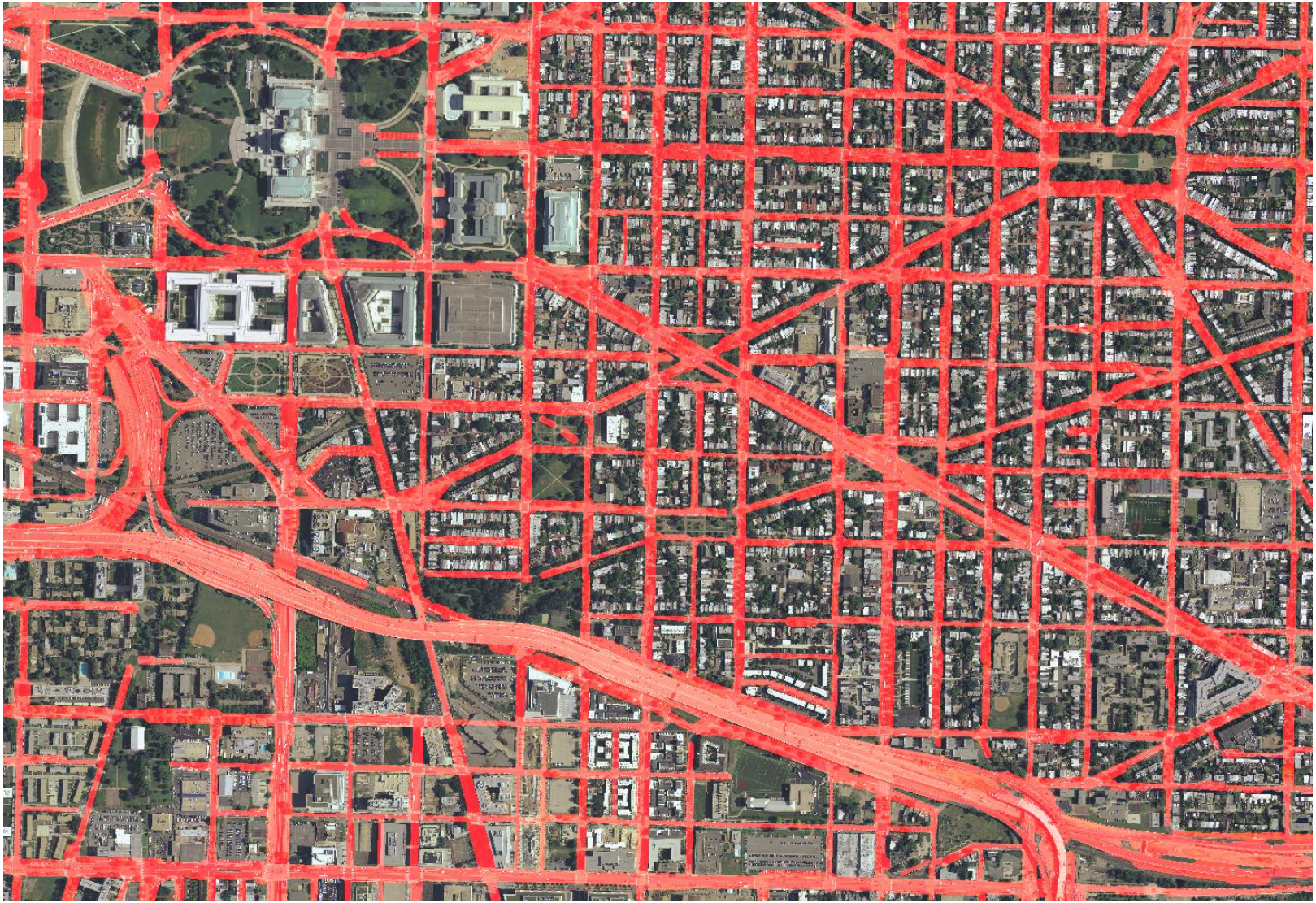
- Database and image sources for urban model generation
  - Satellite and airborne imagery
  - Cartographic data
  - Ground level images
  - Elevation data
  - Building information databases
  - 3D building model databases

	Short Title
Summary	Satellite imagery, including panchromatic and multispectral images
Data type	Image
Company	
Website	
Temporal resolution	Cities - 3-11 times per week
Spatial resolution	0.3 m
Measure accuracy	
Cost	$11 per sq. km
Format	GeoTiff
Mapping to building input variables	Building footprints
Mapping to area properties	Vegetated areas, road surface, buildings, parking lots
Mapping to material properties	Road pavement materials (e.g., concrete, asphalt), parking lots (e.g., gravel, soil)
Coverage of US	Over 10 million km^2 of coverage of the contiguous US
Orientation	Aerial
Existing internal software	N/A
Existing expertise	Remote sensing data analysis tool
Restrictions	N/A
Comments	

Manual Segmentation of Washington D.C.



Automatic Road Extraction



Automatic Building Footprint Extraction

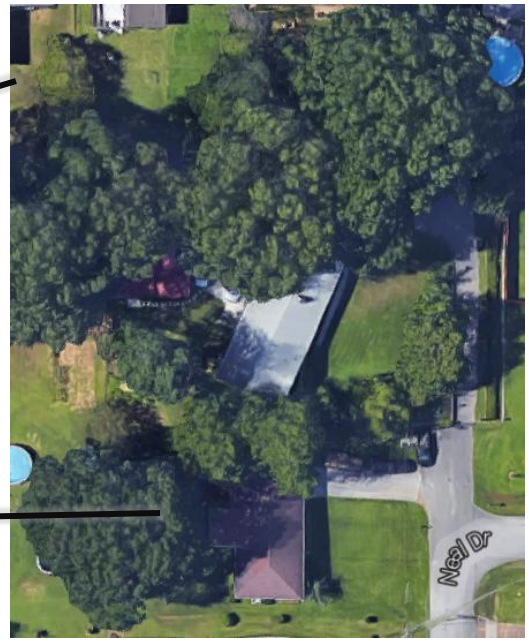
Algorithm: Deep Learning extended and using GPUs for fast building footprint and area extraction over large geographical areas.

Multi-company Competition Precision/Recall – 30/35; Current Precision/Recall – 60+/60+

Comparison to canonical data sets

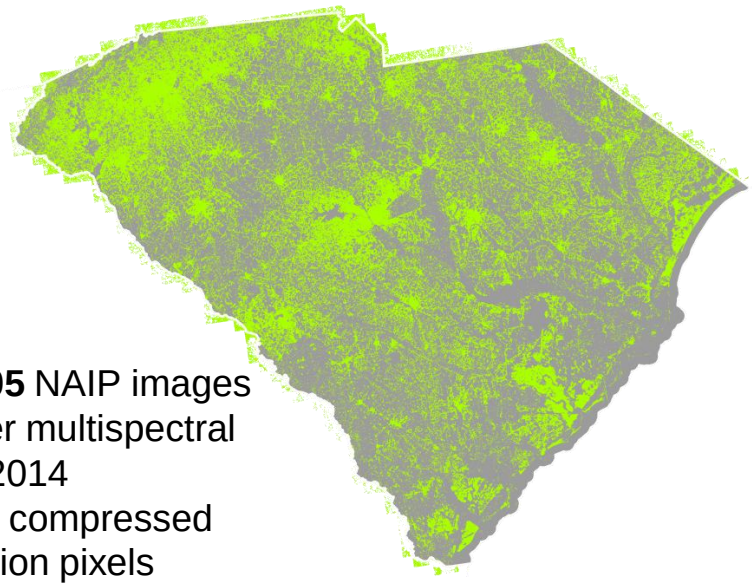
TNGIS Building Data

Lidar to Polygon



- Trees block return for building classification affecting shape.
- Shapes are irregular.

Automatic Building Footprint Extraction



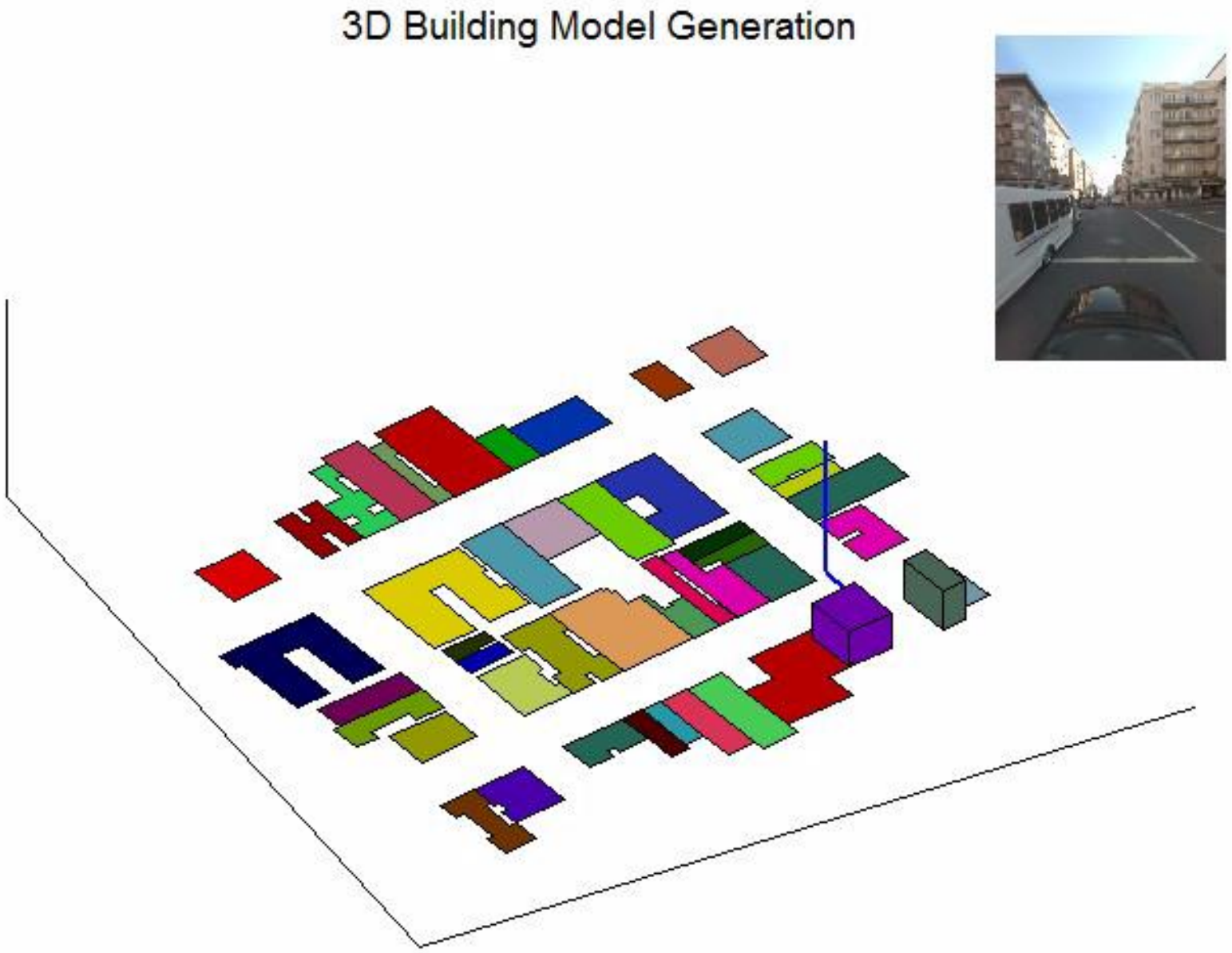
- **220,005** NAIP images
- 1 meter multispectral
- 2012-2014
- 5.8 TB compressed
- 9.8 trillion pixels

Portland, OR (25,393 m²)
Imagery: June – July 2012
Lidar: September 2010

Frankfort, KY (14,801 m²)
Imagery: June 2012
Lidar: June 2011

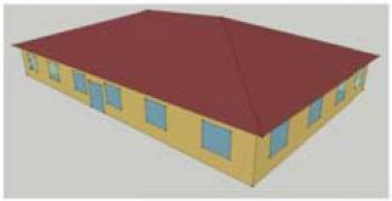
Part of Knox County, TN (18,527 m²)
Imagery: June 2012
Lidar: October 2014

Processing Street-Level Imagery

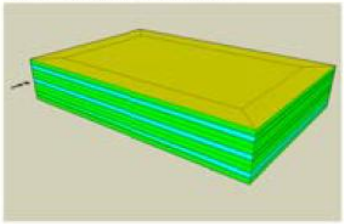


Prototype Buildings

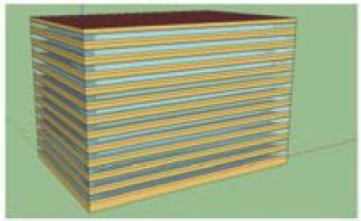
Small Office



Medium Office

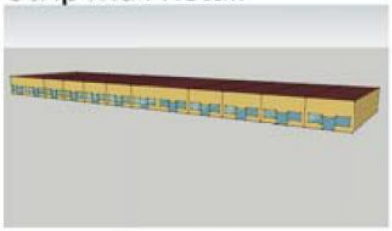


Large Office

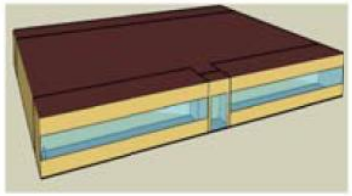


Warehouse

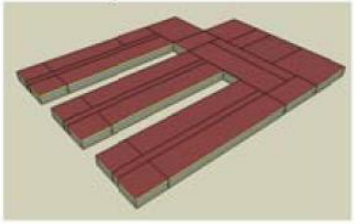
Strip Mall Retail



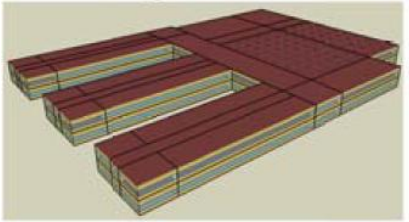
Standalone Retail



Primary School

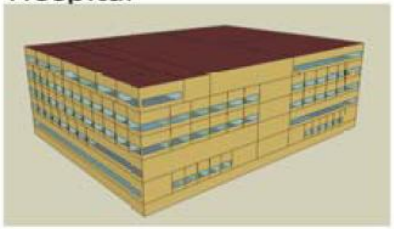


Secondary School



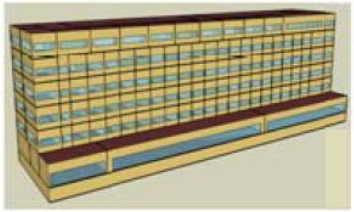
Outpatient Healthcare

Hospital

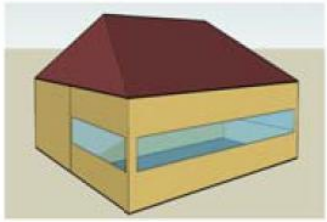


Small Hotel

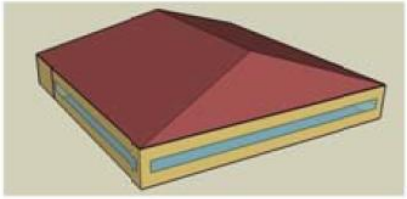
Large Hotel



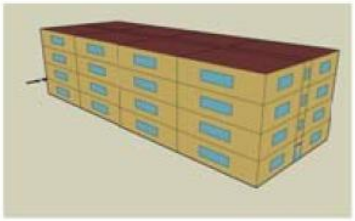
Quick-service Restaurant



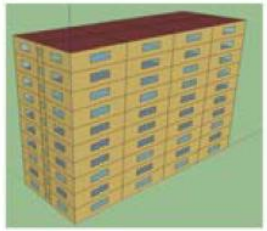
Full-service Restaurant



Mid-rise Apartment



High-rise Apartment



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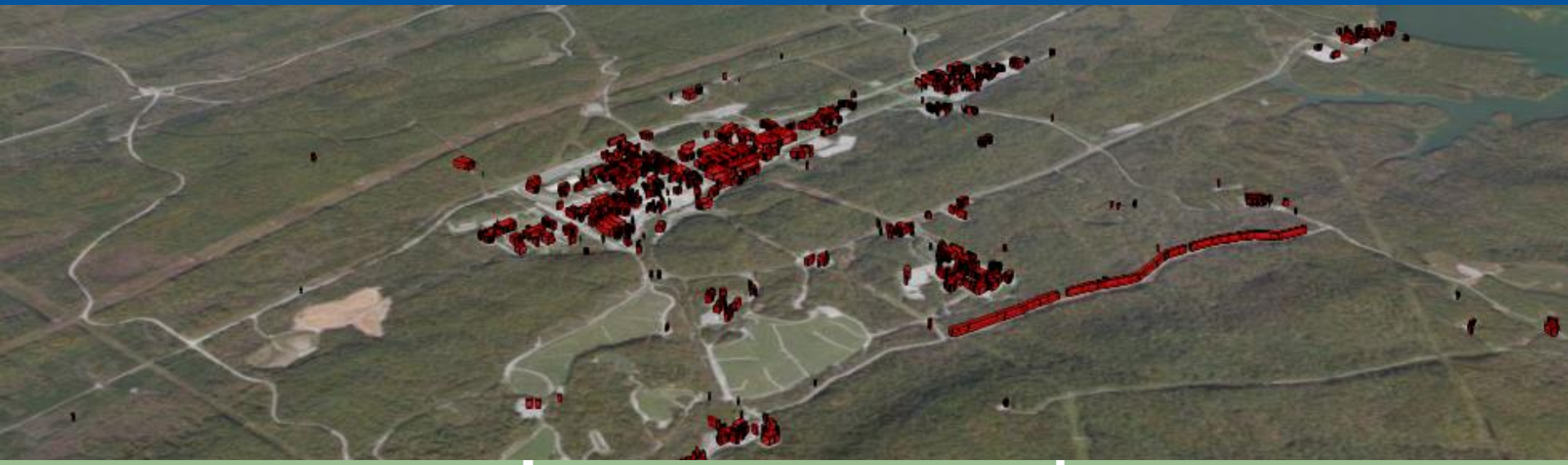

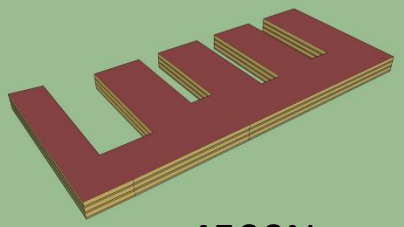

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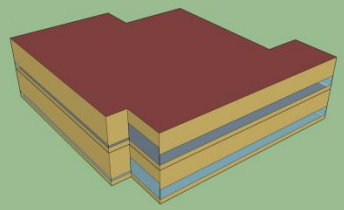

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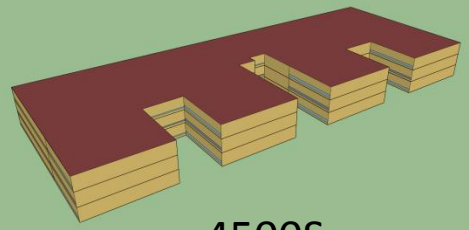

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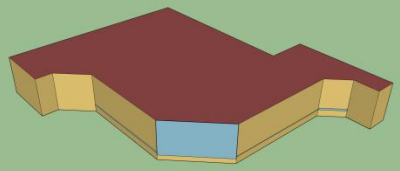

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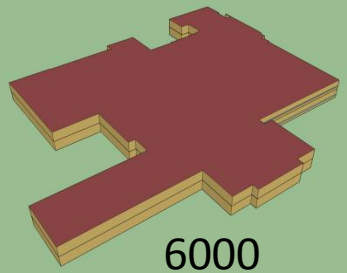

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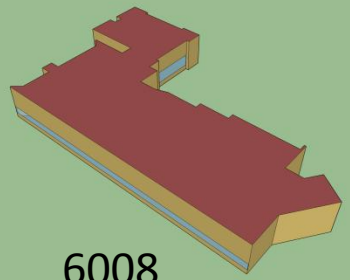

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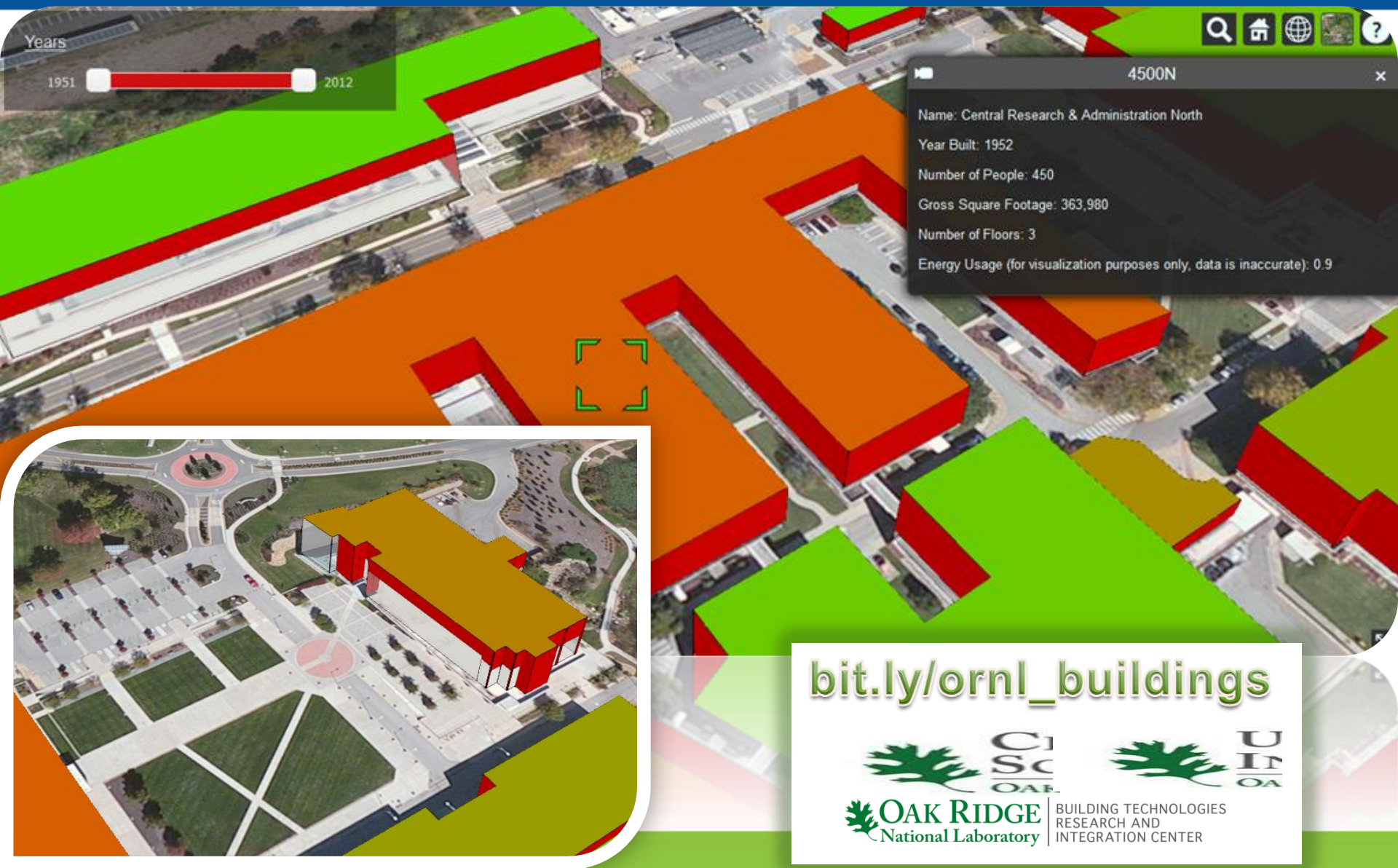
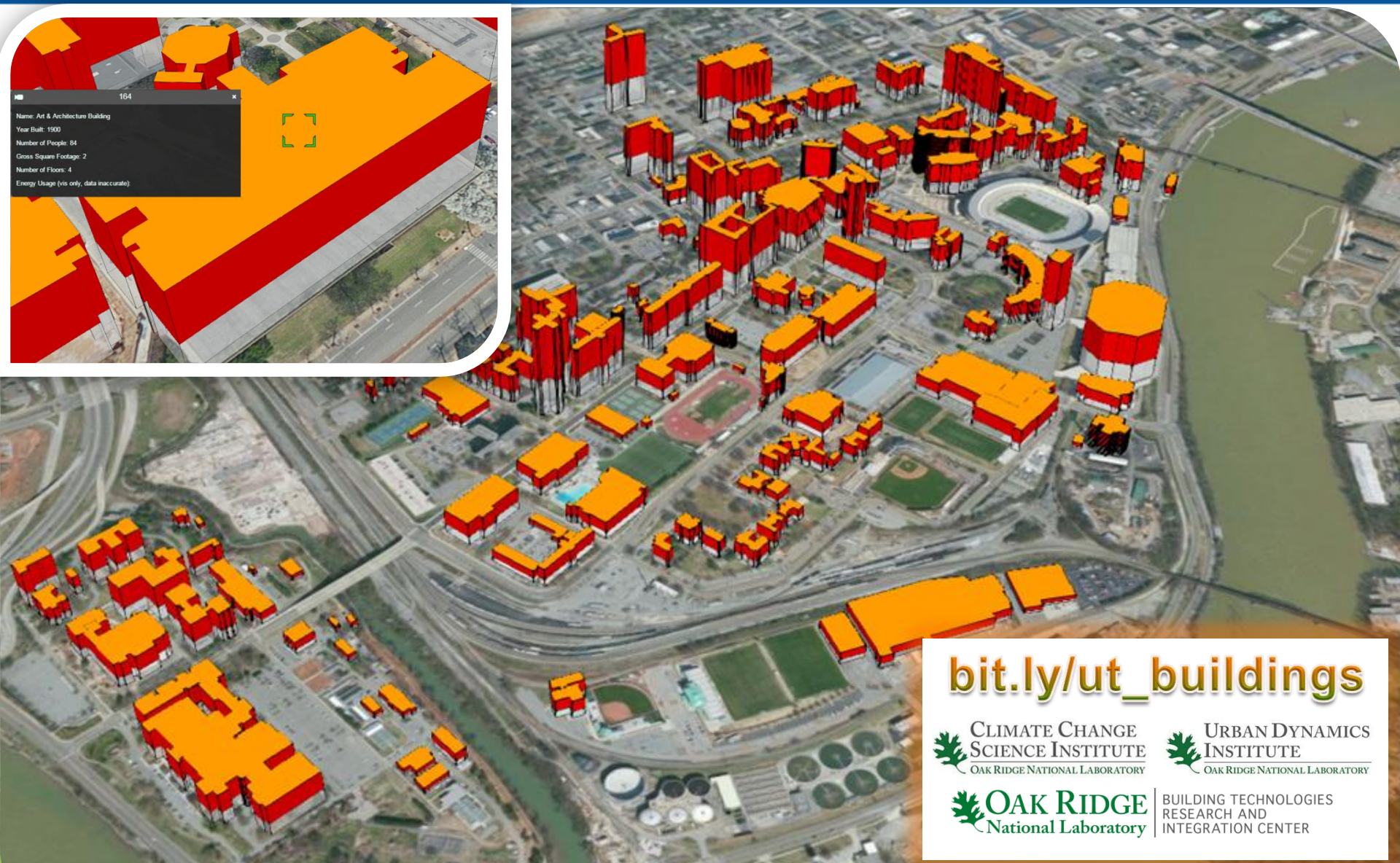
Oak Ridge National Laboratory (interactive)



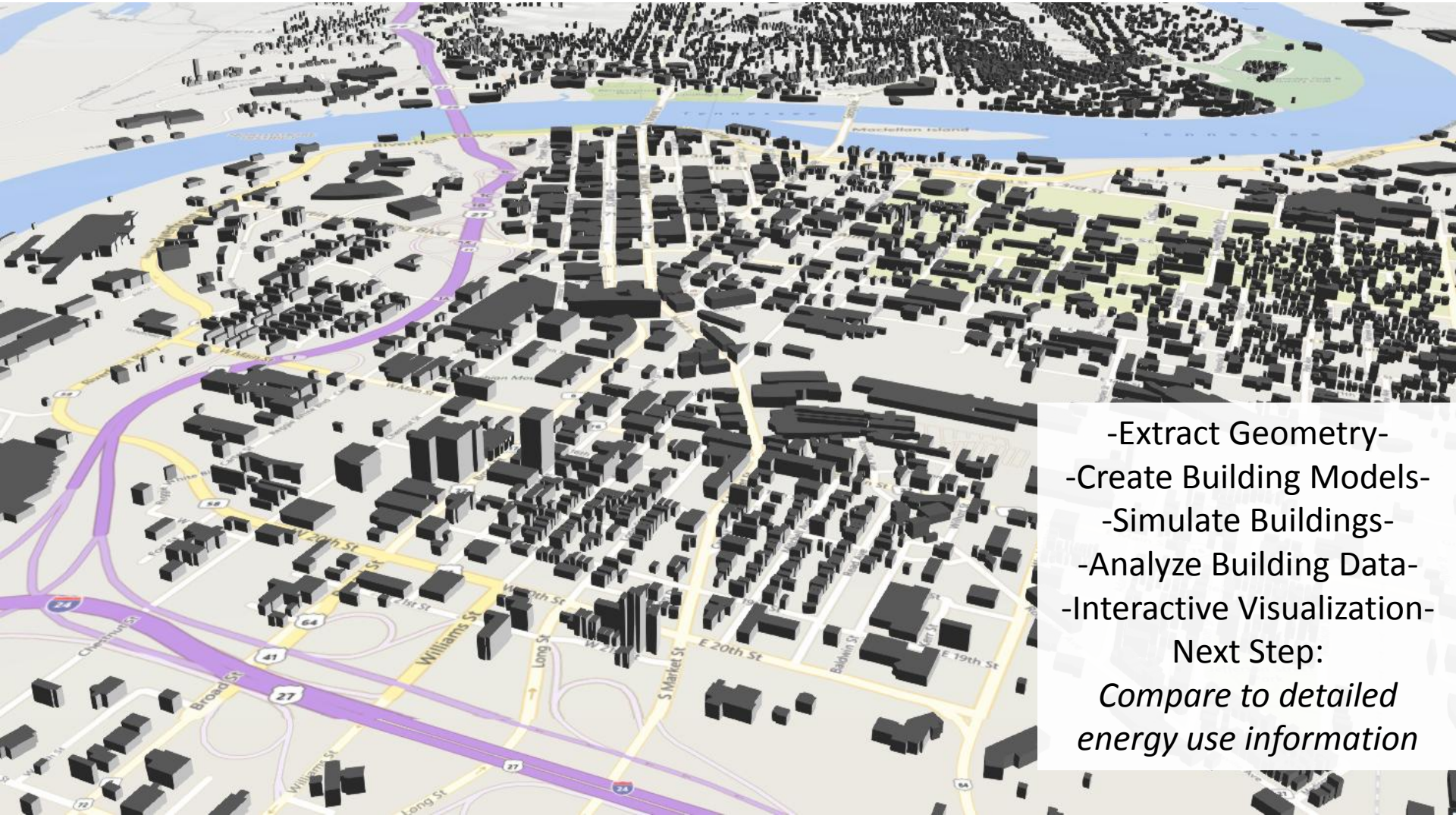
bit.ly/ornl_buildings

OAK RIDGE National Laboratory | BUILDING TECHNOLOGIES RESEARCH AND INTEGRATION CENTER

The University of Tennessee (2 days)

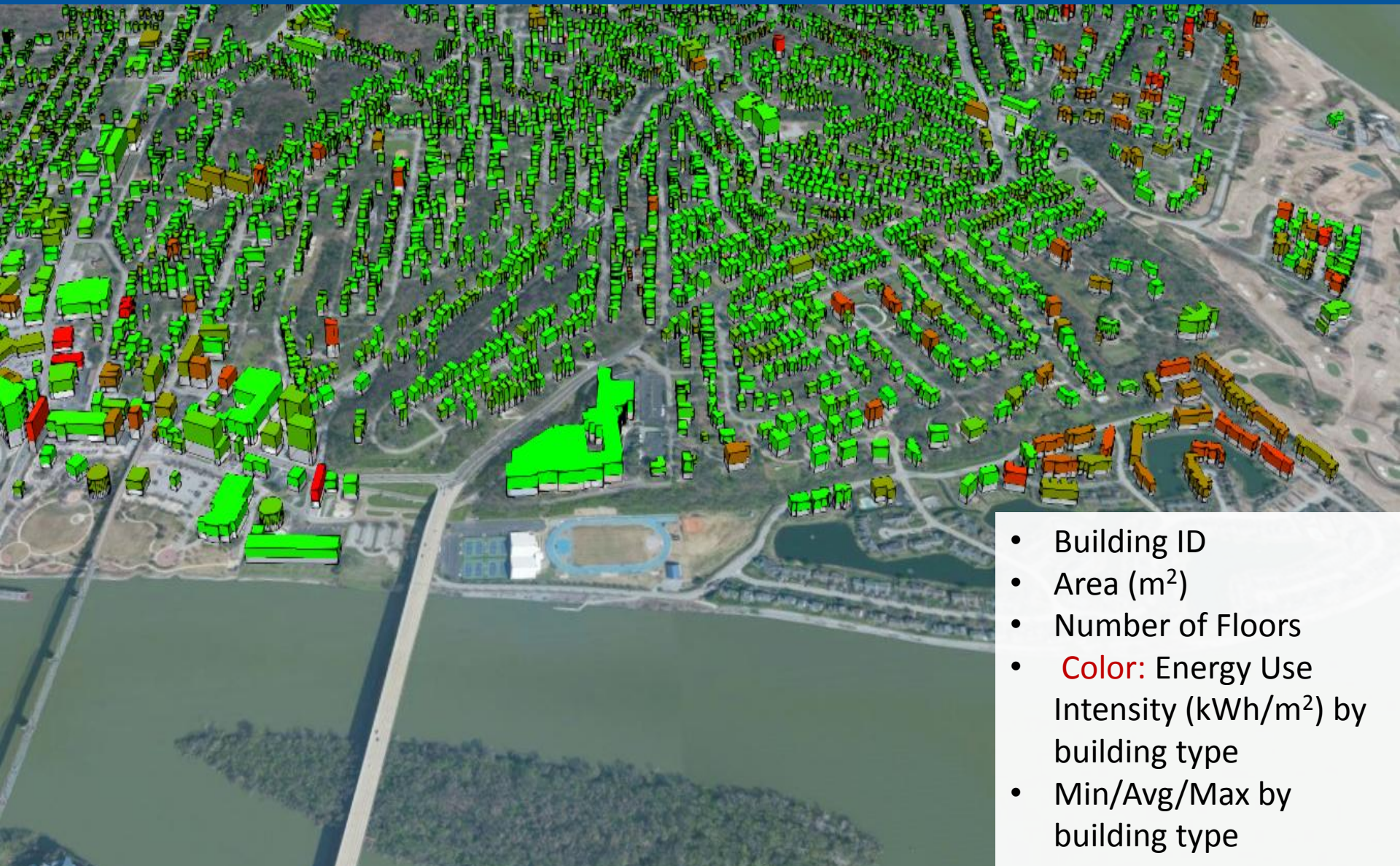


Virtual EPB (135,481 buildings – geometry only)



-Extract Geometry-
-Create Building Models-
-Simulate Buildings-
-Analyze Building Data-
-Interactive Visualization-
Next Step:
Compare to detailed energy use information

Virtual EPB (135,481 buildings – simulation results)



- Building ID
- Area (m^2)
- Number of Floors
- Color: Energy Use Intensity (kWh/m^2) by building type
- Min/Avg/Max by building type

Output: Grid Modernization Load Models, EE programs, Transactive Energy, Utility/Distributor Business Models (EaaS), Actionable Sustainability Plan, Carbon Neutrality

1) Demand-Side Building Efficiency

2) Supply-Side Infrastructure Enhancements

3) Responsible Renewables Implementation

Discussion

Joshua New, Ph.D., C.E.M.

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HPC Tools for
Modeling and Simulation
Capturing building energy consumption