Performance-Driven Design Exploration of Biocomposite Facades

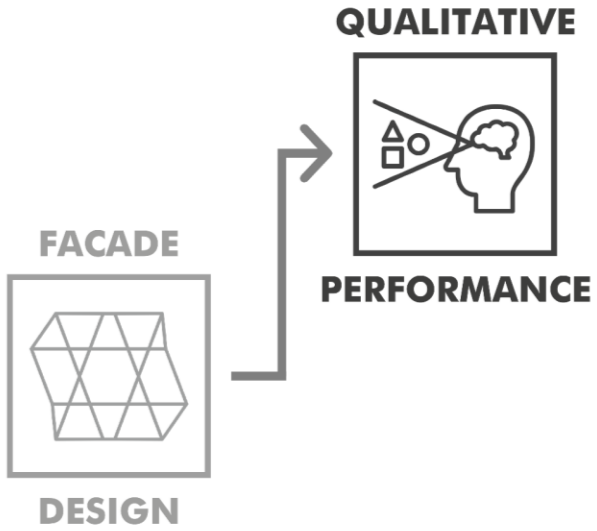
Advancing Facade Design through Enhanced Computational Efficiency, Accuracy, and Interpretability: A Novel AI-Driven Facade Design Framework comprising Self-Organising Maps (SOM) and Kolmogorov-Arnold Networks (KAN)

TU Delft
Building Technology Graduation Studio
Djani Cerneus – 5609305 – P5
13 January 2025

Introduction

FACADE

DESIGN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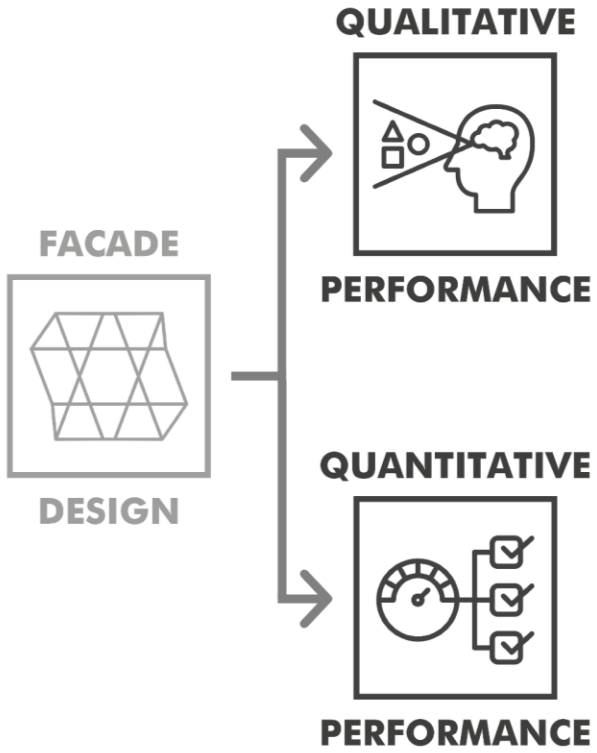
PERFORMANCE
FACADE
DESIGN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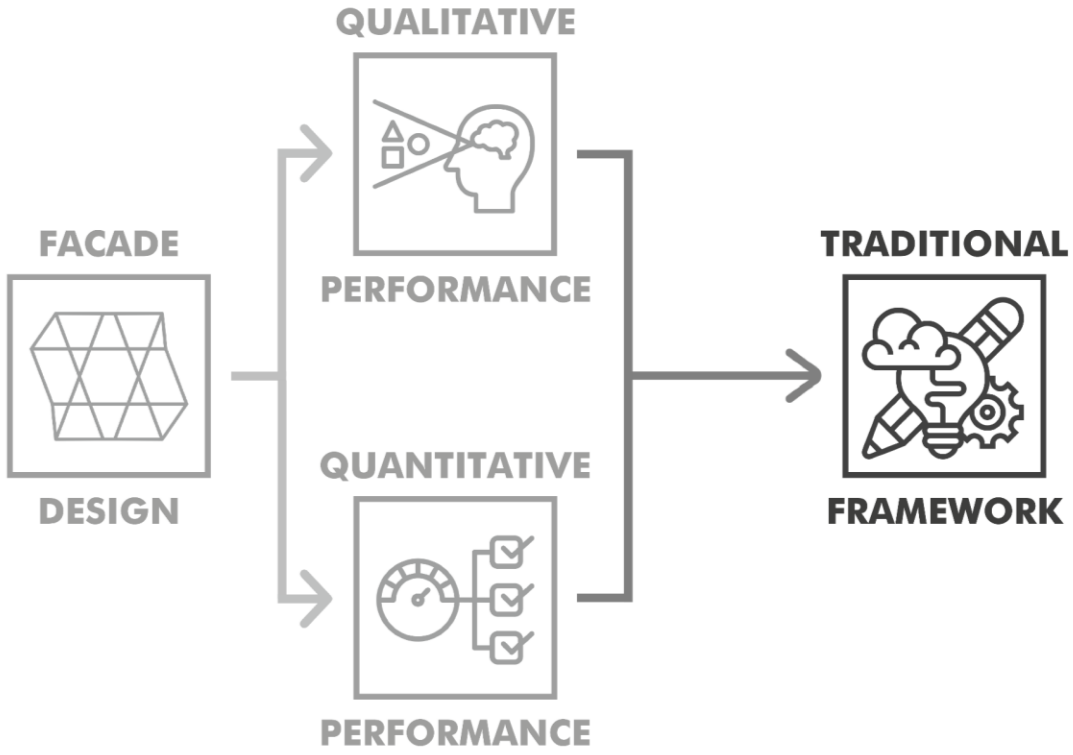
FACADE
PERFORMANCE
DESIGN
QUANTITATIVE
PERFORMANCE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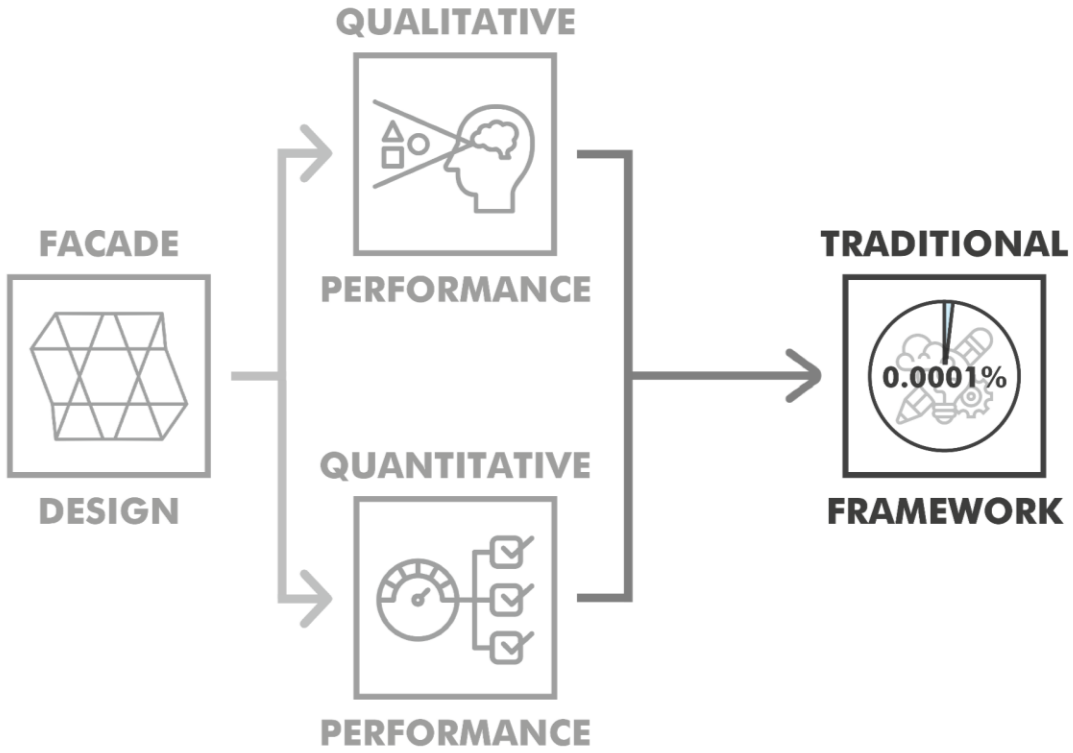
FACADE
PERFORMANCE
TRADITIONAL
QUANTITATIVE
DESIGN
FRAMEWORK
PERFORMANCE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TRADITIONAL
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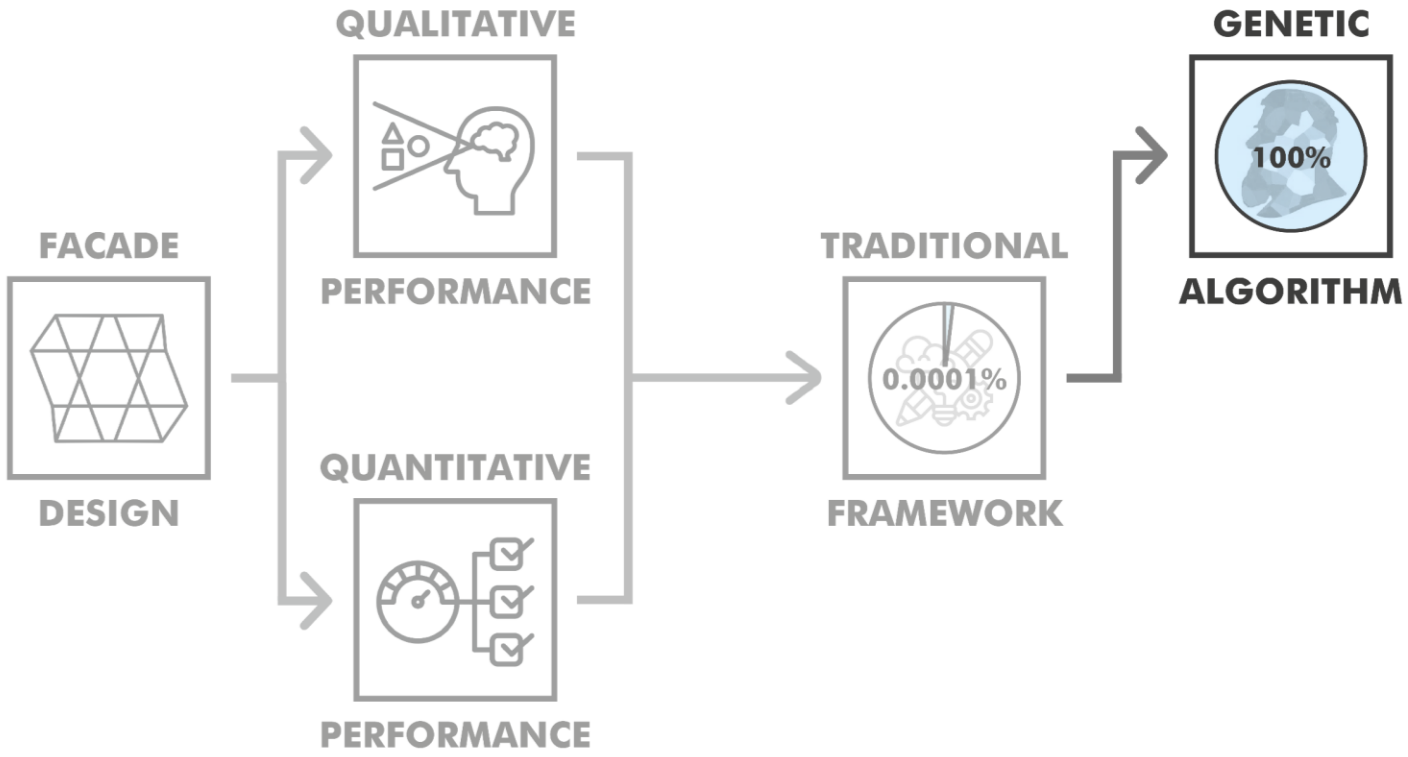
QUANTITATIVE
DESIGN
FRAMEWORK
PERFORMANCE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GENETIC
FACADE
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PERFORMANCE
TRADITIONAL
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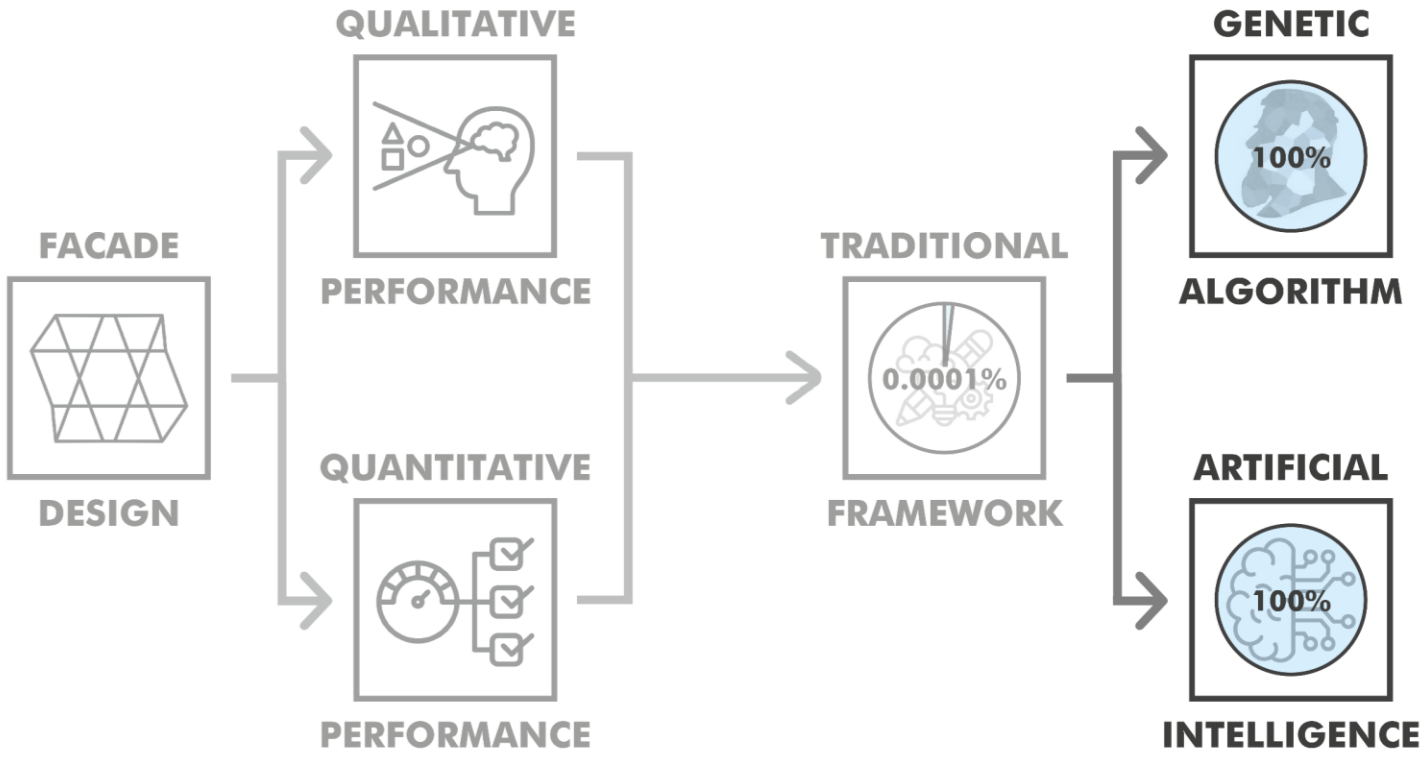
ALGORITHM
QUANTITATIVE
DESIGN
FRAMEWORK
PERFORMANCE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ALGORITHM
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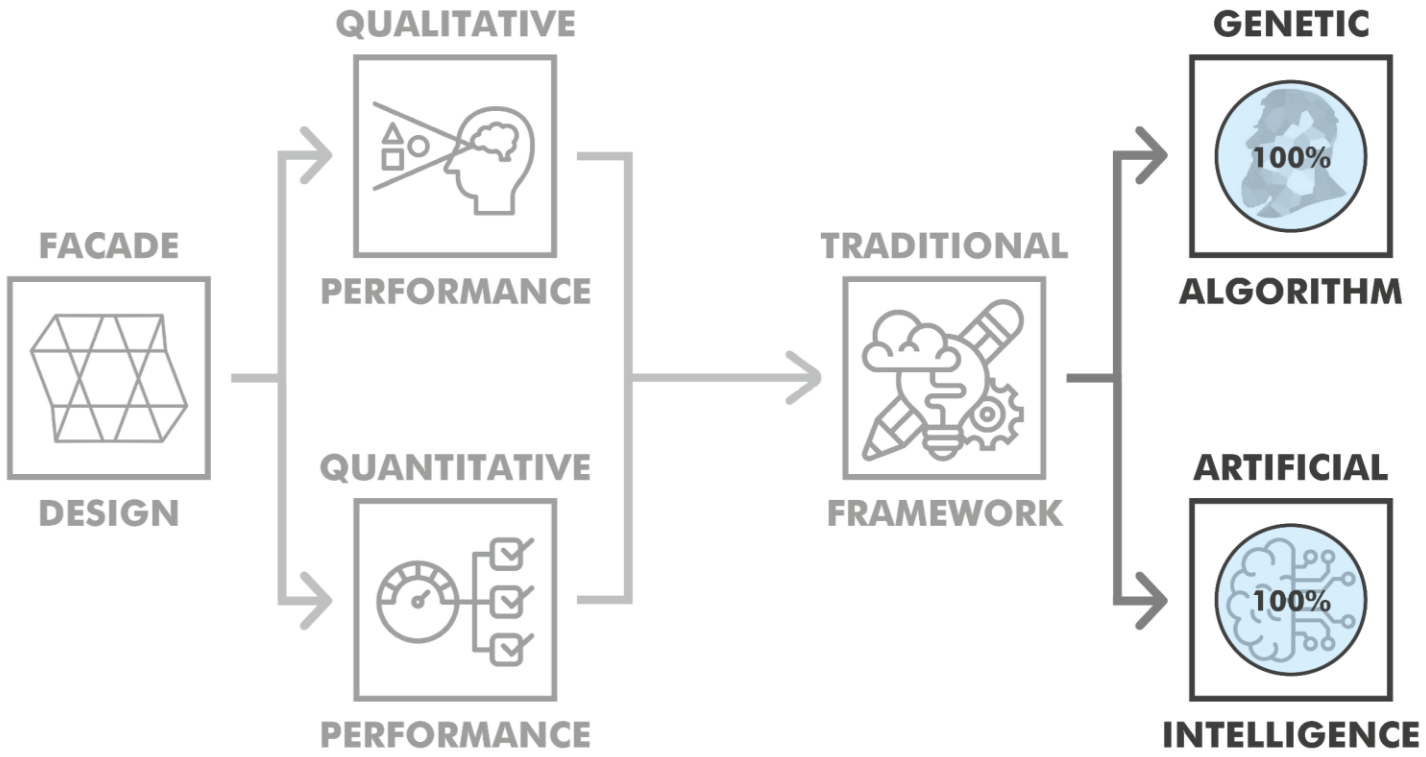
DESIGN
QUANTITATIVE
FRAMEWORK
ARTIFICIAL
100%
PERFORMANCE
INTELLIGENCE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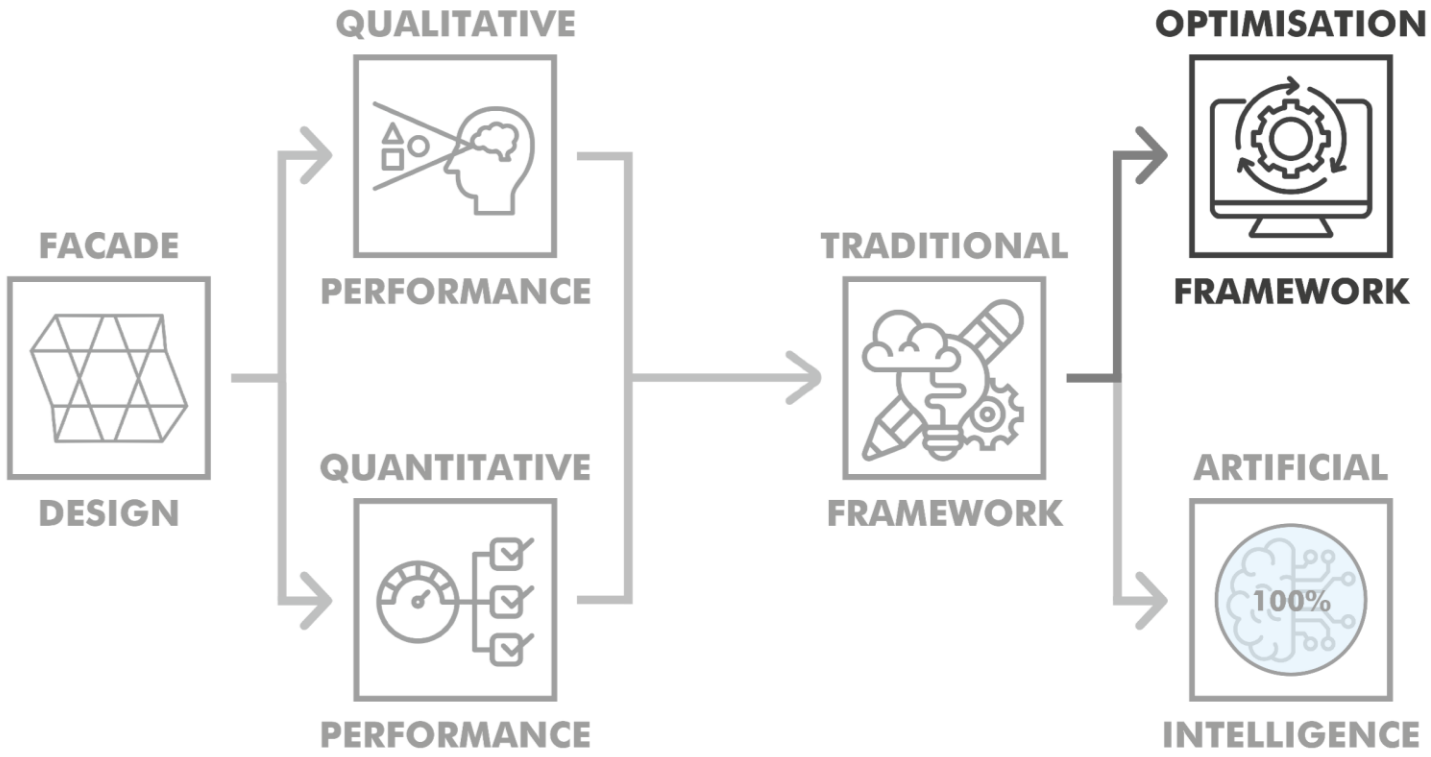
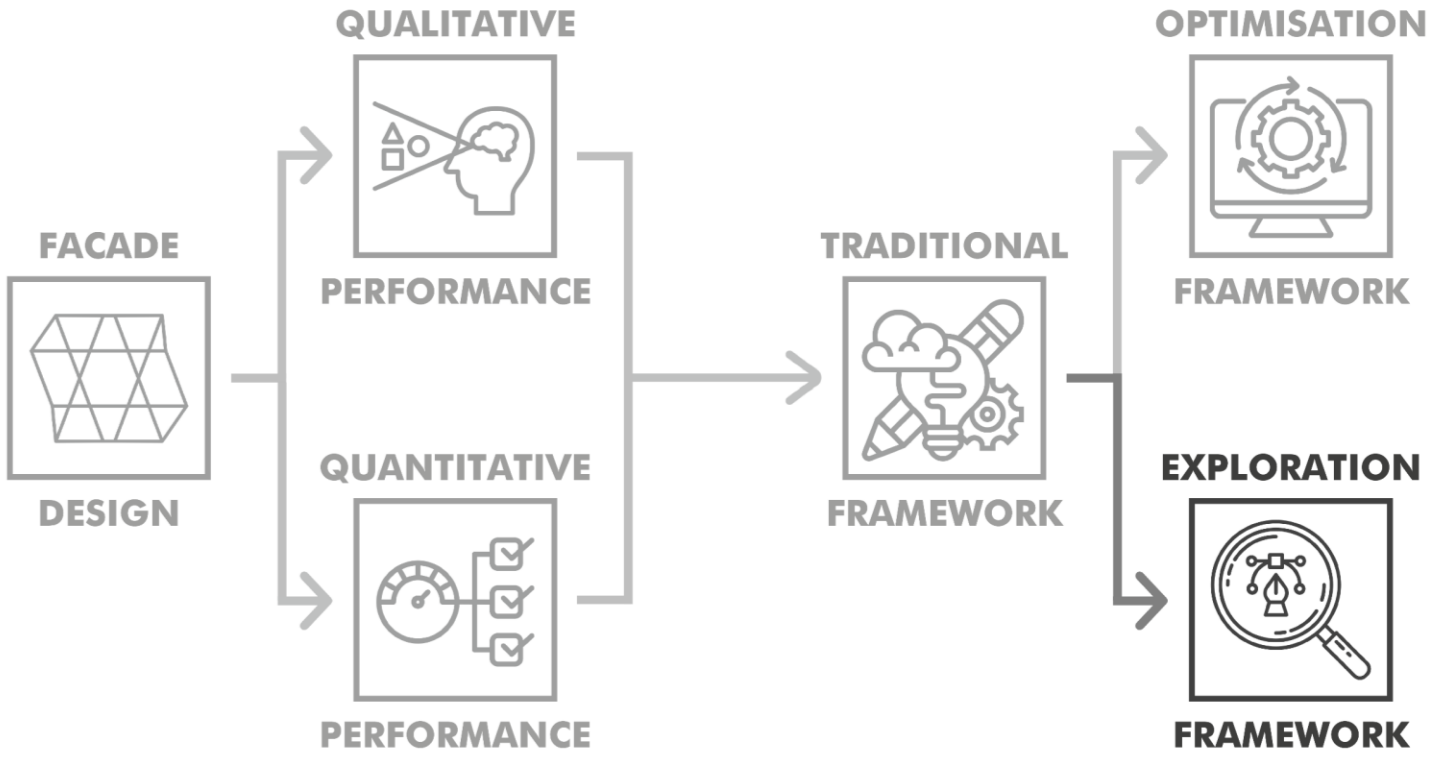
PERFORMANCE
INTELLIGENCE


FACADE
DESIGN
QUALITATIVE
PERFORMANCE
QUANTITATIVE
PERFORMANCE
TRADITIONAL
FRAMEWORK
OPTIMISATION
FRAMEWORK
ARTIFICIAL
100%
INTELLIGENCE


QUALITATIVE
OPTIMISATION
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PERFORMANCE
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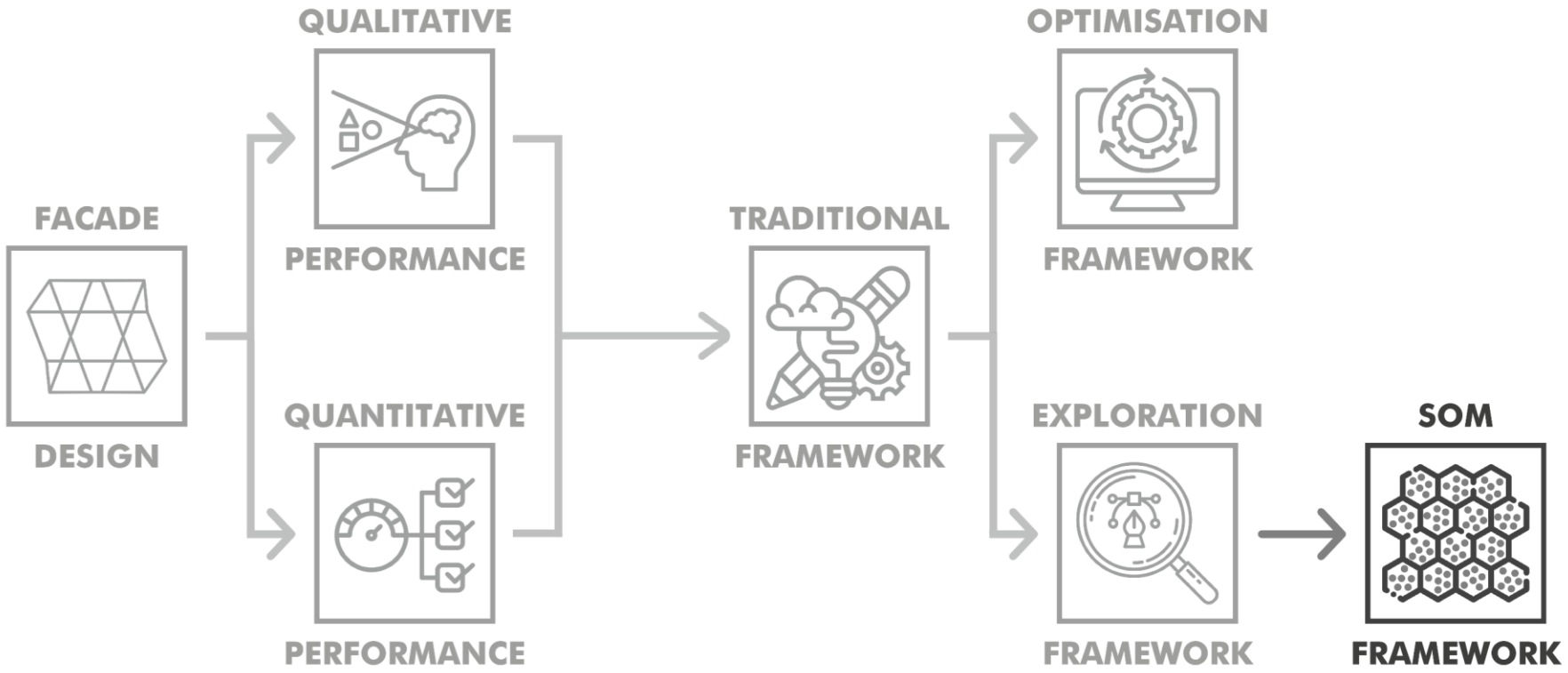
QUANTITATIVE
EXPLORATION
DESIGN
FRAMEWORK
PERFORMANCE
FRAMEWORK


FACADE
DESIGN
QUALITATIVE
PERFORMANCE
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PERFORMANCE
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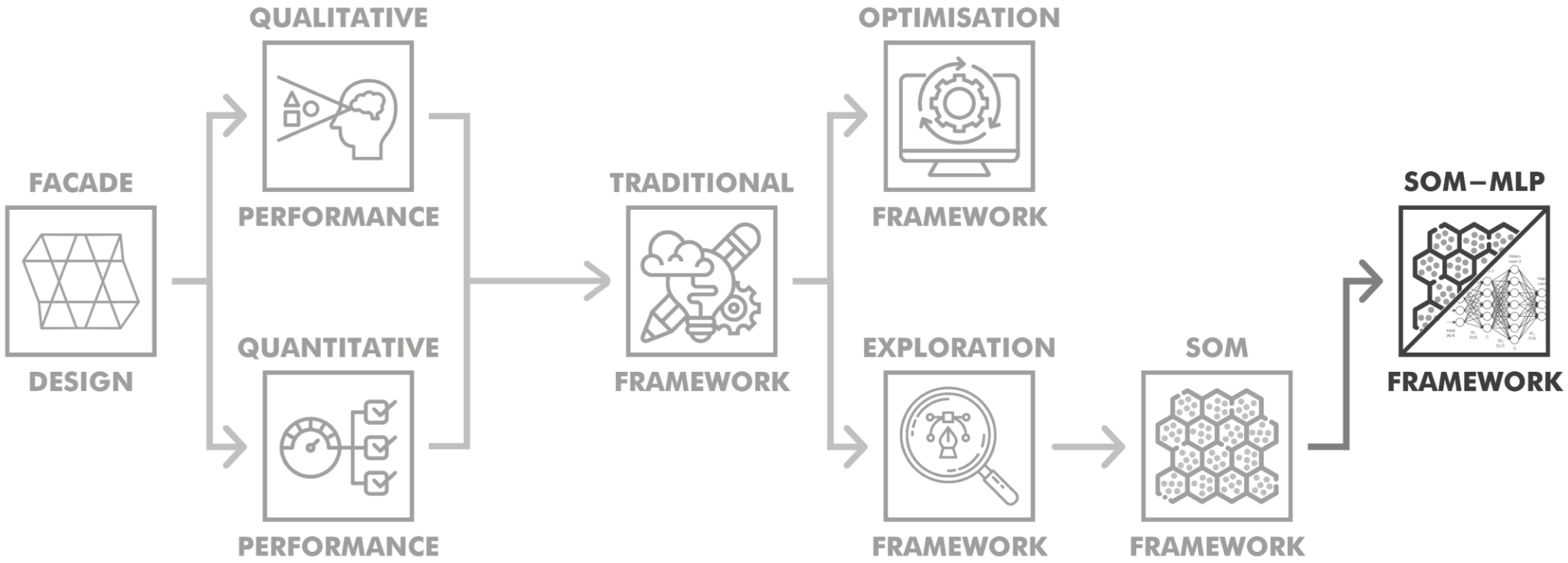
FRAMEWORK
OPTIMISATION
FRAMEWORK
EXPLORATION
FRAMEWORK
SOM
FRAMEWORK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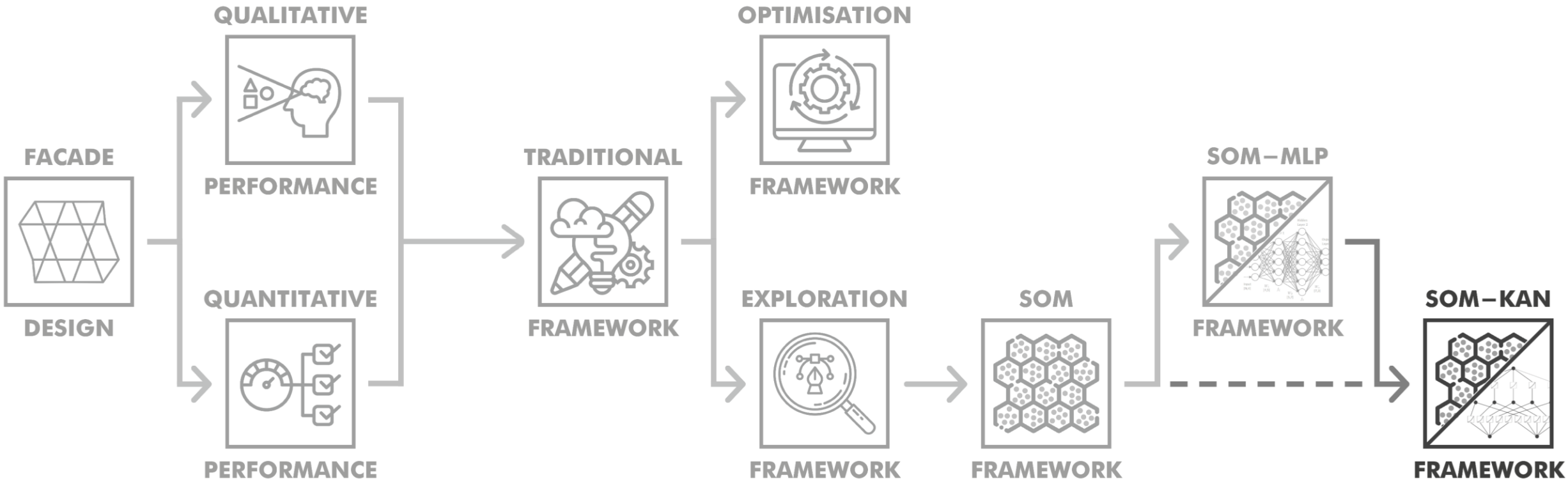
DESIGN
QUALITATIVE
PERFORMANCE
QUANTITATIVE
PERFORMANCE
TRADITIONAL
FRAMEWORK
OPTIMISATION
FRAMEWORK
EXPLORATION
FRAMEWORK
SOM
FRAMEWORK
SOM–MLP
FRAMEWORK


FACADE
DESIGN
QUALITATIVE
PERFORMANCE
QUANTITATIVE
PERFORMANCE
TRADITIONAL
FRAMEWORK
OPTIMISATION
FRAMEWORK
EXPLORATION
FRAMEWORK
SOM
FRAMEWORK
SOM–MLP
FRAMEWORK
SOM–KAN
FRAMEWORK

Design Framework

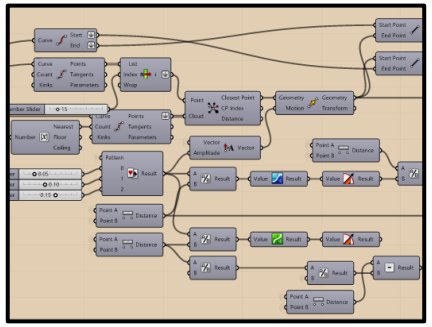
PARAMETRIC

MODEL

PARAMETRIC

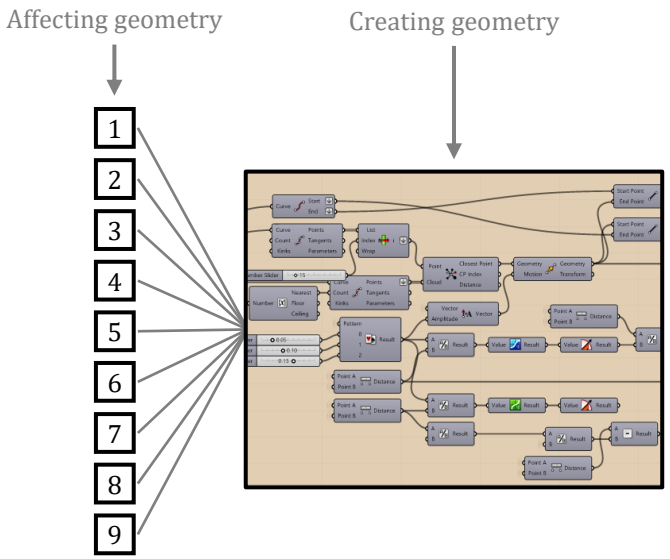
MODEL

Creating geometry



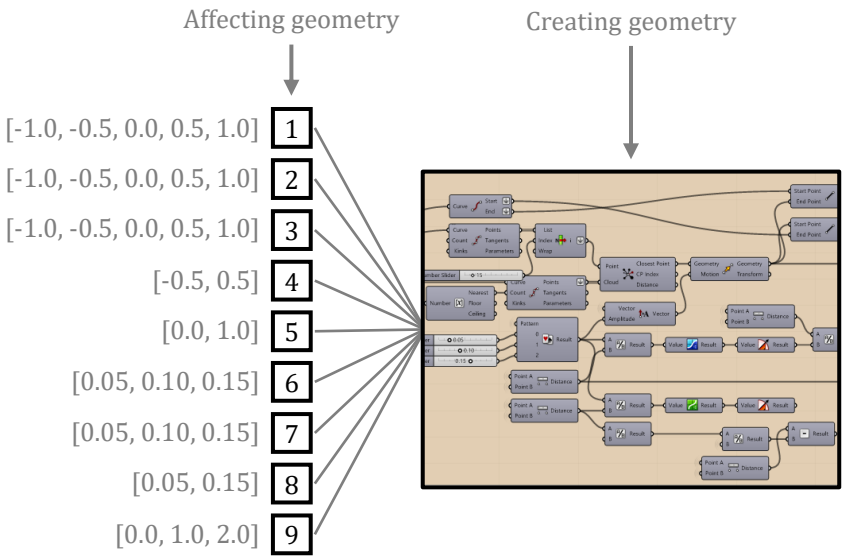
PARAMETRIC

MODEL



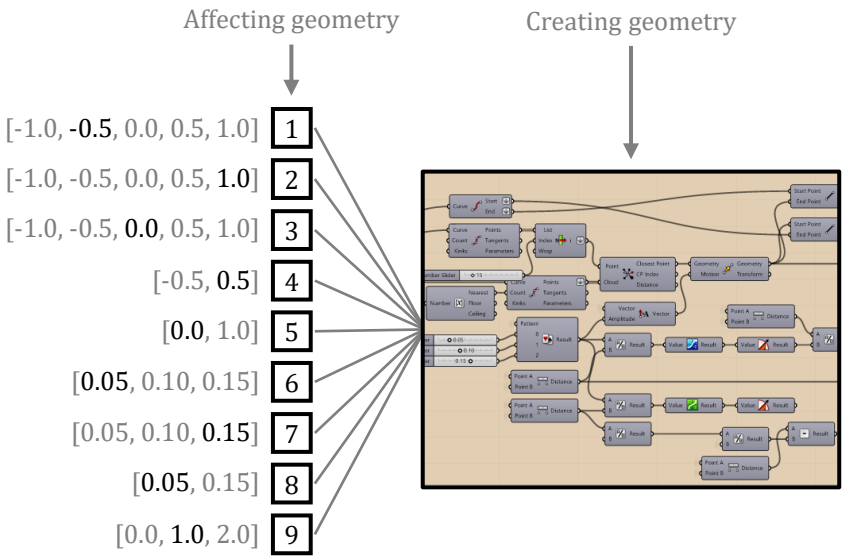
PARAMETRIC

MODEL



PARAMETRIC

MODEL



PARAMETRIC

MODEL

Affecting geometry

Creating geometry

[-1.0, **-0.5**, 0.0, 0.5, 1.0] 1

[-1.0, -0.5, 0.0, 0.5, **1.0**] 2

[-1.0, -0.5, **0.0**, 0.5, 1.0] 3

[-0.5, **0.5**] 4

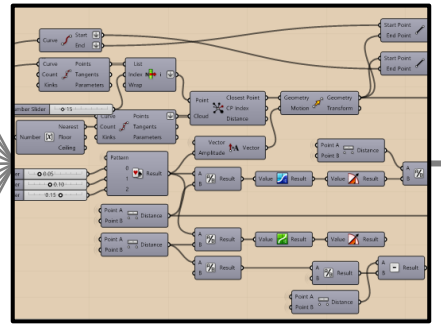
[**0.0**, 1.0] 5

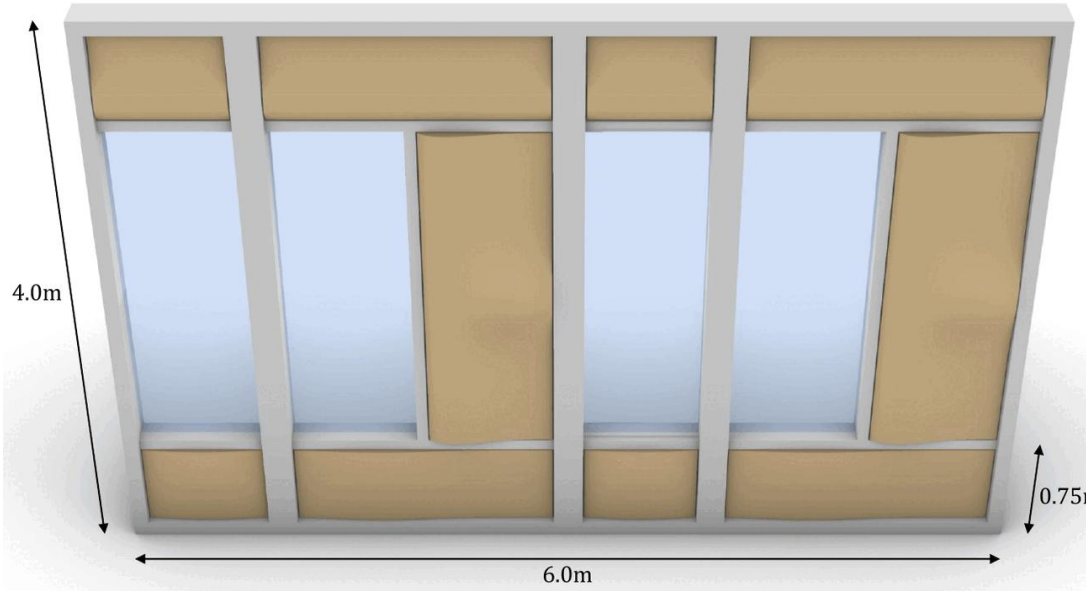
[**0.05**, 0.10, 0.15] 6

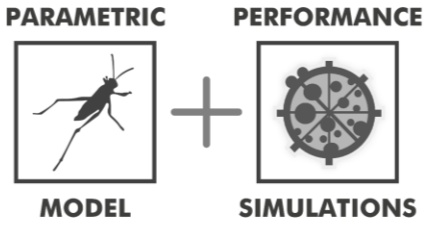
[0.05, 0.10, **0.15**] 7

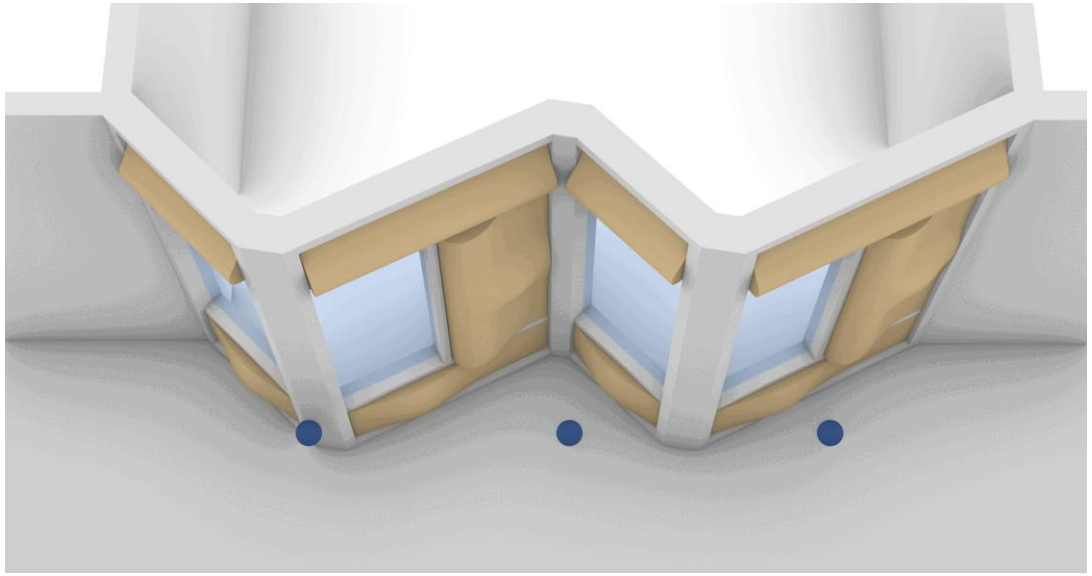
[**0.05**, 0.15] 8

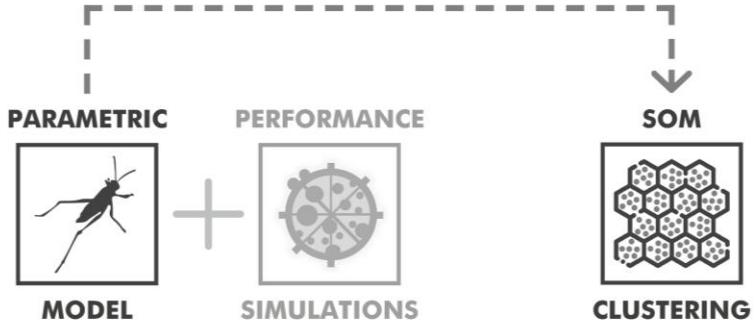
[0.0, **1.0**, 2.0] 9

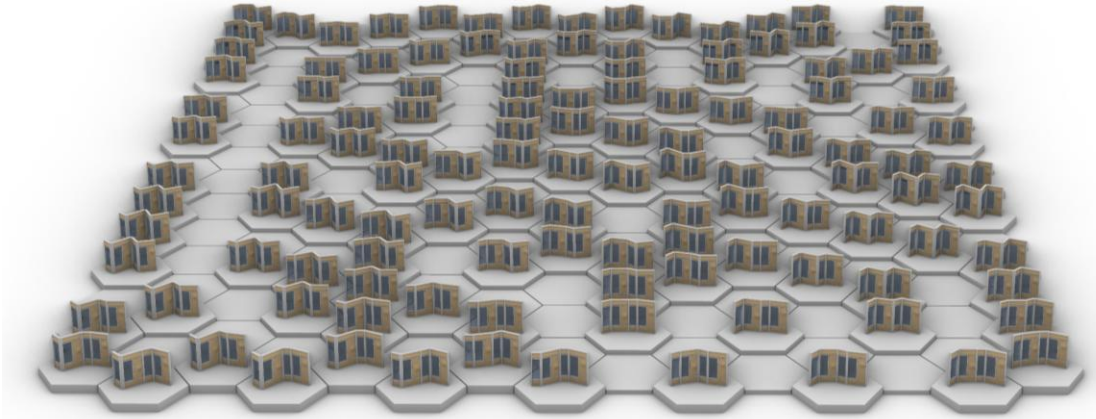


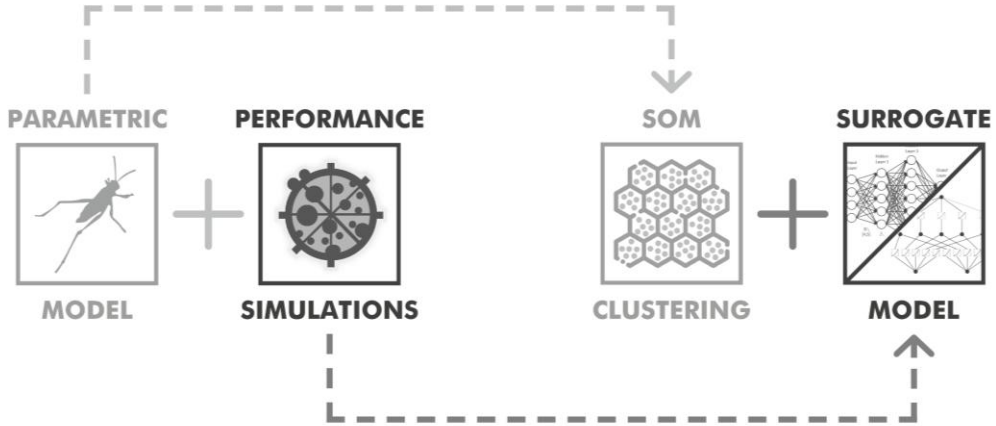


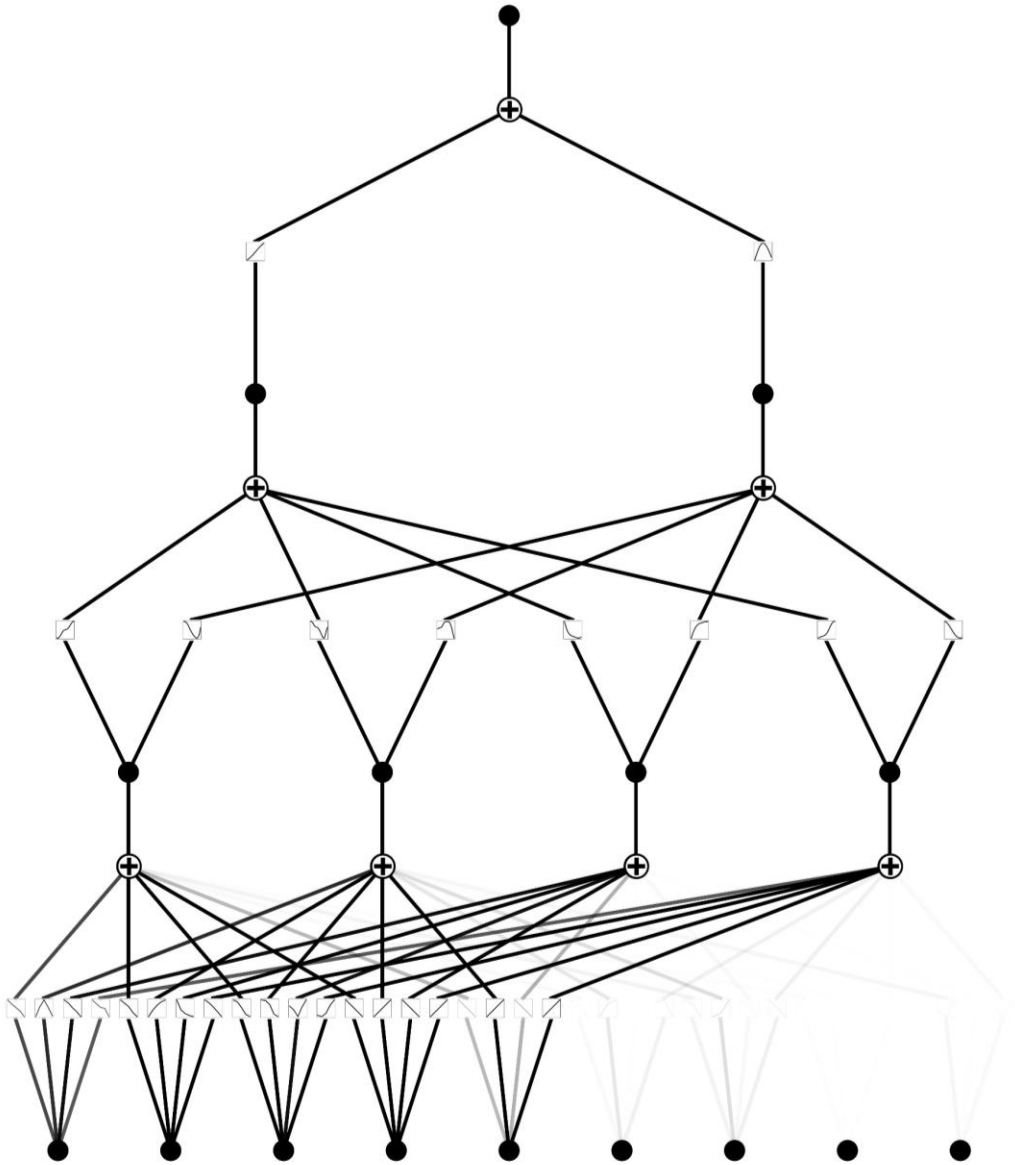

PARAMETRIC
PERFORMANCE
MODEL
SIMULATIONS




PARAMETRIC
PERFORMANCE
SOM
MODEL
SIMULATIONS
CLUSTERING




PARAMETRIC
MODEL
PERFORMANCE
SIMULATIONS
SOM
CLUSTERING
SURROGATE
MODEL



Performance

PARAMETRIC

MODEL

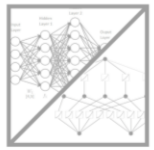
PERFORMANCE

SIMULATIONS

SOM

CLUSTERING

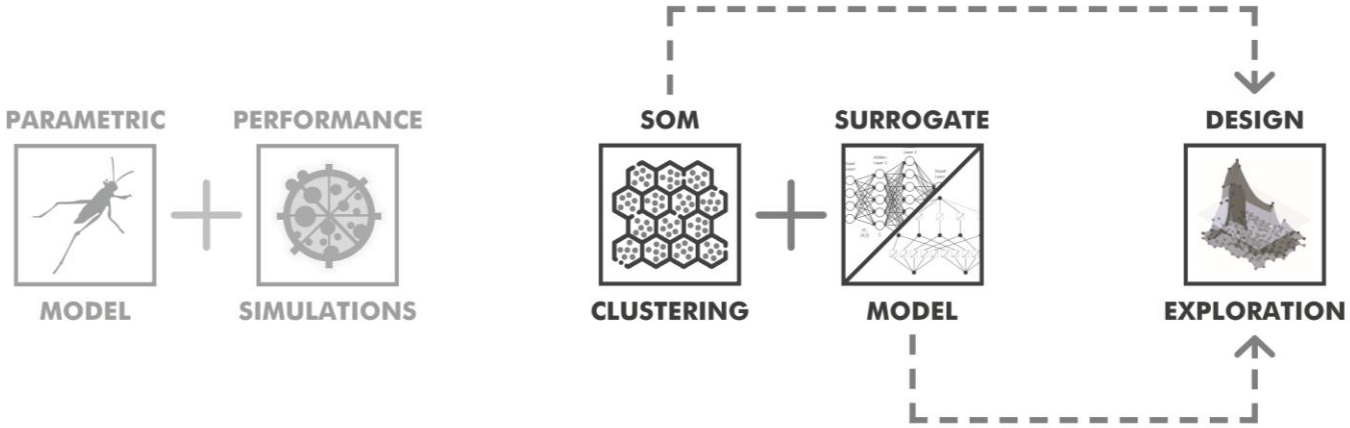
SURROGATE

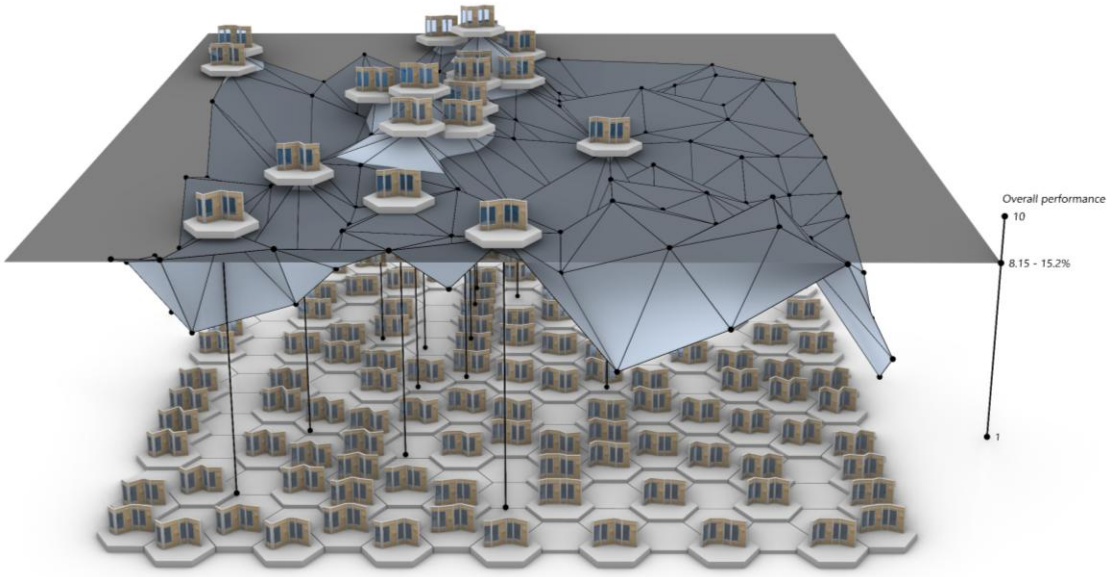


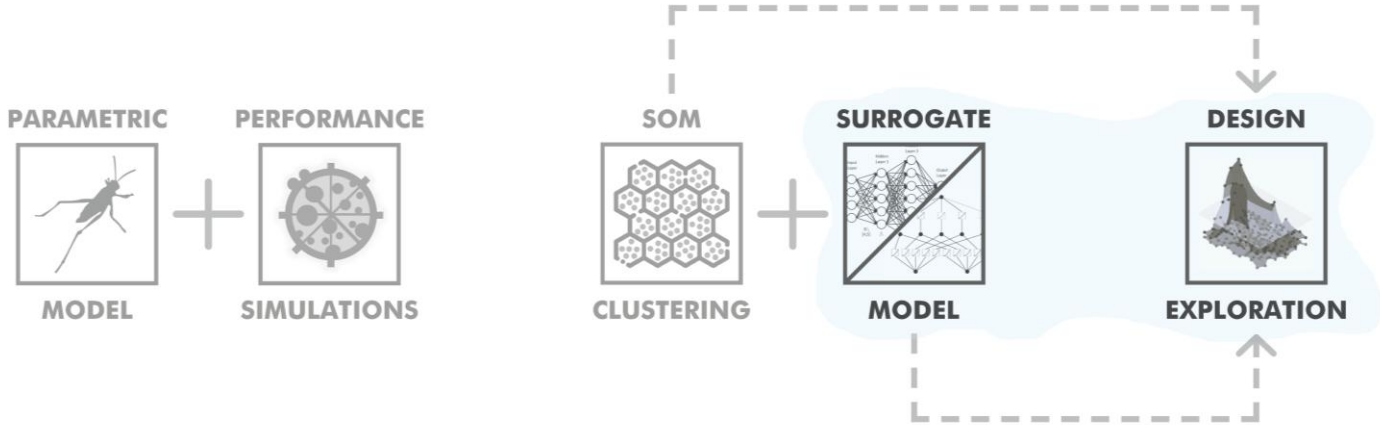
MODEL

Magic

1 2 3 4 5 6 7 8 9


PARAMETRIC
PERFORMANCE
MODEL
SIMULATIONS
SOM
SURROGATE
DESIGN
CLUSTERING
MODEL
EXPLORATION


Overall performance
10
8.15 - 15.2%
1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PERFORMANCE
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SIMULATIONS
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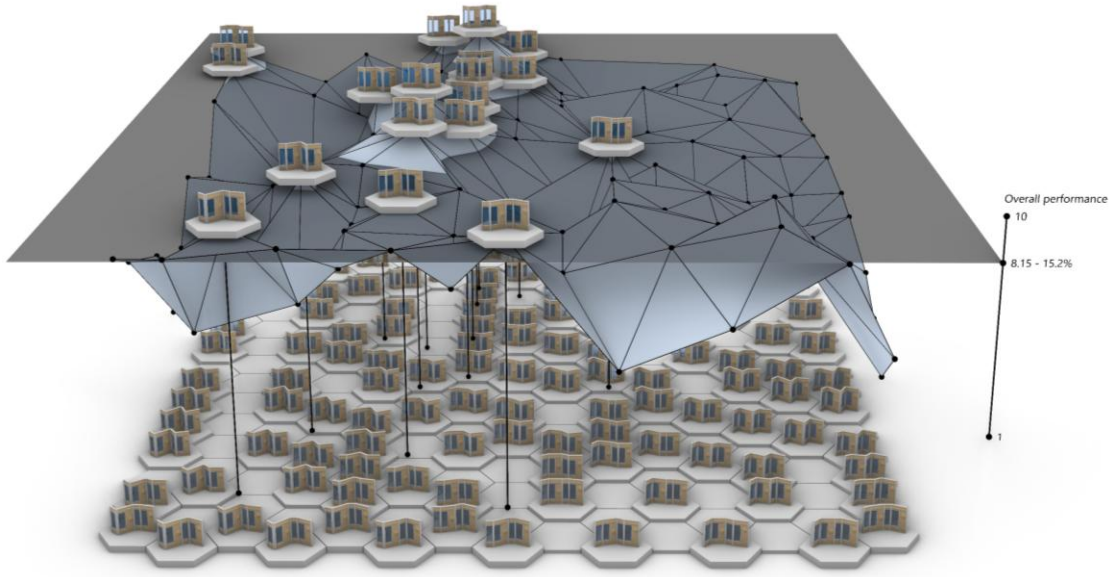
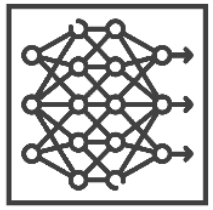
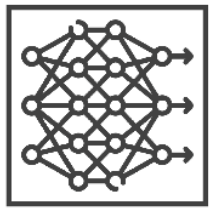
SURROGATE
DESIGN
CLUSTERING
MODEL
EXPLORATION


Overall performance
10
8.15 - 15.2%
1

MLP vs KAN



Trained model



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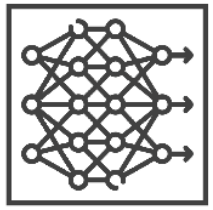

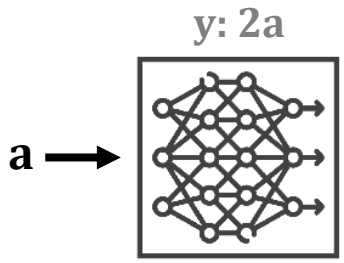
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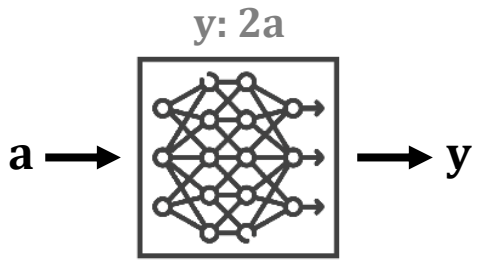
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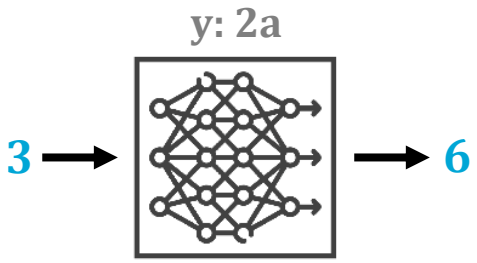
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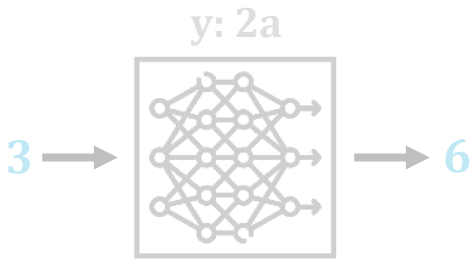
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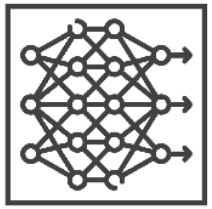

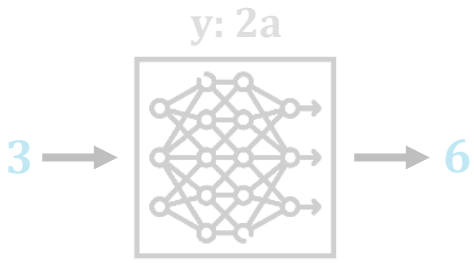
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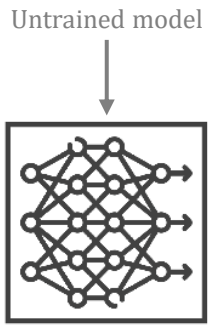
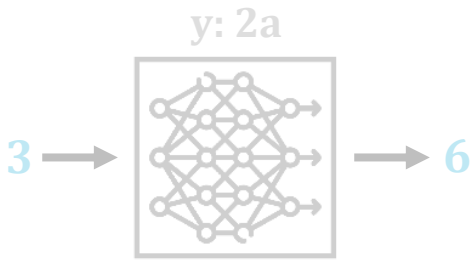

Untrained model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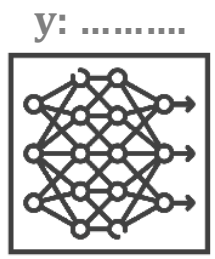
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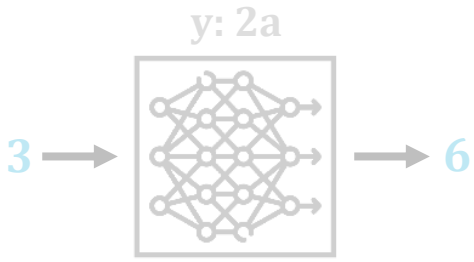
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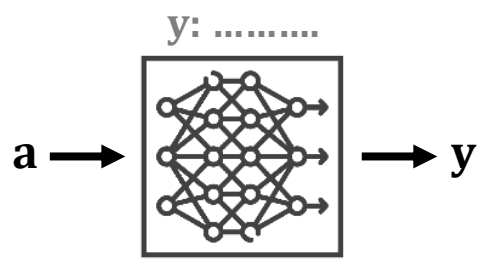
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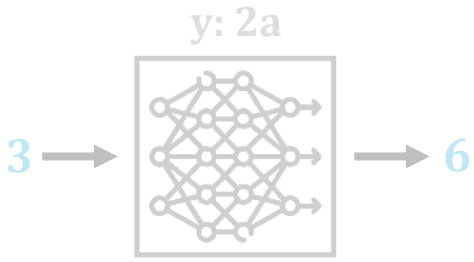
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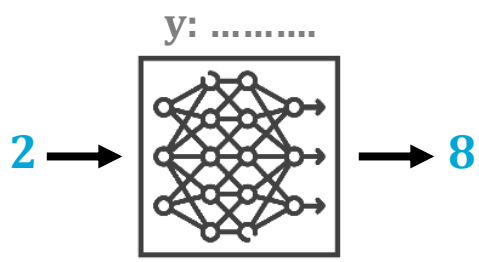
y: .....
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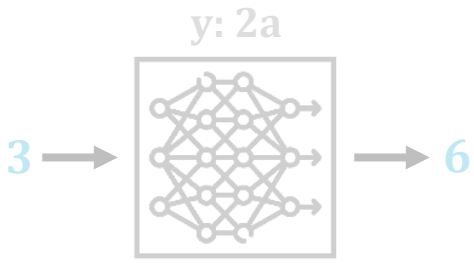
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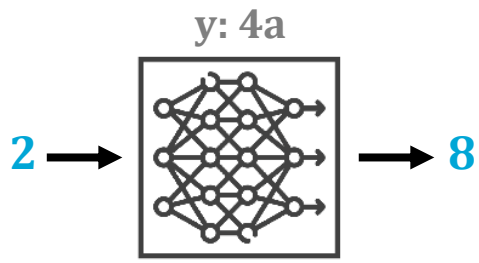
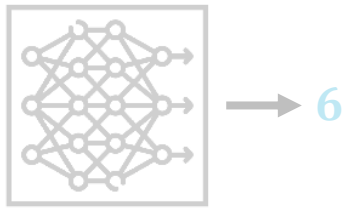
6


y: 4a
2
8

y: 2a



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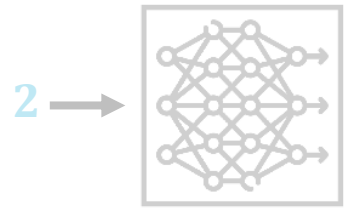
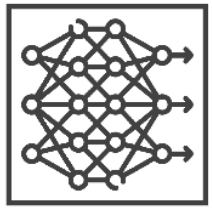


Untrained model



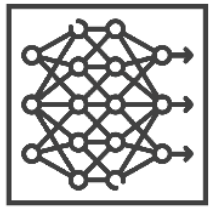
y: 2a

3 → → 6

y: 4a

2 → → 8

y: .....



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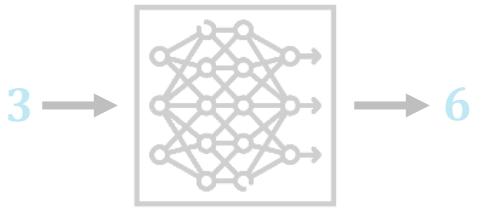

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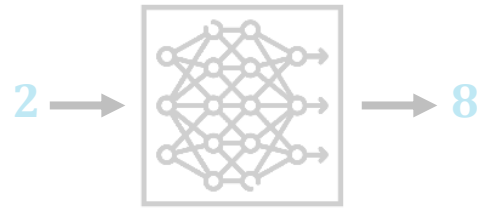

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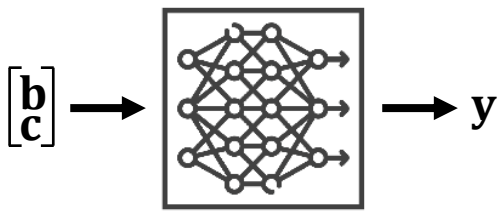

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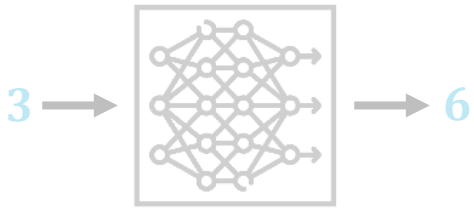

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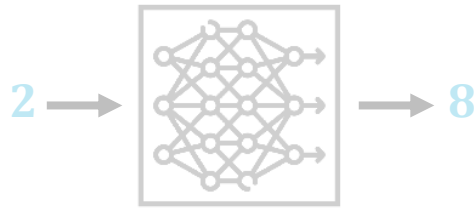
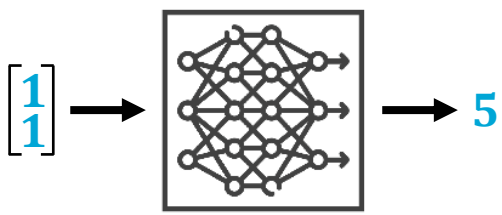


y: .....



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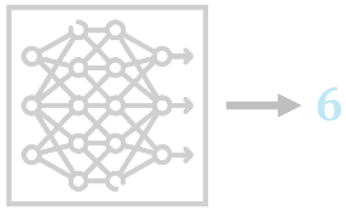

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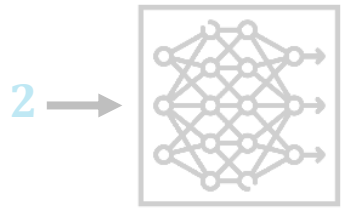
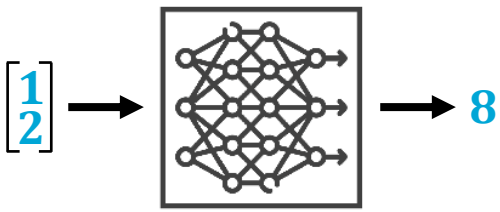


y: .....



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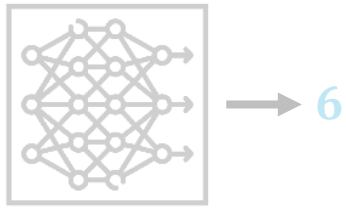

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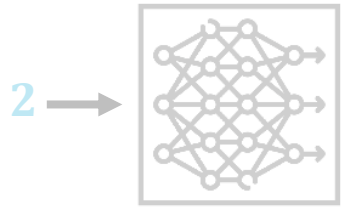
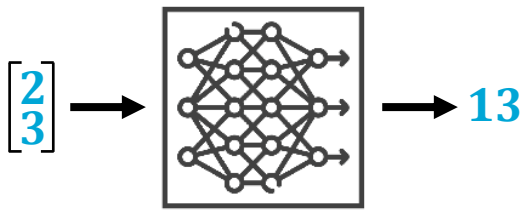
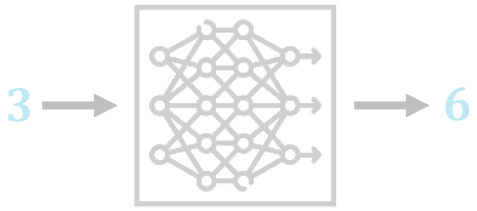


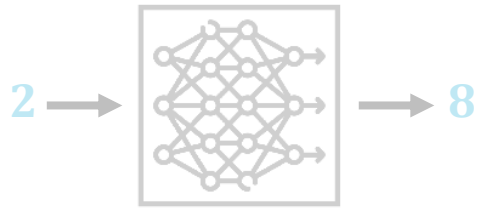
y: .....



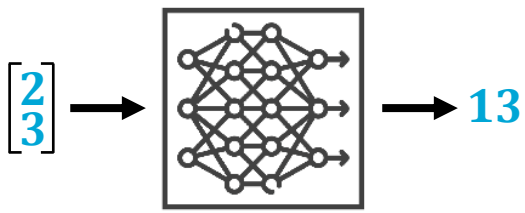
y: 2a



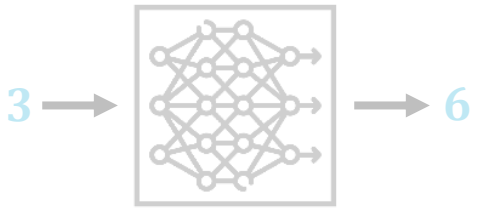
y: 4a



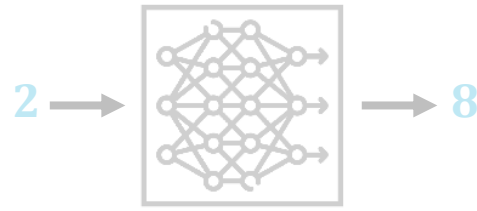
y: 2b+3c



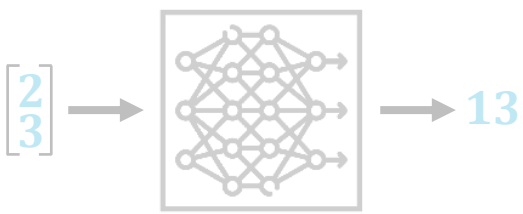
y: 2a



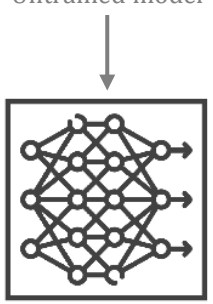
y: 4a



y: 2b+3c



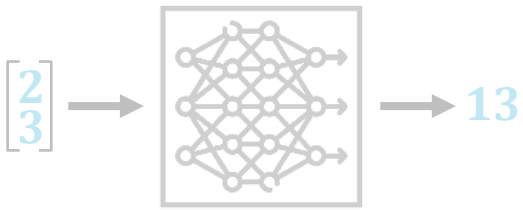
Untrained model



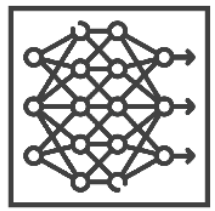
y: 2a

y: 4a

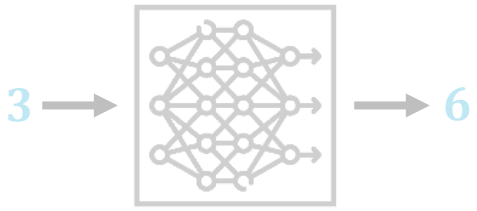
y: 2b+3c



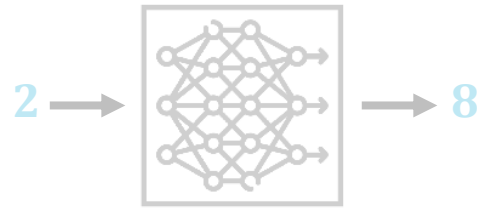
y: .....



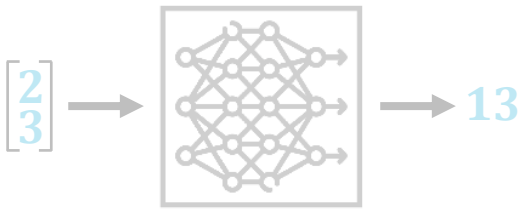
y: 2a



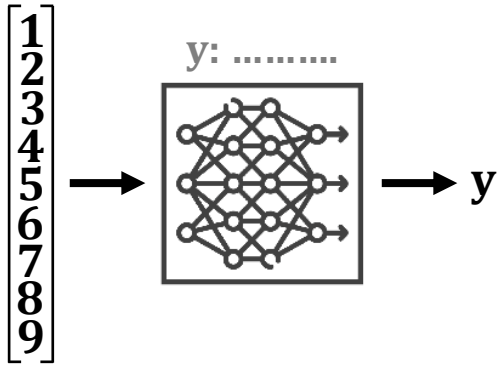
y: 4a



y: 2b+3c



y: .....



y: 2a

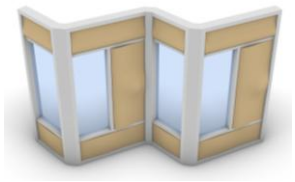
3 → → 6

y: 4a

2 → → 8

y: 2b+3c

$\begin{bmatrix} 2 \\ 3 \end{bmatrix}$ → → 13



$\begin{bmatrix} 0.50 \\ 1.00 \\ 0.00 \\ 0.50 \\ 0.00 \\ 0.05 \\ 0.15 \\ 0.05 \\ 1.00 \end{bmatrix}$ → y: ..... → **34.21** kWh/m^2

y: 2a

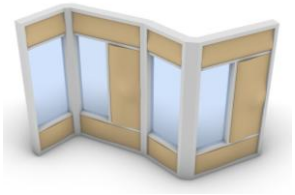
3 → → 6

y: 4a

2 → → 8

y: 2b+3c

$\begin{bmatrix} 2 \\ 3 \end{bmatrix}$ → → 13



$\begin{bmatrix} 1.00 \\ 0.00 \\ 0.50 \\ 0.50 \\ 1.00 \\ 0.15 \\ 0.10 \\ 0.05 \\ 2.00 \end{bmatrix}$ → y: ..... → → **37.83** kWh/m^2

y: 2a

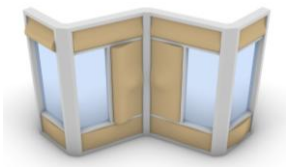
3 → → 6

y: 4a

2 → → 8

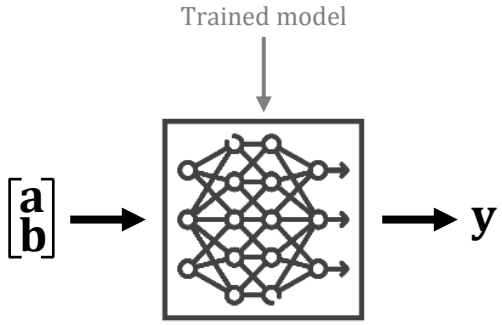
y: 2b+3c

$\begin{bmatrix} 2 \\ 3 \end{bmatrix}$ → → 13

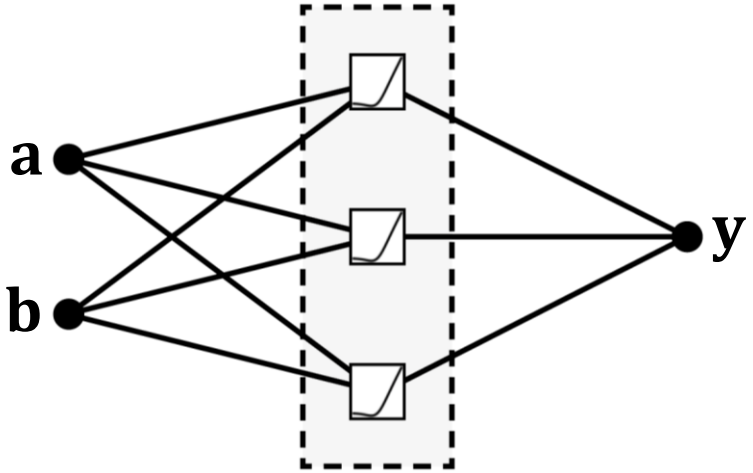


$\begin{bmatrix} 0.50 \\ 0.50 \\ 1.00 \\ 0.50 \\ 1.00 \\ 0.10 \\ 0.05 \\ 0.15 \\ 0.00 \end{bmatrix}$ → y: ..... → **35.47** kWh/m^2

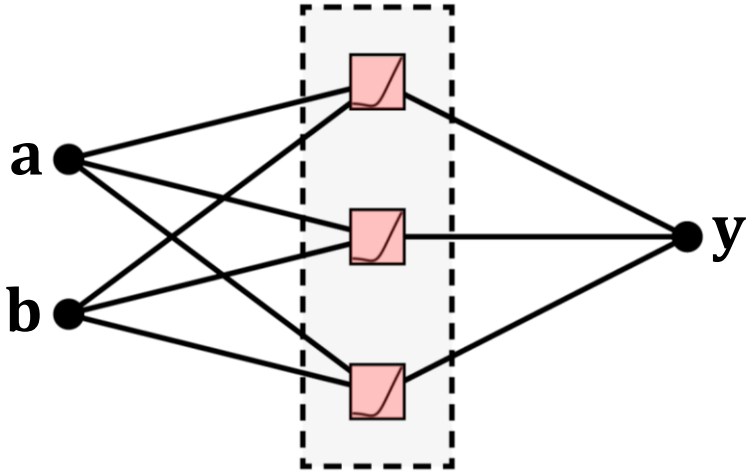
Multi-Layer Perceptron (MLP)



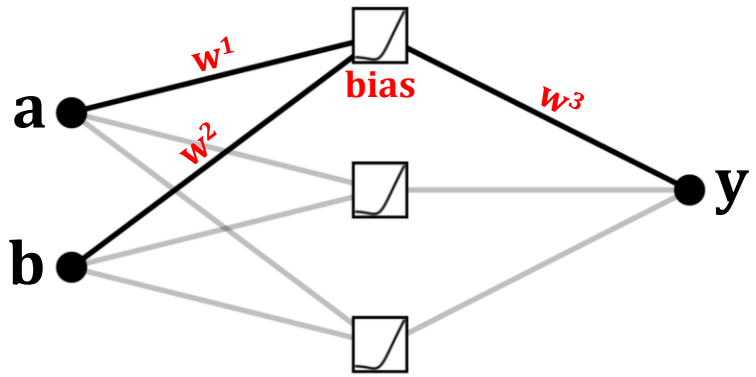
Multi-Layer Perceptron (MLP)



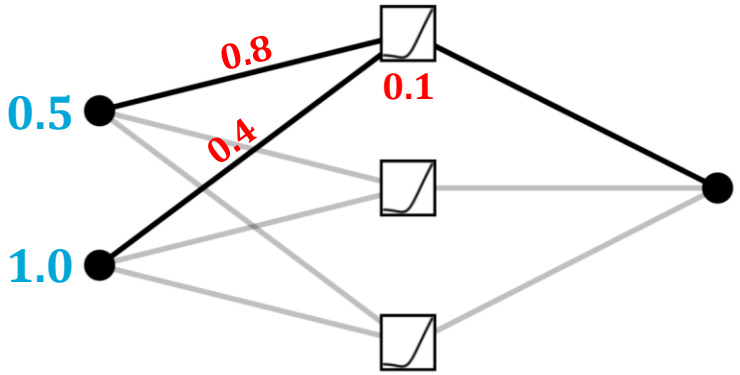
Multi-Layer Perceptron (MLP)



Multi-Layer Perceptron (MLP)

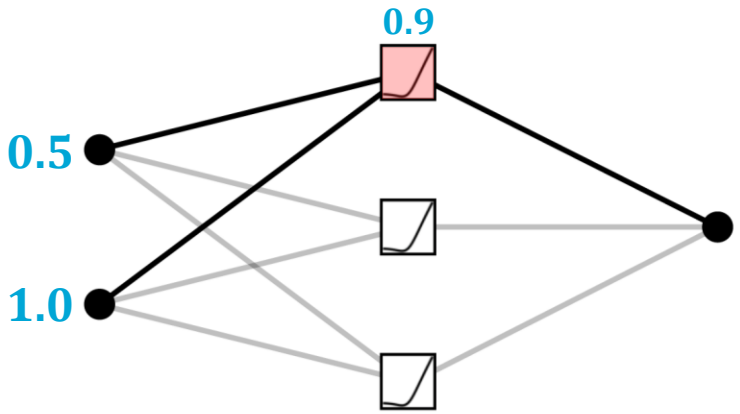


Multi-Layer Perceptron (MLP)



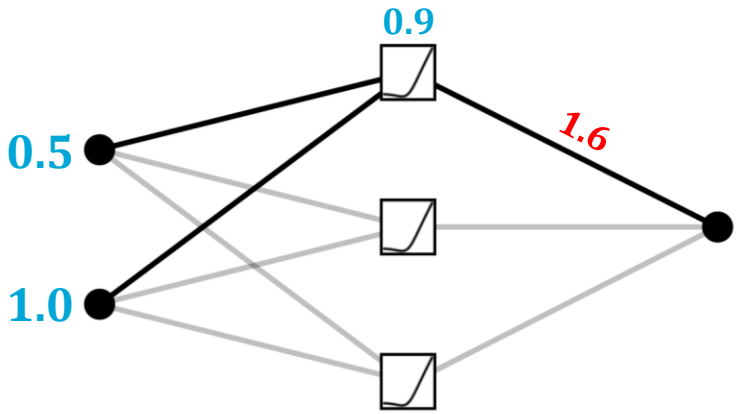
$(0.5 \cdot 0.8) + (1.0 \cdot 0.4) + 0.1 = 0.9$

Multi-Layer Perceptron (MLP)



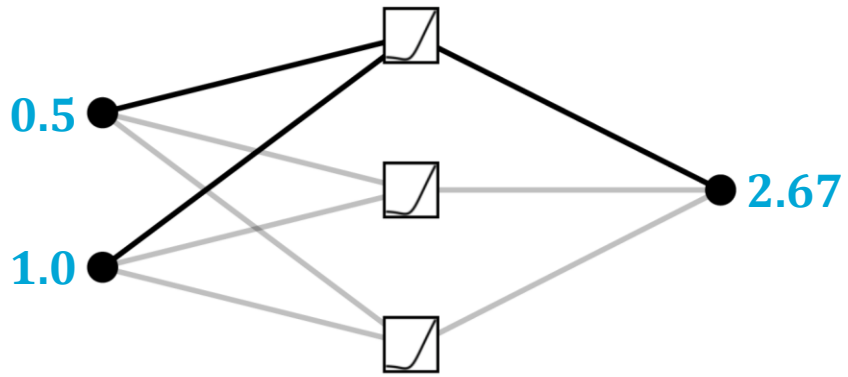
ReLU (0.9) = 0.9

Multi-Layer Perceptron (MLP)

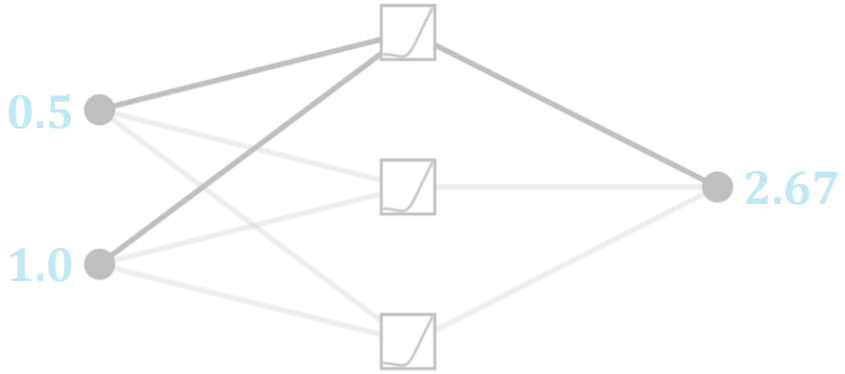


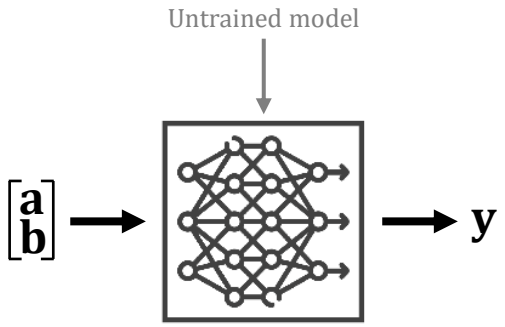
$(0.9 \cdot 1.6) = 1.44$

Multi-Layer Perceptron (MLP)

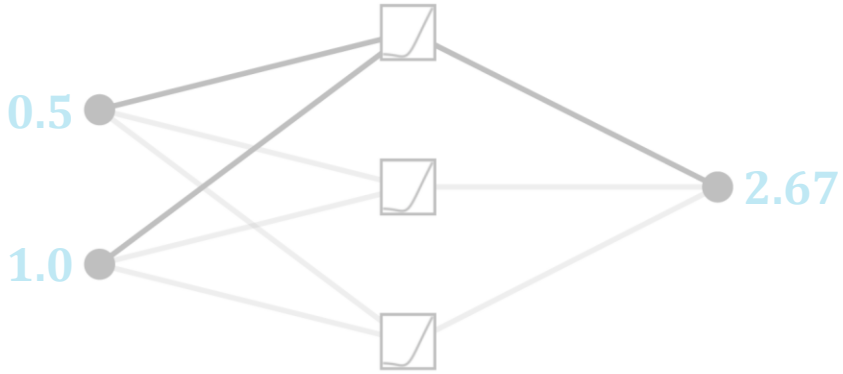


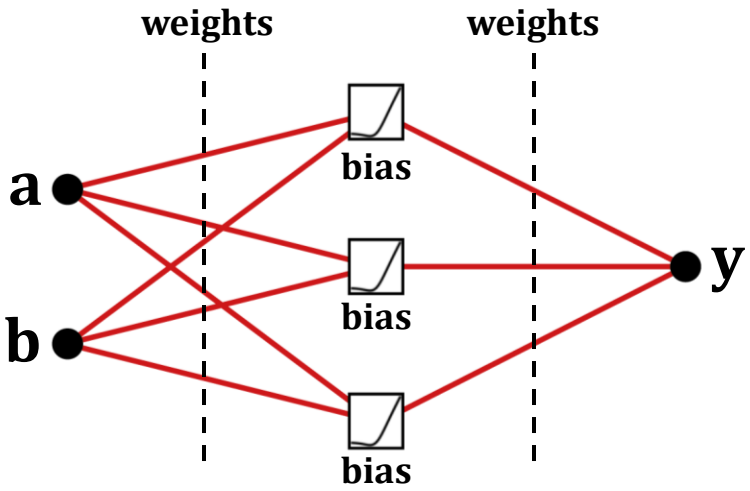
Multi-Layer Perceptron (MLP)



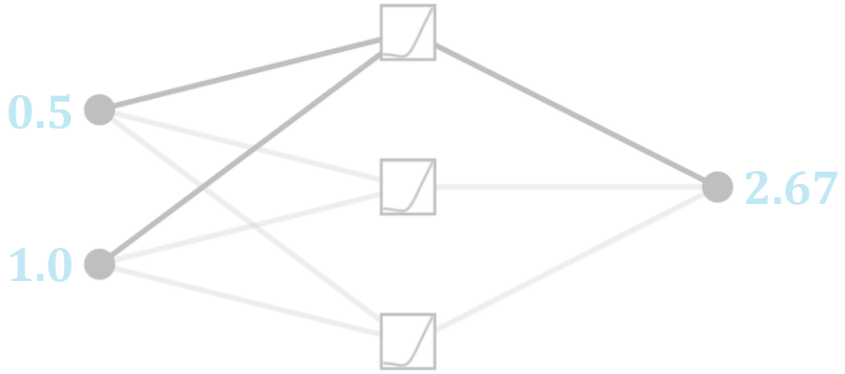


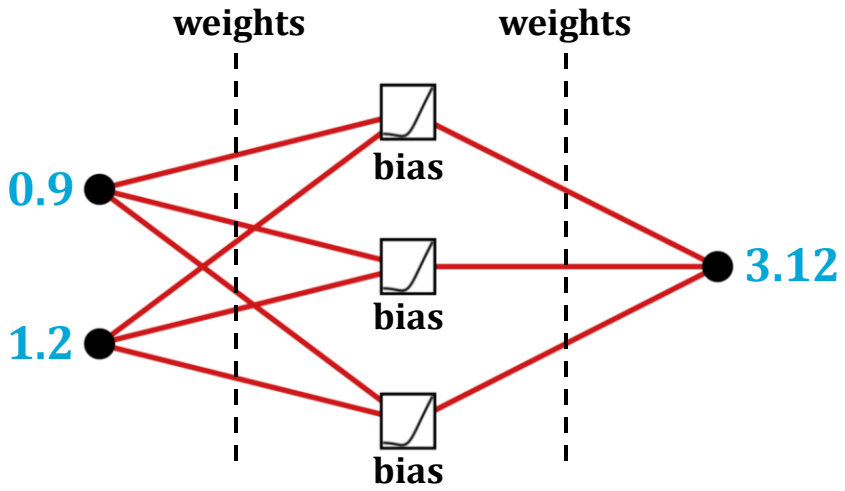
Multi-Layer Perceptron (MLP)



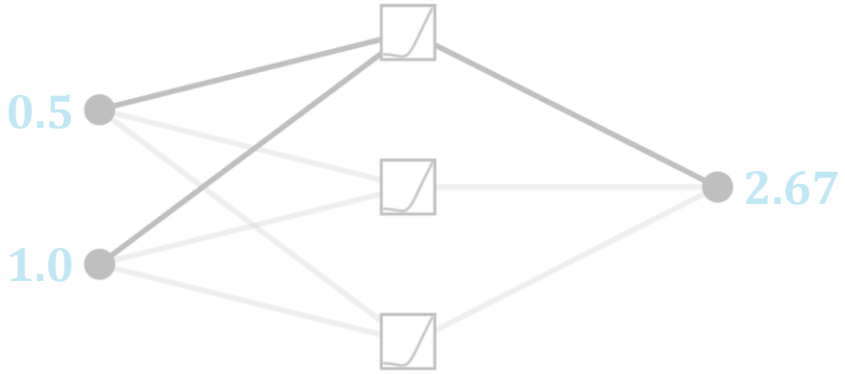


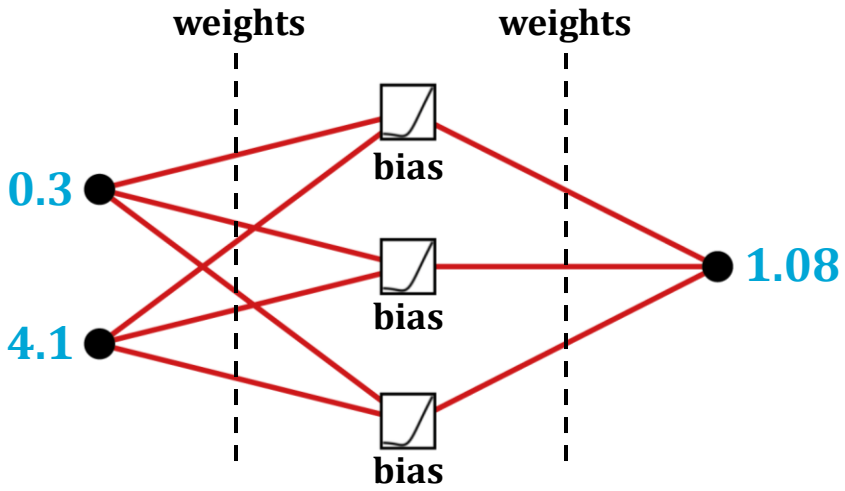
Multi-Layer Perceptron (MLP)



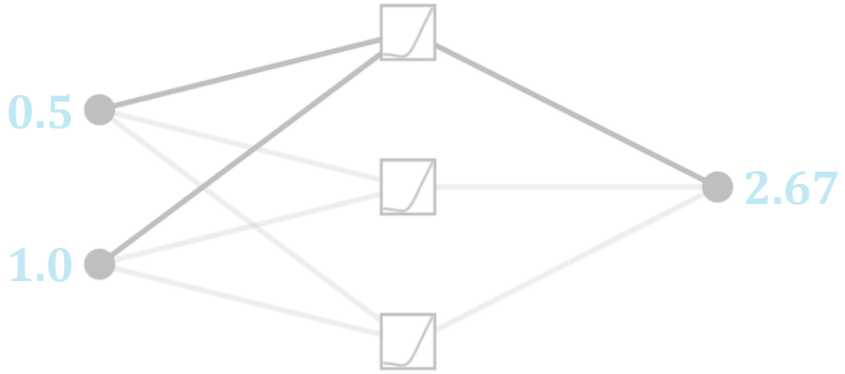


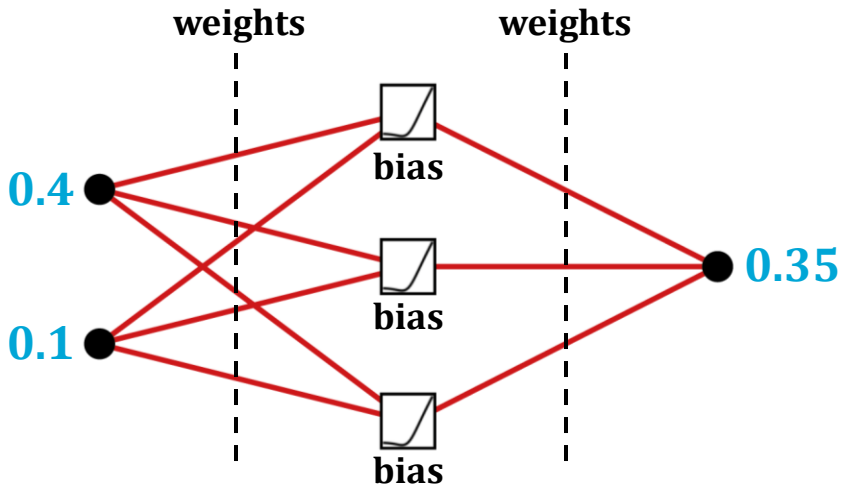
Multi-Layer Perceptron (MLP)



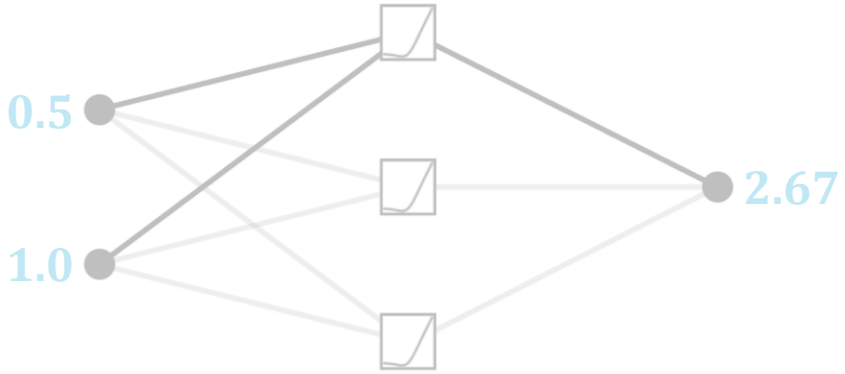


Multi-Layer Perceptron (MLP)

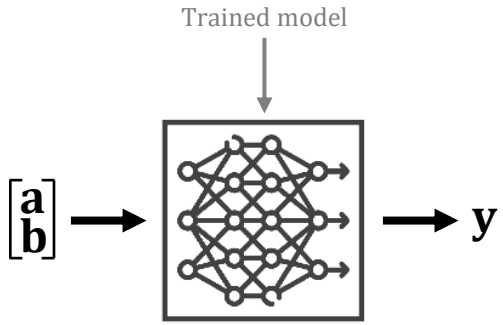


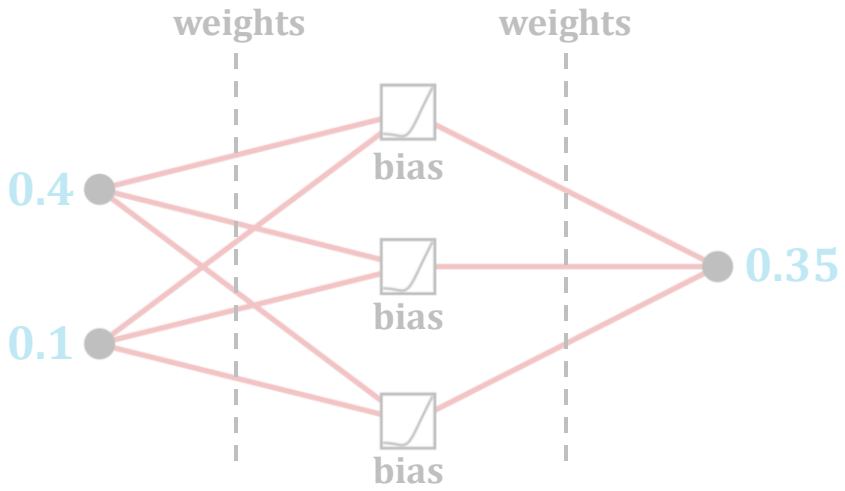


Multi-Layer Perceptron (MLP)

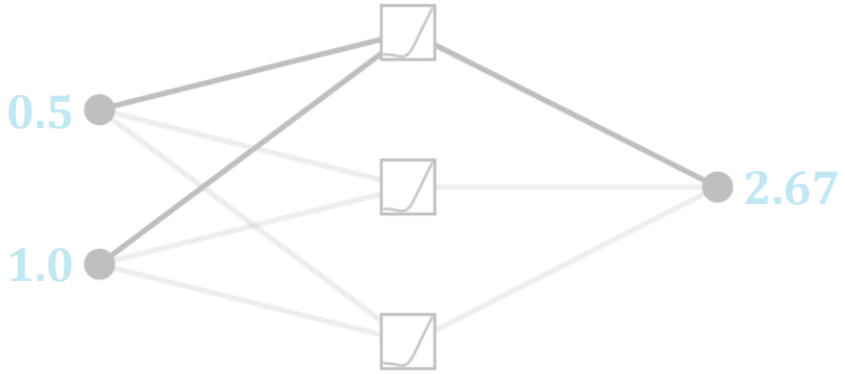


Kolmogorov-Arnold Network (KAN)

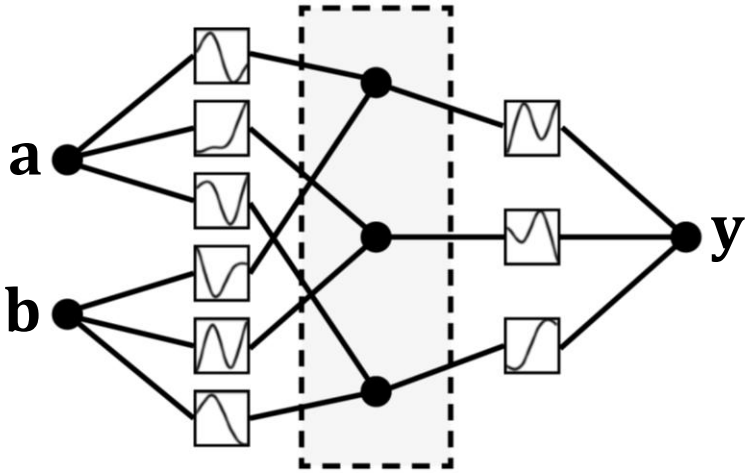


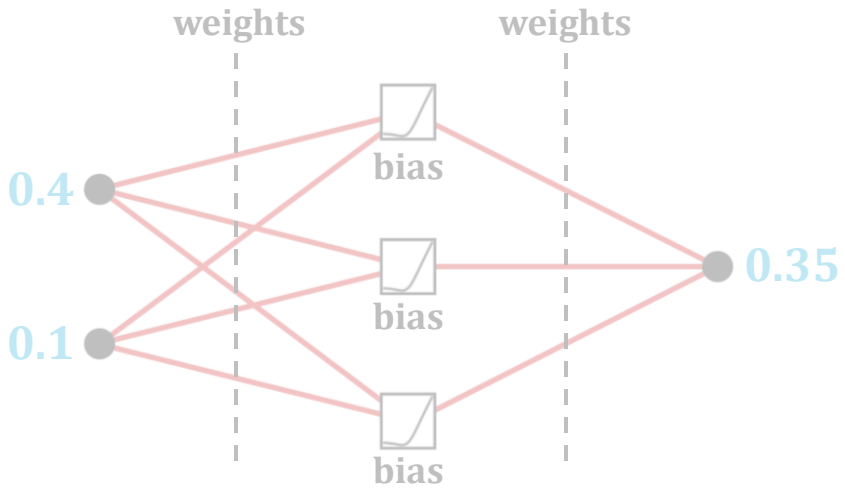


Multi-Layer Perceptron (MLP)

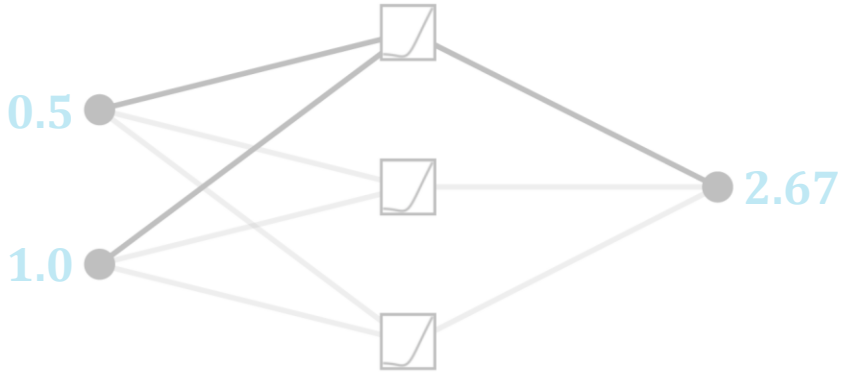


Kolmogorov-Arnold Network (KAN)

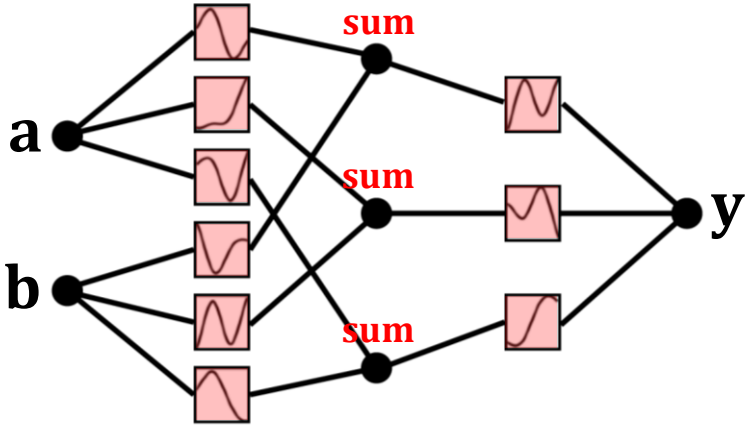


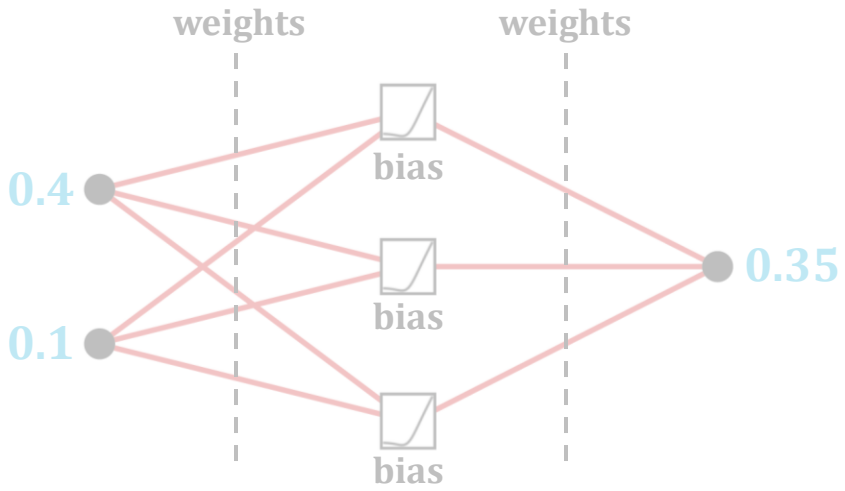


Multi-Layer Perceptron (MLP)

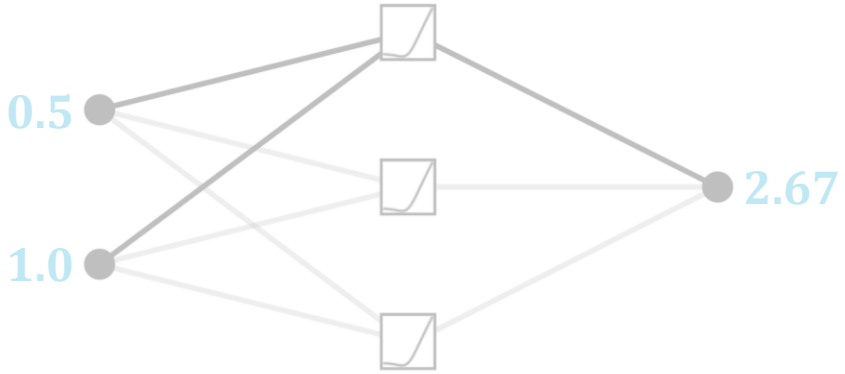


Kolmogorov-Arnold Network (KAN)

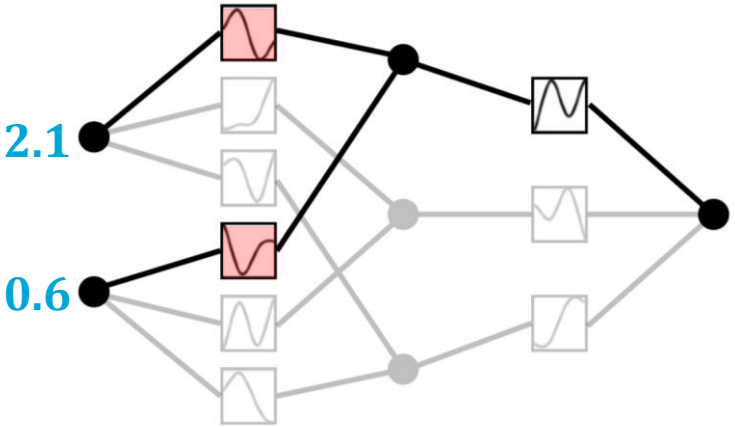




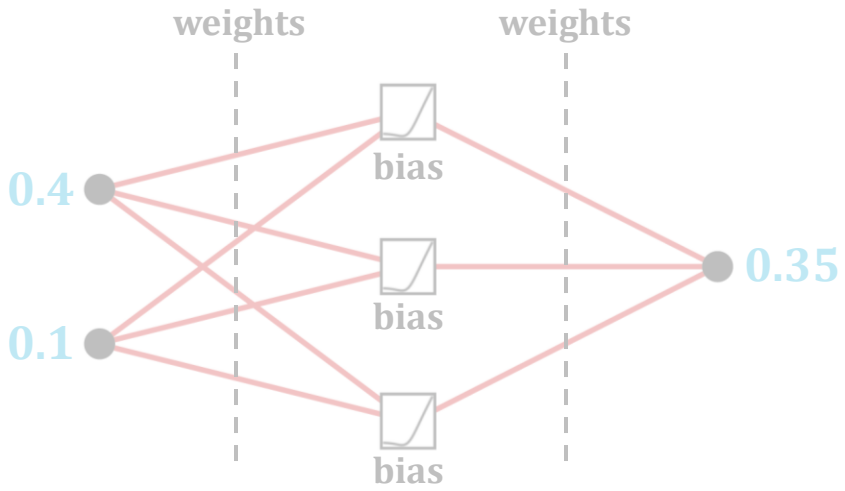
Multi-Layer Perceptron (MLP)



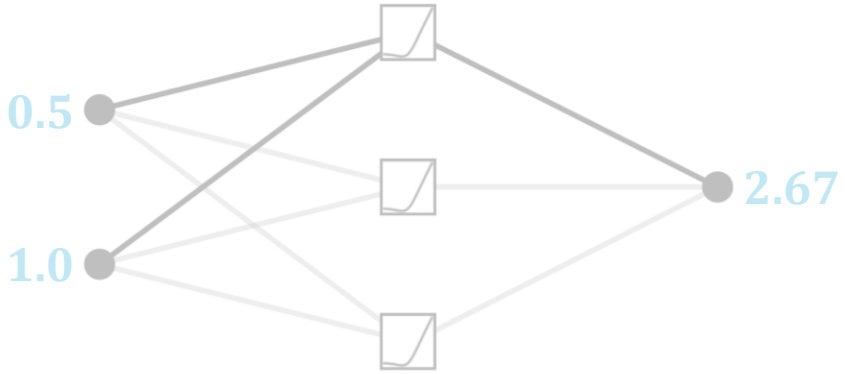
Kolmogorov-Arnold Network (KAN)



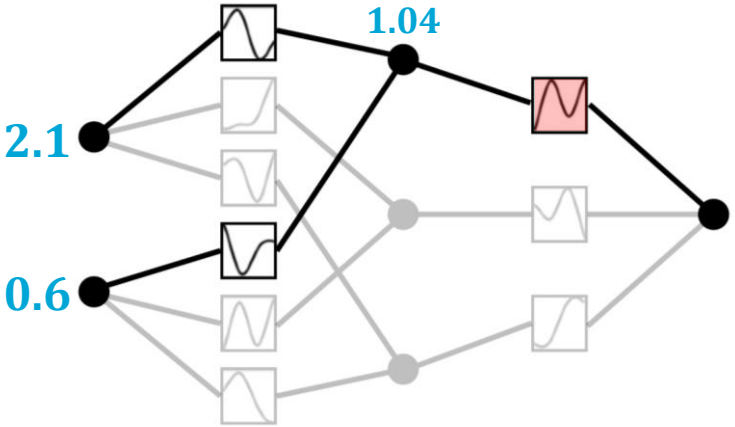
sin(2.1) + cos(0.6) = 1.04



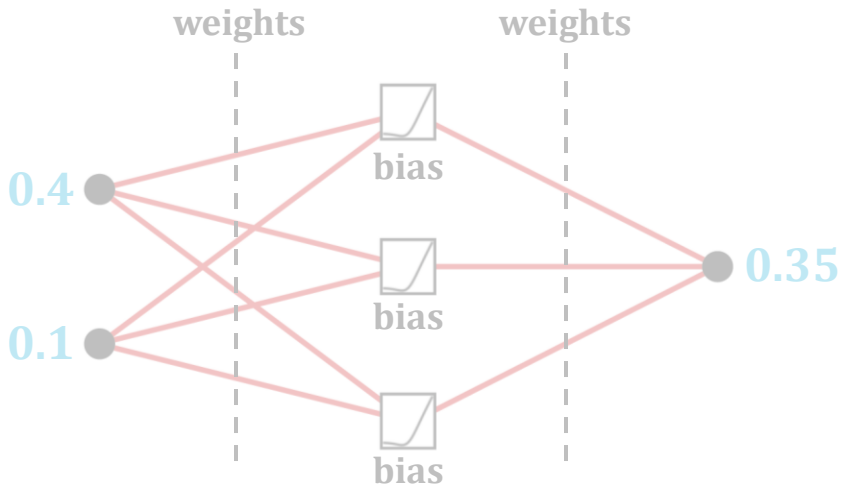
Multi-Layer Perceptron (MLP)



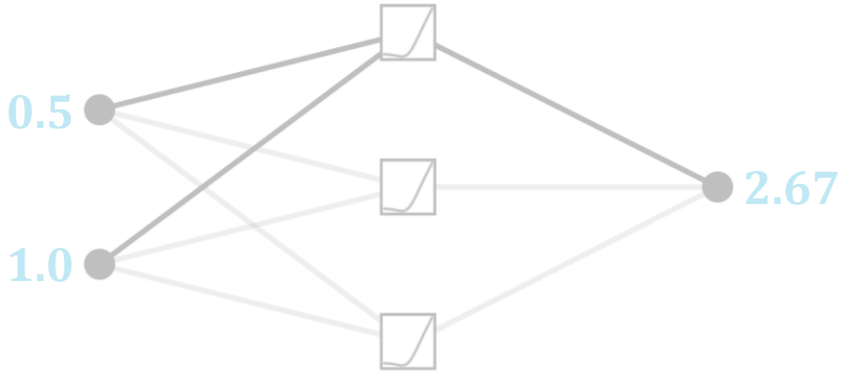
Kolmogorov-Arnold Network (KAN)



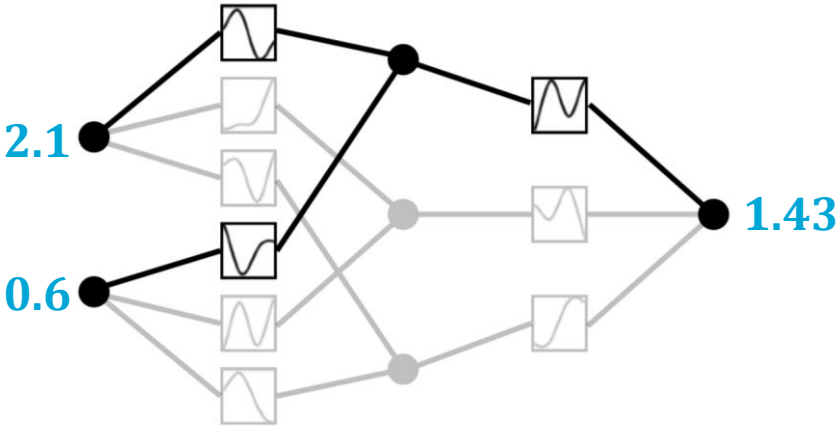
$(1.04)^2 = 1.08$

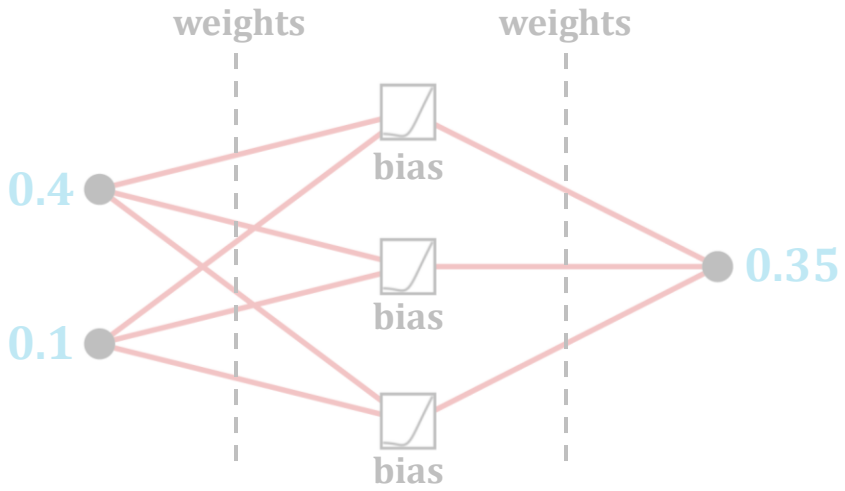


Multi-Layer Perceptron (MLP)

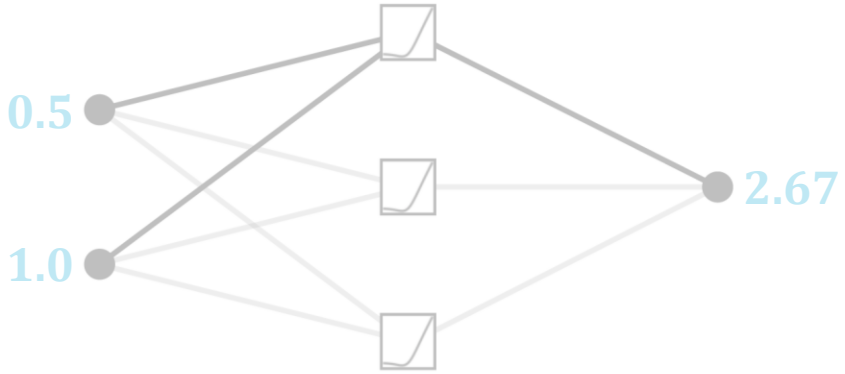


Kolmogorov-Arnold Network (KAN)

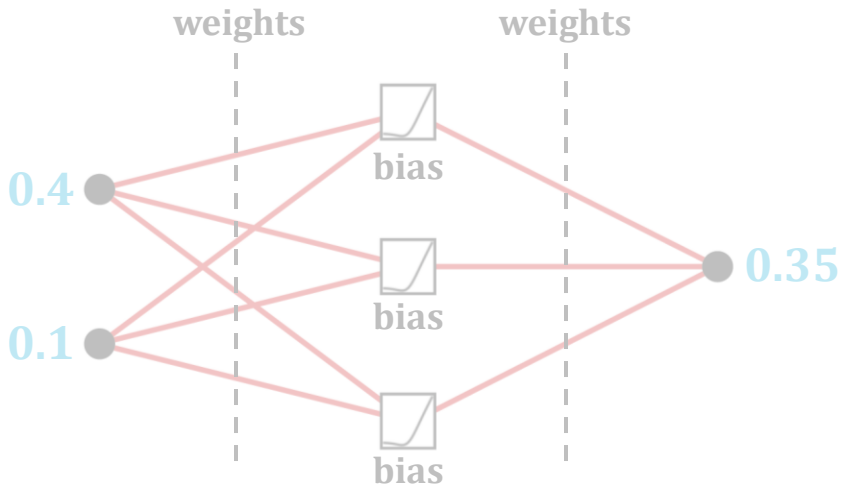


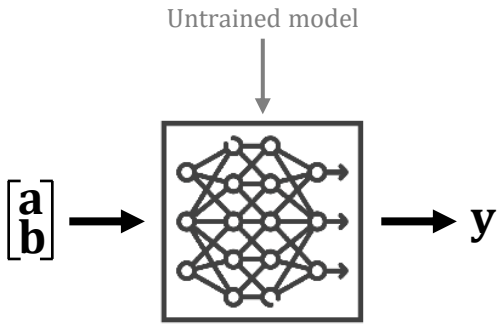


Multi-Layer Perceptron (MLP)



Kolmogorov-Arnold Network (KAN)





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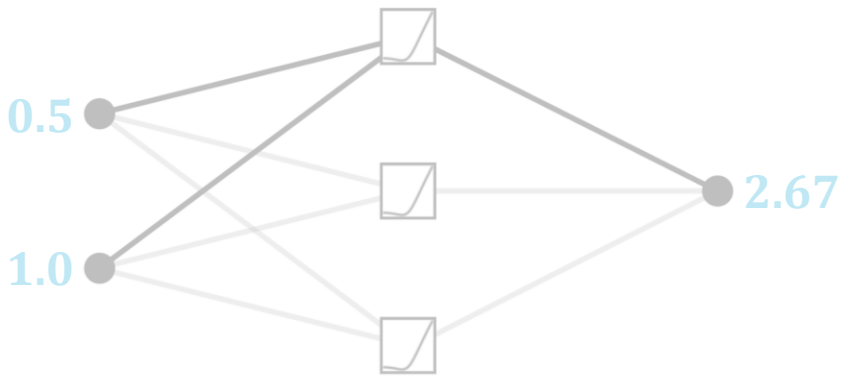
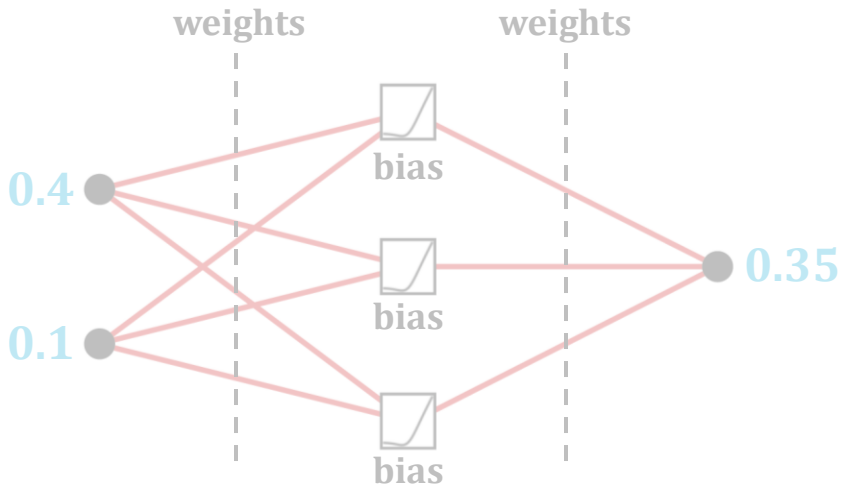
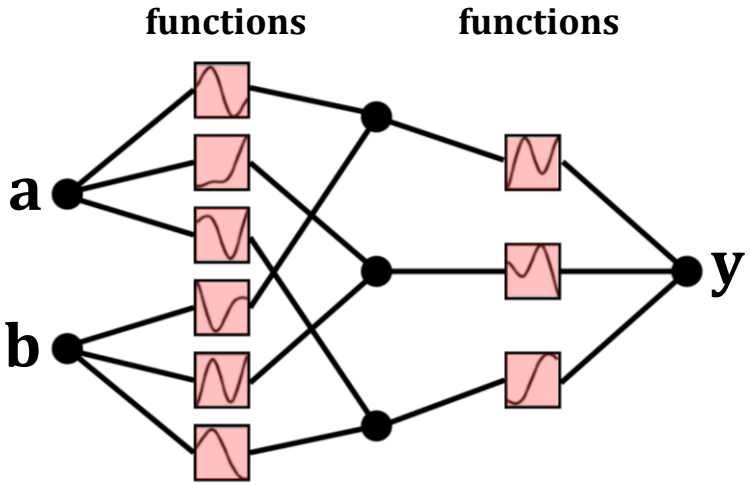
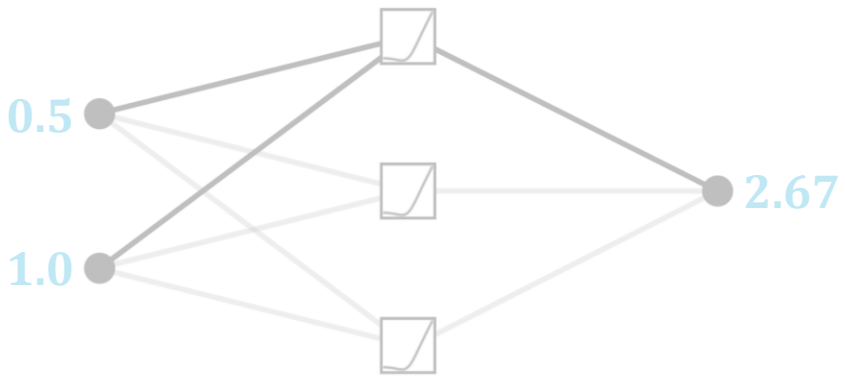


Kolmogorov-Arnold Network (KAN)

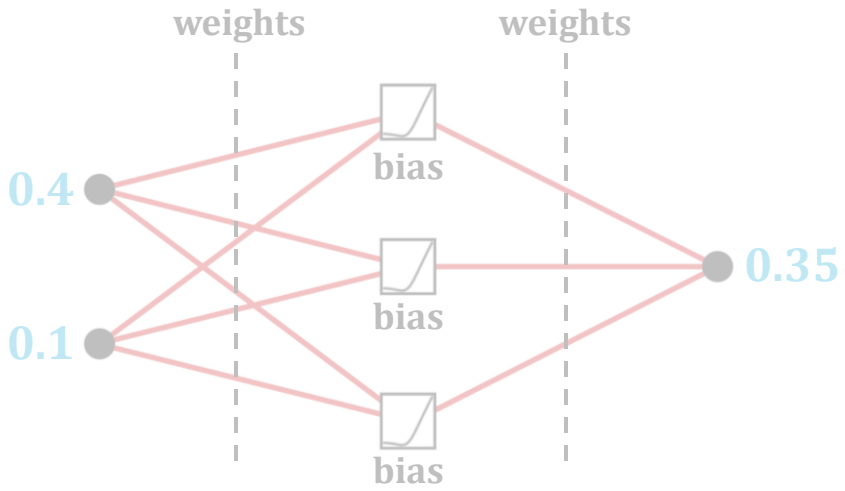


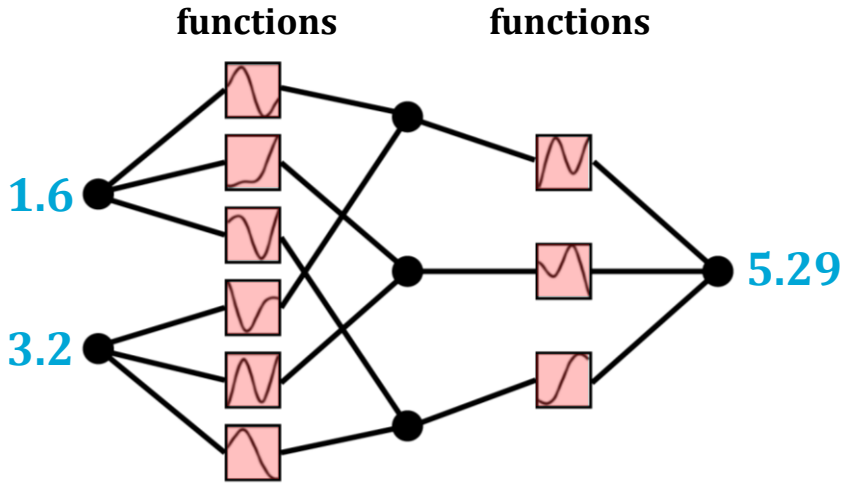


Multi-Layer Perceptron (MLP)

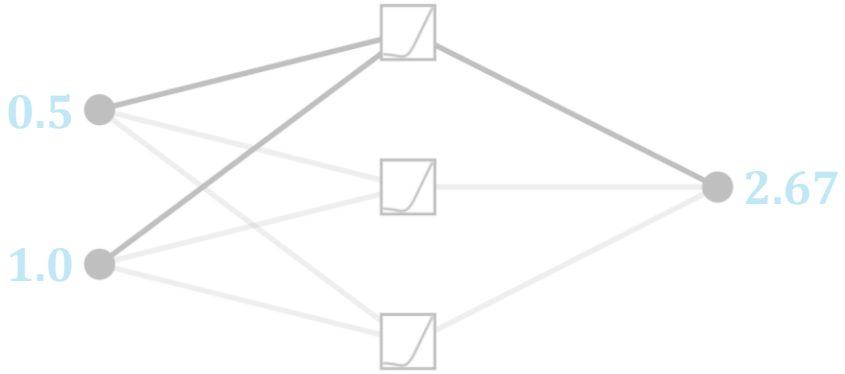


Kolmogorov-Arnold Network (KAN)

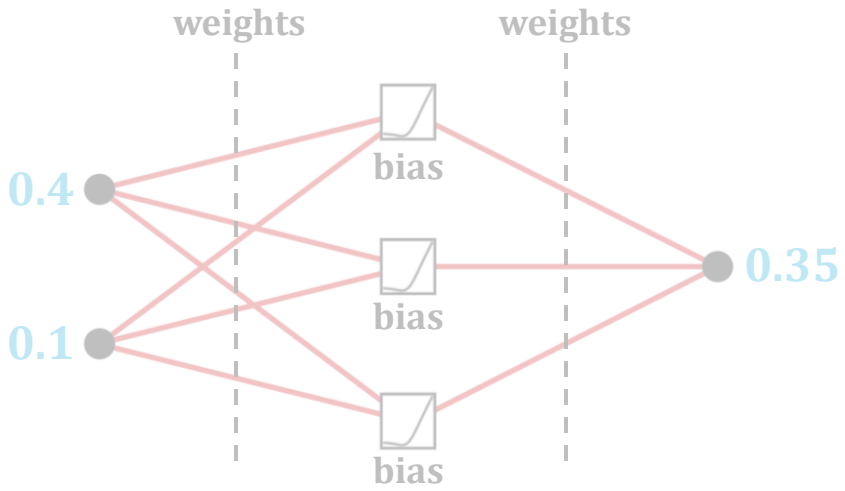


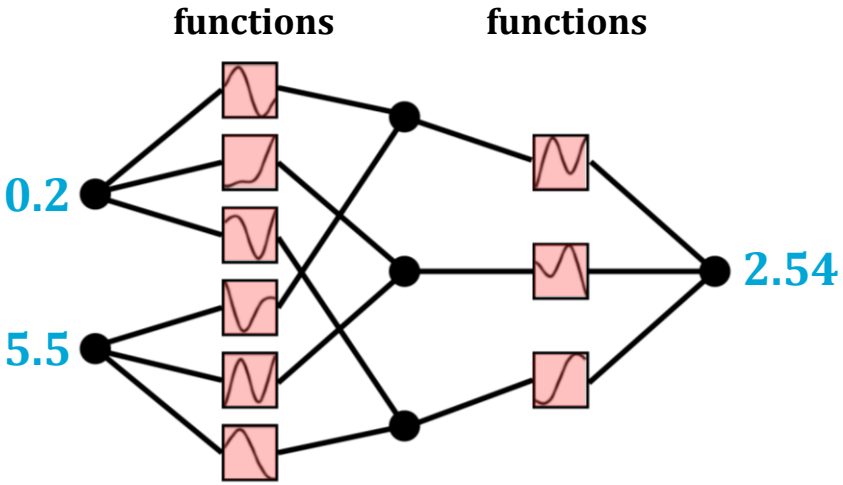


Multi-Layer Perceptron (MLP)

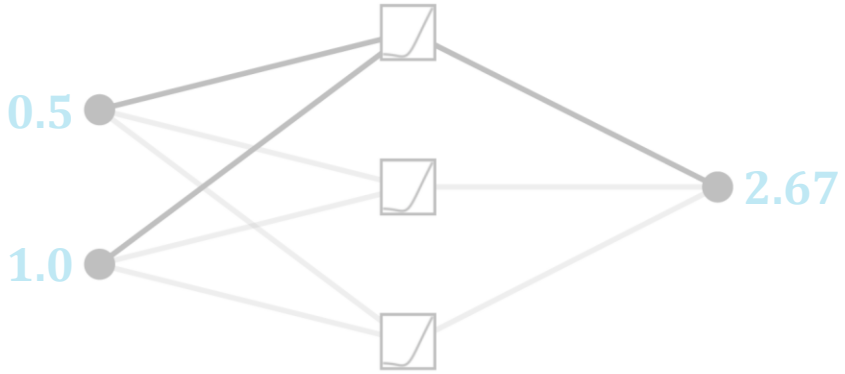


Kolmogorov-Arnold Network (KAN)

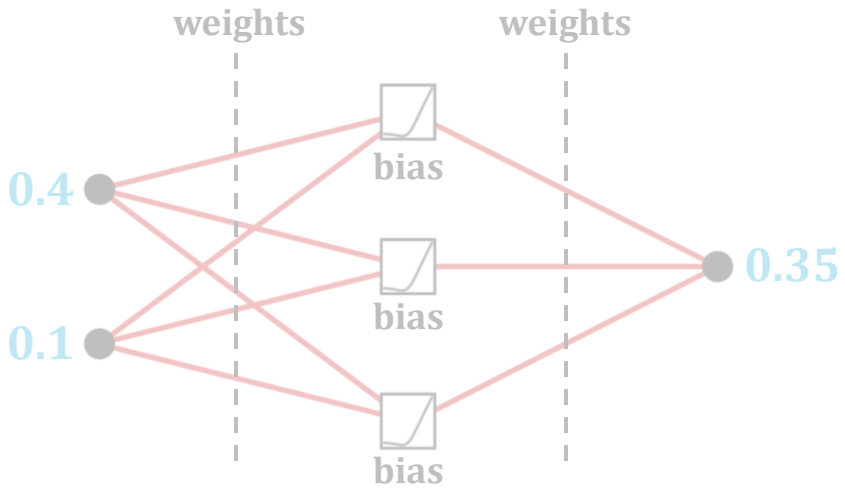


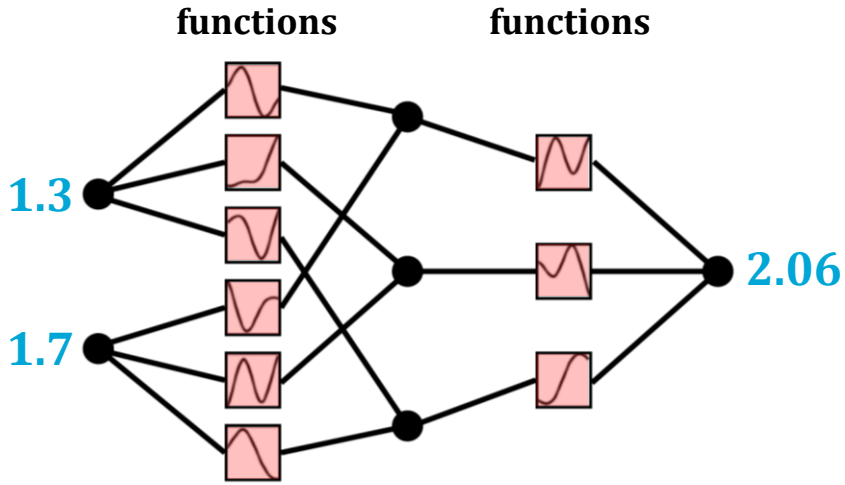


Multi-Layer Perceptron (MLP)

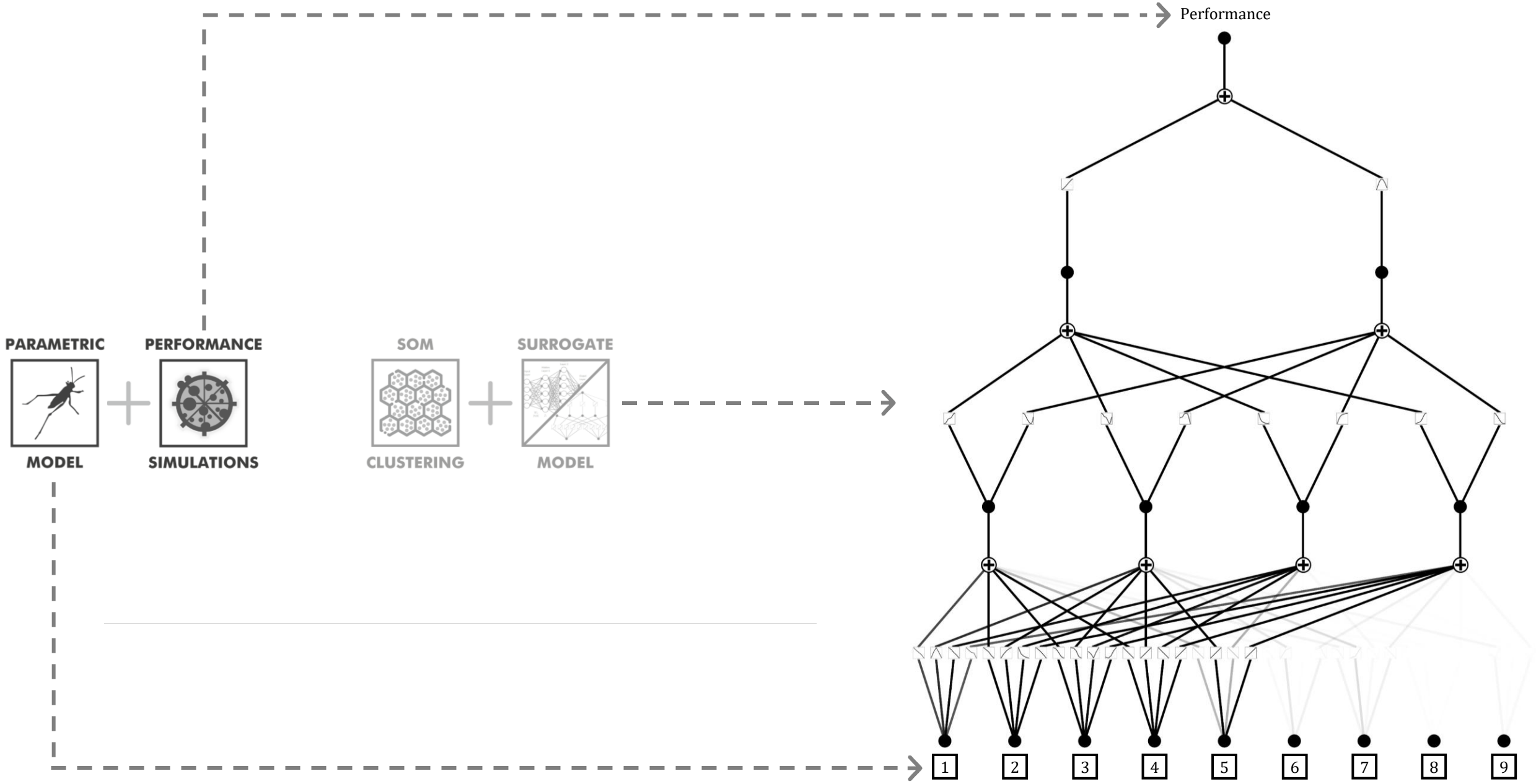


Kolmogorov-Arnold Network (KAN)



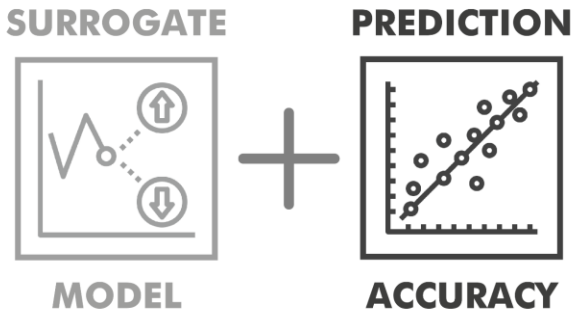


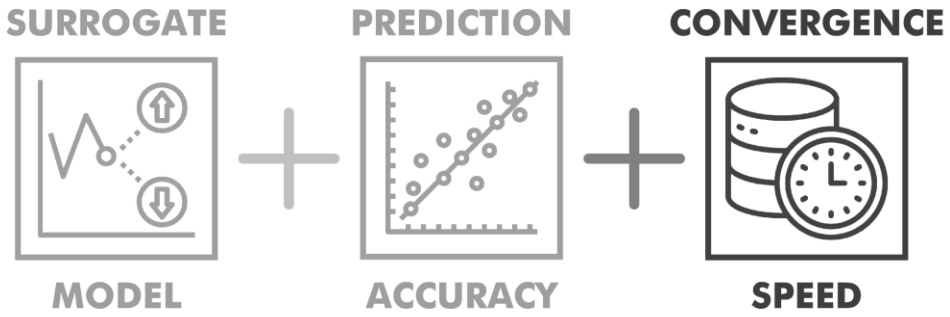
Results

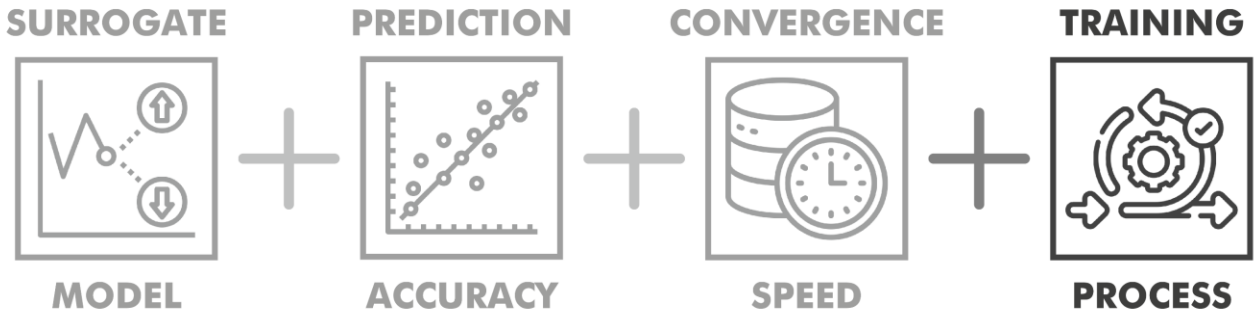

Performance
PARAMETRIC
PERFORMANCE
SOM
SURROGATE
MODEL
SIMULATIONS
CLUSTERING
MODEL
1
2
3
4
5
6
7
8
9

SURROGATE

MODEL


SURROGATE
PREDICTION
MODEL
ACCURACY


SURROGATE
PREDICTION
CONVERGENCE
MODEL
ACCURACY
SPEED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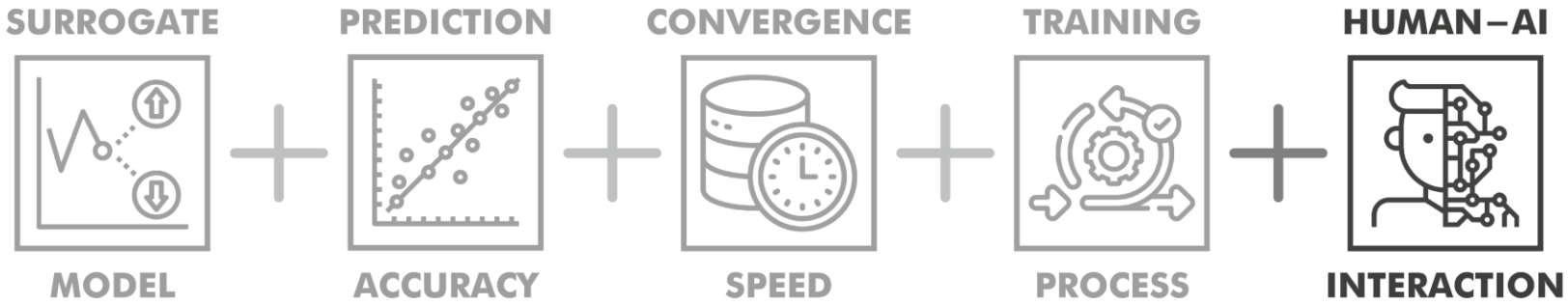
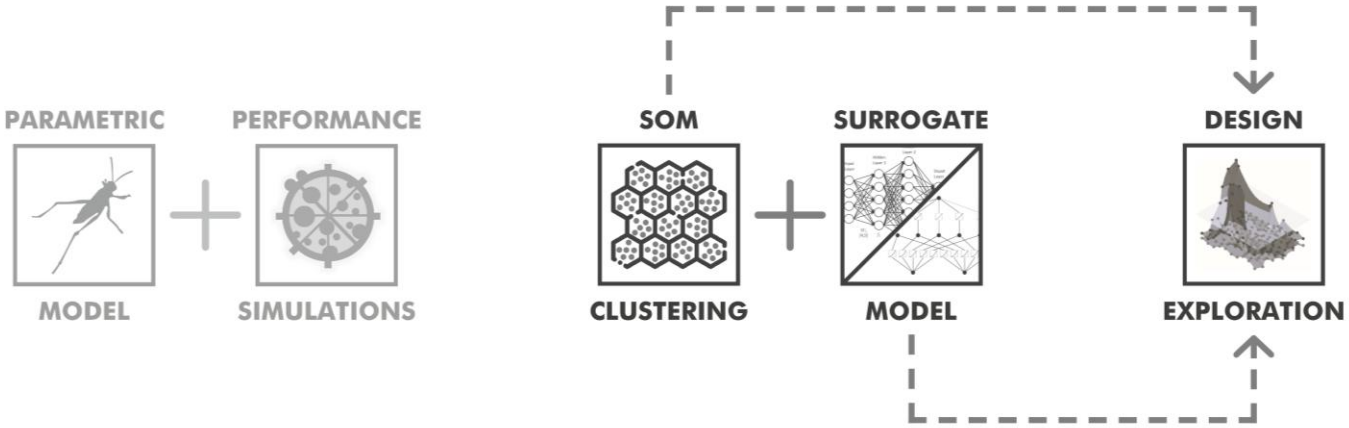
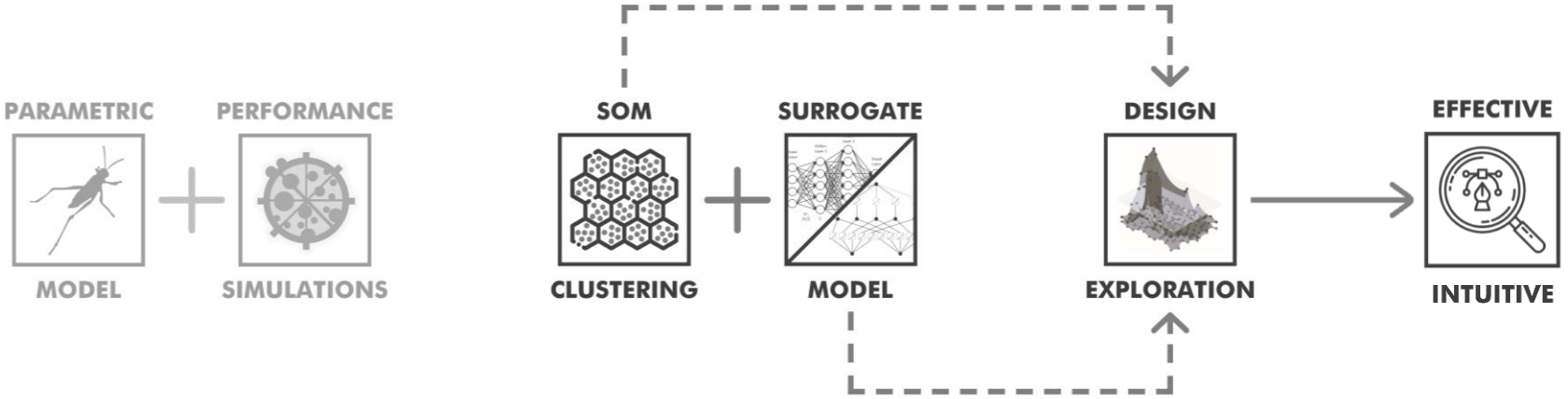
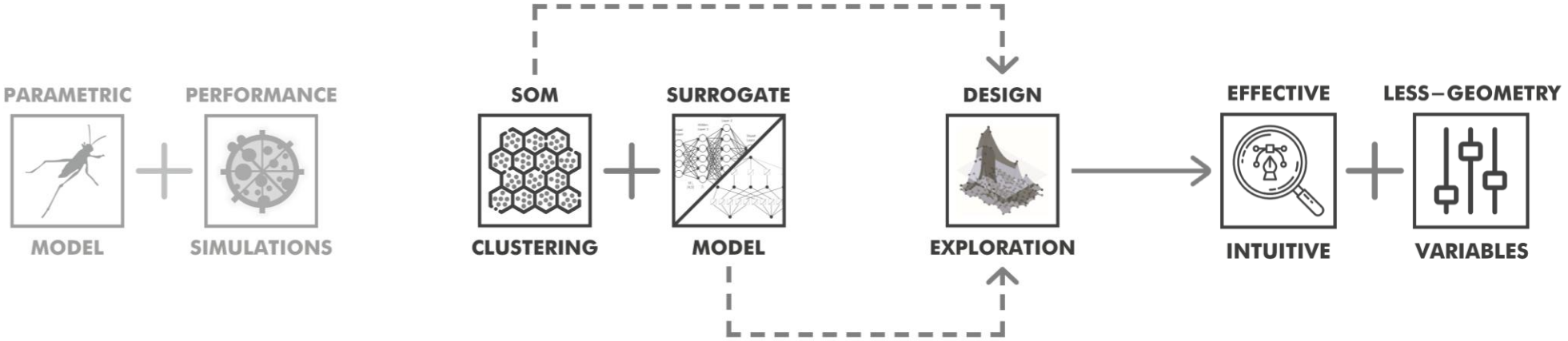
PREDICTION
CONVERGENCE
TRAINING
MODEL
ACCURACY
SPEED
PROCESS

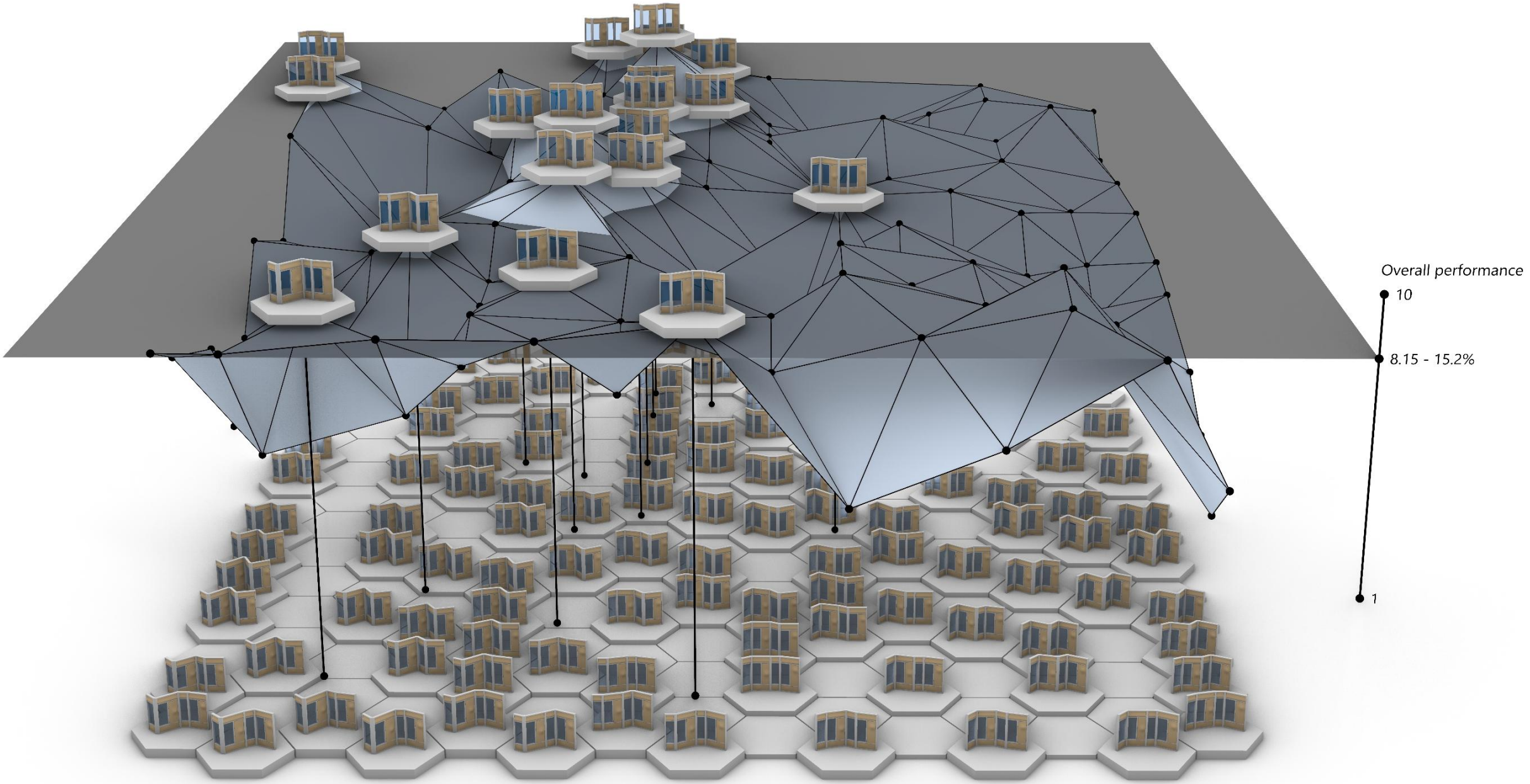

SURROGATE
MODEL
PREDICTION
ACCURACY
CONVERGENCE
SPEED
TRAINING
PROCESS
HUMAN–AI
INTERACTION

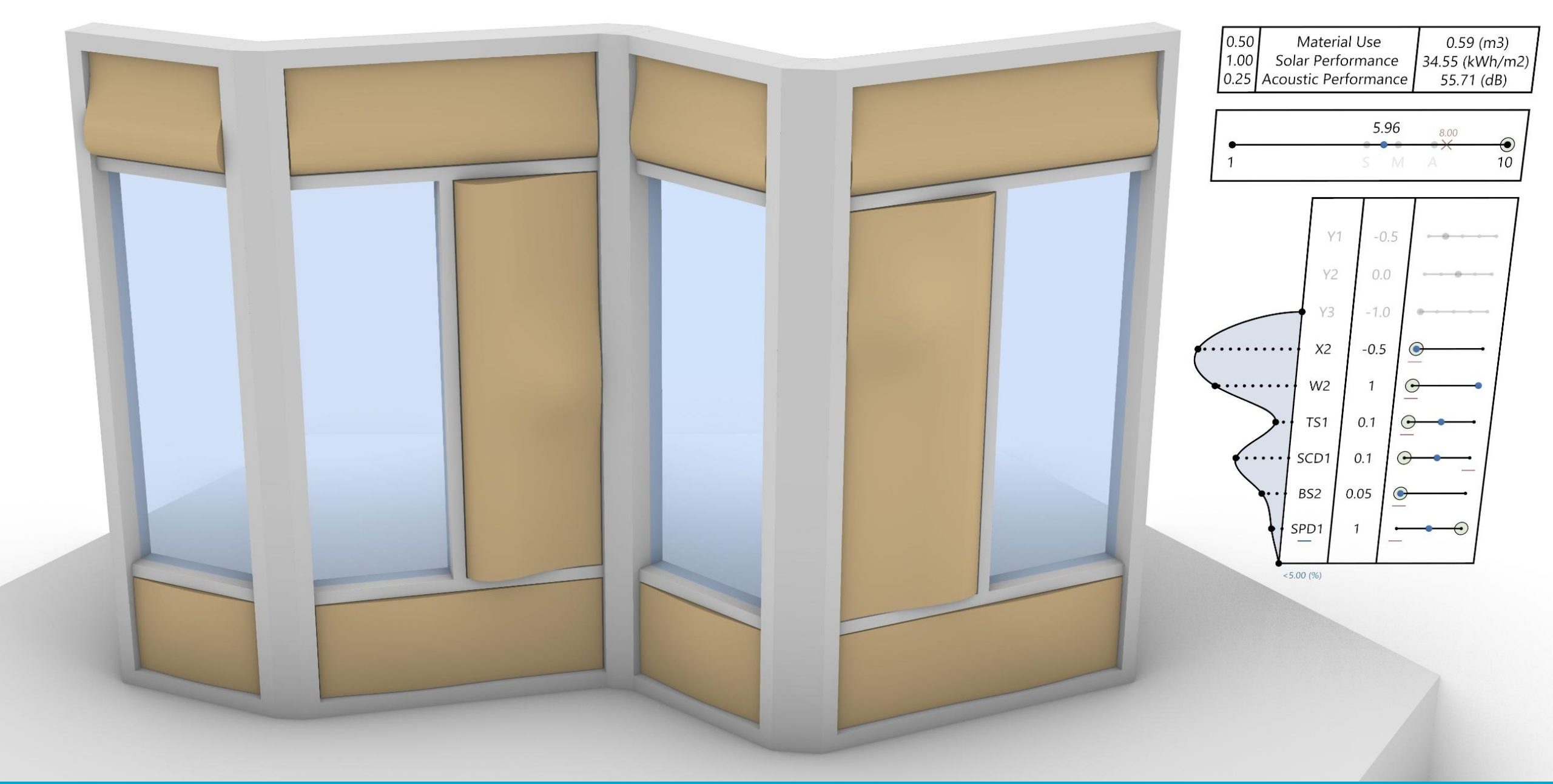
Design Exploration

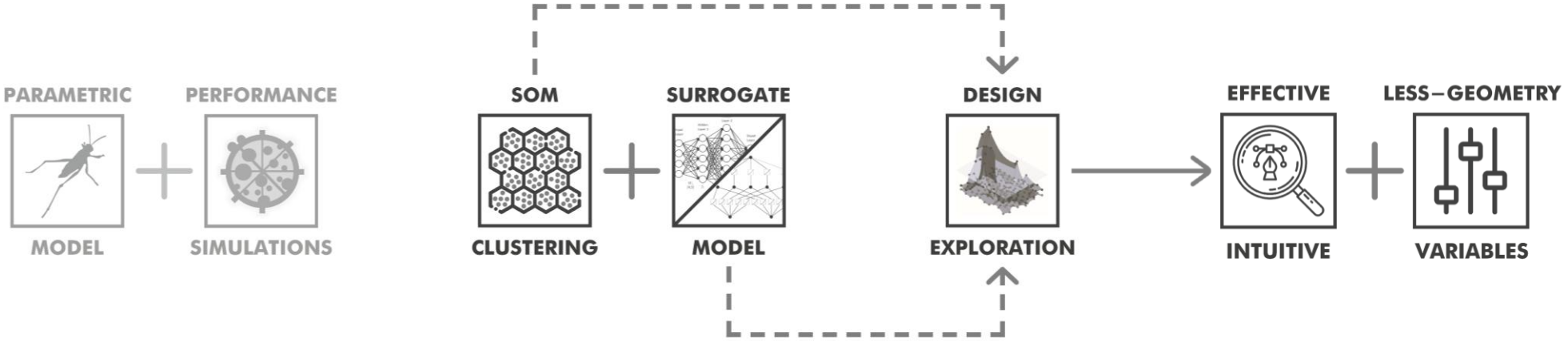

PARAMETRIC
PERFORMANCE
MODEL
SIMULATIONS
SOM
SURROGATE
DESIGN
CLUSTERING
MODEL
EXPLORATION


PARAMETRIC
PERFORMANCE
MODEL
SIMULATIONS
SOM
SURROGATE
CLUSTERING
MODEL
DESIGN
EXPLORATION
EFFECTIVE
INTUITIVE


PARAMETRIC
PERFORMANCE
MODEL
SIMULATIONS
SOM
SURROGATE
DESIGN
CLUSTERING
MODEL
EXPLORATION
EFFECTIVE
LESS–GEOMETRY
INTUITIVE
VARIABLES


Overall performance
10
8.15 - 15.2%
1

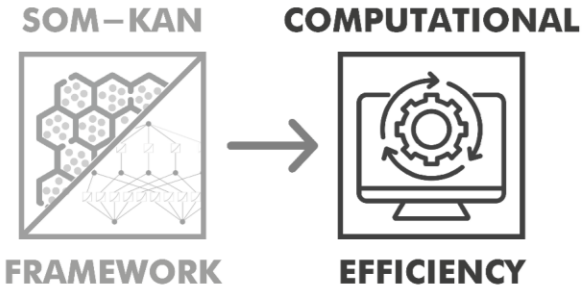

0.50
1.00
0.25
Material Use
Solar Performance
Acoustic Performance
0.59 (m3)
34.55 (kWh/m2)
55.71 (dB)
5.96
8.00
1
S
M
A
10
Y1
Y2
Y3
X2
W2
TS1
SCD1
BS2
SPD1
-0.5
0.0
-1.0
-0.5
1
0.1
0.1
0.05
1
<5.00 (%)

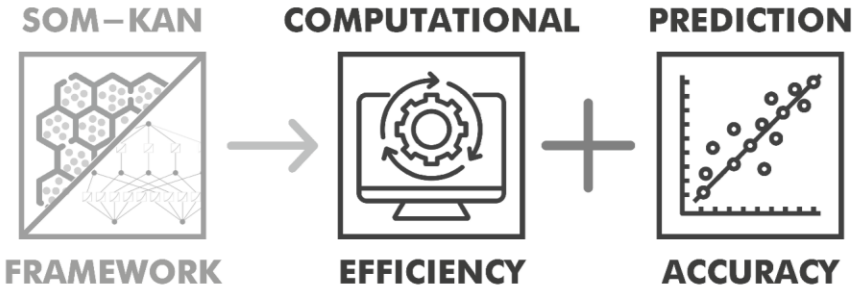

PARAMETRIC
PERFORMANCE
MODEL
SIMULATIONS
SOM
SURROGATE
DESIGN
CLUSTERING
MODEL
EXPLORATION
EFFECTIVE
LESS–GEOMETRY
INTUITIVE
VARIABLES

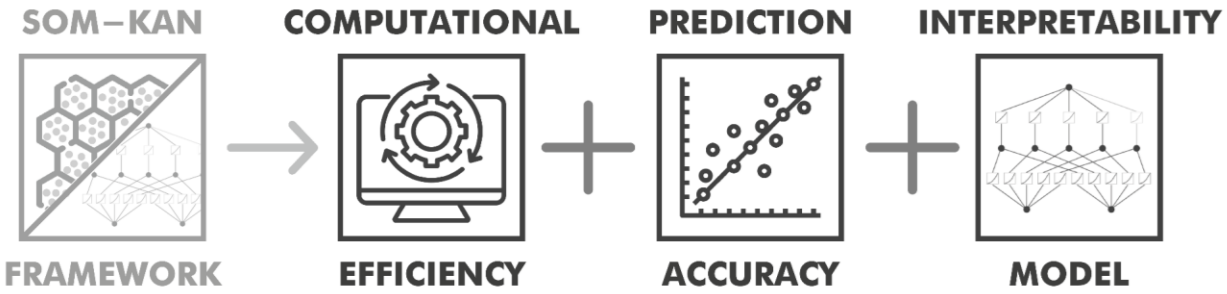
Conclusion

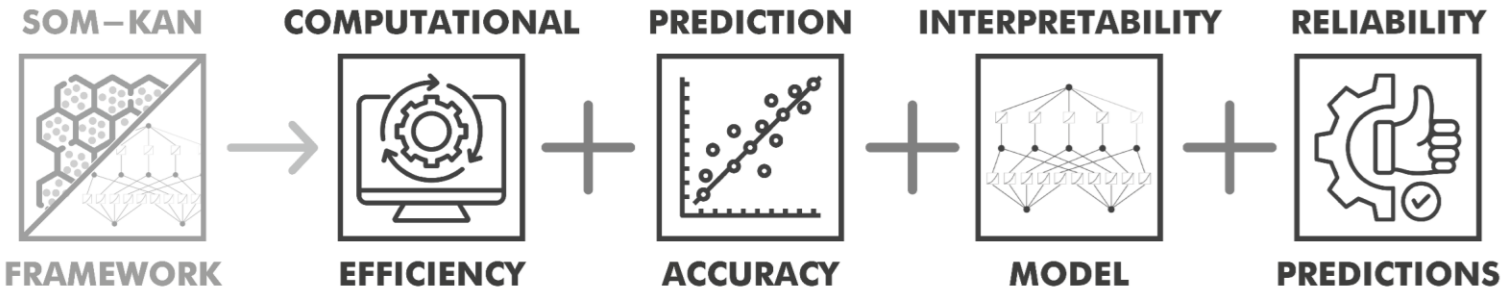
SOM–KAN

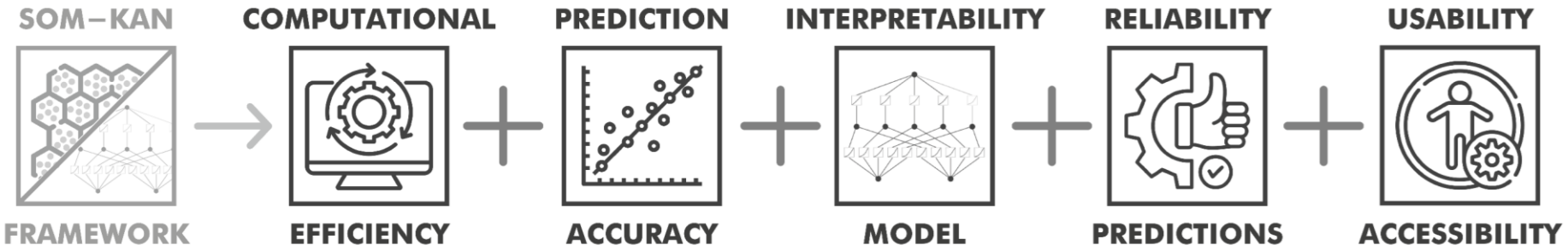
FRAMEWORK

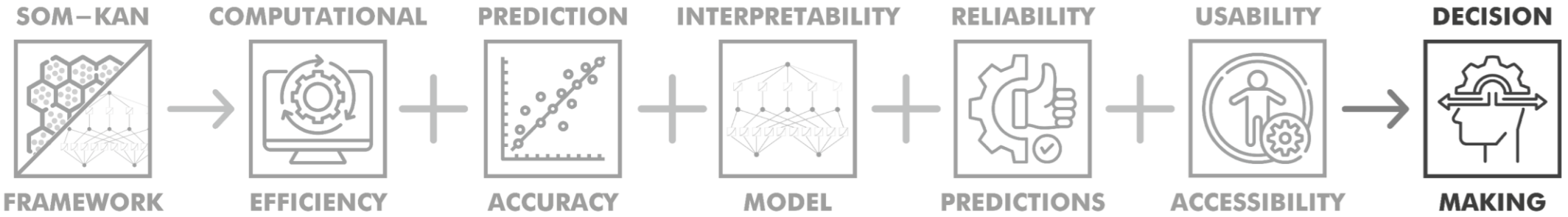

SOM–KAN
COMPUTATIONAL
FRAMEWORK
EFFICIENCY

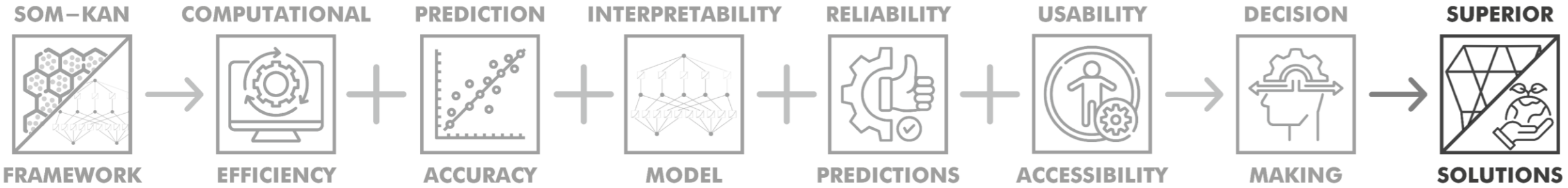

SOM–KAN
COMPUTATIONAL
PREDICTION
FRAMEWORK
EFFICIENCY
ACCURACY


SOM–KAN
FRAMEWORK
COMPUTATIONAL
EFFICIENCY
PREDICTION
ACCURACY
INTERPRETABILITY
MODEL


SOM–KAN
FRAMEWORK
COMPUTATIONAL
EFFICIENCY
PREDICTION
ACCURACY
INTERPRETABILITY
MODEL
RELIABILITY
PREDICTIONS


SOM–KAN
FRAMEWORK
COMPUTATIONAL
EFFICIENCY
PREDICTION
ACCURACY
INTERPRETABILITY
MODEL
RELIABILITY
PREDICTIONS
USABILITY
ACCESSIBILITY


SOM–KAN
FRAMEWORK
COMPUTATIONAL
EFFICIENCY
PREDICTION
ACCURACY
INTERPRETABILITY
MODEL
RELIABILITY
PREDICTIONS
USABILITY
ACCESSIBILITY
DECISION
MAKING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Performance-Driven Design Exploration of Biocomposite Facades

Advancing Facade Design through Enhanced Computational Efficiency, Accuracy, and Interpretability: A Novel AI-Driven Facade Design Framework comprising Self-Organising Maps (SOM) and Kolmogorov-Arnold Networks (KAN)

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Building Technology Graduation Studio
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13 January 2025