OAK RIDGE National Laboratory

Artificial Intelligence: AI-facilitated Building Design

Presenters:
ORNL – Brett Bass, Ph.D. and Joshua New, Ph.D., C.E.M., PMP, CMVP, CSM, IREE

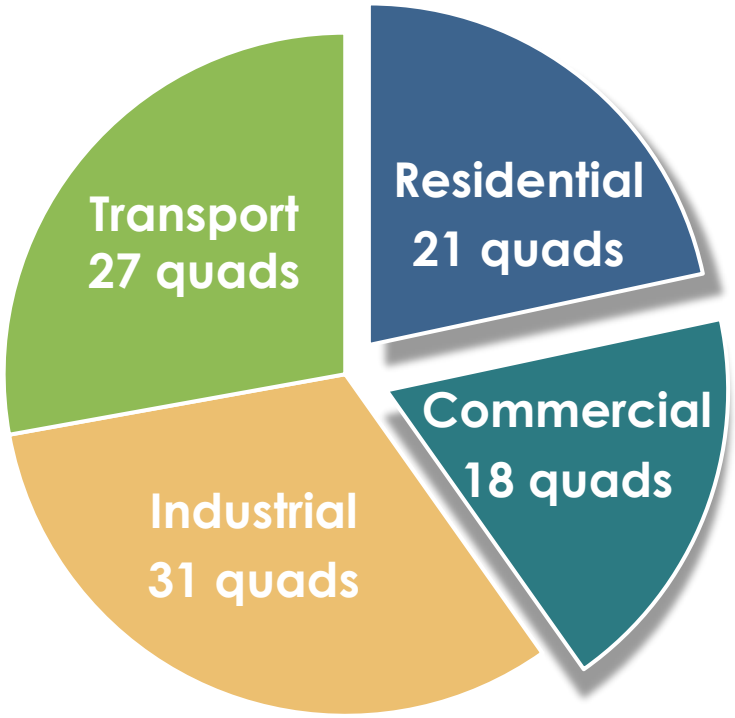
SmithGroup – Peter McNally, Stet Sanborn

Computational Design Detroit (co.de.D) and Turing School of Software & Design – Leland Curtis

ORNL is managed by UT-Battelle LLC for the US Department of Energy

U.S. DEPARTMENT OF ENERGY

U.S. Energy and Buildings Overview



40% energy use
39% emissions

125 million buildings

~$400 billion in energy bills

73% of electricity use
80% of peak demand

Goal of DOE's Building Technologies Office:
30% EUI reduction
by 2030 compared to 2010 baseline

Building Energy Modeling
building descriptions + weather = estimated building energy consumption, demand, emissions, equity, …

5-year vision

Digital Twin of every U.S. Building by 2020
Methodology: Scalable compute, data, simulation, and empirical validation

1. Quantitatively rank most important building inputs

	Small Office	Outpatient	Large Office	Medium Office	Hospital	Warehouse	Small Hotel	Large hotel
Inputs	458	3483	1072	760	1955	333	1823	887
	Strip Mall	Retail	Quick Service Restaurant	Full Service Restaurant	Mid Rise Apt	High Rise Apt	Secondary School	Primary School
Inputs	800	438	281	286	1464	4617	1621	1051

Sensitivity Analysis

2. Time on world's #1 fastest high-performance machines

Supercomputers

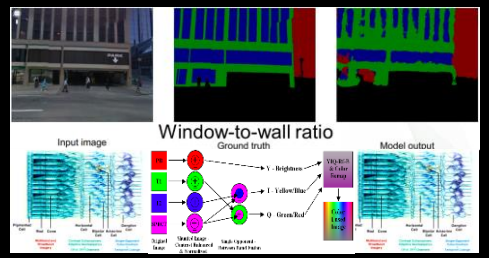
3. Identify and compare data sources for important inputs

	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 km² of coverage of the contiguous US
Orientation	Aerial
Existing internal software	N/A
Existing expertise	Remote sensing data analysis tool
Restrictions	N/A
Comments	

Comparison Matrix

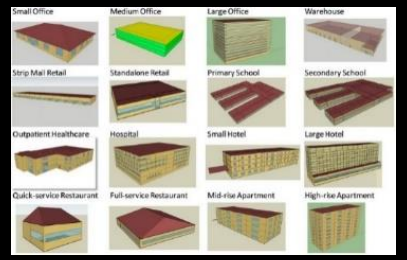
4. Establish partnerships and APIs for scalable data retrieval

5. Algorithms to extract building properties

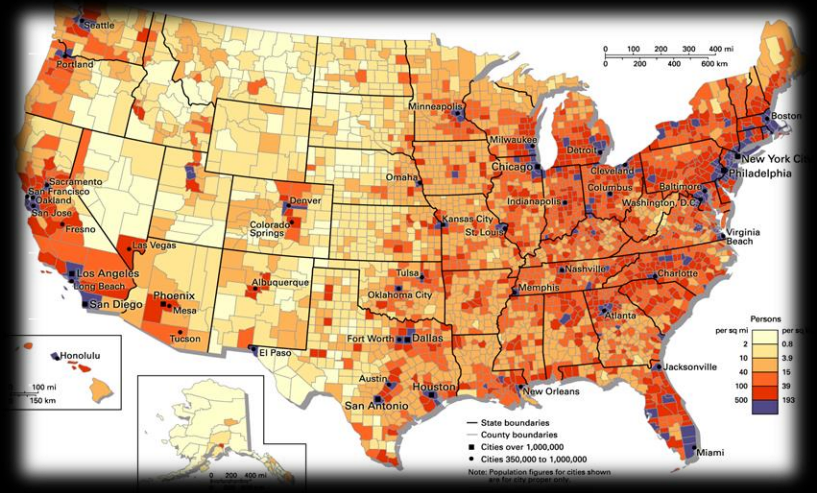


Computer Vision

6. Create OpenStudio & EnergyPlus models



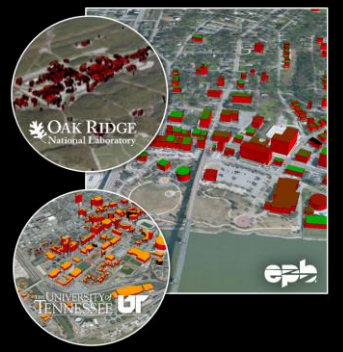
DOE Prototype Buildings



7. Make models freely available online

Download BEM for your building(s)

HPC Tools for Modeling and Simulation
Capturing building energy consumption



Demonstrate and stimulate opportunities toward a sustainable built environment

Use cases:
- Simulation-informed analysis
- Utility program formulation (utility)
- Business model evaluation (ESCO)
- City-scale emissions (cities)
- Sales/marketing leads (local jobs)
- New building design (AEC firms)
- Resilience (government, insurance)
- Automated financing (PACE, banks)

Building simulation at scale

Simulation Engine and Analysis Platform
U.S. Dept. of Energy
$100+M, 1995–?

EnergyPlus

OpenStudio

Free, open-source (GitHub), community support
100 – 2,000 improvements per building

Theta is the world's fastest buildings energy model (BEM) simulator

Use over 80% of the HPC resource

125M US buildings could be simulated in 2 weeks

8M simulations of DOE prototypes (270 TB)

Titan supercomputer

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
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

1,068,813 bldgs/hr
6 utilities/hour

Theta supercomputer

CPU Cores	Wall-clock Time (mm:ss)	Data Size	EnergyPlus Simulations
57,344	20:44	440 GB	229,376
114,688	28:20	880 GB	458,752

45 million core-hours (2021) and
51 million core-hours (2022) on
Argonne's Theta supercomputer

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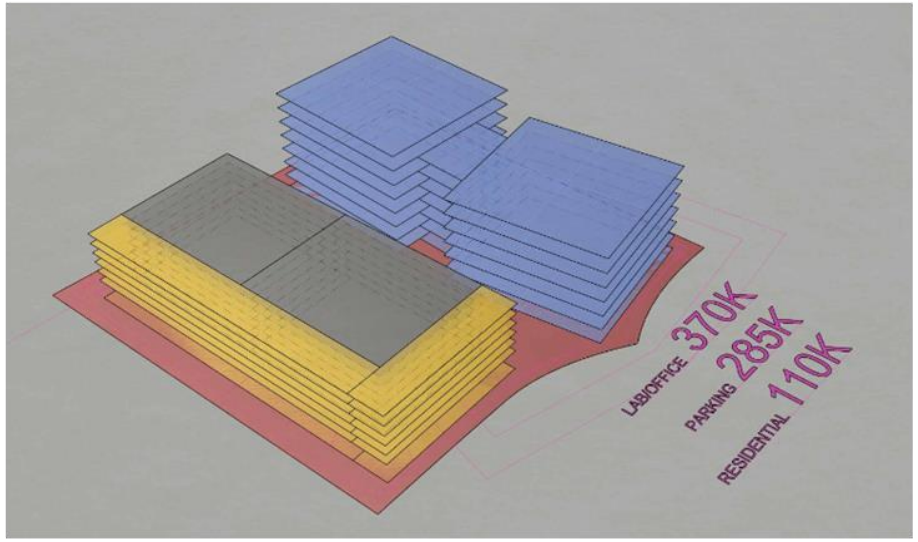
Nation-scale…

- **Free model of every U.S. building (bit.ly/ModelAmerica)**
  - OpenStudio (v3.1.0) and EnergyPlus (v9.4)
  - State_county.zip (requires free Globus Connect Personal)
  - New, Joshua R., Adams, Mark, Bass, Brett, Berres, Anne, and Clinton, Nicholas (2021). "Model America – data and models of every U.S. building." ORNL Constellation, https://doi.ccs.ornl.gov/ui/doi/339, April 14, 2021.
- 125,714,640 buildings, 124,178,694 simulated, 122,930,327 (97.8%) shared
- Dynamic archetypes of models and floor area multipliers for any geographical region
- Automatic Building Energy Modeling (AutoBEM) software
  - Related publications: bit.ly/AutoBEM

Design Pace

Project Information

ARCHITECTURAL SITE PLAN A



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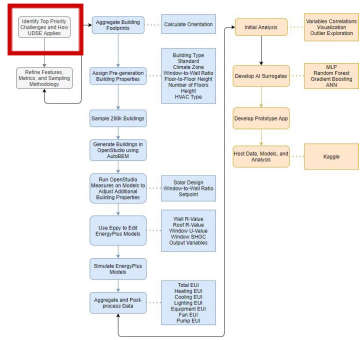
The Problem With Performance Analysis



Current:

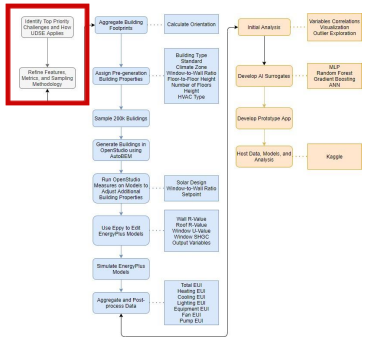
CONSULT PERFORMANCE ANALYSIS

Proposed:

DESIGN SPACE DATA

- IDENTIFY KEY DESIGN DRIVERS
- SET BOUNDARIES ("BUMPERS")
- IDENTIFY PATH TO HIGH PERFORMANCE

Design Space Exploration



WHAT IS A DESIGN SPACE?

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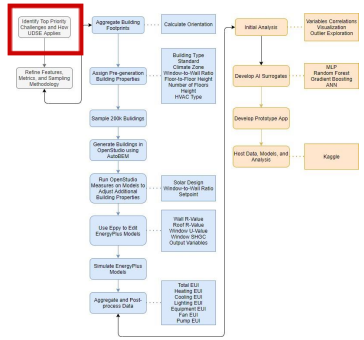
Design Space Exploration

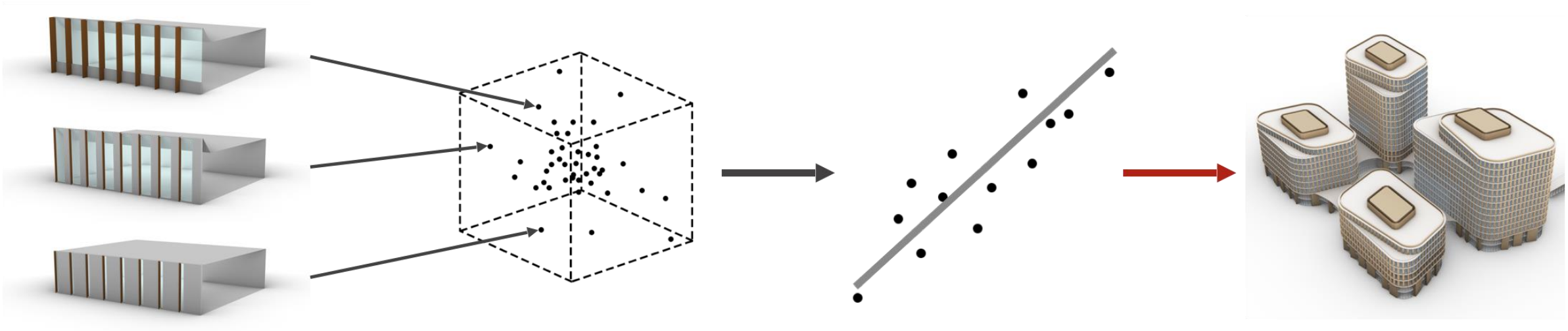


MODEL DESIGN DECISIONS

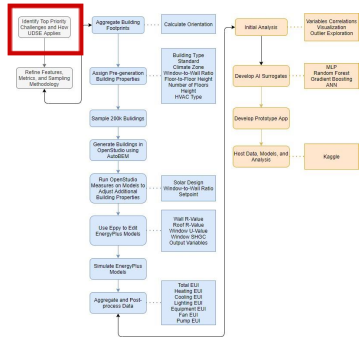
SIMULATE ITERATIONS

DATA ANALYTICS

INFORM DESIGN

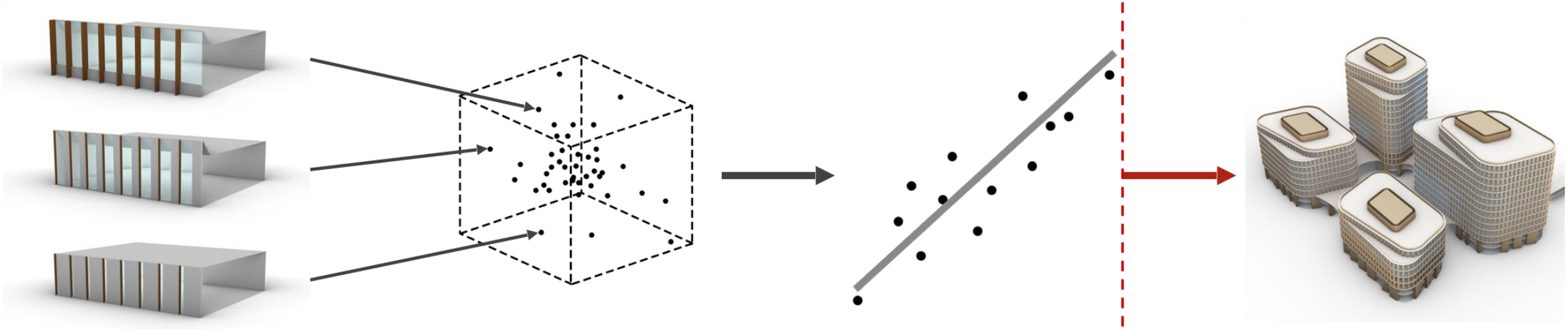


Universal Design Space Exploration

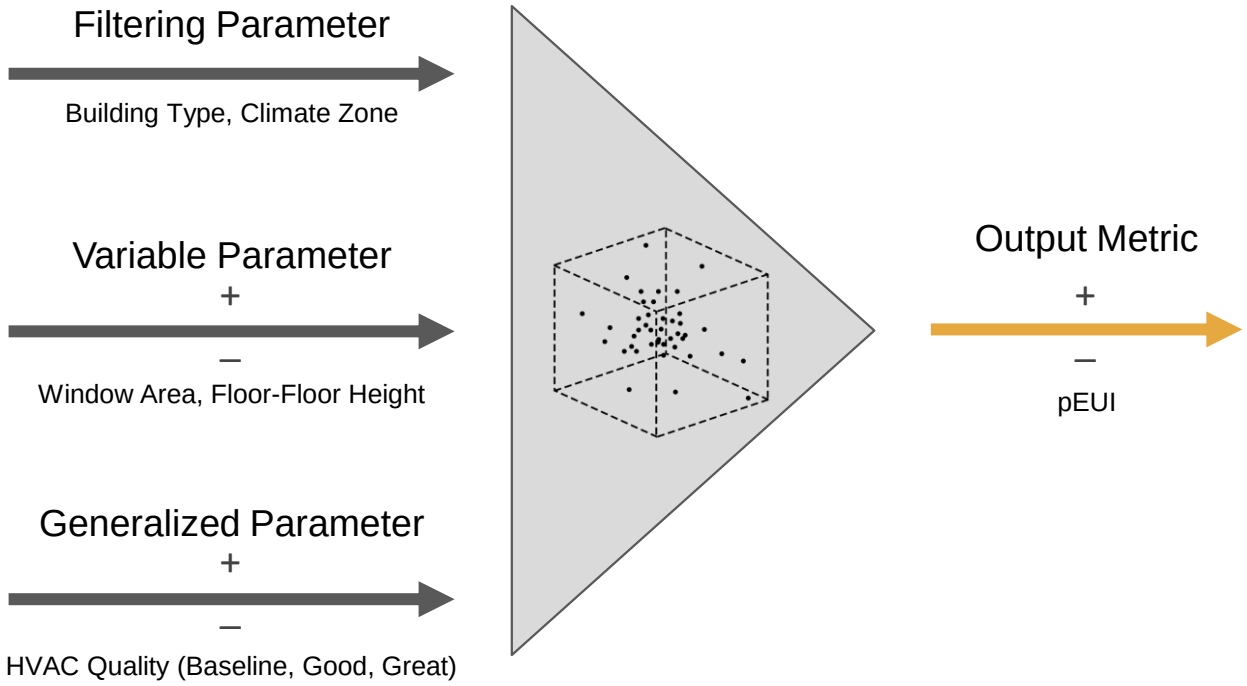


Pre-simulated analysis that encapsulates a common problem

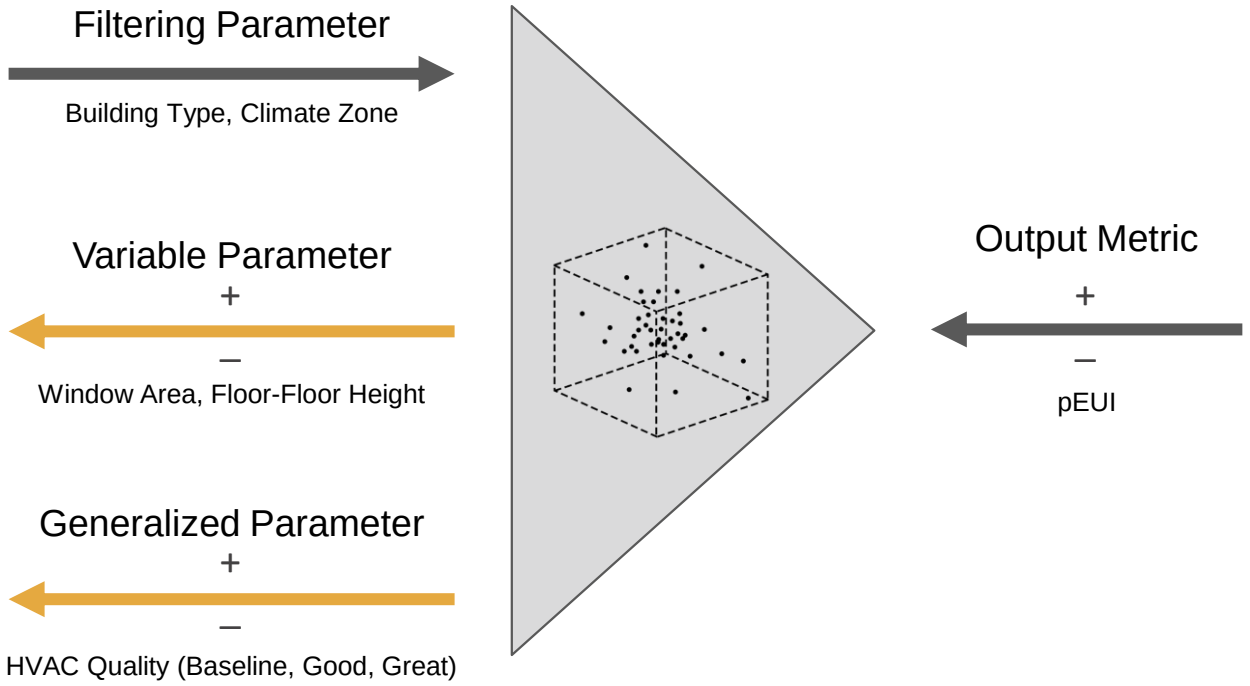
MODEL DESIGN DECISIONS **SIMULATE ITERATIONS** **DATA ANALYTICS** **INFORM DESIGN**



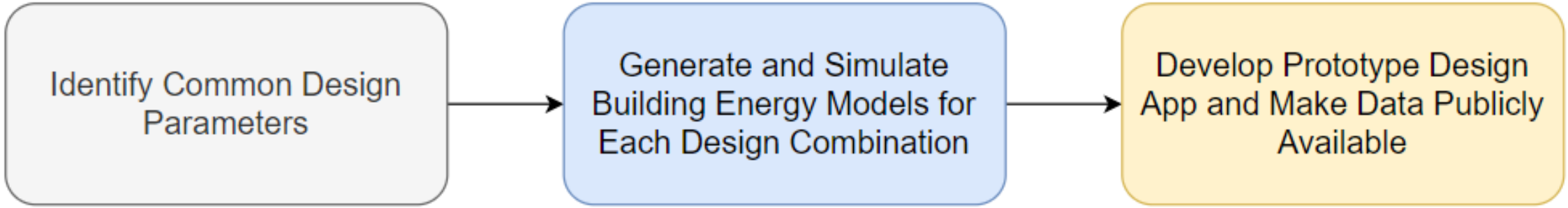
UDSE: Assign Inputs => Explore Outputs



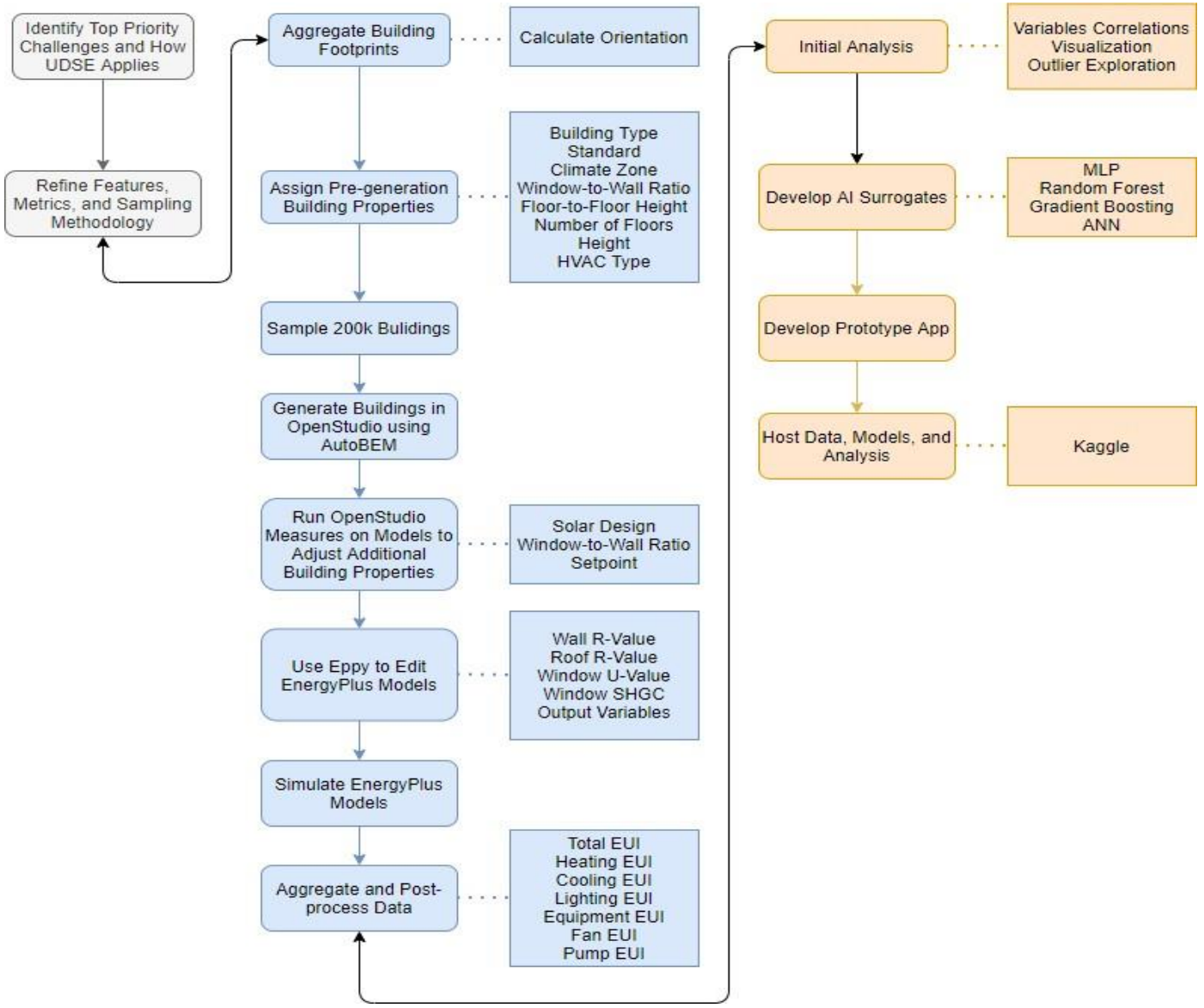
UDSE: Assign Outputs => Explore Input Ranges



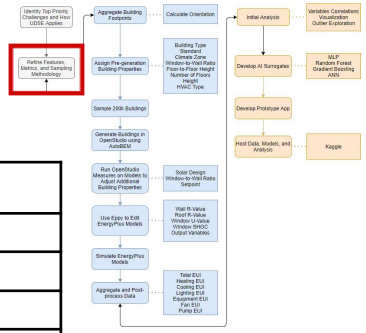
Universal Design Space Exploration Workflow



Universal Design Space Exploration Workflow



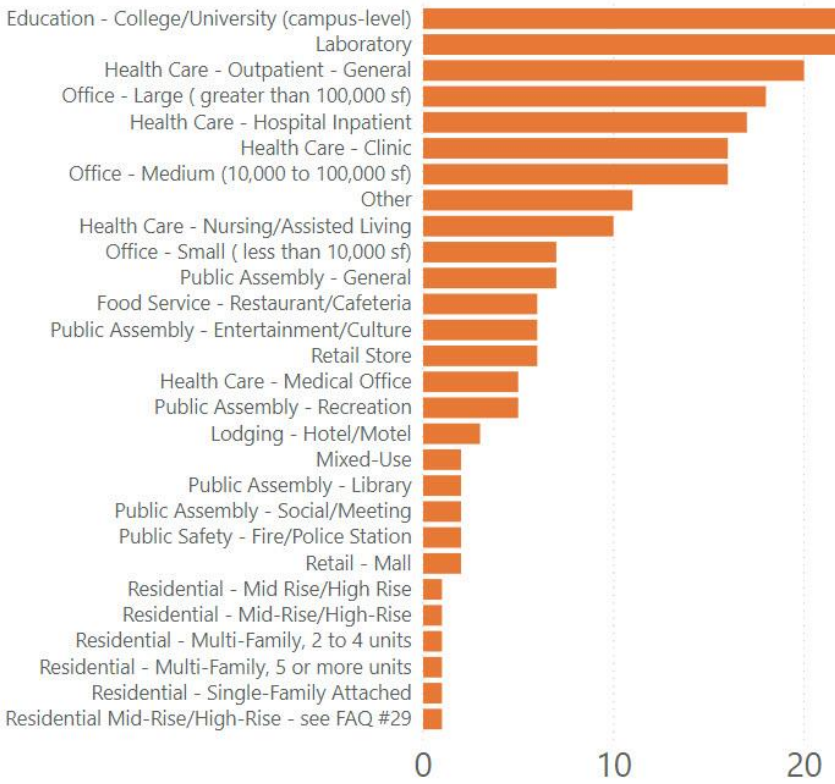
Parametric Sampling

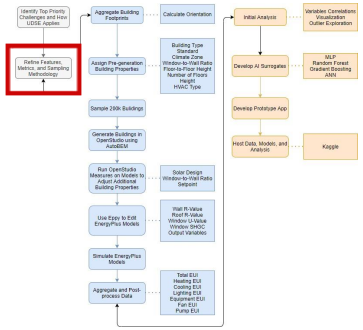


Sampling parameter	Inputs	Sampling parameter	Inputs
Program type	Higher education	Plate depth	Low
	Lab - high intensity		Typical
	Office		High
	Hospital	Floor-to-floor height	Low
	Healthcare - outpatient		Typical
	Residential (Apartments)		High
Climate zone	1A	Solar design	Bad
	1B		Typical
	2A		Good
	2B	Average window-to-wall ratio	0.25
	3A		0.4
	3B		0.7
	3C	Envelope quality	Baseline
	4A		High
	4B		Ultra
	4C	Construction type	Common
	5A		Less Common
	5B	Lighting power density	Baseline
	5C		Better
	6A		Best
	6B	HVAC system	Baseline
	7A		Good
	7B		Great
Total square footage	Low		Ultra
	Typical	Set points	Baseline
	High		Expanded
Target floor area	Low		
	Typical		
	High		

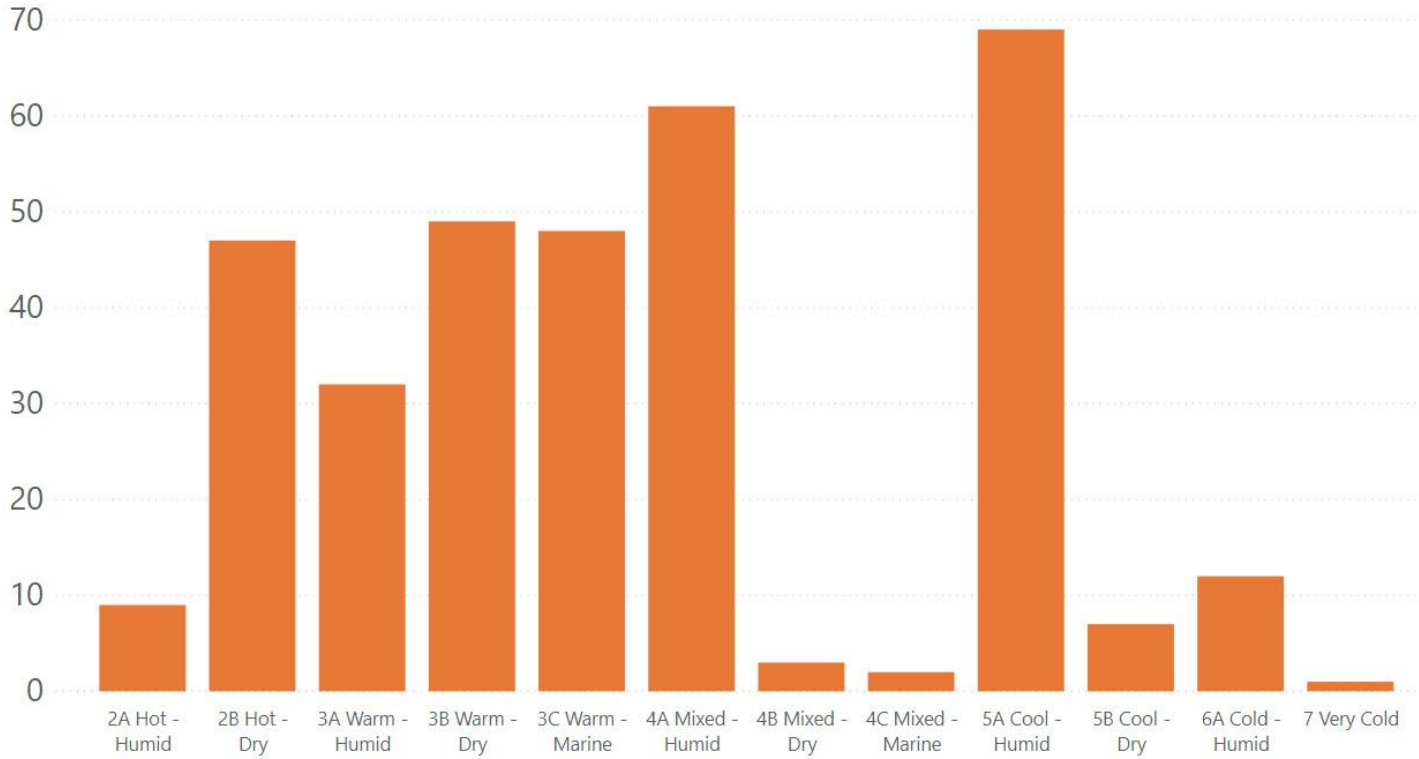
SmithGroup Projects

of Projects by Use Type





of Projects per Climate Zone



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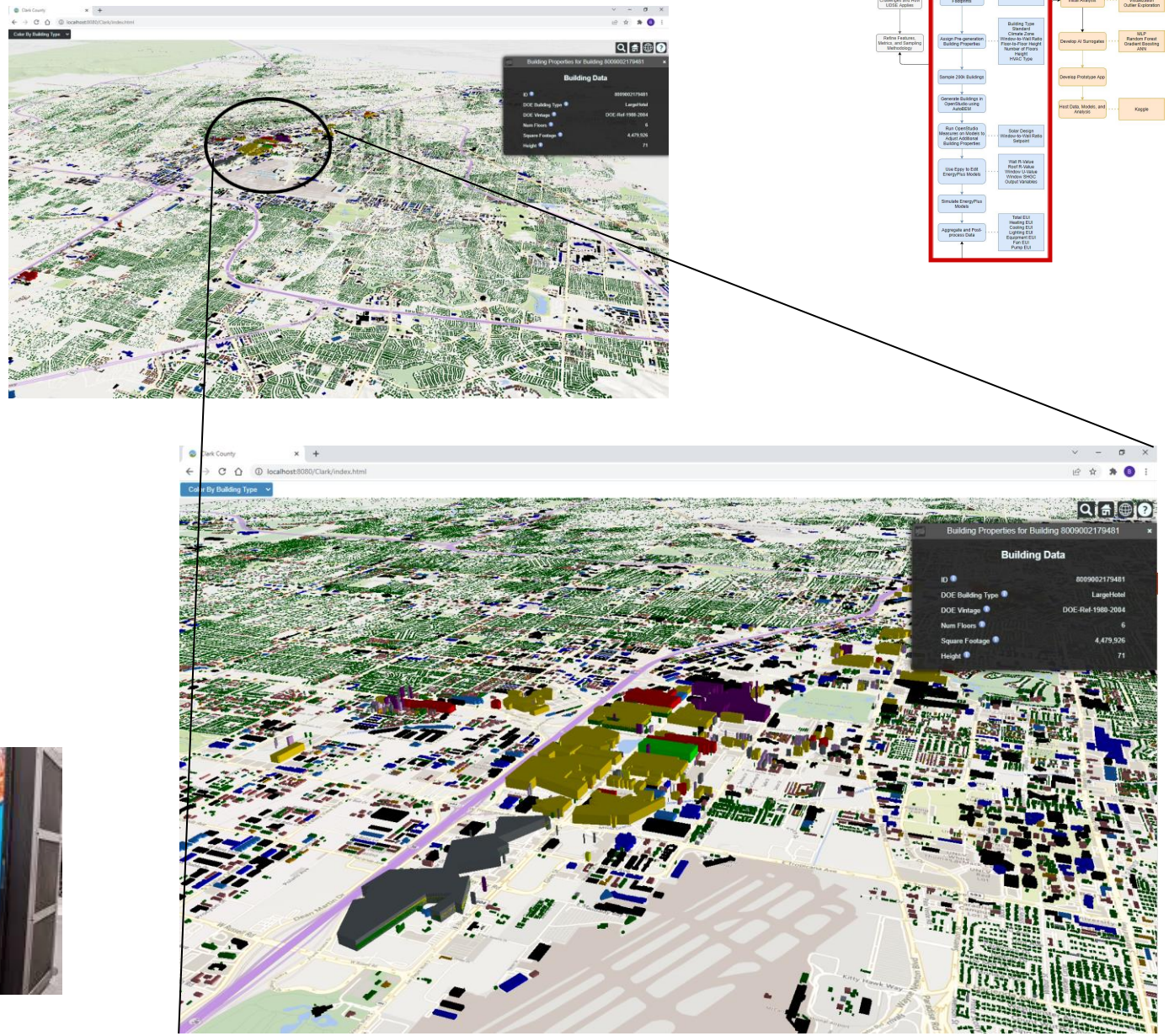
ORNL Resources

- **AutoBEM** (Automatic Building Energy Modeling)
  - Uses building properties as inputs to generate building energy models
  - EnergyPlus/OpenStudio
- Access to Supercomputing Resources



Clark County (Las Vegas) Modeling Example

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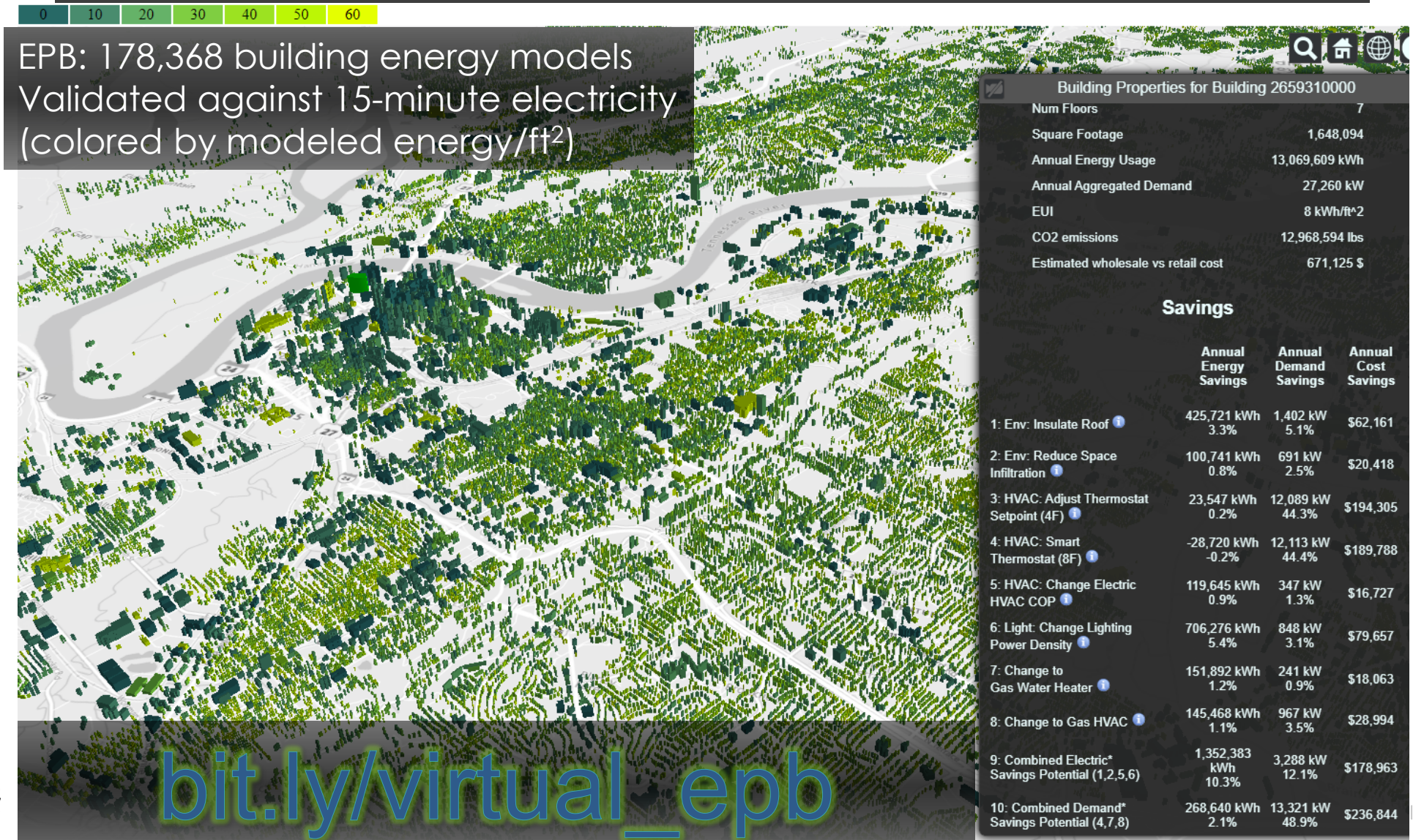
Digital Twin: Energy, Demand, Emissions, $ Savings

Results: Digital Twin of a Utility (every building)



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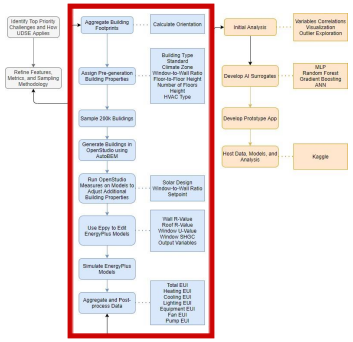
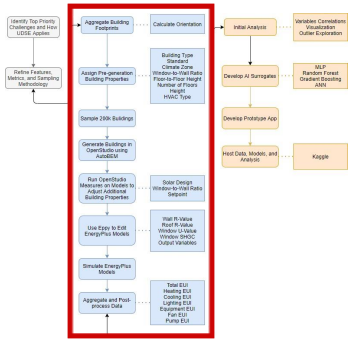
Scalable Computing



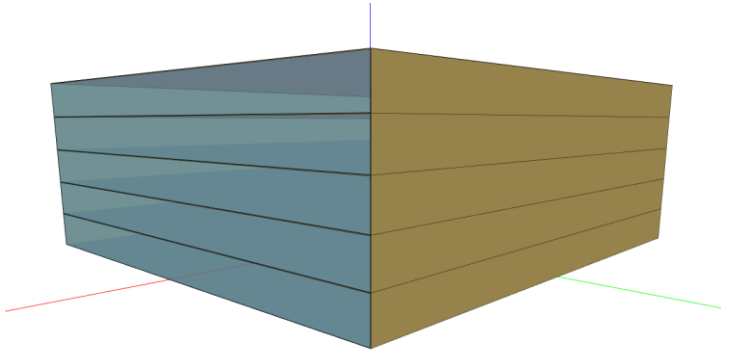
- Models typically take days to develop
- AutoBEM allows for massive scalability
  - AutoBEM can be used by a single person to develop and simulate *200k* models in **less than a day**
  - Modeler rate of $150/hr
  - 2 days for basic model (16 hours)
  - **$480 million dollars** and **365.3 years** for this modeler to develop *200k* basic models

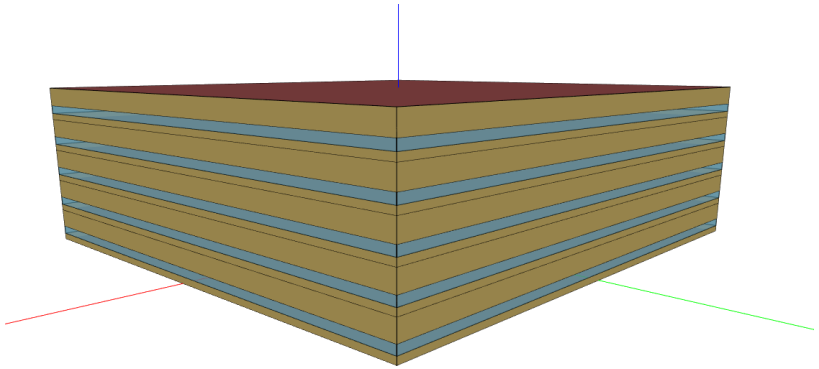
Modeling Quality	Typical Model Development Time
Basic	2 Days
Functional	1 Week
Detailed	2 Weeks

AutoBEM Workflow

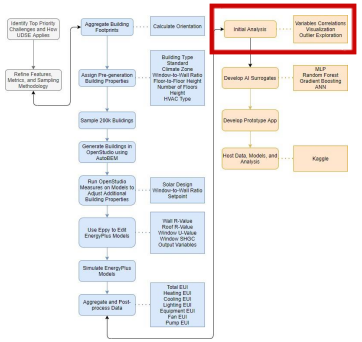


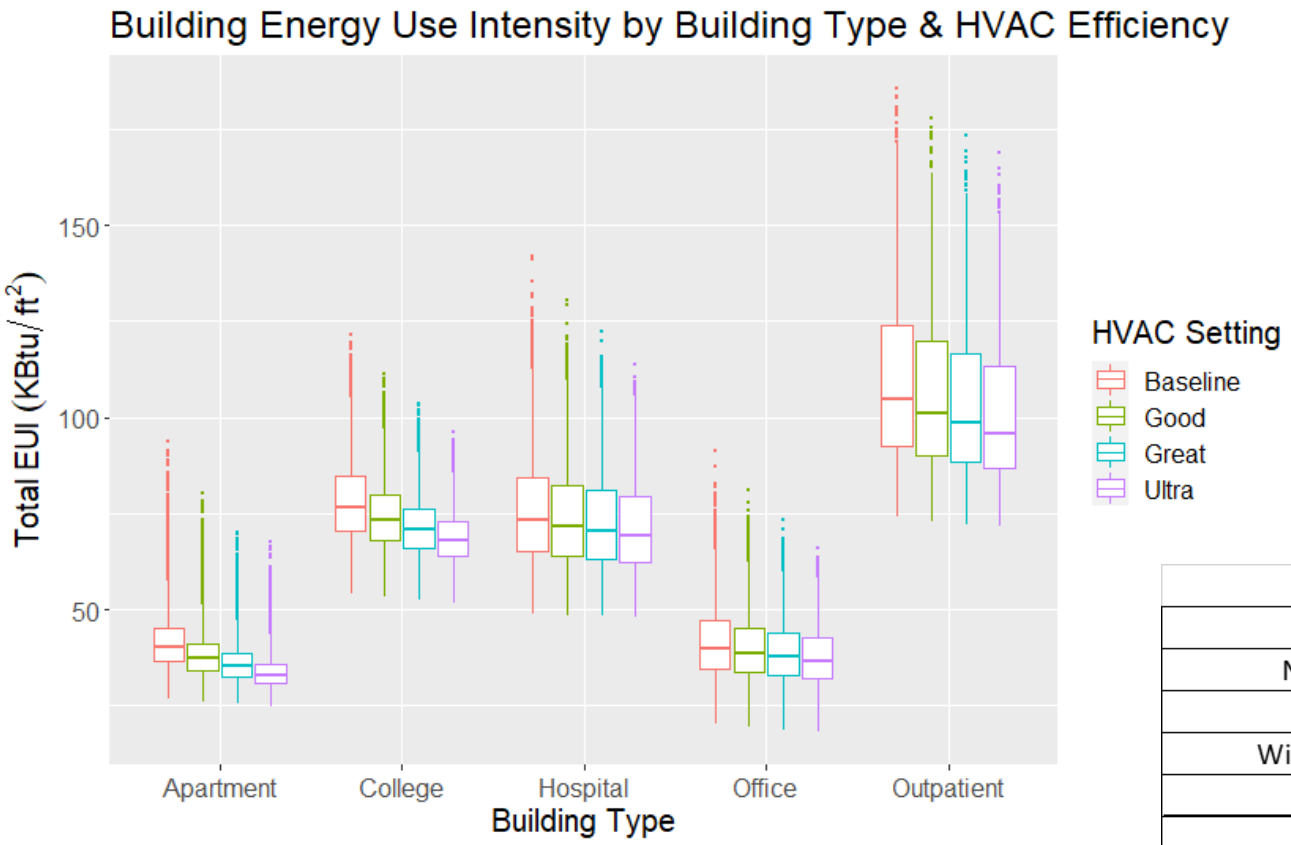
- Create input table from parametric sampling matrix
- Generate building energy models using AutoBEM
  - Building geometry, building type, HVAC type, etc.
- Fine tune models for more specific changes
  - Lighting, HVAC COP, etc.
- Simulate models using HPC resources





Data Exploration

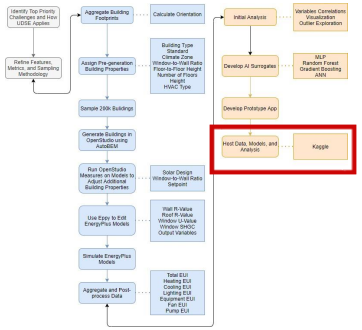




	Outpatient_1A	Outpatient_2A	Outpatient_3A	Outpatient_4A
Height	-0.50	-0.57	-0.55	-0.42
NumberFloors	-0.50	-0.56	-0.57	-0.45
TotalArea	-0.77	-0.79	-0.78	-0.67
WindowWallRatio	-0.02	-0.06	0.11	0.00
FloorHeight	0.06	0.00	-0.04	0.19
PlateDepth	0.05	0.14	-0.13	0.08
PlateLength	-0.13	-0.22	-0.09	-0.16
SkinArea	-0.47	-0.52	-0.51	-0.39
SkinFloorRatio	0.28	0.25	0.17	0.26
GlassArea	-0.43	-0.50	-0.46	-0.36
EnvelopeFloorAreaRatio	0.30	0.27	0.19	0.28
EnvelopeQuality	0.04	-0.04	0.01	0.13
LightingPowerDensity	-0.18	-0.47	-0.37	-0.17
SetpointSetting	-0.14	-0.14	-0.12	-0.18
HVACSetting	0.36	0.27	0.19	0.15

Data Hosting

[UDSE Kaggle]



https://www.kaggle.com/petermcnallysg/universal-design-space-building-energy-simulation

kaggle

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Code

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Courses

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Data | Code | Discussion | Activity | Metadata

Download (149 MB) | New Notebook

Data Explorer

148.58 MB

Universal_Design_Space_Bu...

Universal_Design_Space_Building_Energy_Simulation_input_output.csv (14...

Detail | Compact | Column

10 of 49 columns

TotalArea_Setting		FloorArea	FloorArea_Setting		NumFloors	PlateDepth
high	35%	14.5k – 40.4k	typ	34%	1 – 67	45 – 153
typ	34%		low	33%		
Other (79244)	30%		Other (85488)	33%		

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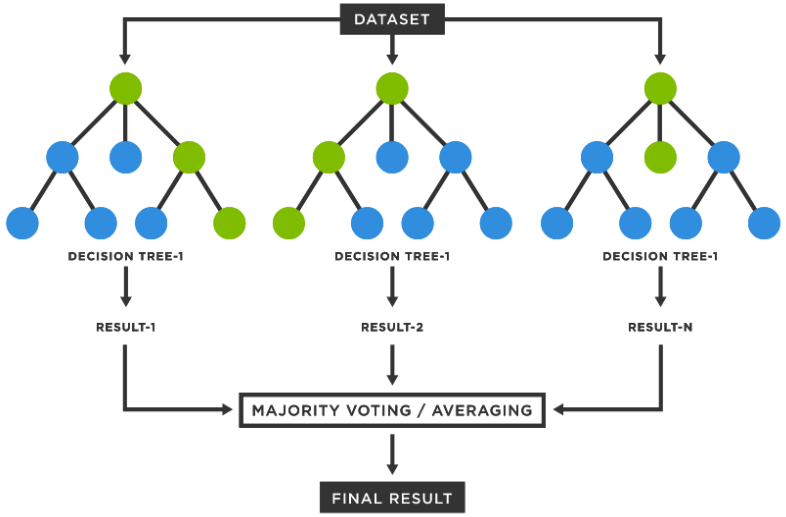
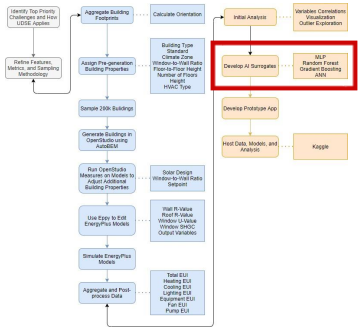
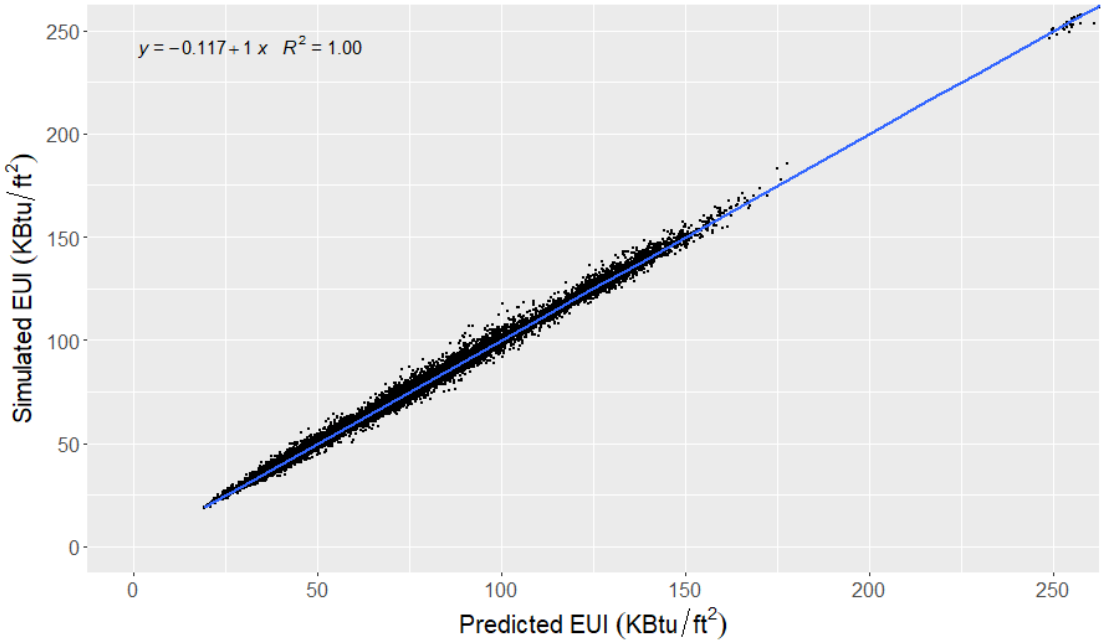
Artificial Intelligence

- AI can be used as surrogate for EnergyPlus simulations
  - Don't need every point of design space
- Use input variables (building type, area, height, etc.) to predict building energy usage
- Several algorithms evaluated
  - Linear Regression
  - Neural Network
  - **Random Forest**





Random Forest



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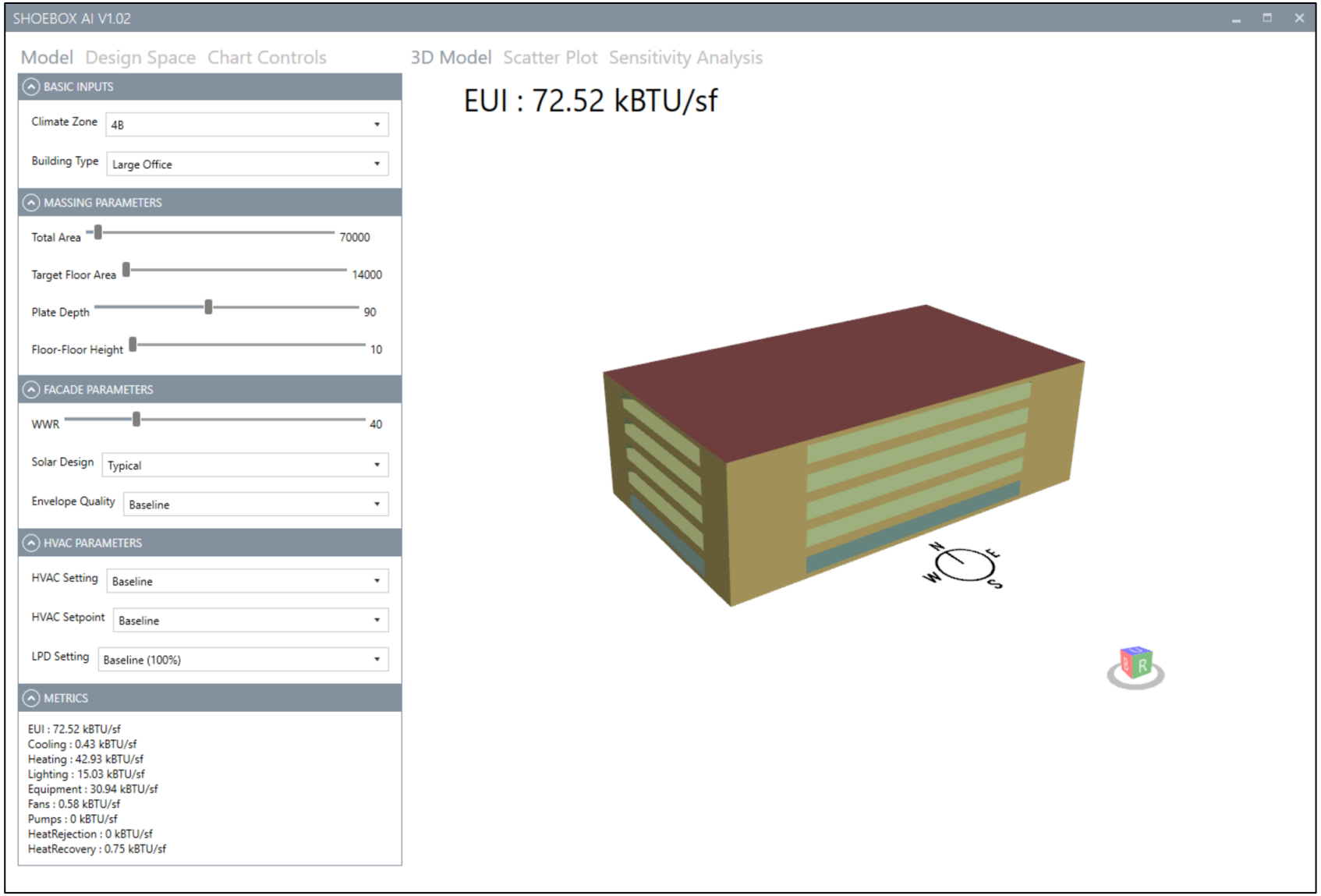
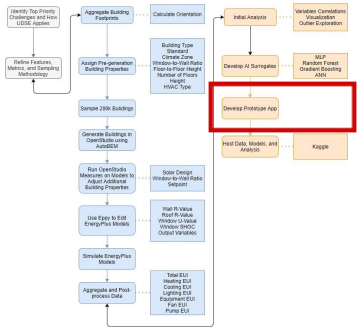
Prototype App: Single Design





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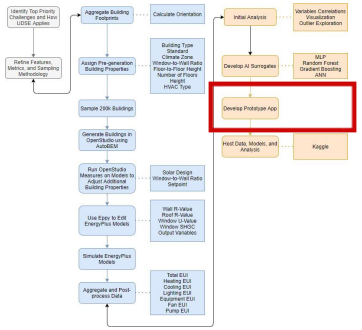
Prototype App: Design Space Exploration



SHOEBOX AI V1.02

Model Design Space Chart Controls

3D Model Scatter Plot Sensitivity Analysis

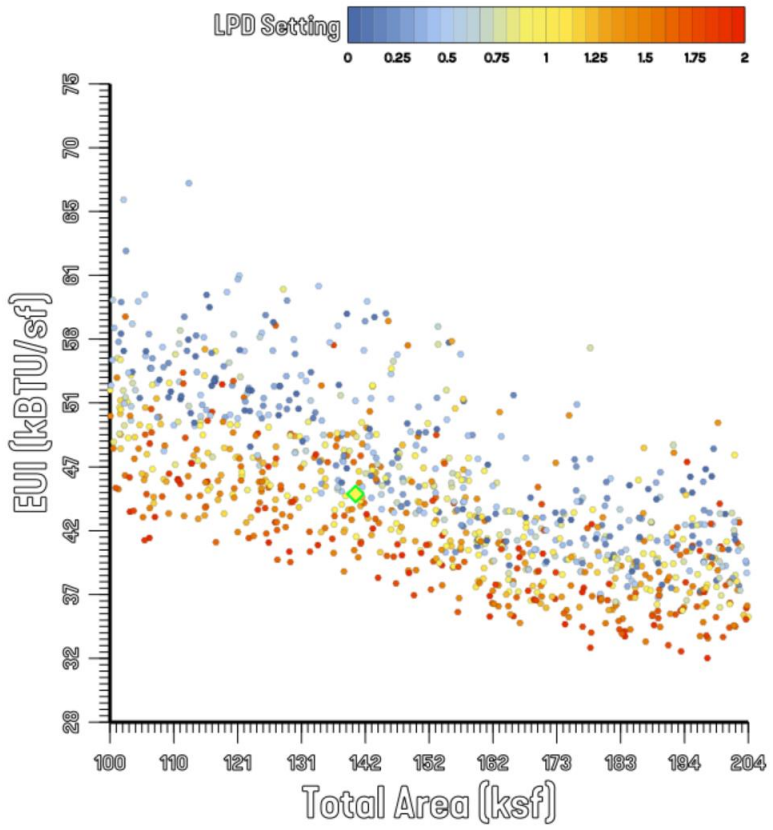
GENERATE DATA

# of Samples to Generate 1000

Generating Data

MASSING PARAMETERS

Total Area	40000 To 500
Target Floor Area	14000 To 500
Plate Depth	45 To 150
Floor-Floor Height	10 To 18
WWR	25 To 90
Solar Design	0.81 To 1.1
HVAC Setting	0 To 3
Envelope Quality	0 To 0.3
LPD Setting	0 To 2
HVAC Setpoint	0 To 0.13



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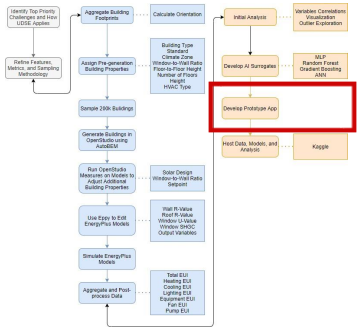
Prototype App: Real-time Analytics



SHOEBOX AI V1.02

Model Design Space Chart Controls

SCATTER PLOT CONTROLS

X Variable: Total Area

Decimals: 0

Y Variable: EUI

Decimals: 0

Color Variable: LPD Setting

DISPLAY SETTINGS

Toggle to turn on Y lines

Toggle to turn on X lines

SENSITIVITY ANALYSIS CONTROLS

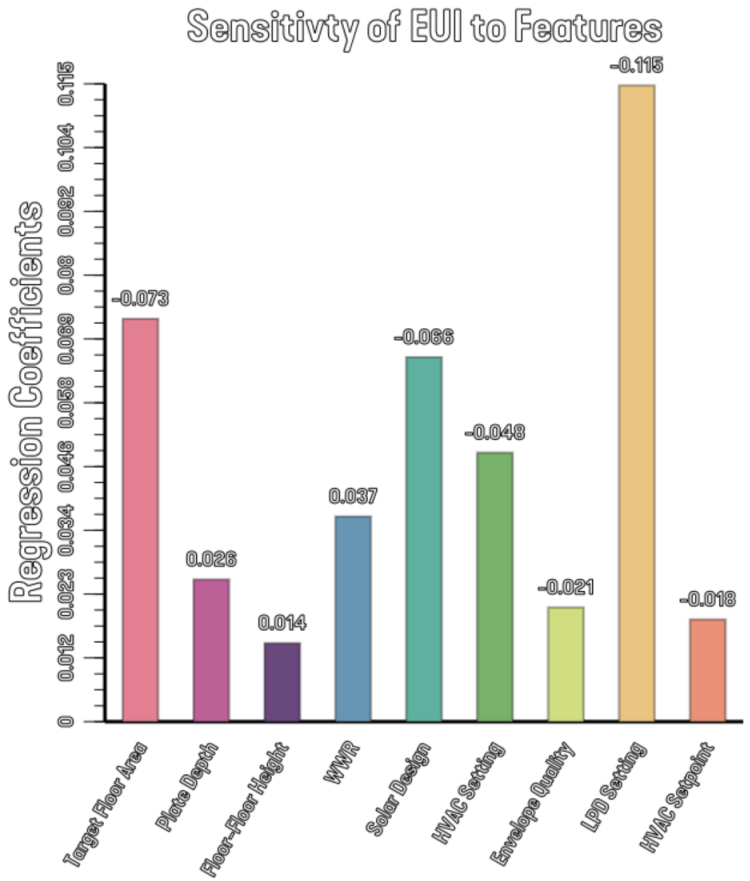
Choose metric to run sensitivity analysis on: EUI

Choose Sensitivity Features

- [ ] Total Area
- [x] Target Floor Area
- [x] Plate Depth
- [x] Floor-Floor Height
- [x] WWR
- [x] Solar Design
- [x] HVAC Setting
- [x] Envelope Quality
- [x] LPD Setting
- [x] HVAC Setpoint

Decimals: 3

3D Model Scatter Plot Sensitivity Analysis



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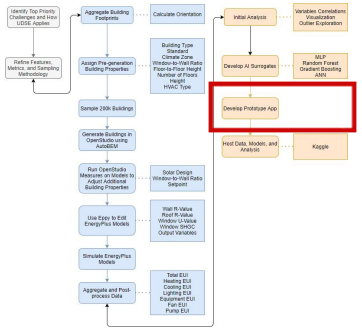
Prototype App: Real-time Analytics



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Questions?