

Using generative design and machine learning for faster analysis feedback

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Spyridon Ampanavos Harvard University Doctoral Candidate

Michael Floyd Autodesk AEC Sustainability Strategy Manager

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About the speakers



Michael Floyd

AEC Sustainability Strategy Manager at Autodesk. Environmental technologist working to bring better sustainability solutions to life through Autodesk's products. 14 years experience in design & sustainability.



Varvara Toulkeridou

Sr. Research Engineer for Autodesk's AEC Generative Design group. Doctoral candidate in Computational Design at Carnegie Mellon University, researching how machine learning can augment parametric modeling tools for supporting design exploration.



Vishal Vaidhyanathan

Computational BPA Researcher at Autodesk and a Graduate Student Researcher at Carnegie Mellon University. Researching on the confluence of computational methods, Data Science and Artificial Intelligence for fostering synergies through the coexistence of early-phase design and real-time impact assessment.



Spyridon Ampanavos

Doctoral candidate at Harvard Graduate School of Design, researching the use of machine learning methods to support early phase performance driven design. Background in Architectural Engineering and Computational Design.

What will I learn?

LEARNING OBJECTIVE 1

Learn how to design workflows with Generative Design in Revit and Dynamo for building synthetic data sets to be used in training machine-learning models.

LEARNING OBJECTIVE 2

Discover the diversity of mass model geometry required to represent a comprehensive set of possible building types.

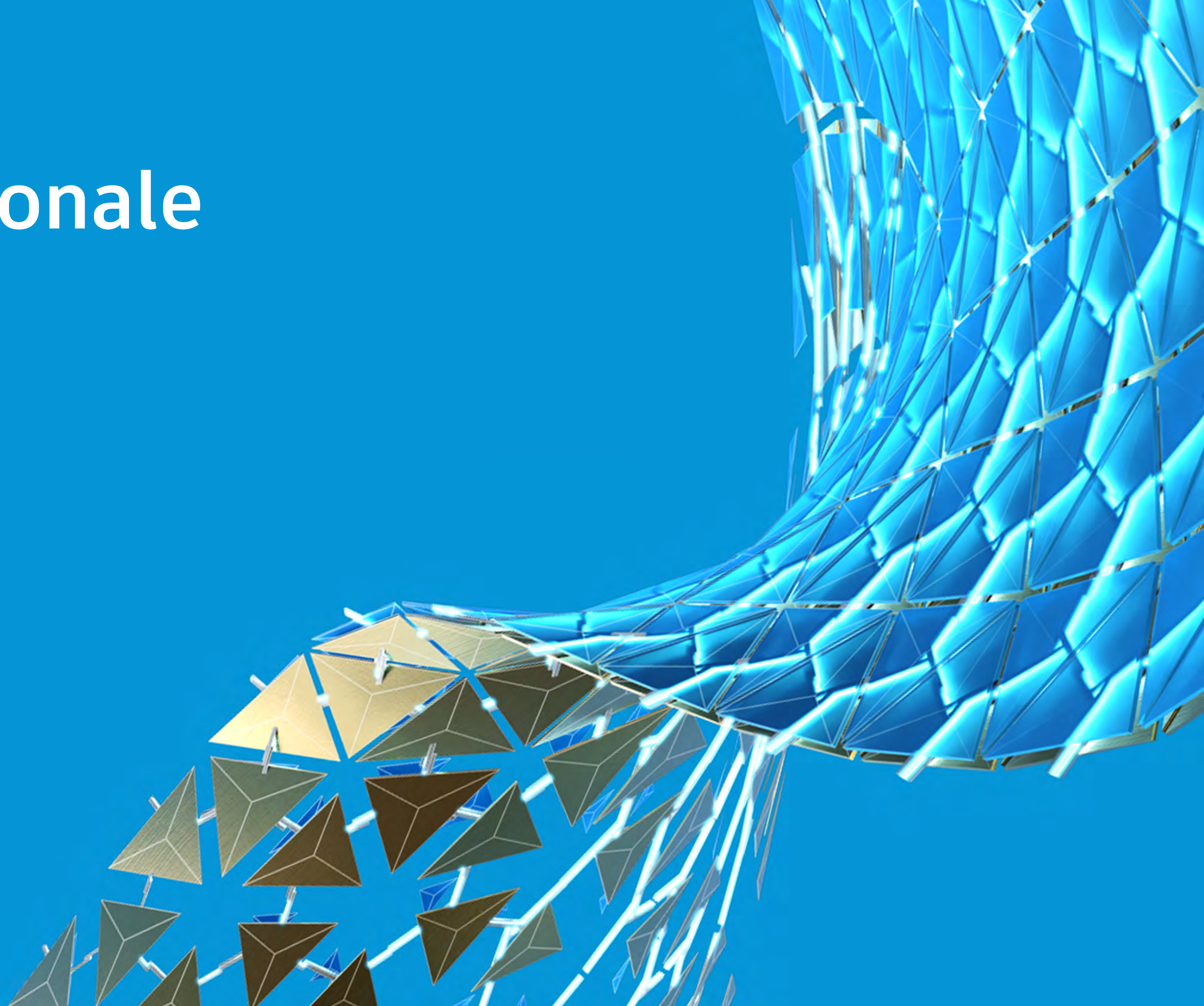
LEARNING OBJECTIVE 3

Learn how to represent your data to be used in training machine-learning models.

LEARNING OBJECTIVE 4

Discover potential uses of machine-learning models toward achieving faster analysis in early conceptual design stages.

Project Rationale



A wide-angle photograph of a city skyline at sunset. The sky is filled with soft, orange and yellow clouds. A tall, slender skyscraper on the left side of the frame is emitting a thick plume of white smoke or steam that rises into the air. The city below is densely packed with various buildings, and a body of water is visible in the lower-left foreground. The overall atmosphere is hazy and atmospheric.

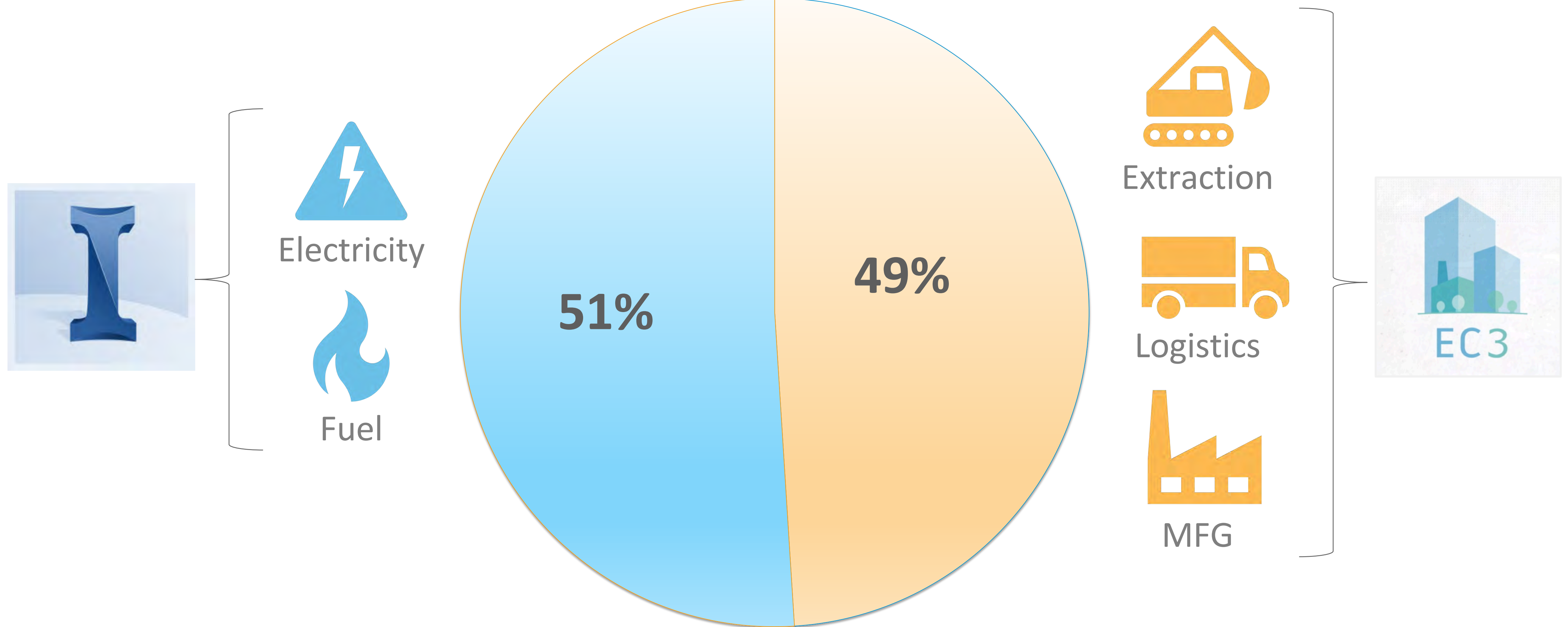
40%

CARBON EMISSIONS

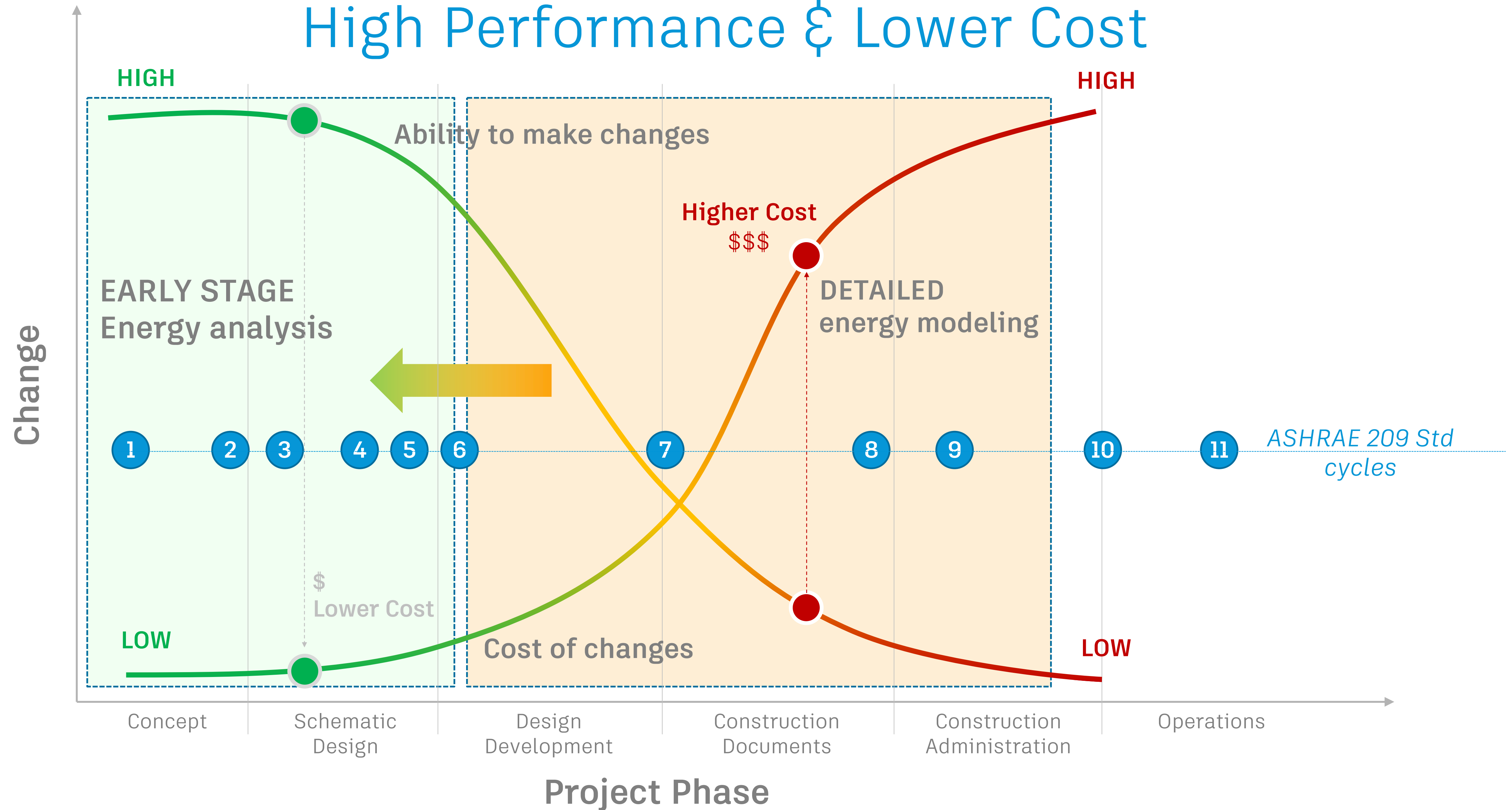
A city skyline at sunset, with a large white arrow pointing down and the text '50% BY 2030' overlaid. The background shows a dense urban landscape with many skyscrapers and buildings, with a prominent tower on the left. The sky is filled with soft, golden light from the setting sun, creating a hazy atmosphere.

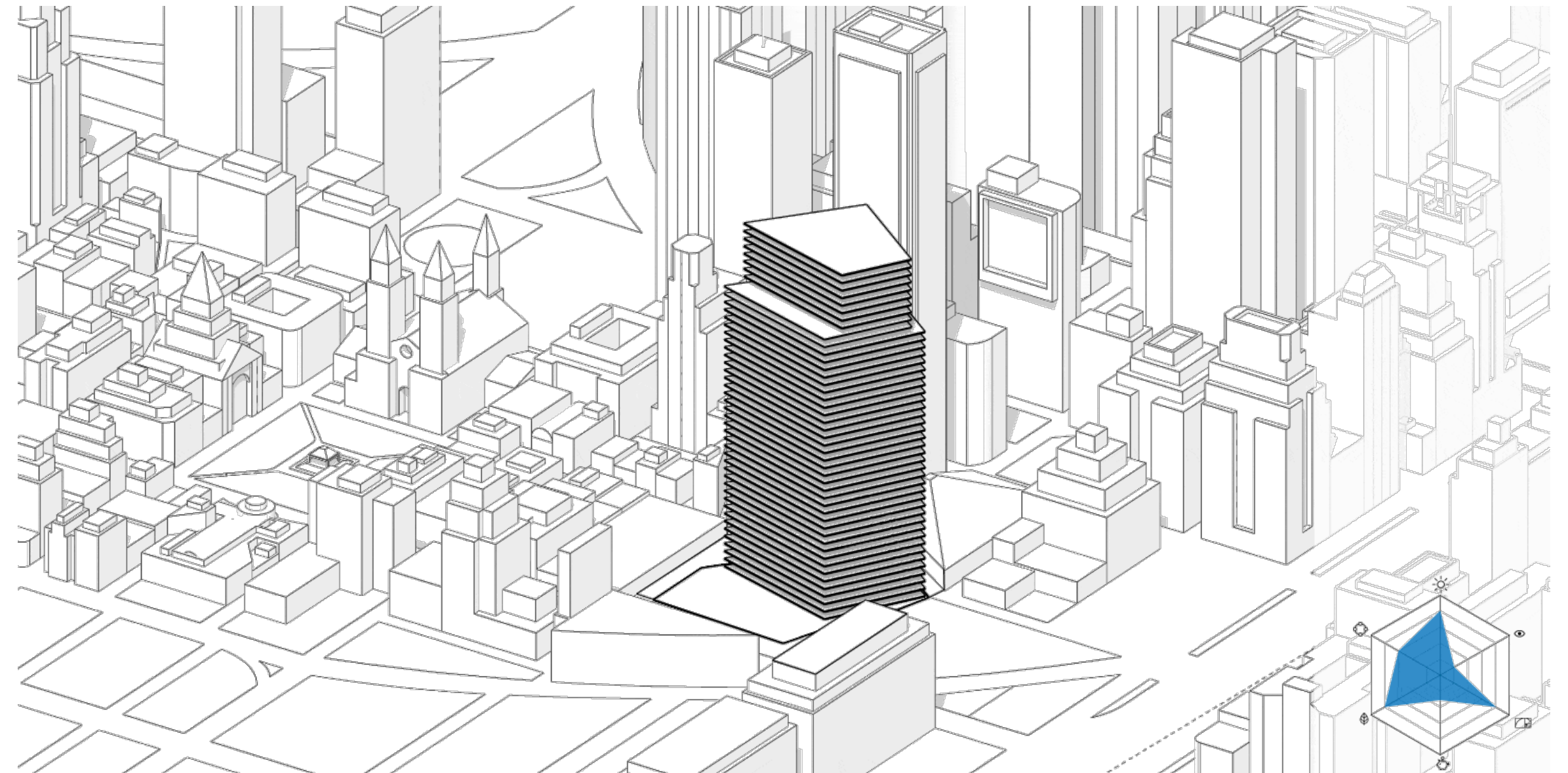
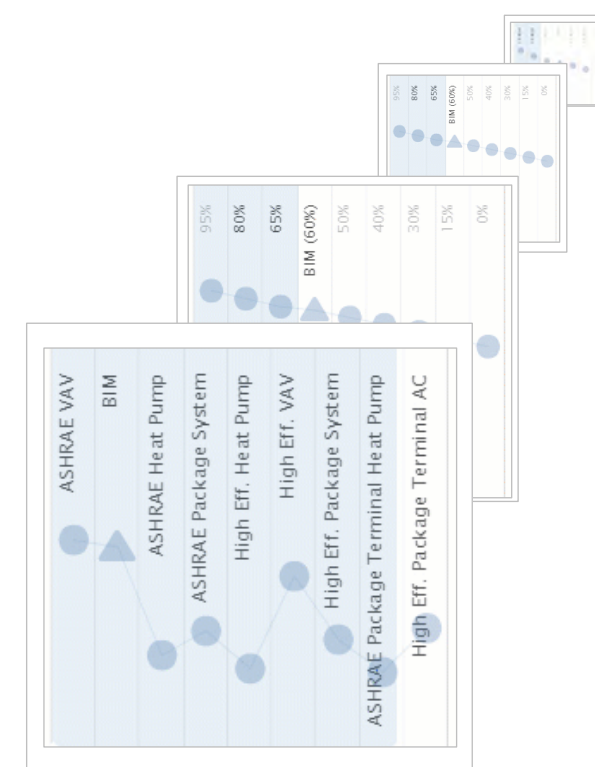
↓ 50%
BY 2030

Total carbon from buildings → 2050



Early Stage Analysis = High Performance & Lower Cost

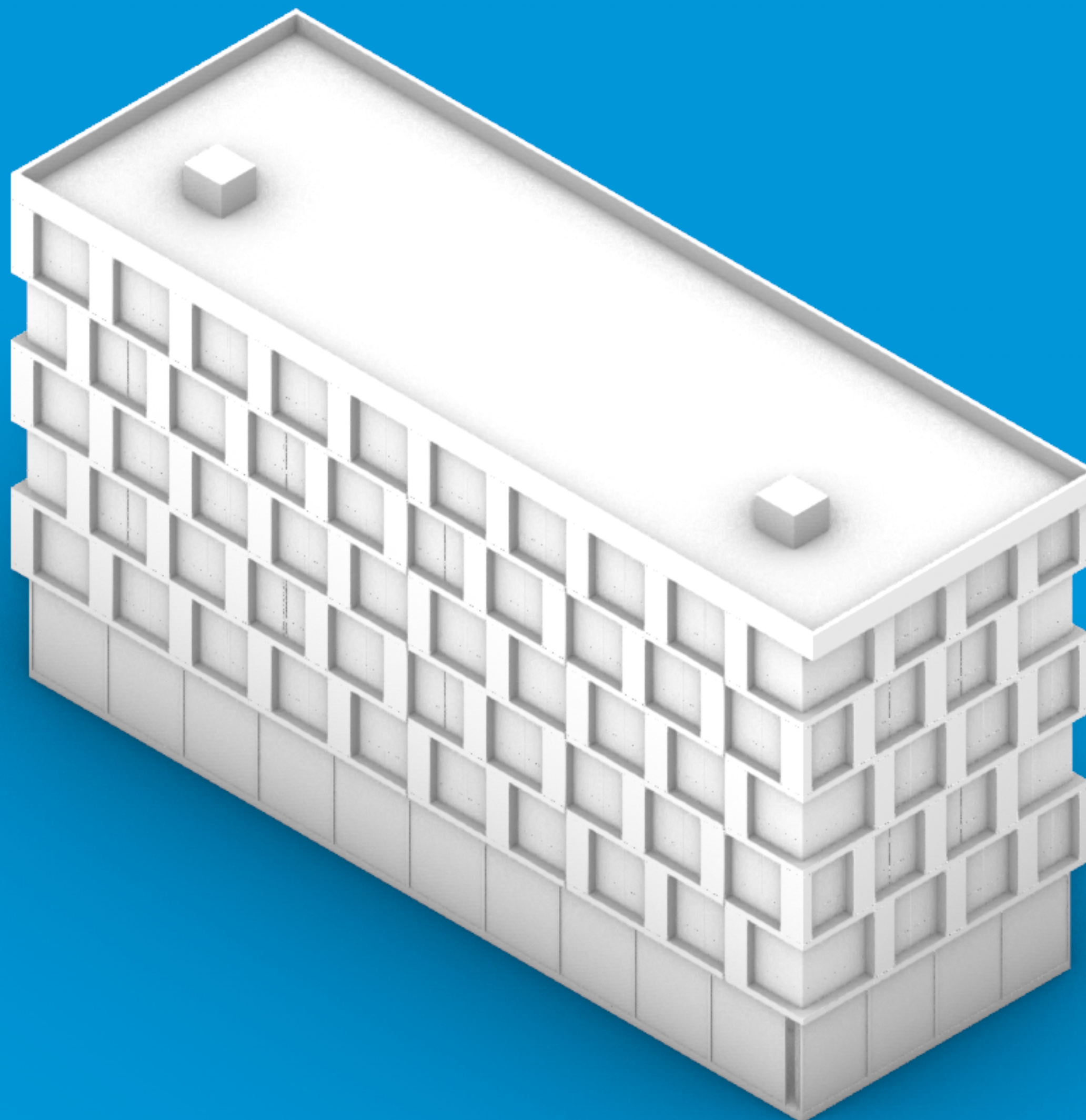


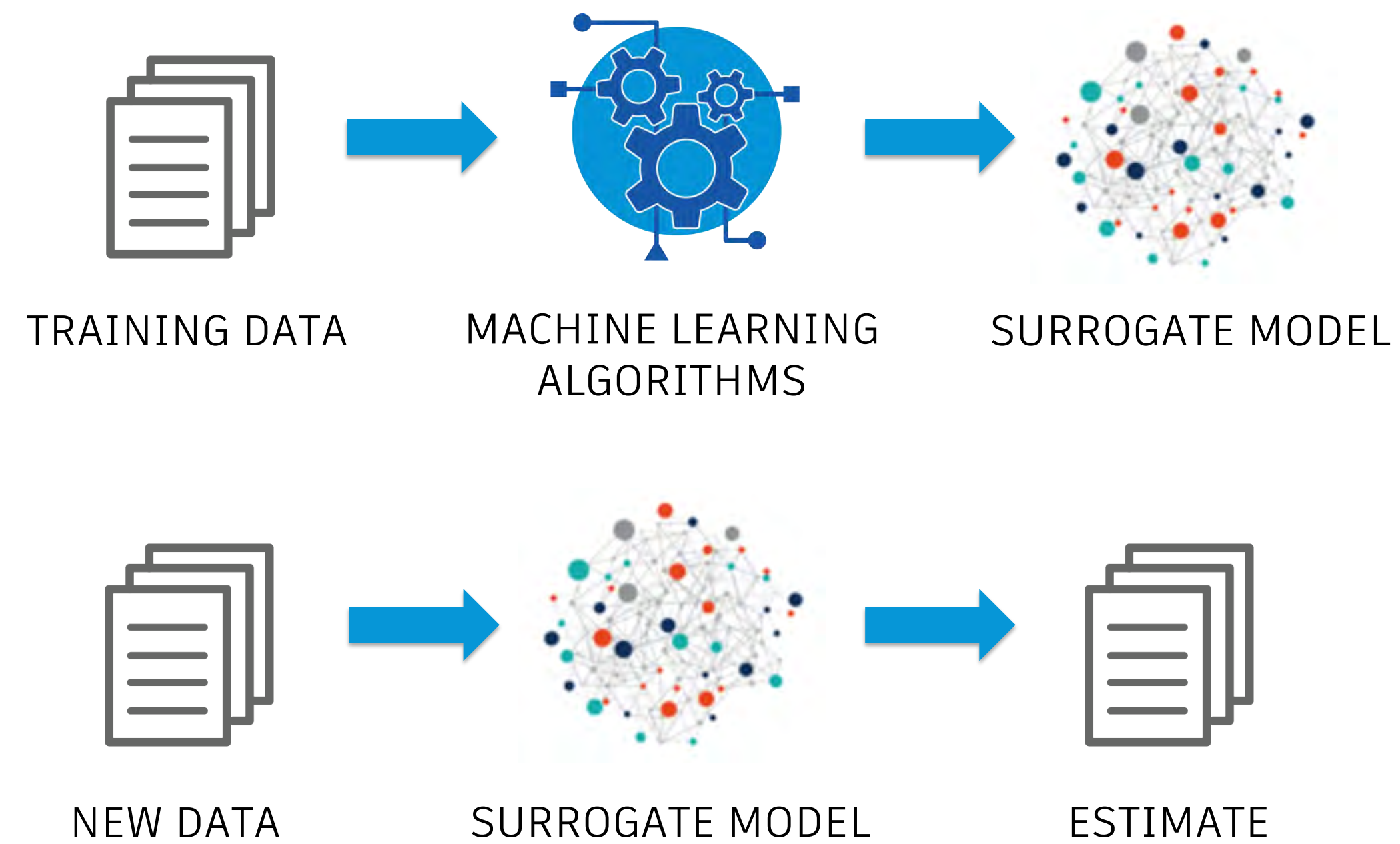


Energy Use Intensity (kWh/m²) :
201.42

Energy Cost Mean (\$/m²) :
3021.3

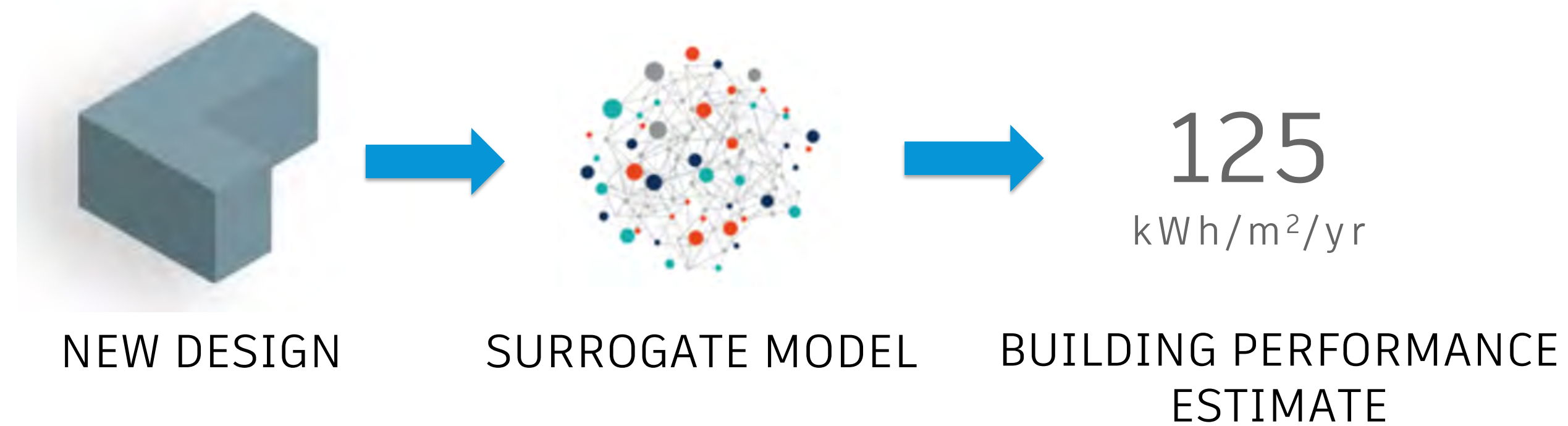
Embodied Carbon (kg-CO₂e/m²) :
273.9312





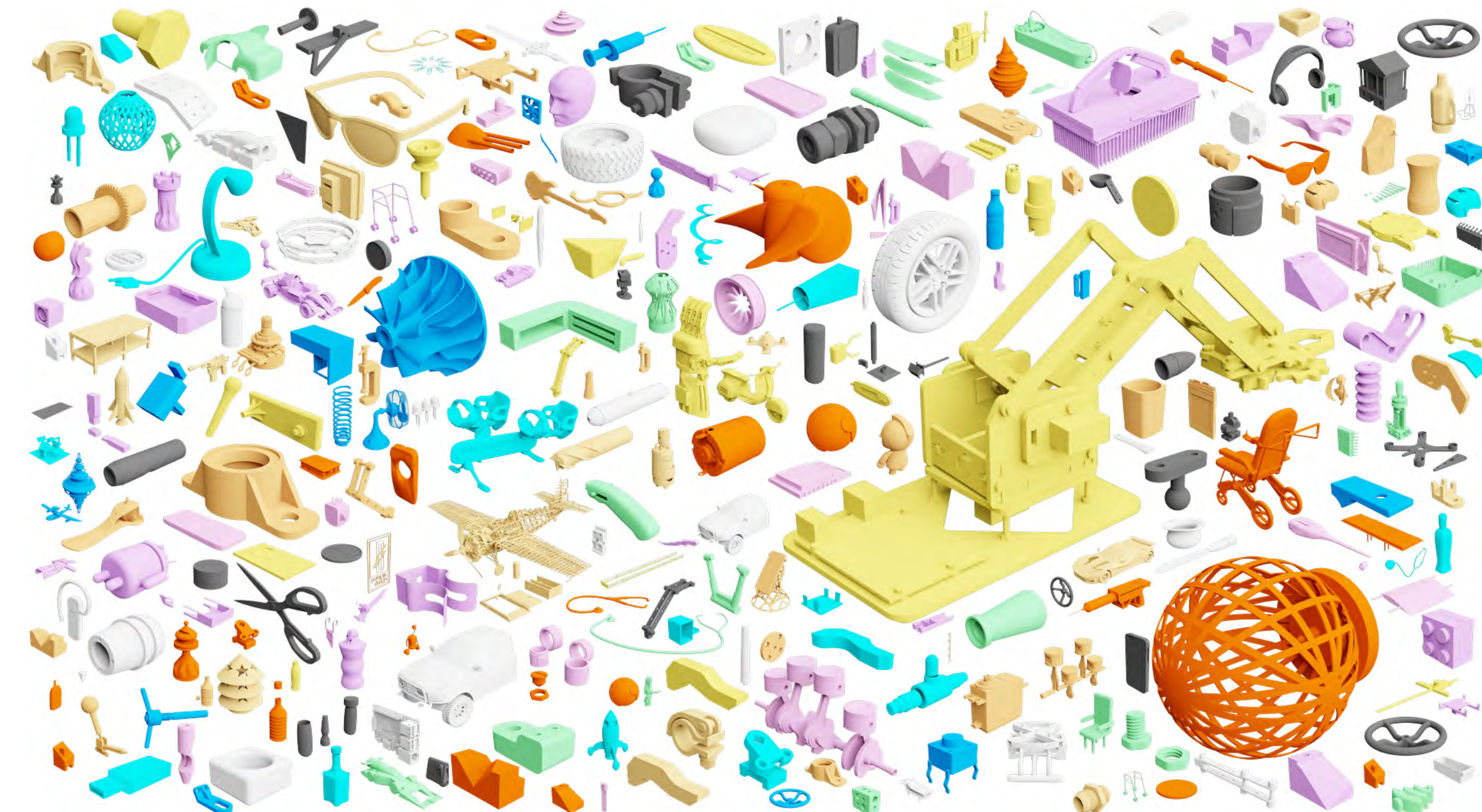
Surrogate modeling

Statistical models can be used as surrogates of detailed simulation models.

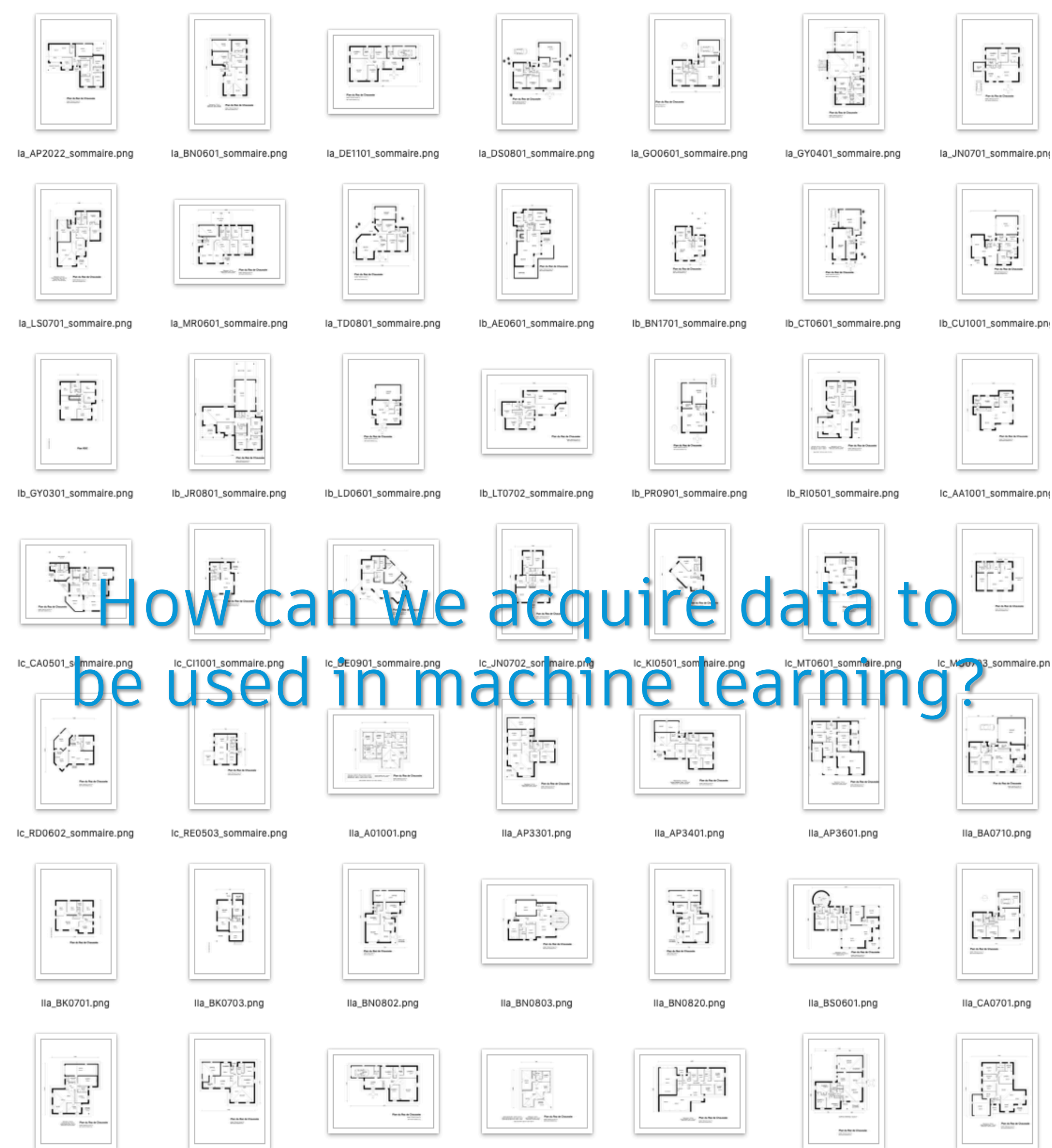
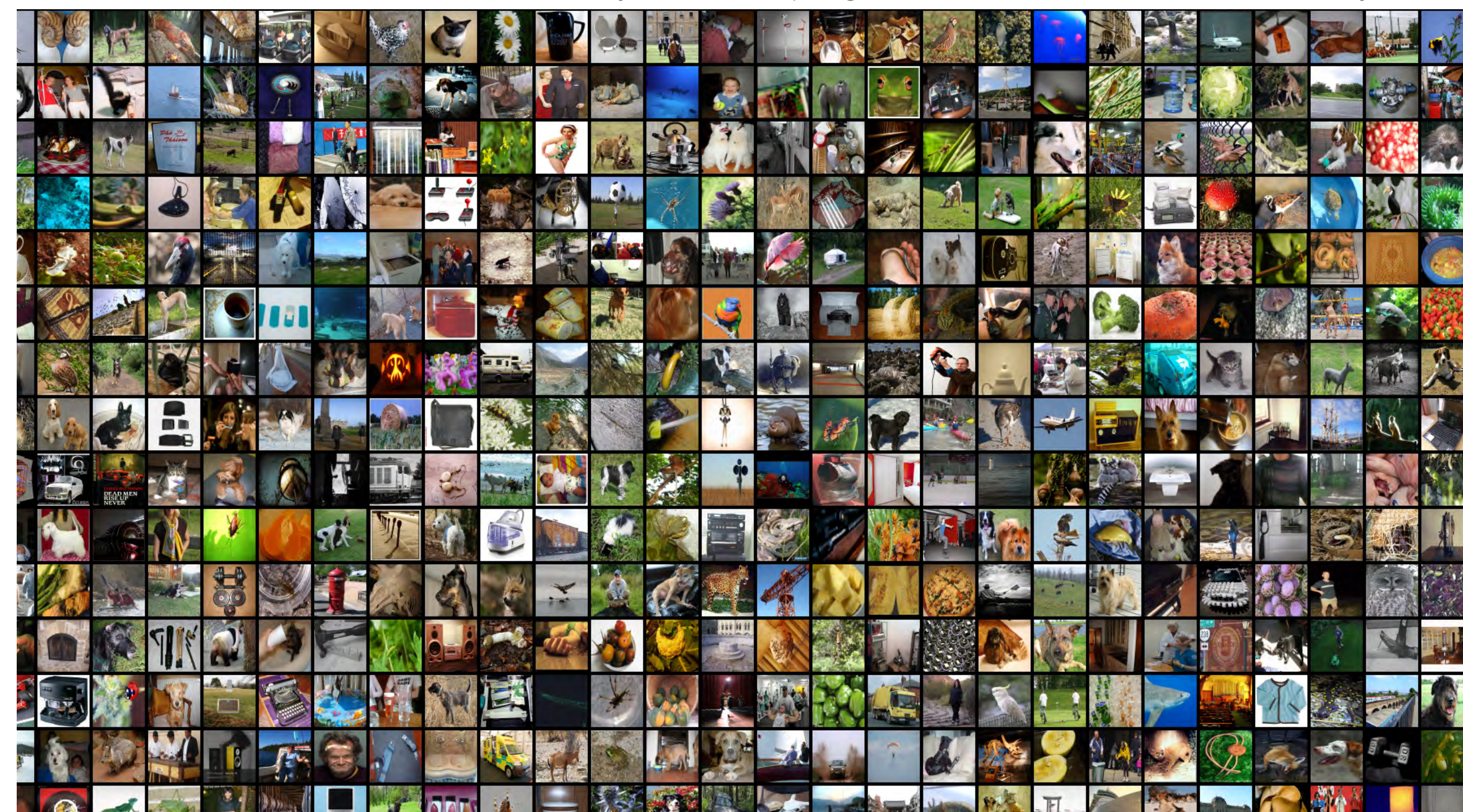


How can a surrogate model help in the conceptual design stage?

Surrogate models can be evaluated instantly and provide estimates of the building performance. This enables designers to rapidly assess a design concept and explore the design space.



Fusion 360 Gallery Dataset - <https://github.com/AutodeskAILab/Fusion360GalleryDataset>

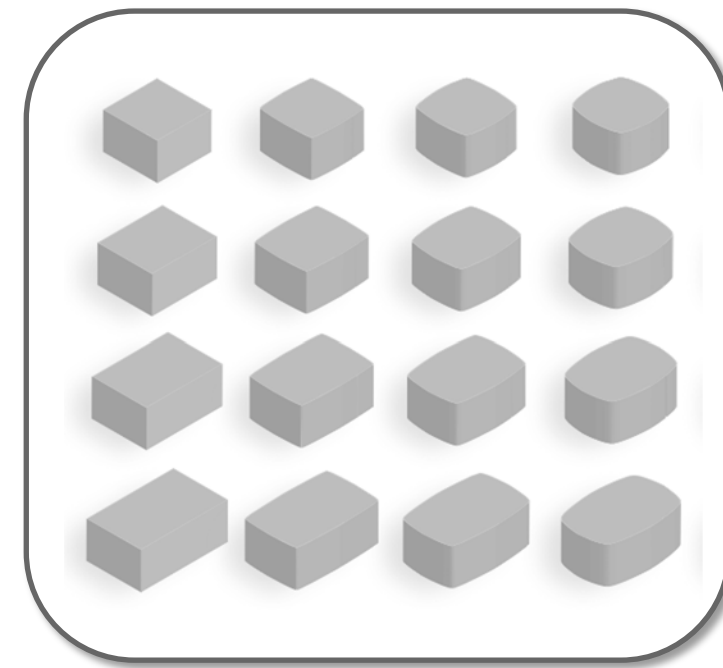


Floor plans from the CVC-FP dataset - <http://dag.cvc.uab.es/resources/floorplans/>

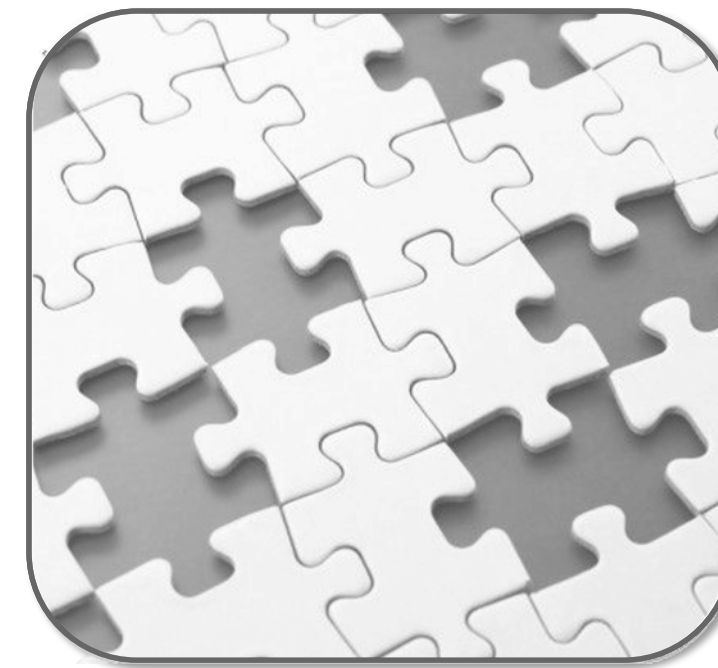
How can we acquire data to be used in machine learning?



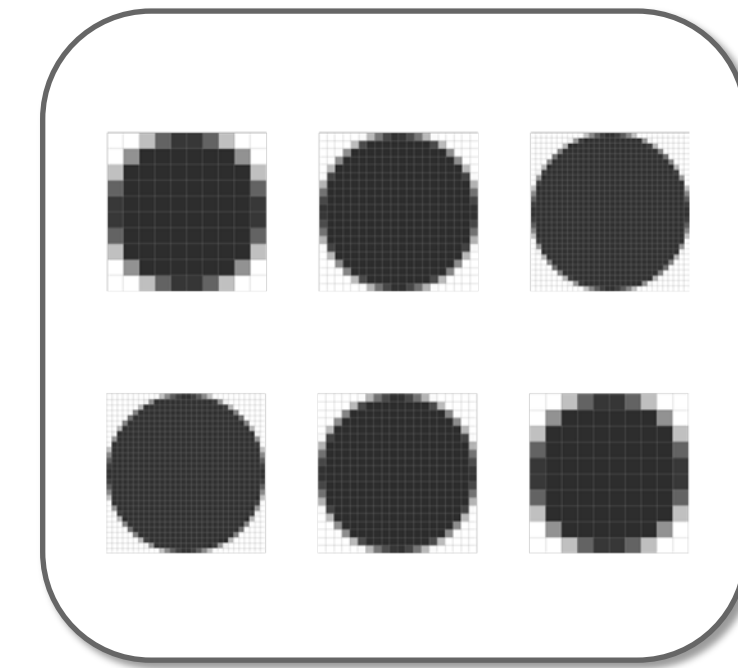
NOT ENOUGH



NOT DIVERSE



INCOMPLETE



INCOSISTENT
QUALITY & FORMAT

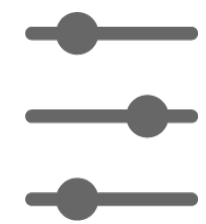
Limitations of collected data in AEC



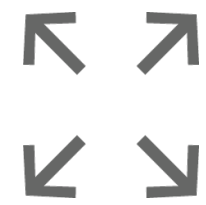
LARGE SIZE



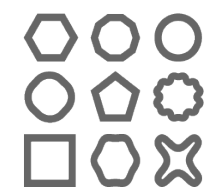
GROUND TRUTH LABELS



PARAMETRIC REPRESENTATION



EXPANDABLE



VARIATION

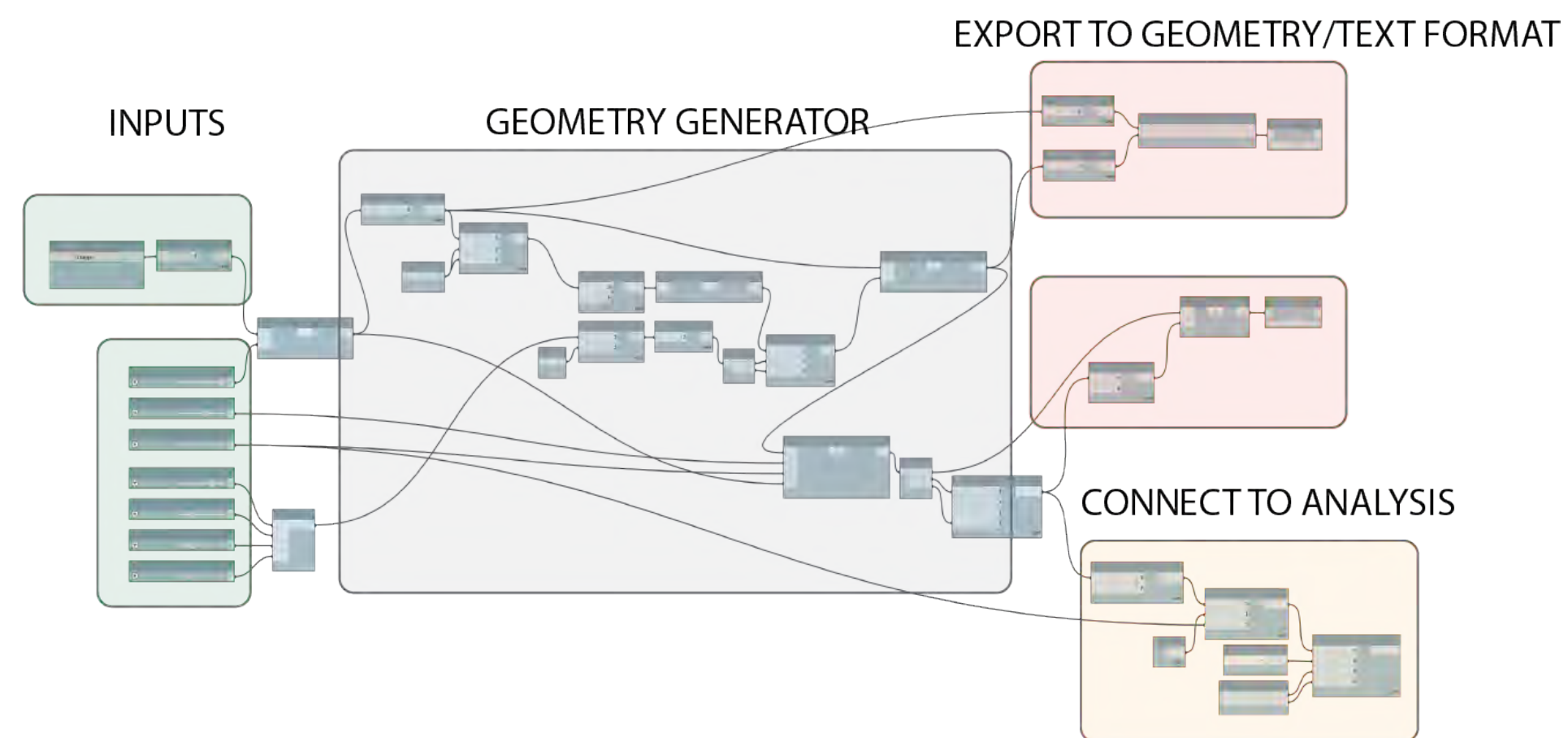


BALANCED

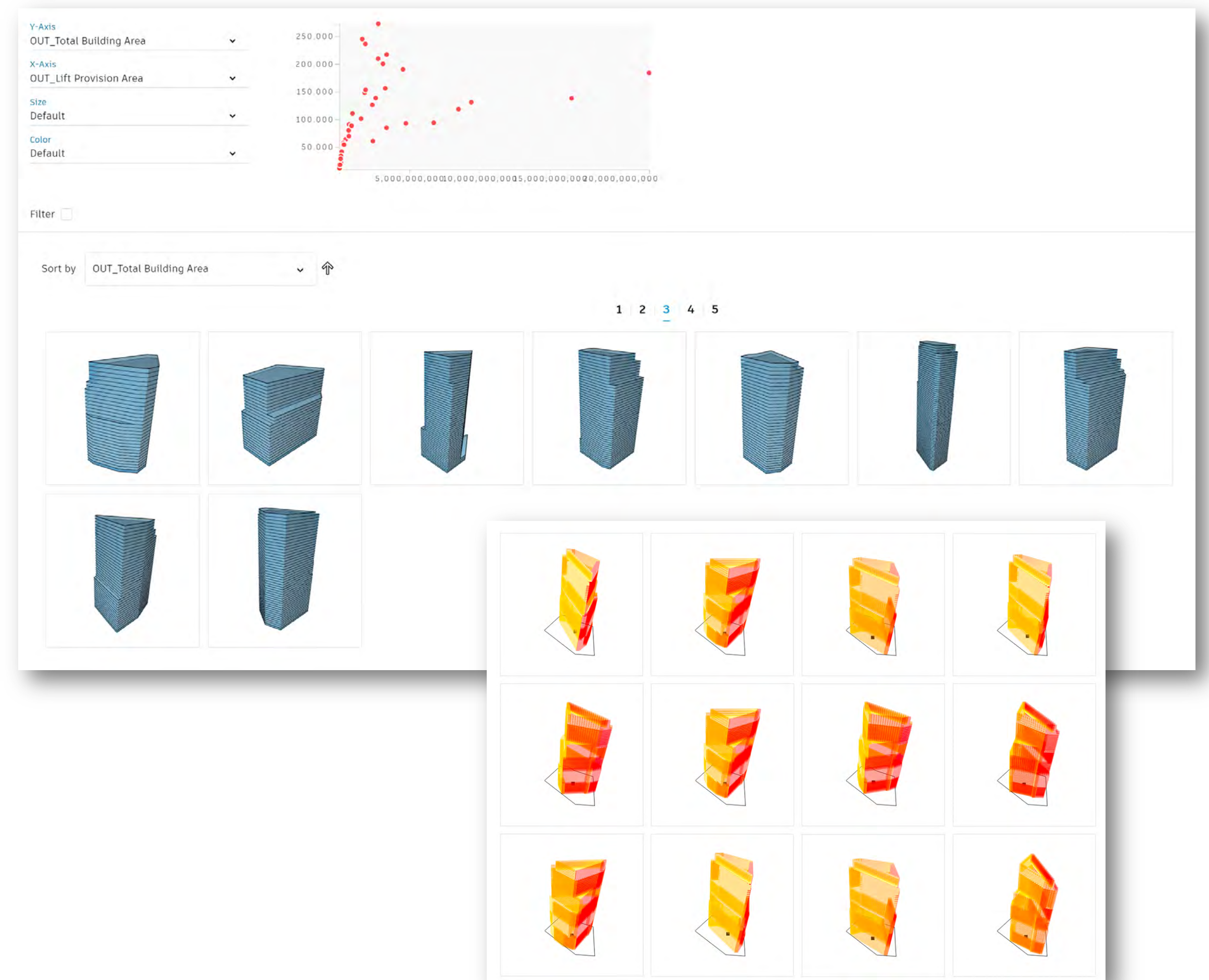
Koch et al. (2019), ABC: A Big CAD Model Dataset For Geometric Deep Learning

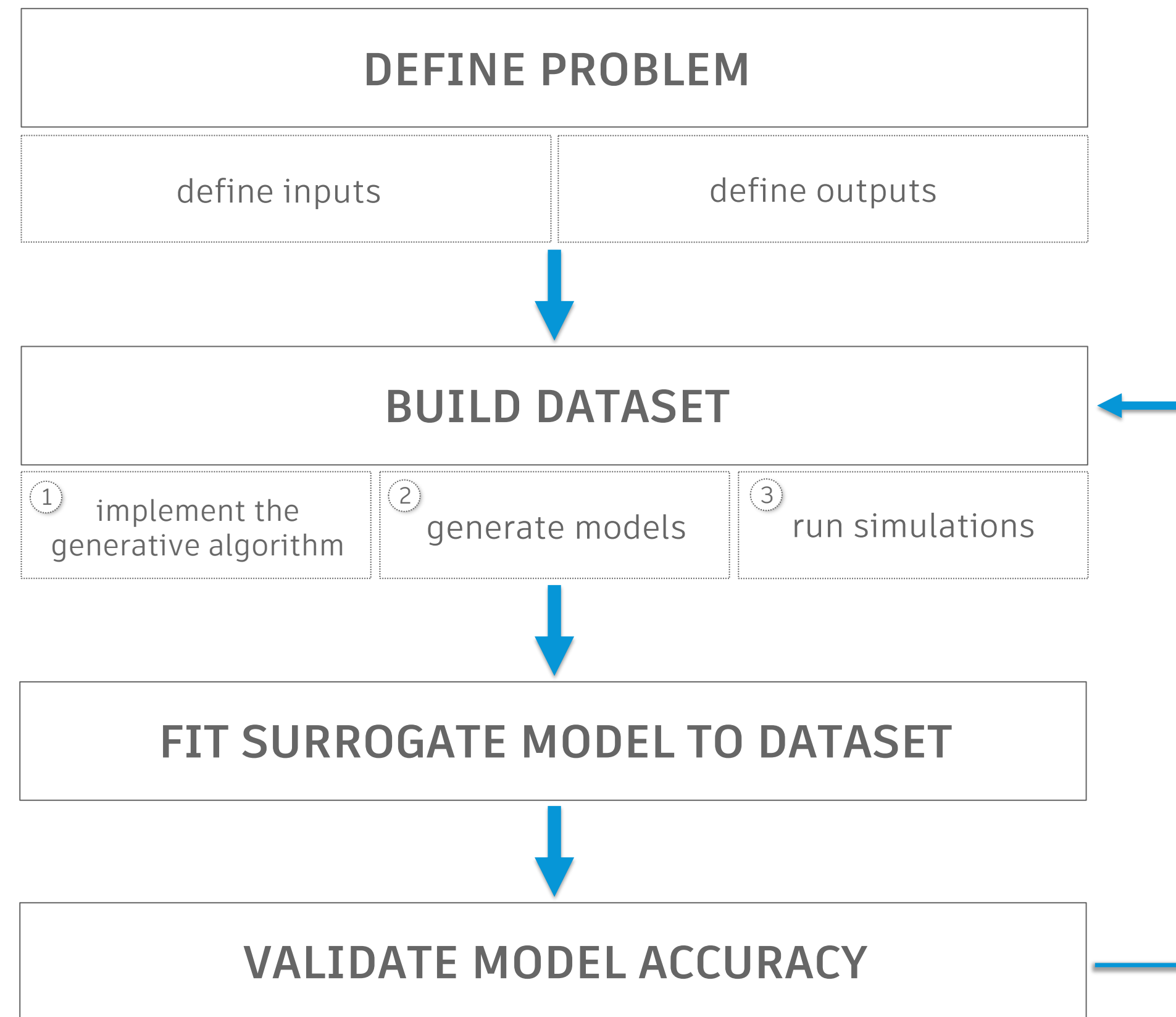
Which are the properties of a good dataset?

Synthetic data creation via generative design workflows

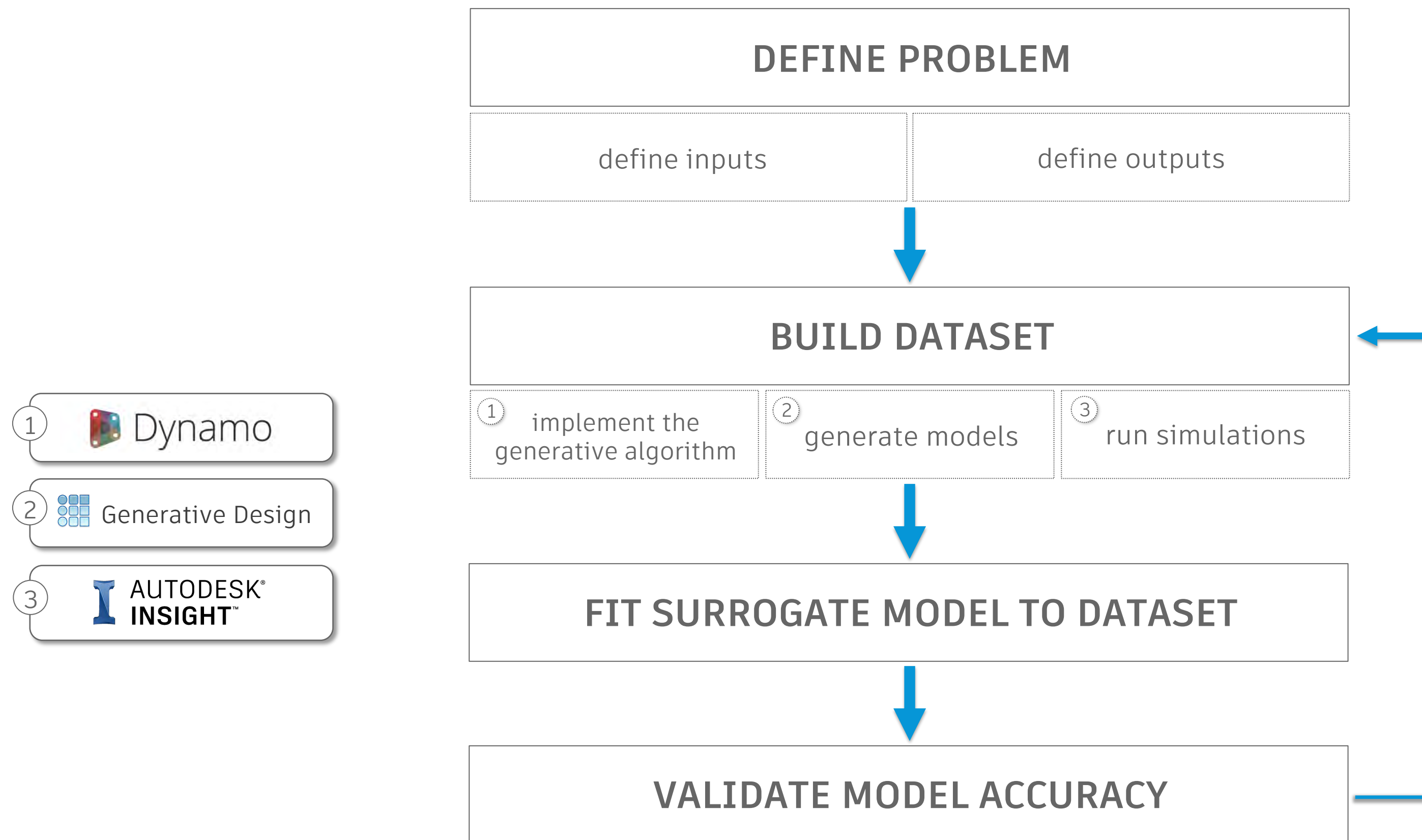


Generative Design in Revit

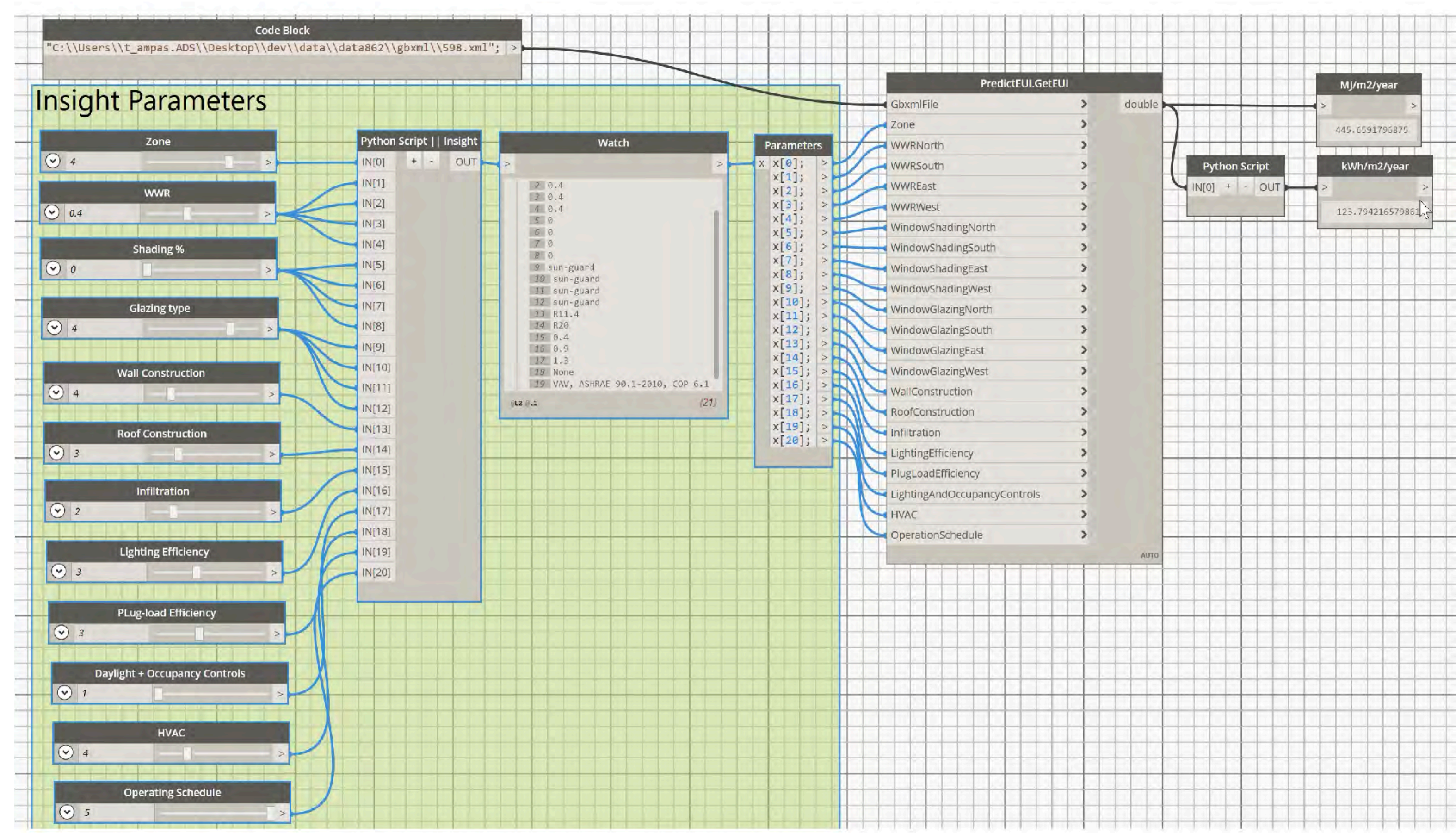




How do we structure a workflow for deriving a surrogate model?

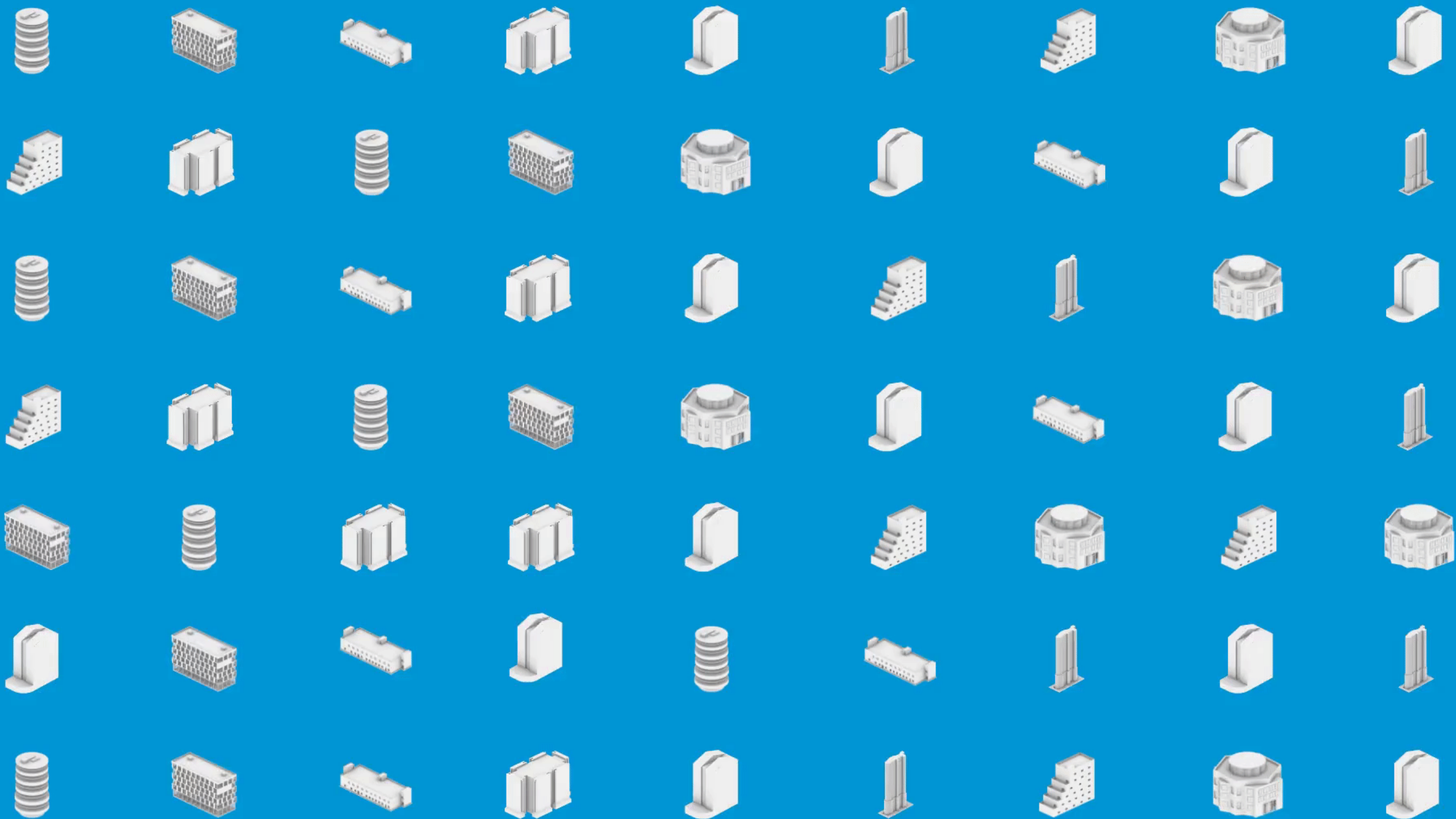


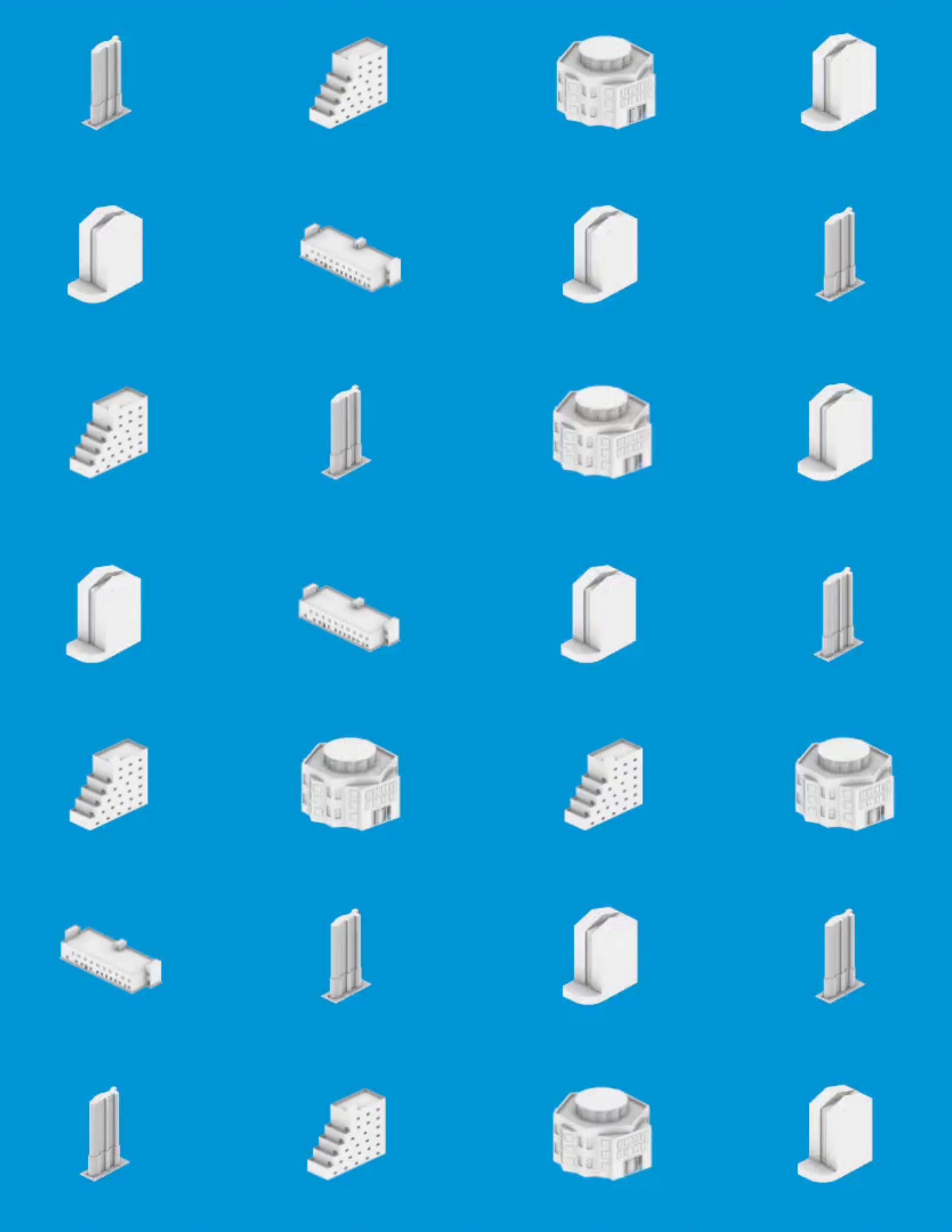
How do we structure a workflow for deriving a surrogate model?



Defining the problem
for synthetic data generation
..the generative design way!



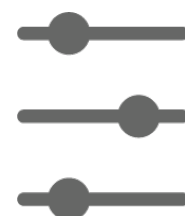




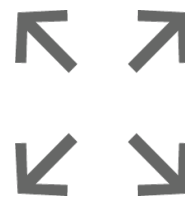
LARGE SIZE



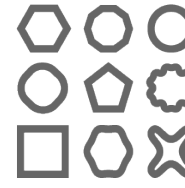
GROUND TRUTH LABELS



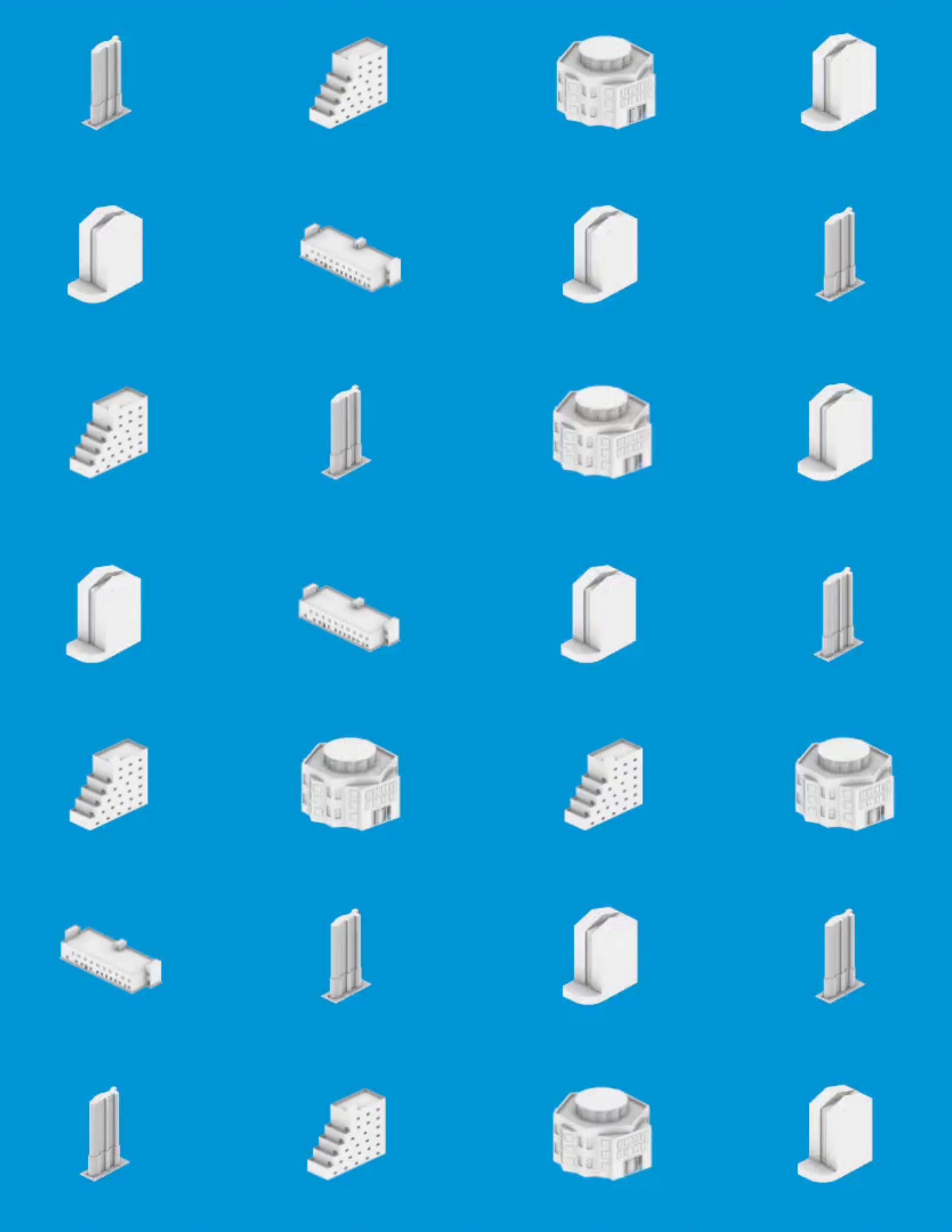
PARAMETRIC REPRESENTATION



EXPANDABLE



VARIATION



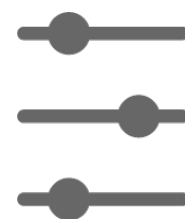
LARGE SIZE

AUTOMATED GENERATION



GROUND TRUTH LABELS

SIMULATED PERFORMANCE
RESULTS



PARAMETRIC REPRESENTATION

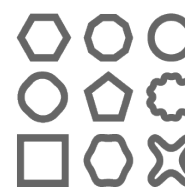
REPRODUCIBLE WORKFLOW



EXPANDABLE



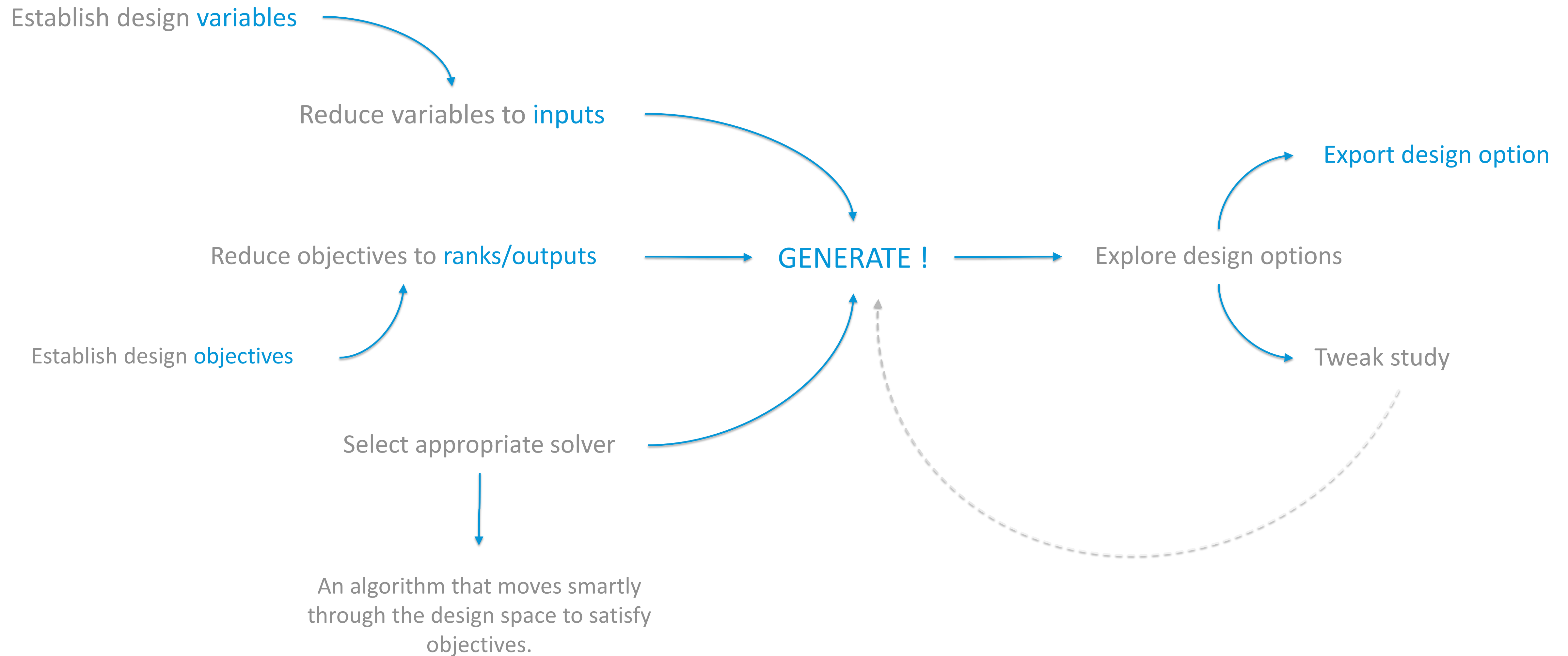
SCALABLE WORKFLOW



VARIATION

UNBIASED

Generative design workflow

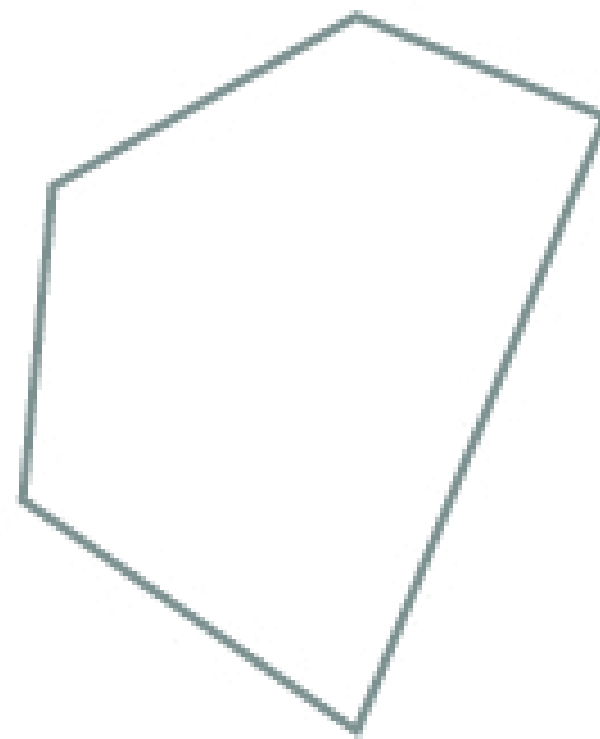


Generative design workflow

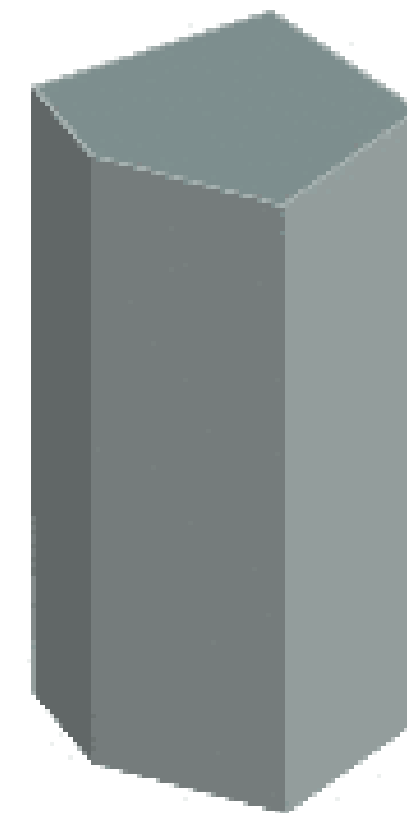
IDENTIFY

TARGET TAXONOMIES

Footprint level

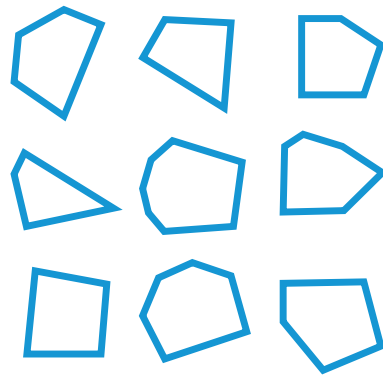


Massing level

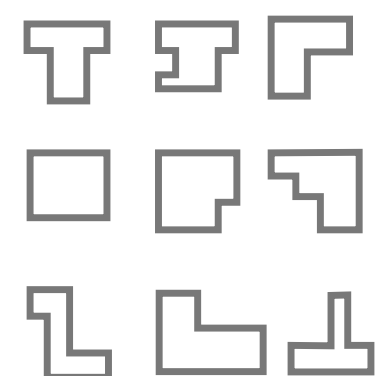


IDENTIFY TARGET TAXONOMIES

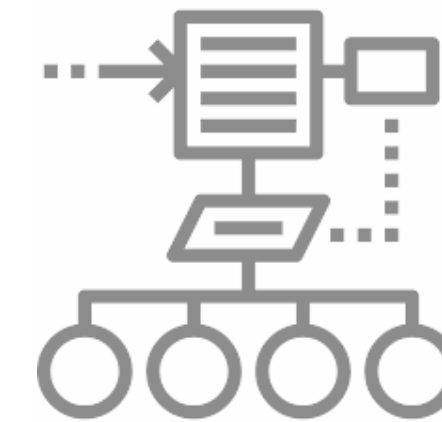
CATEGORY I



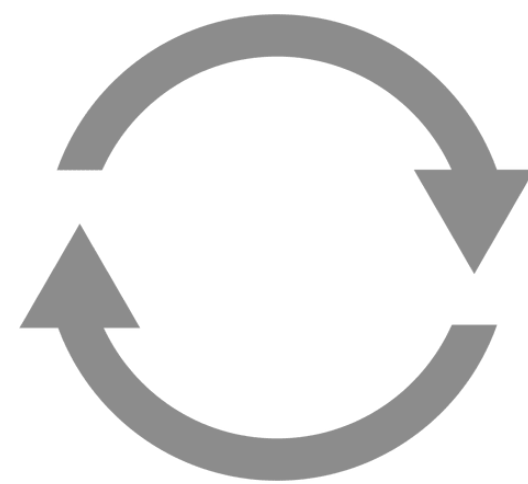
CATEGORY II



Categorically differentiable



Algorithmically representable

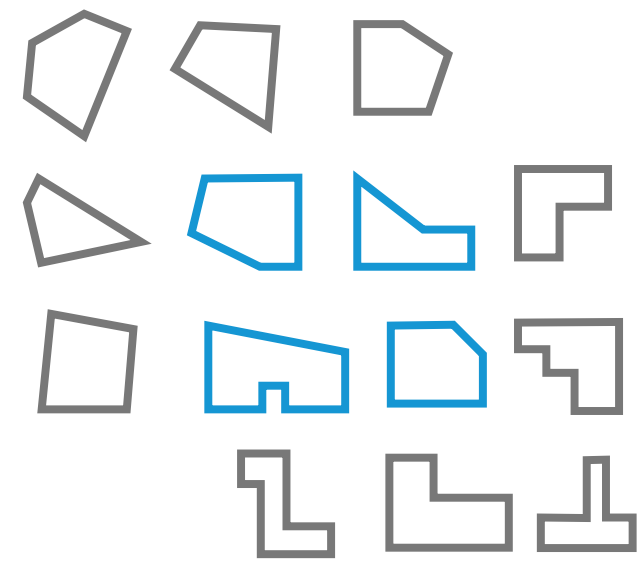


Reproducible and scalable

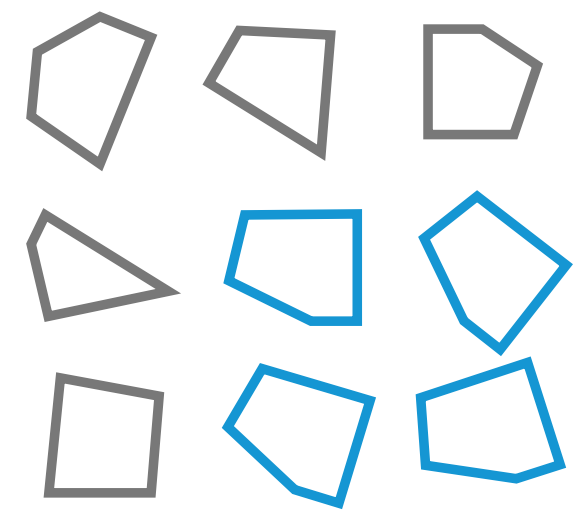


Modular generative
workflows

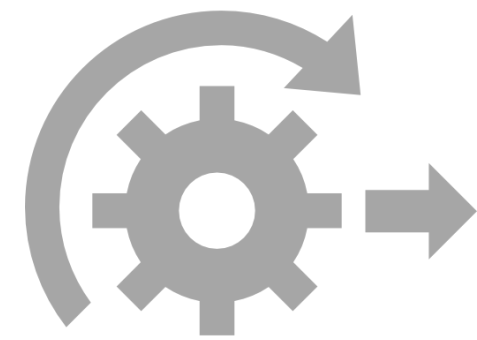
IDENTIFY TARGET TAXONOMIES



Avoid overlaps

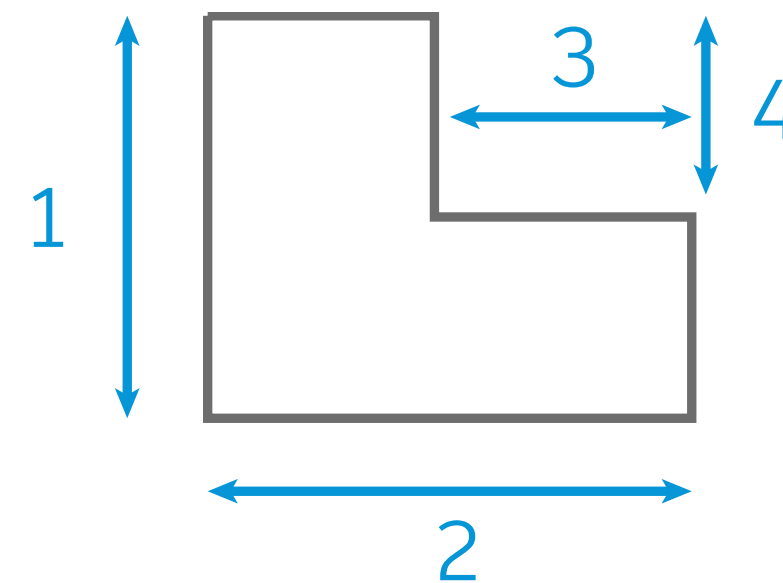
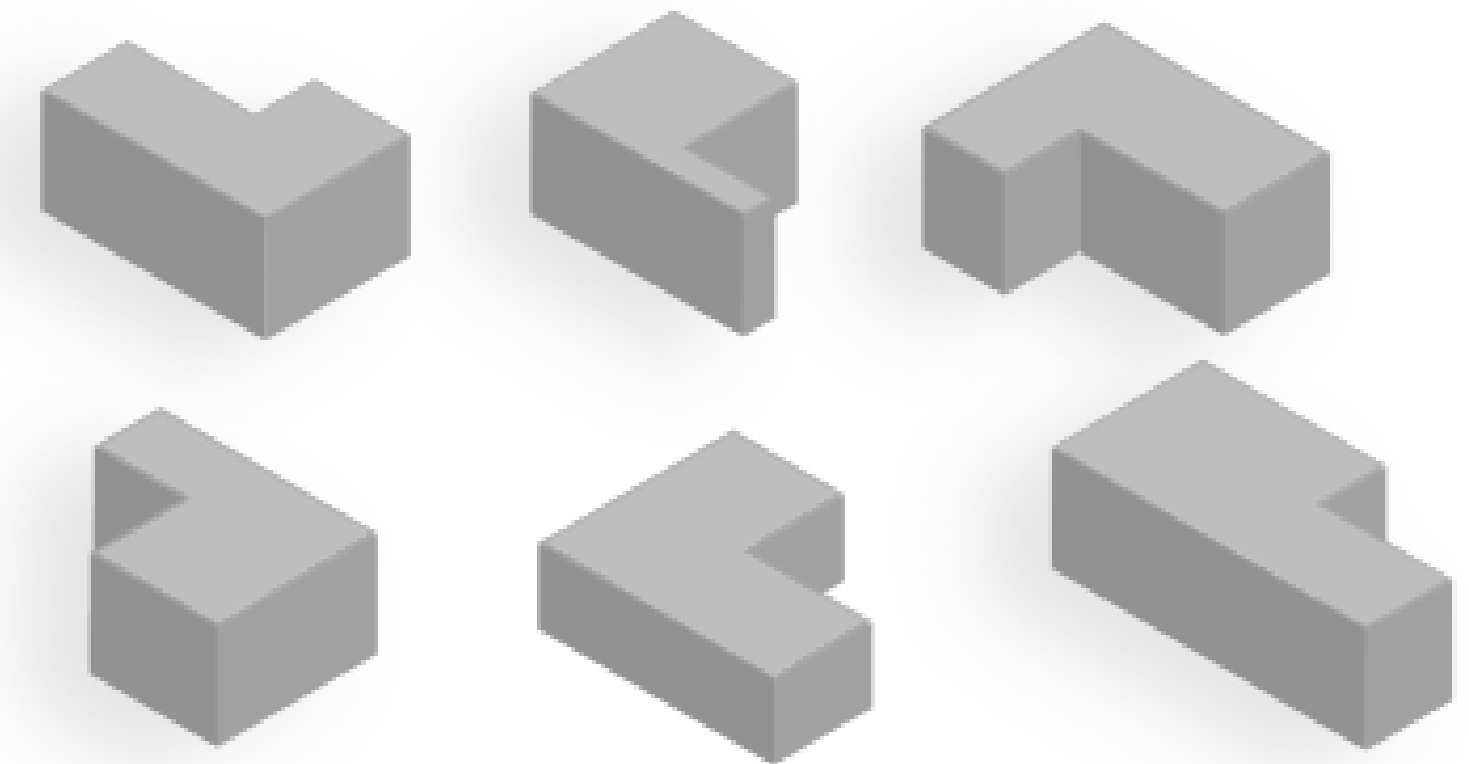


Avoid repetition / bias

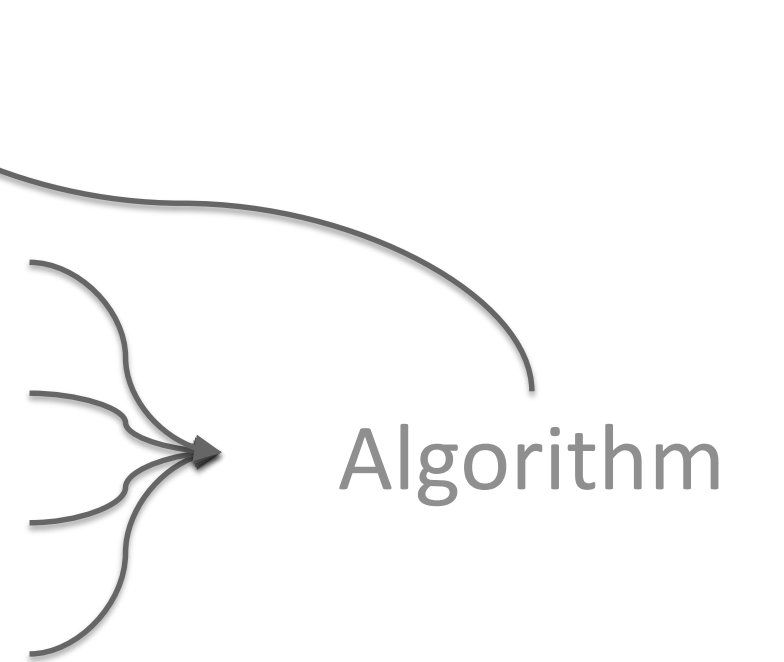


Breakdown algorithmically

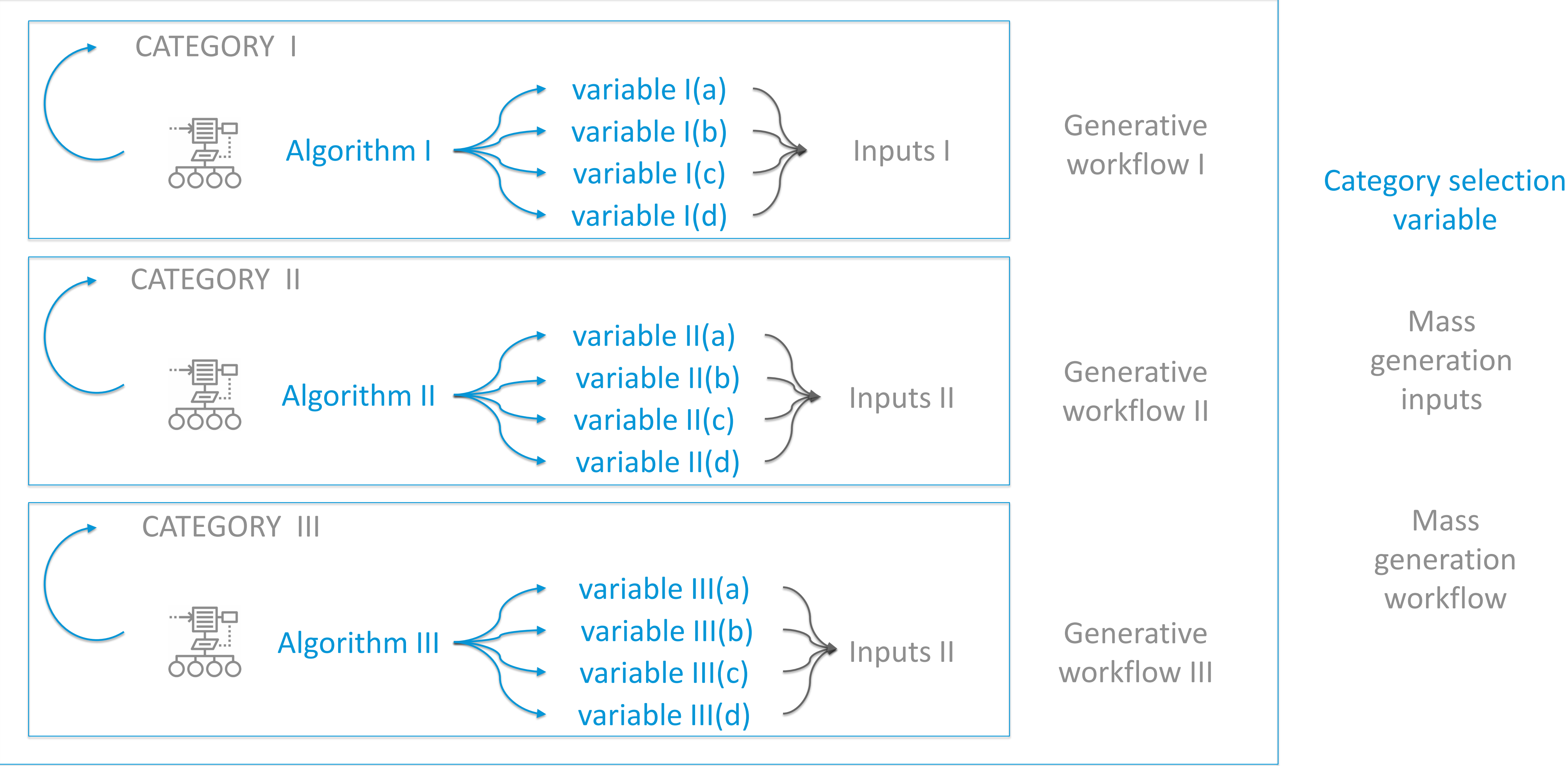
Category of 'L' shaped geometries



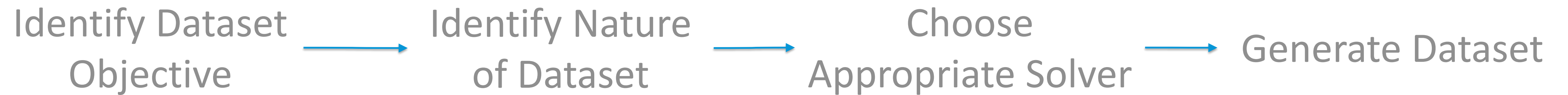
1. Height
2. Width
3. Horizontal indent
4. Vertical indent



Synthetic building data : establishing variables

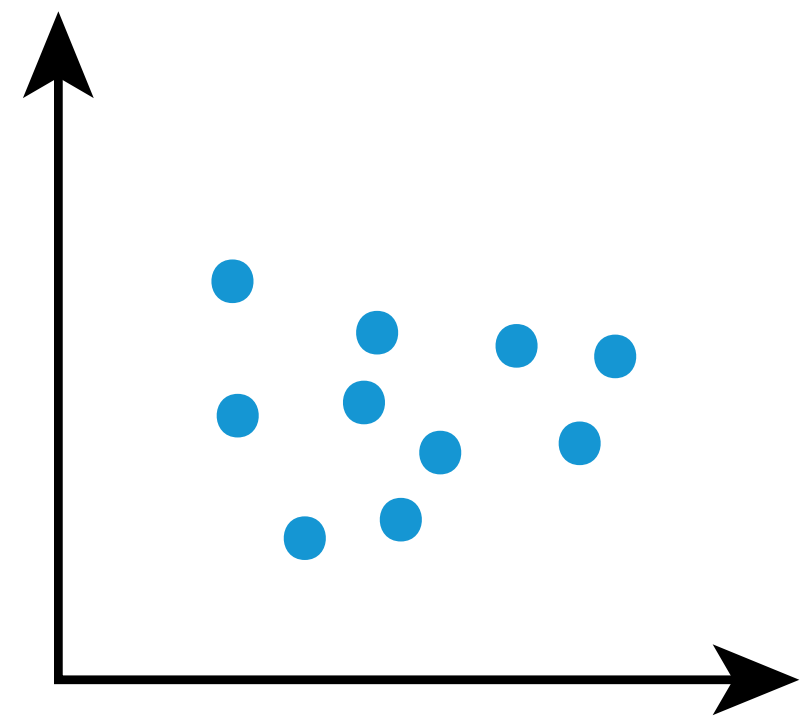


Synthetic building data : establishing objectives



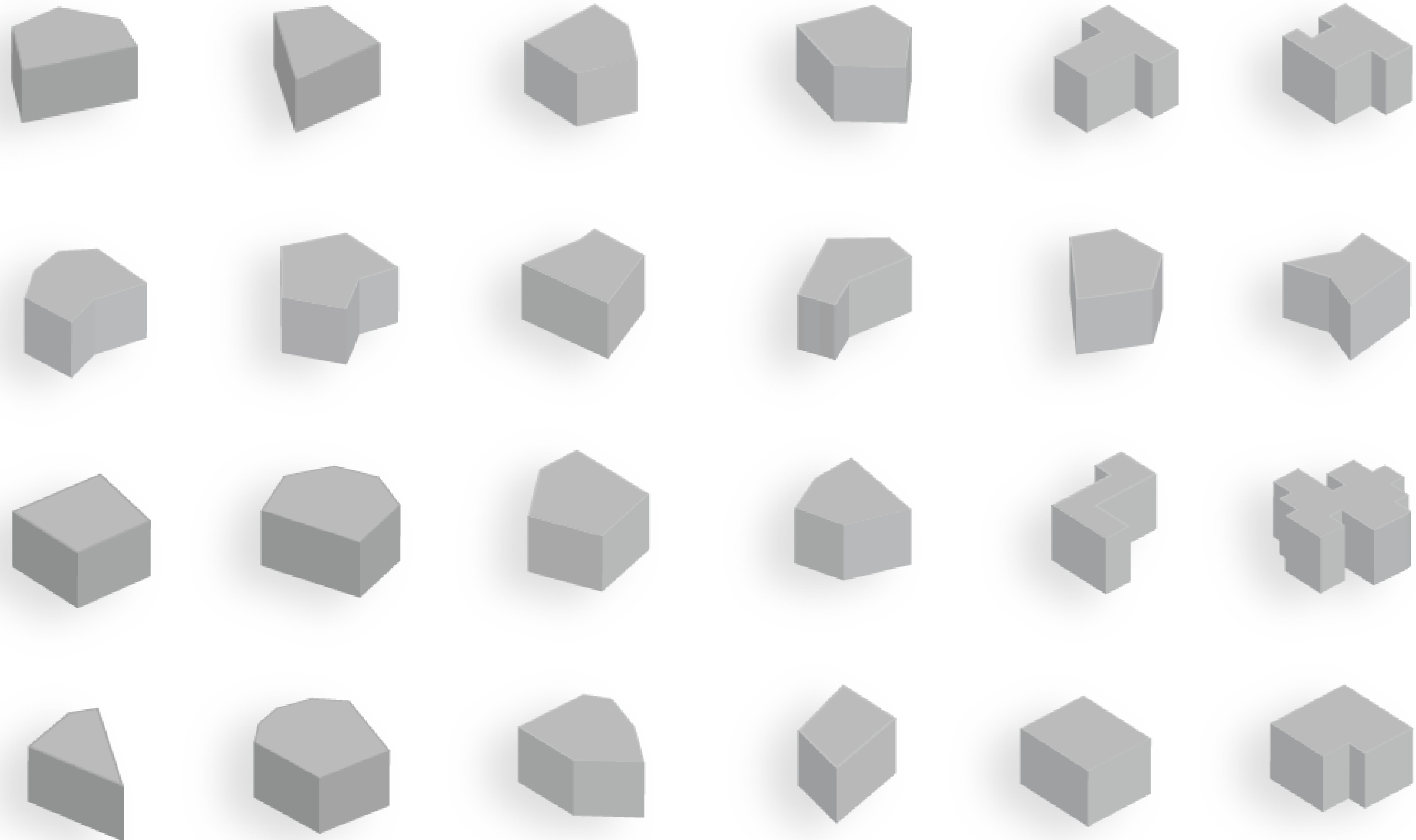
Synthetic building data : establishing objectives

RANDOMIZE SOLVER



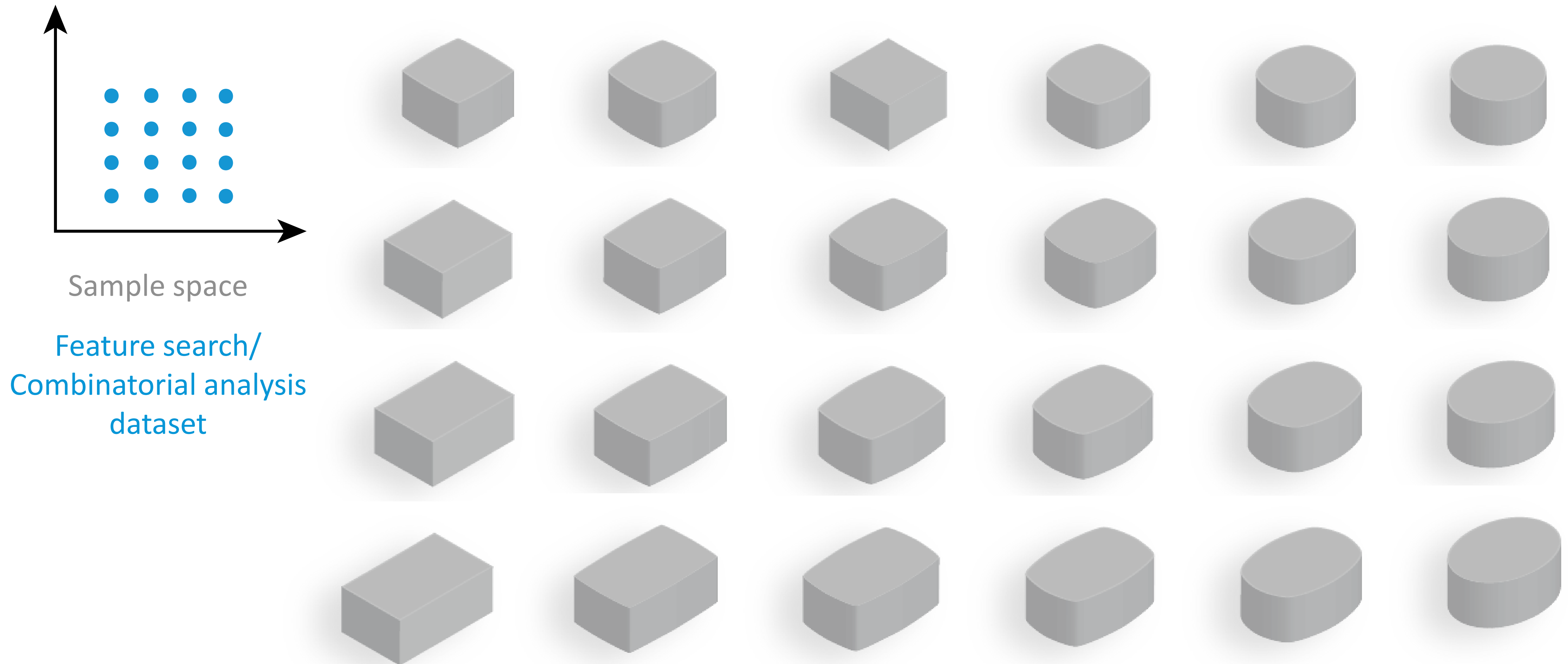
Sample space

Diverse datasets



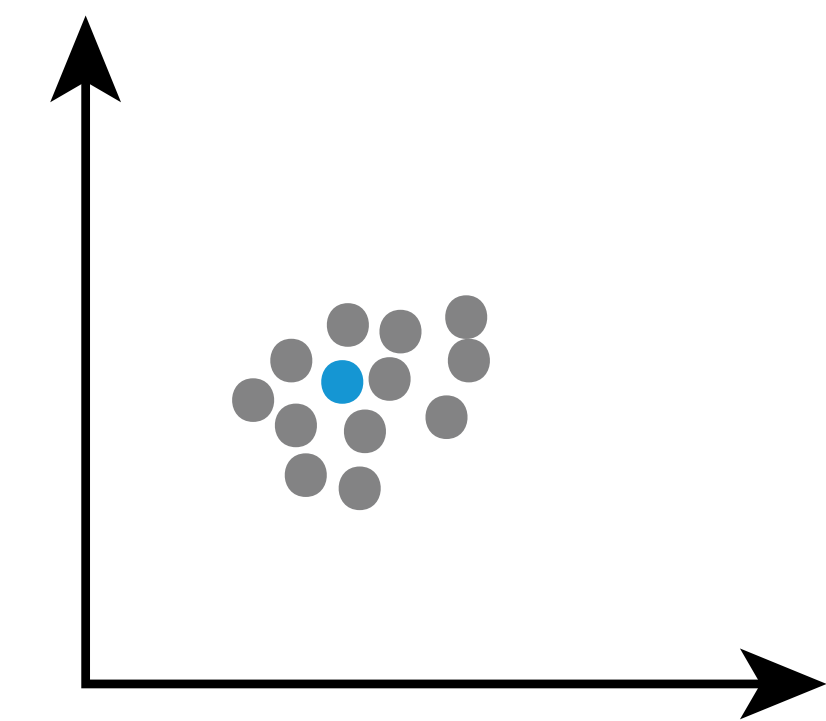
Synthetic building data : establishing objectives

CROSS-PRODUCT SOLVER



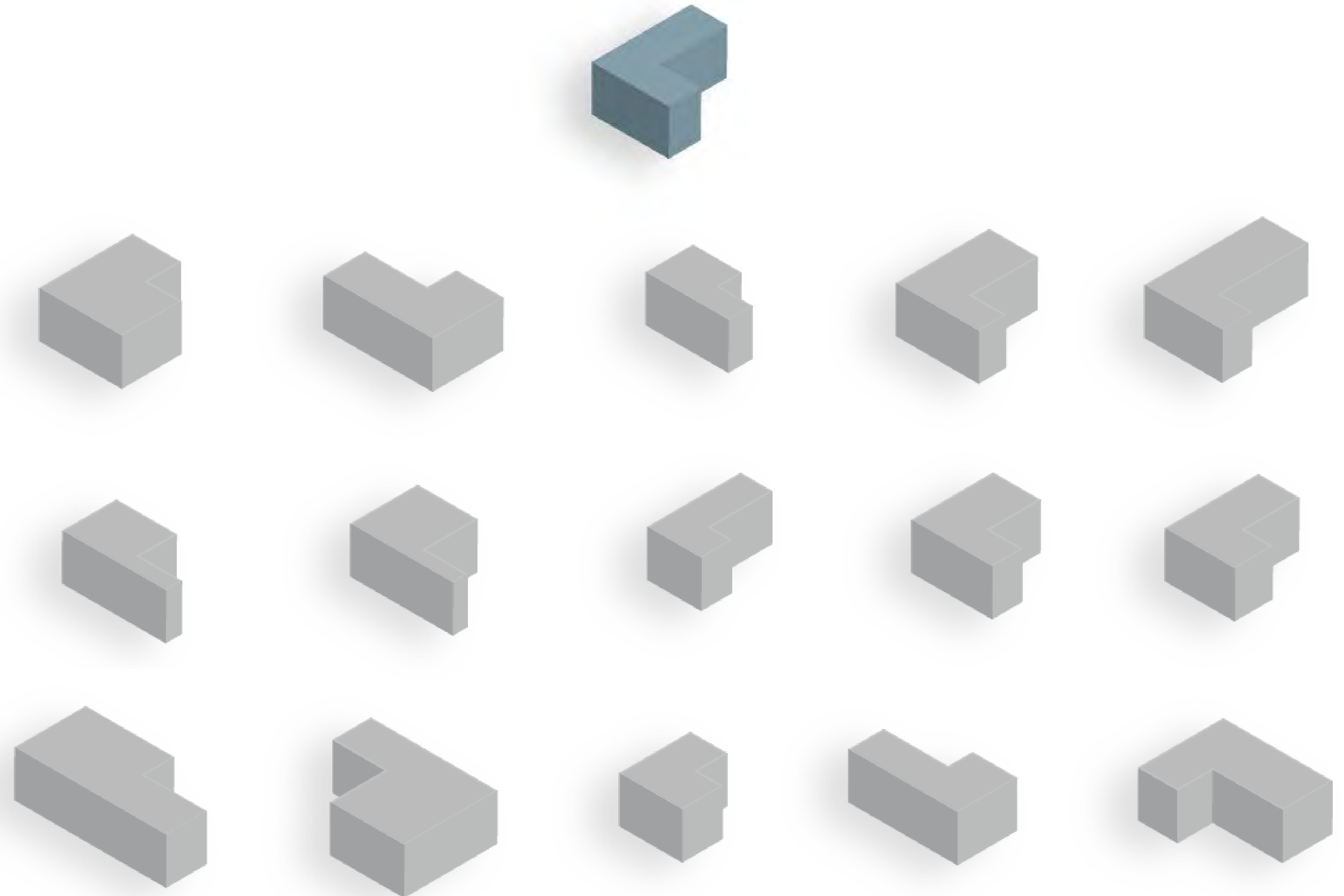
Synthetic building data : establishing objectives

LIKE – THIS SOLVER



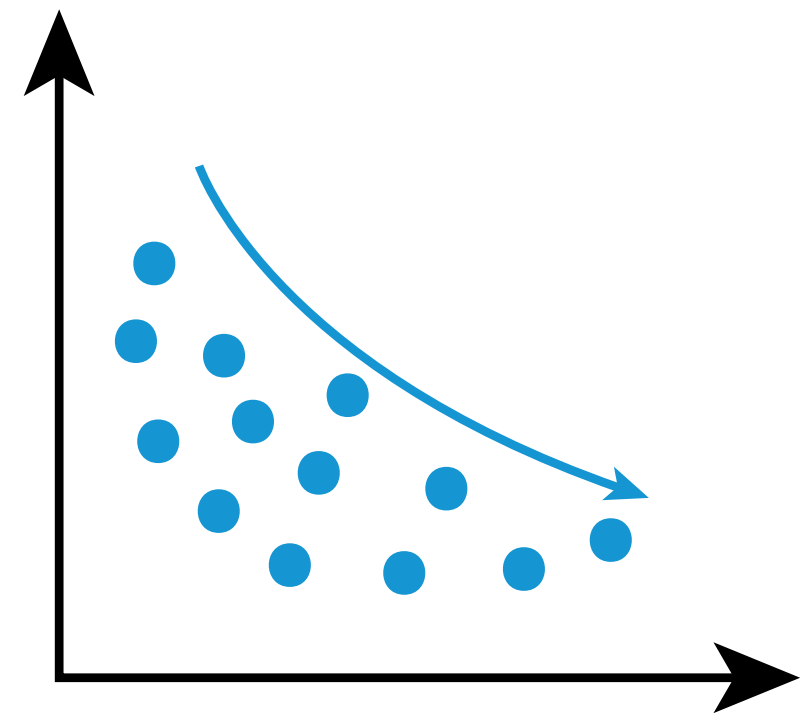
Sample space

Form finding /
Sensitivity analysis
dataset



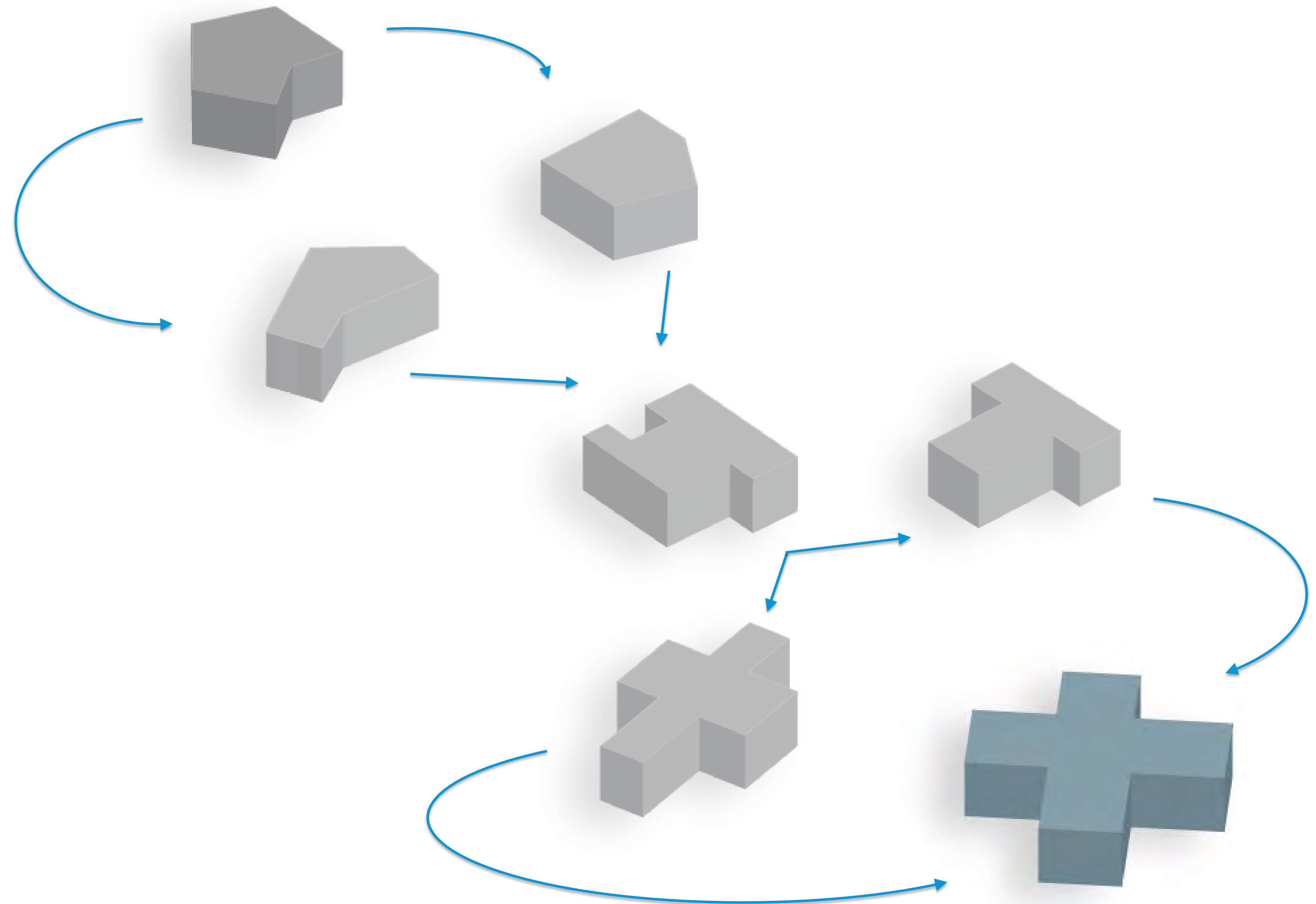
Synthetic building data : establishing objectives

OPTIMIZE SOLVER

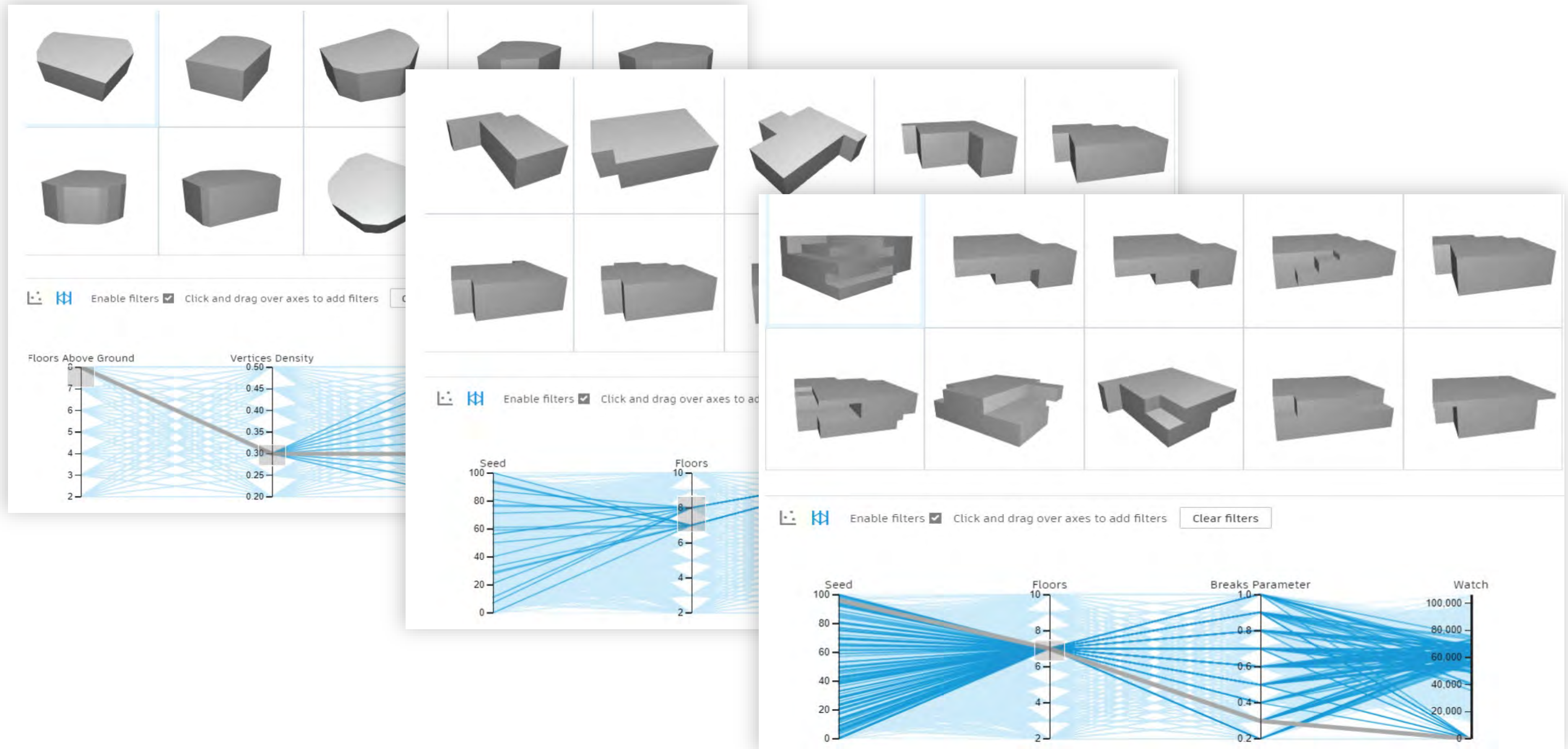


Sample space

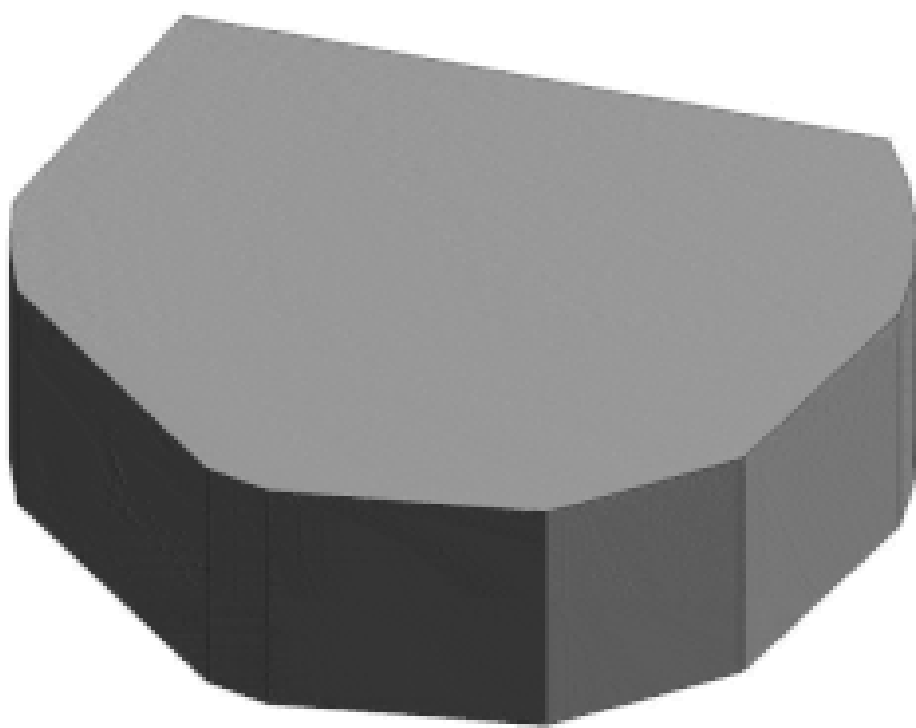
Design Optimization /
Performance oriented
form-finding dataset



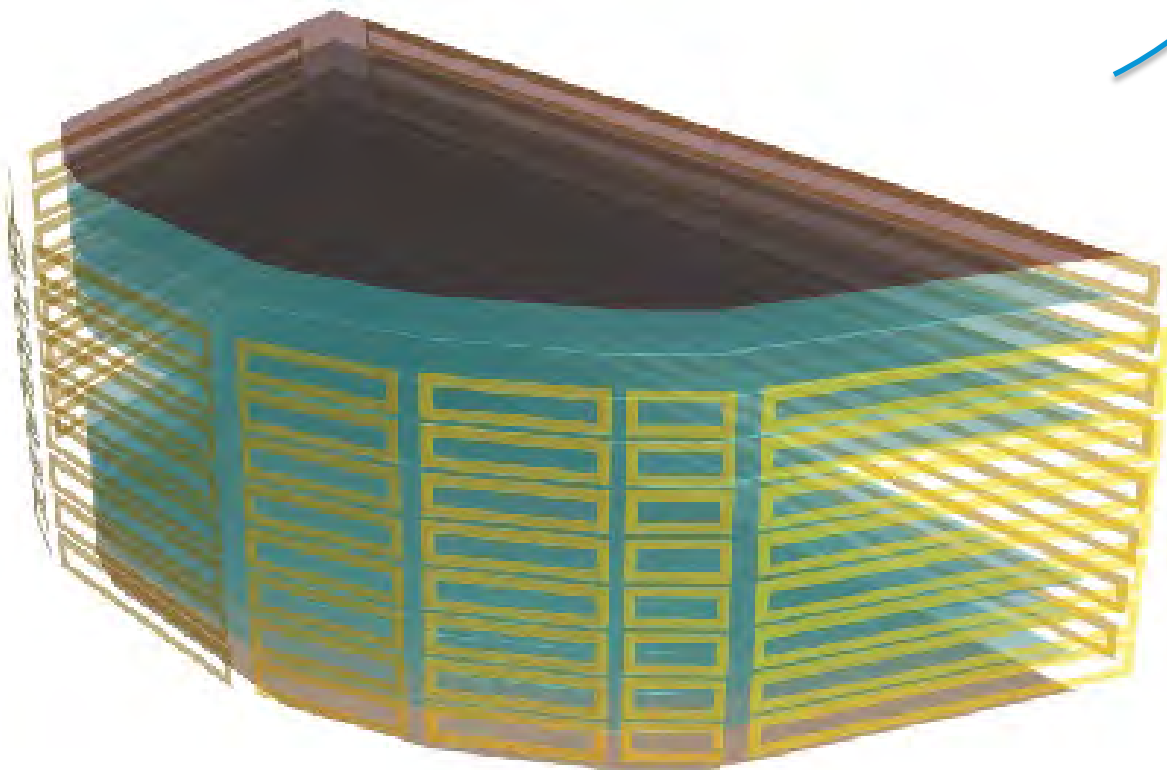
Synthetic building data : generating the dataset



Synthetic analytical data : ground truth labels



Generated solids



Analytical model
(GbXML)



Ground truth labels
(Simulation)



Revit energy settings

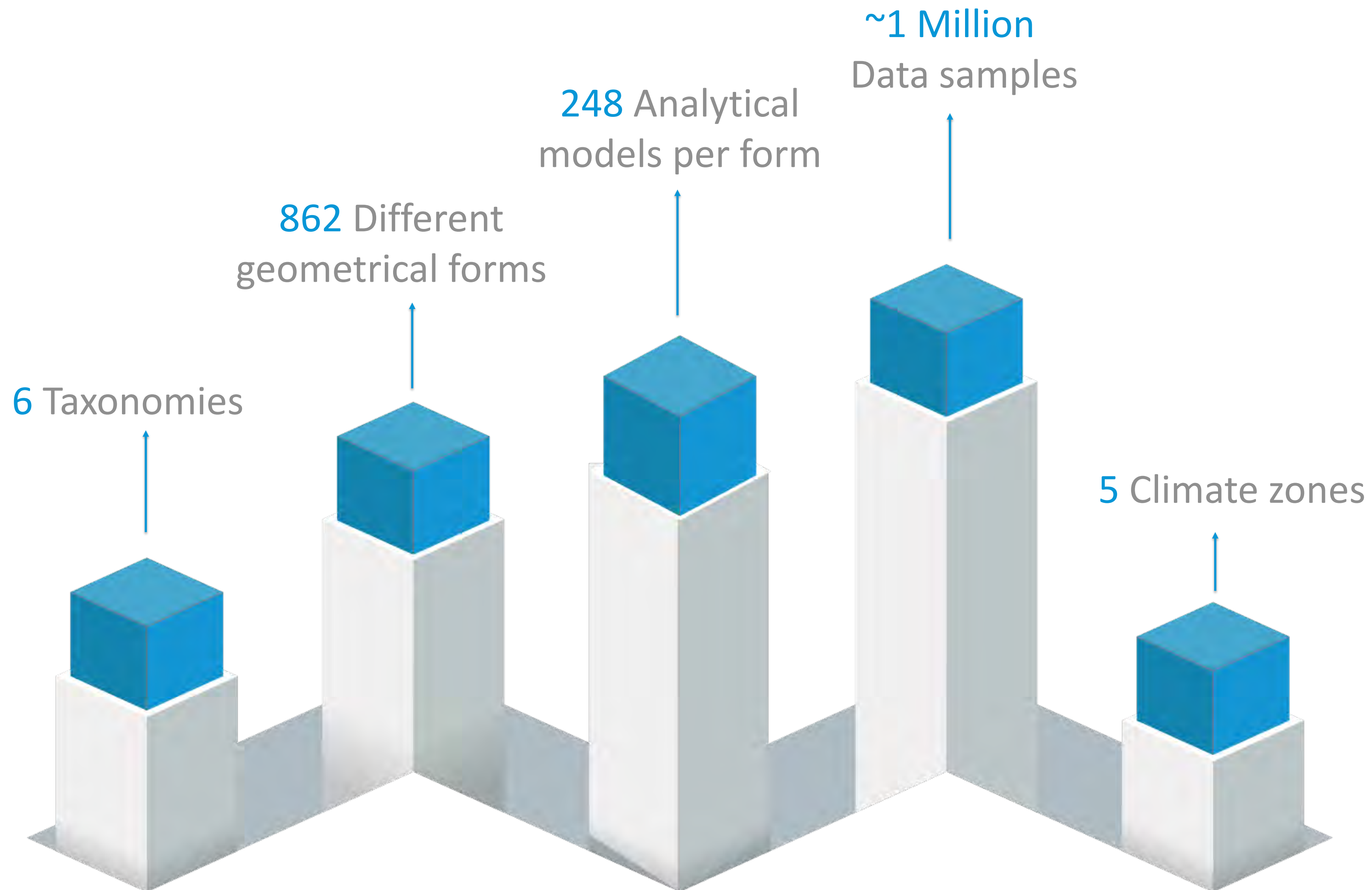
Energy Settings

Parameter	Value
Energy Analytical Model	
Mode	Use Conceptual Masses
Ground Plane	
Project Phase	Project Completion
Analytical Space Resolution	0.4572
Analytical Surface Resolution	0.3048
Perimeter Zone Depth	4.5700
Perimeter Zone Division	☒
Average Vertical Void Height Threshold	1.8288
Horizontal Void/Chase Area Threshold	0.093 m²
Advanced	
Other Options	Edit...

Advanced Energy Settings

Parameter	Value
Detailed Model	
Target Percentage Glazing	40%
Target Sill Height	0.7620
Glazing is Shaded	☐
Shade Depth	0.4572
Target Percentage Skylights	0%
Skylight Width & Depth	0.9144
Building Data	
Building Type	Office
Building Operating Schedule	Default
HVAC System	Central VAV, HW Heat, Chiller 5.96 COP, Bo
Outdoor Air Information	Edit...
Room/Space Data	
Export Category	Rooms
Material Thermal Properties	

Synthetic data: a glance



Machine learning for performance prediction

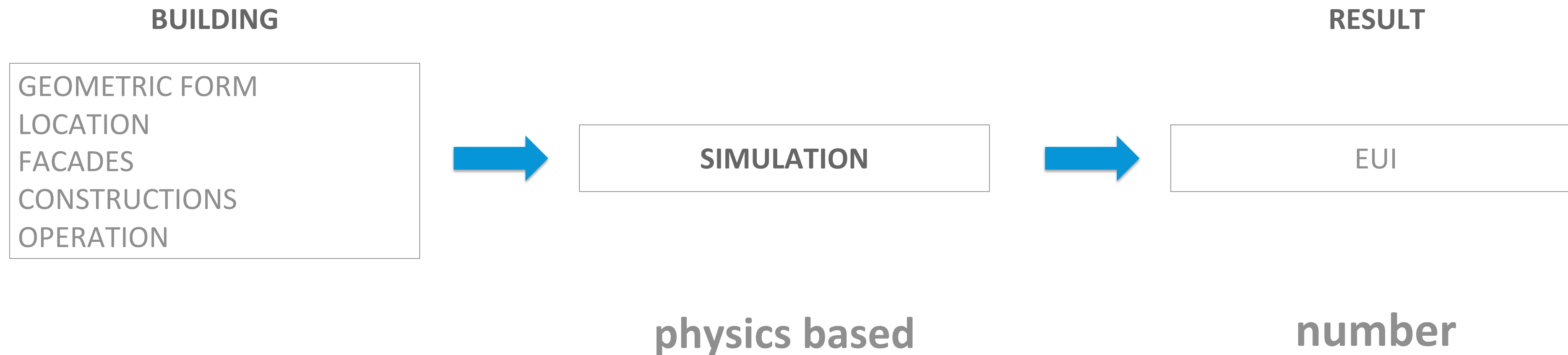


Describing the problem

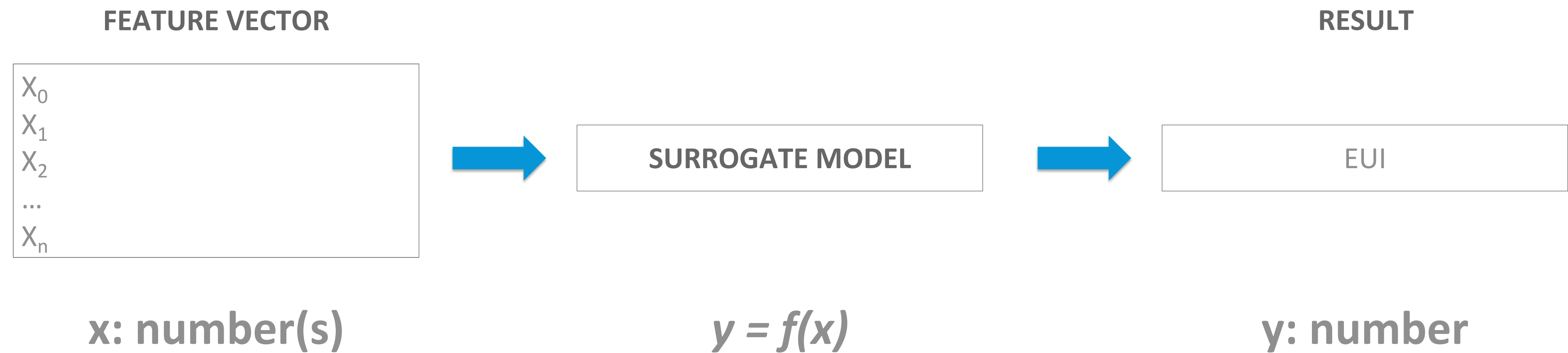


Describing the problem

Define the inputs and outputs



Describing the problem



Representing the data

BUILDING

GEOMETRIC FORM
LOCATION
FACADES
CONSTRUCTIONS
OPERATION

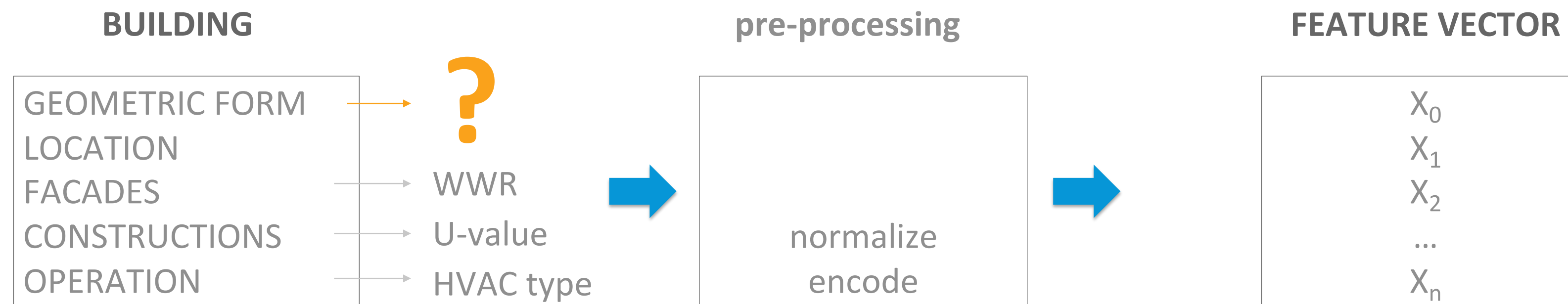


FEATURE VECTOR

X_0
 X_1
 X_2
...
 X_n

Representing the data

From buildings to feature vectors



Representing the data

Handling the Geometries

- **High Level Representations**

- Parameters of the generative model
- Post process geometries to extract parameters



selecting and
engineering features

- **Generic Geometric Format**

- ~~Meshes ?~~
- Images
- Voxels
- Point clouds



learning features

Model types

- **Linear Regression**
- **Gaussian Process**
- **Random Forest**
- **Deep Learning**
- ...

Training a model

TRAINING SET

Fit model to data

VALIDATION SET

Model selection, tuning

TEST SET

Evaluate final model

How to start?

SELECT MODELS, DATA REPRESENTATIONS

Use domain knowledge

Use precedents

BUILD DATASET

Identify sources

Combine data

Cleanup data

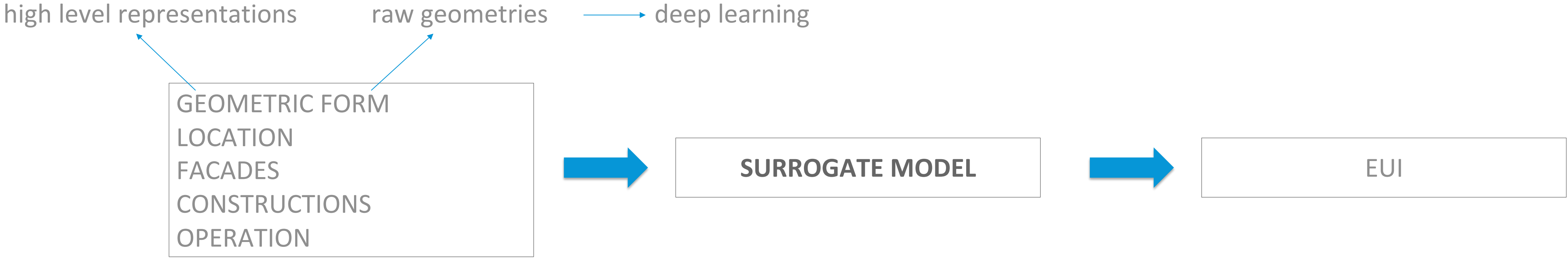
TEST AND REPEAT

Simplify problem

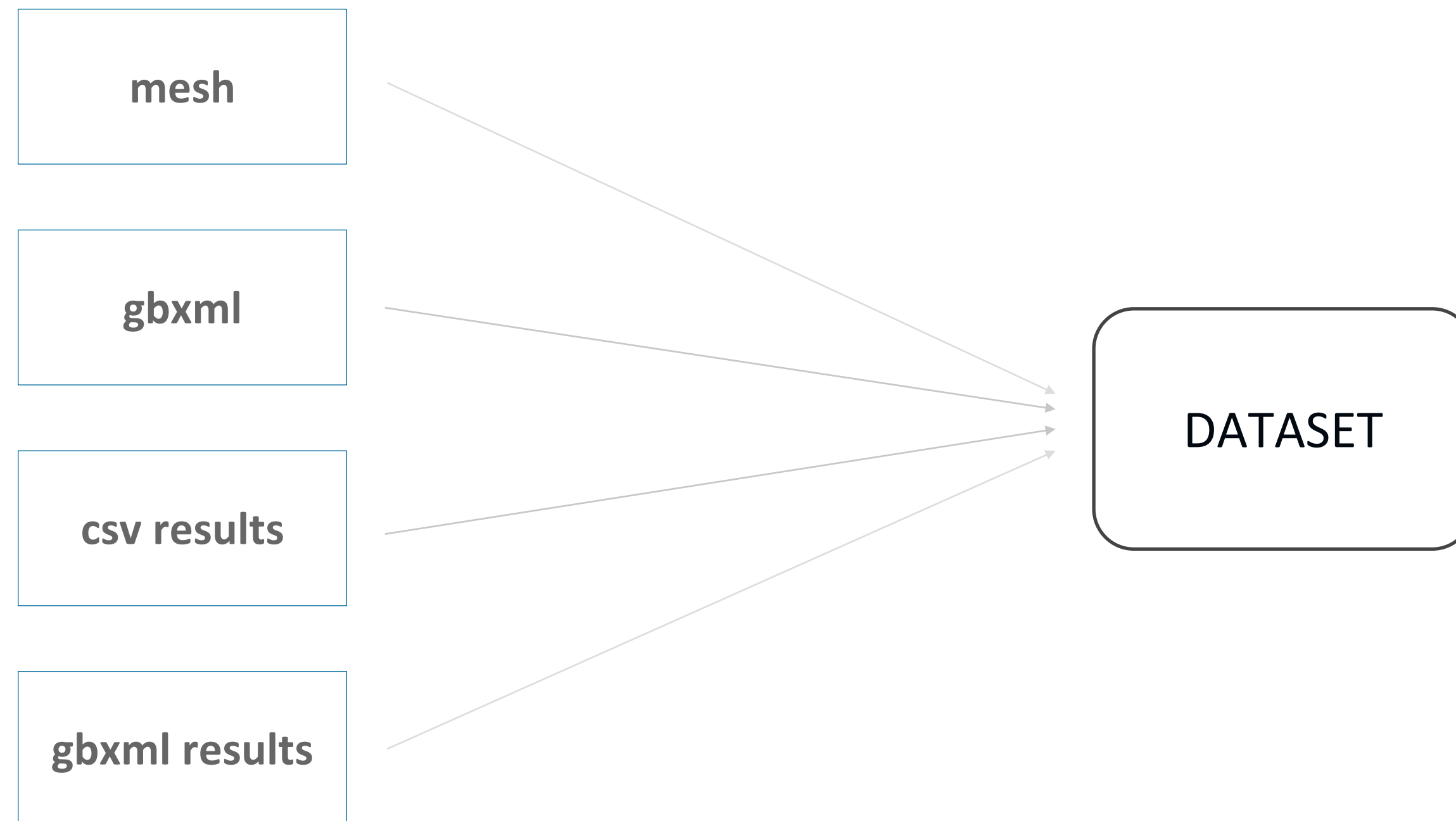
Use subset of data

Add complexity

Annual EUI prediction



Data sources



Annual EUI prediction



Annual EUI prediction



Results inform the:

model type

geometry representations

dataset diversity

Annual EUI prediction



Annual EUI prediction

GEOMETRIC FORM
LOCATION
FACADES
CONSTRUCTIONS
OPERATION



SURROGATE MODEL



EUI

~862 geometric forms

X

242 parameter variations

X

5 climate zones

1.91 % error

Annual EUI prediction

Get annual EUI result in milliseconds

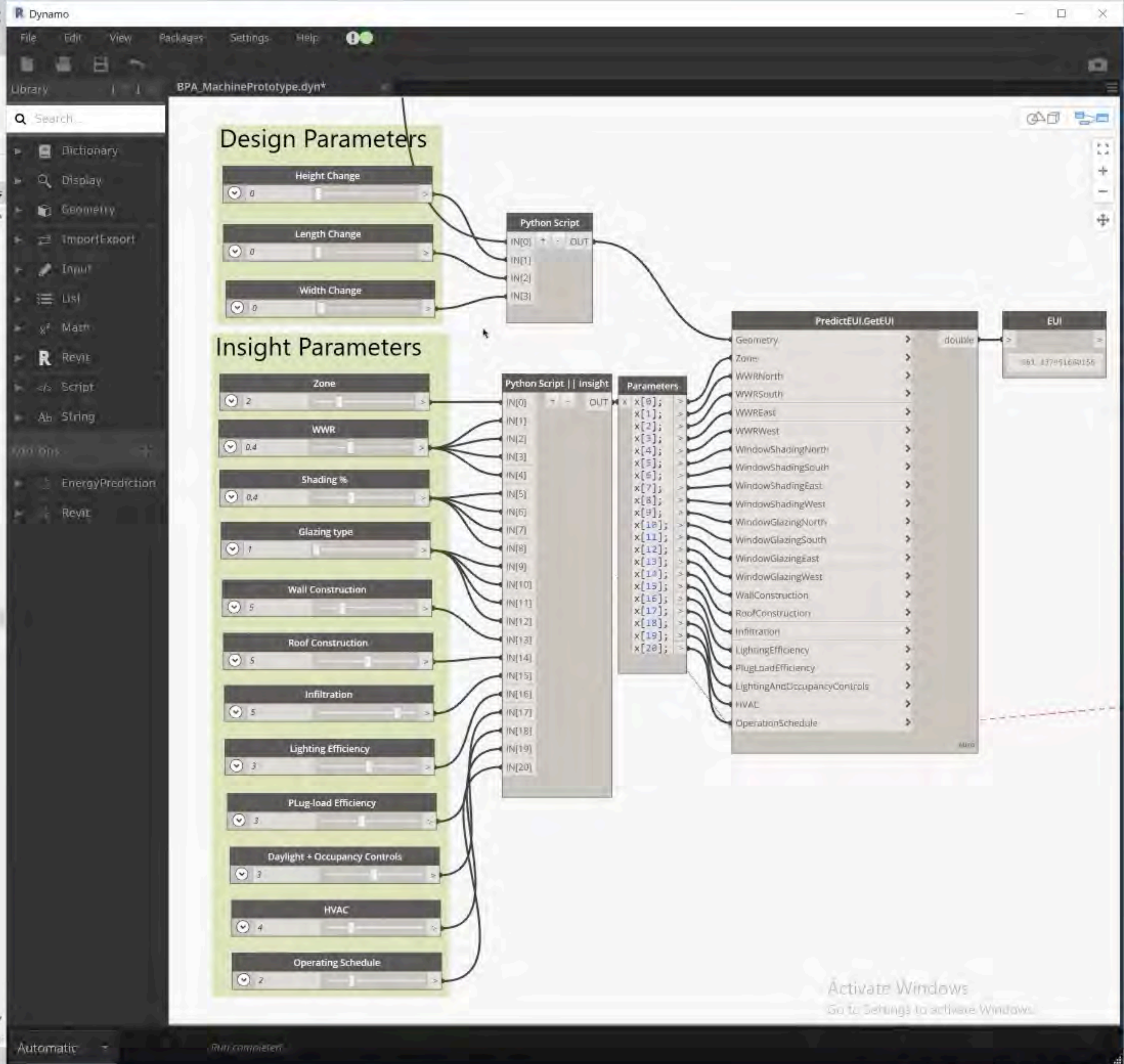
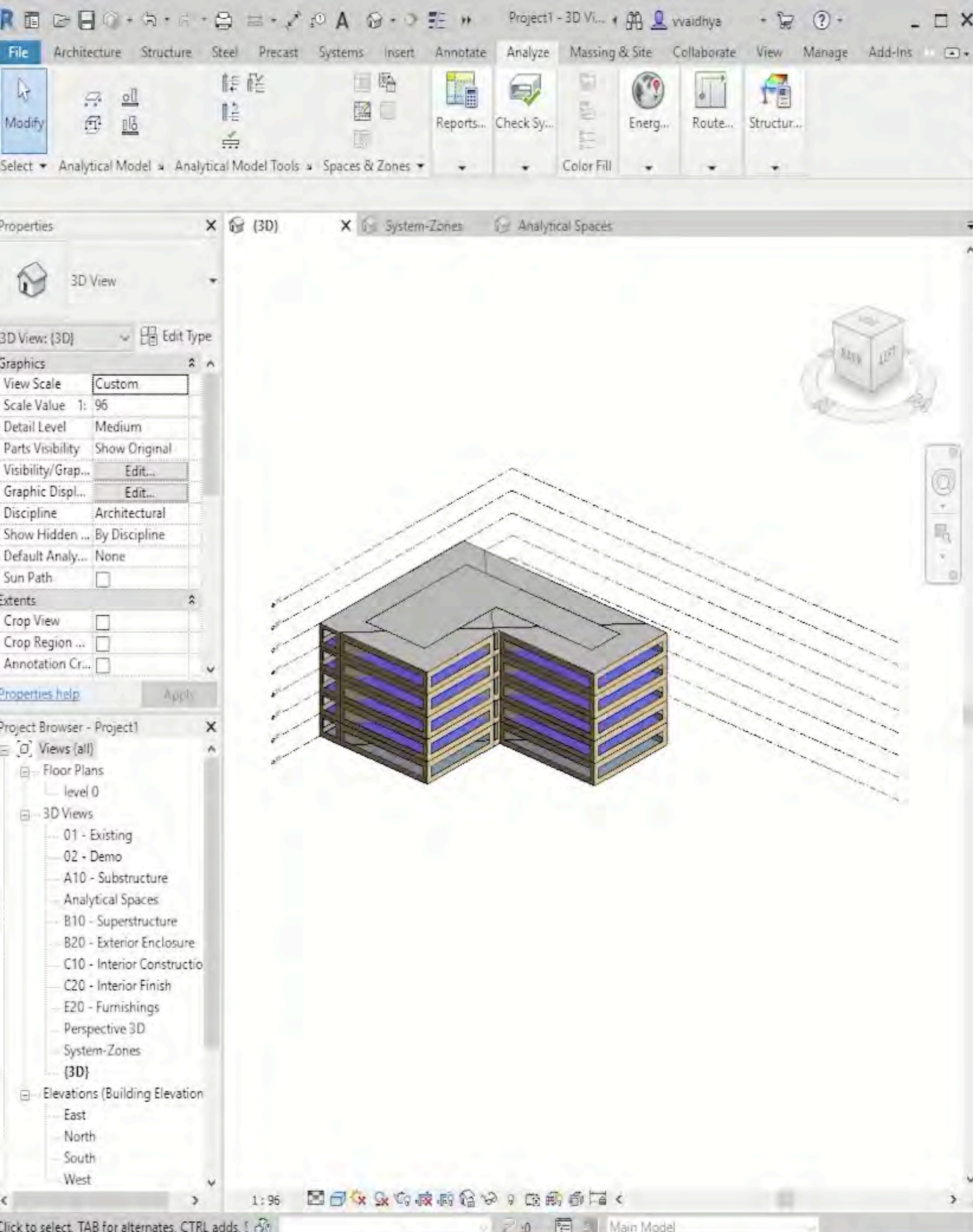
GEOMETRIC FORM
LOCATION
FACADES
CONSTRUCTIONS
OPERATION



SURROGATE MODEL



EUI



To Sum Up

[1]

Discussed the importance and current obstacles of integrating energy prediction early in design.

[2]

Introduced the potential of ML methods as a solution, and the necessity of synthetic data.

[3]

Demonstrated an example of generating a diverse dataset of labeled synthetic data.

[4]

Introduced the steps for training and evaluating a ML model and demonstrated how achieved real-time EUI predictions.

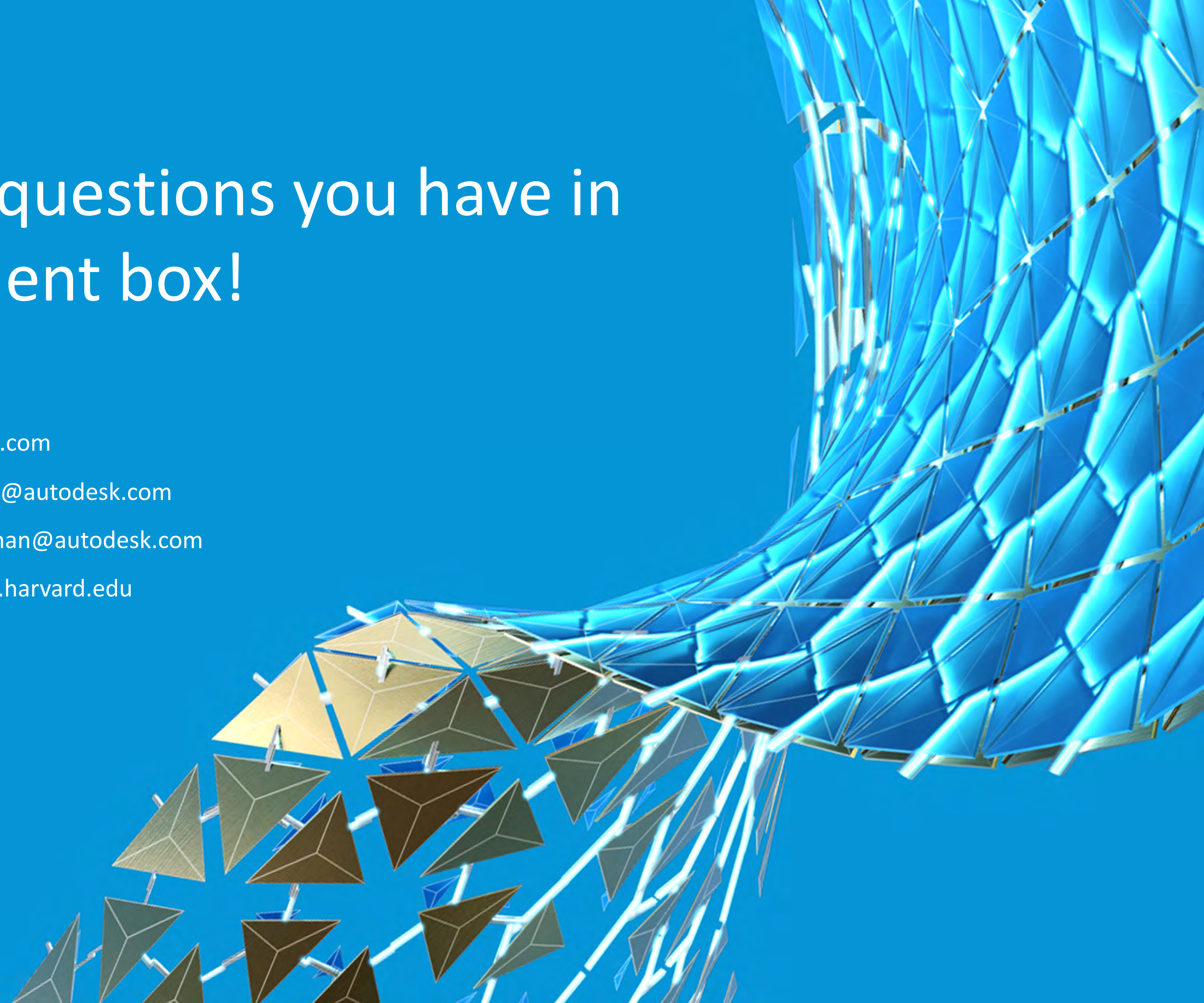
Please put any questions you have in the class comment box!

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Vishal Vaidhyanathan · vishal.vaidhyanathan@autodesk.com

Spyridon Ampanavos · sampanavos@gsd.harvard.edu





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