

visual comfort l(AI)outs

A FRAMEWORK FOR DAYLIGHT AND VIEW GUIDANCE
DURING THE EARLY LAYOUT DESIGN PROCESS

MSc Building Technology Thesis

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Supervised by:

Michela Turrin

Eleonora Brembilla

Pushing forward performance quality

Limits solutions

Pushing performance quality testing forward in the design
process results **limited design solutions**

Background knowledge

research framework

machine learning

ML design process framework

“Swiss dwellings” dataset

labels & features

ML training & performance

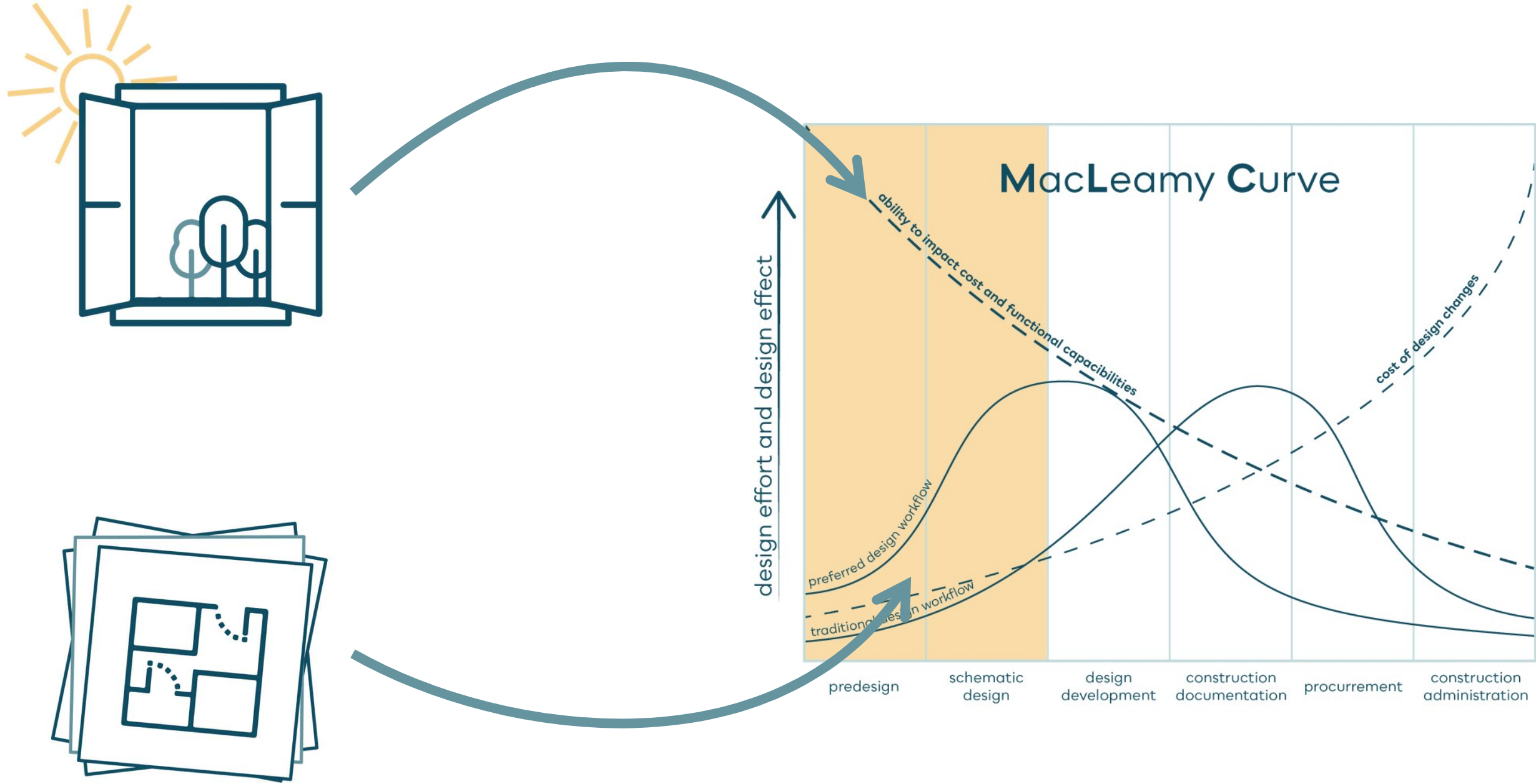
layout evaluation system

framework test

conclusion

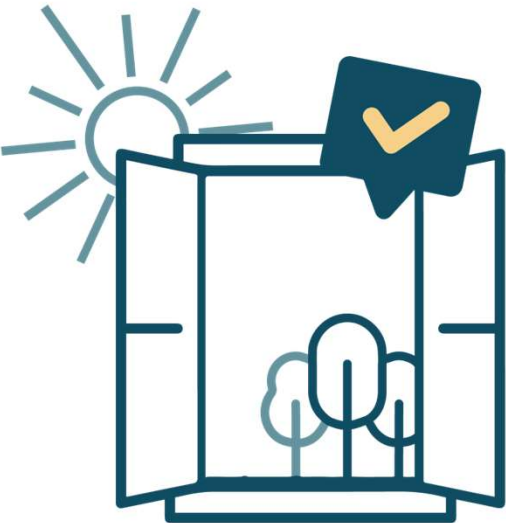
Design decisions effects over time

Early design phase

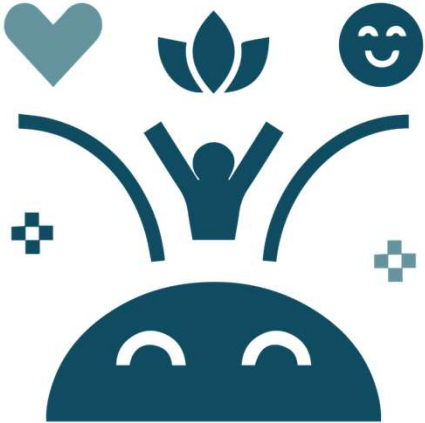


Visual comforts affects

Good visual comfort results in...



Good visual comfort



Healthier occupants



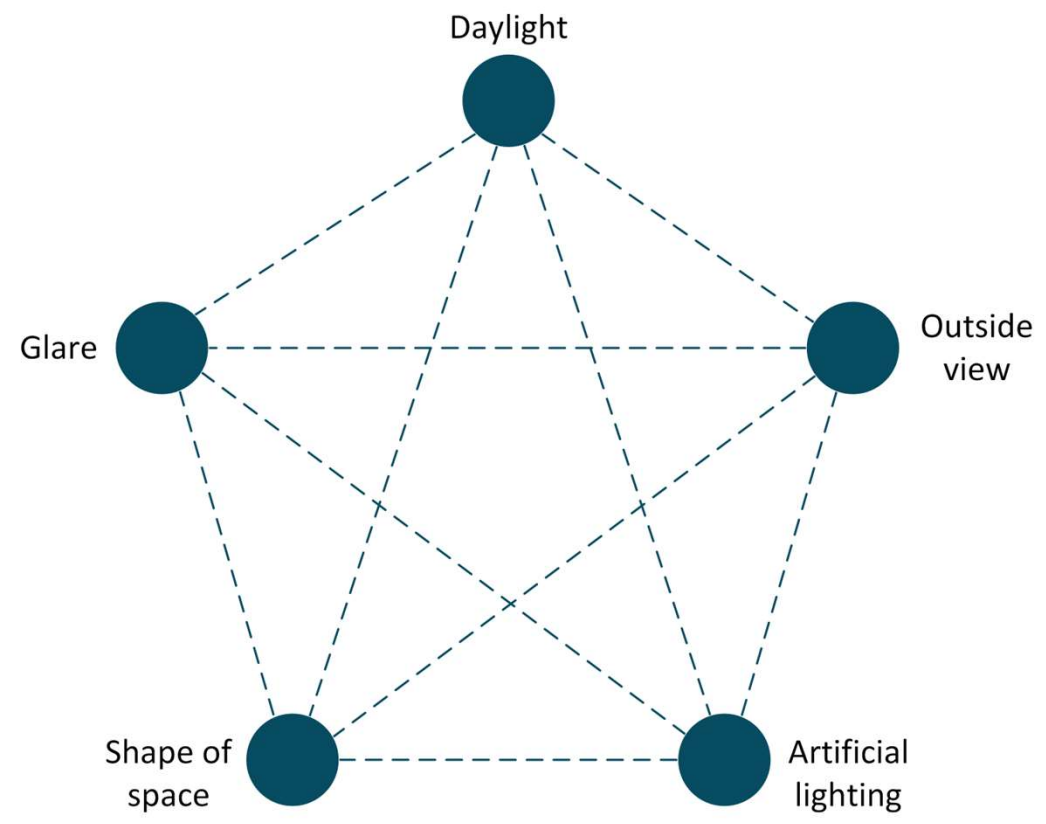
Connection to outdoors



Lower energy demand

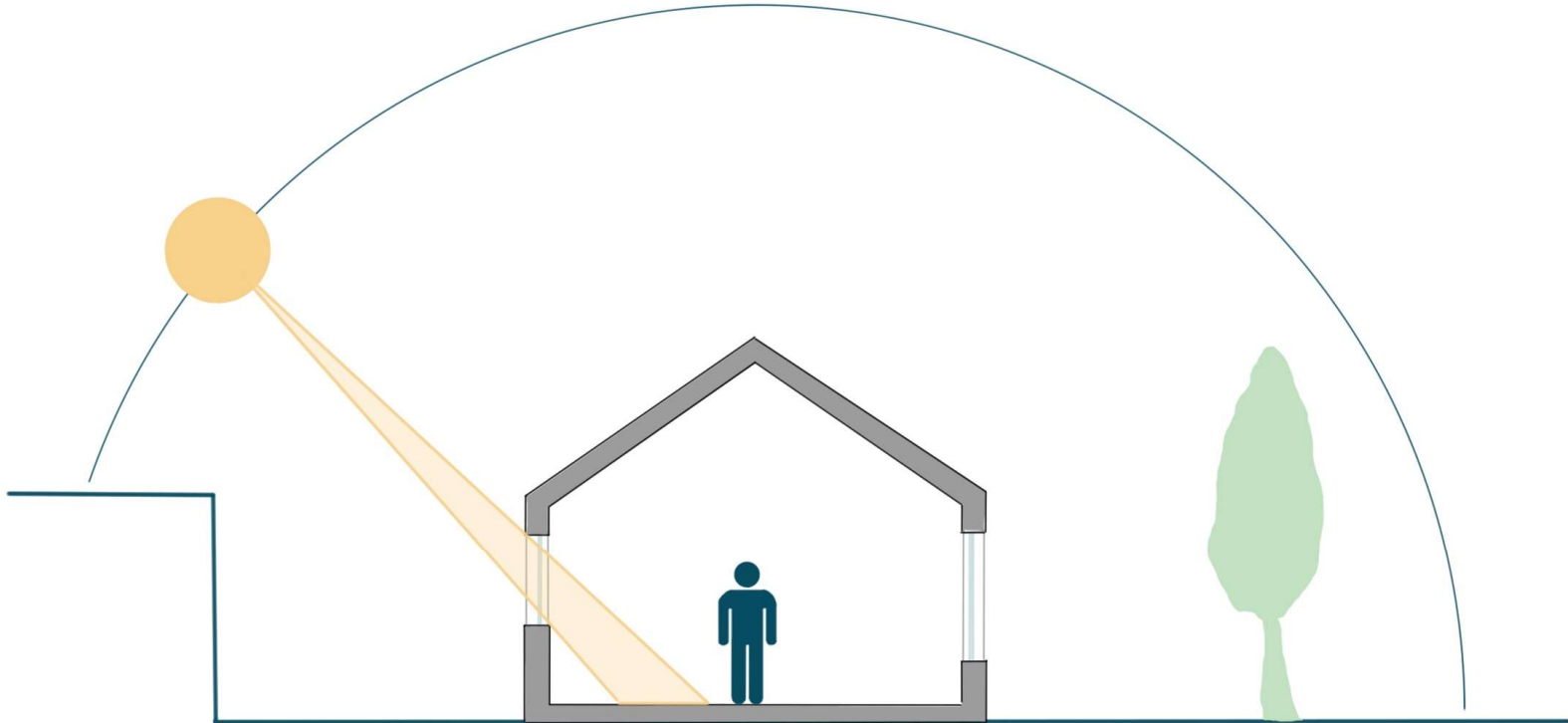
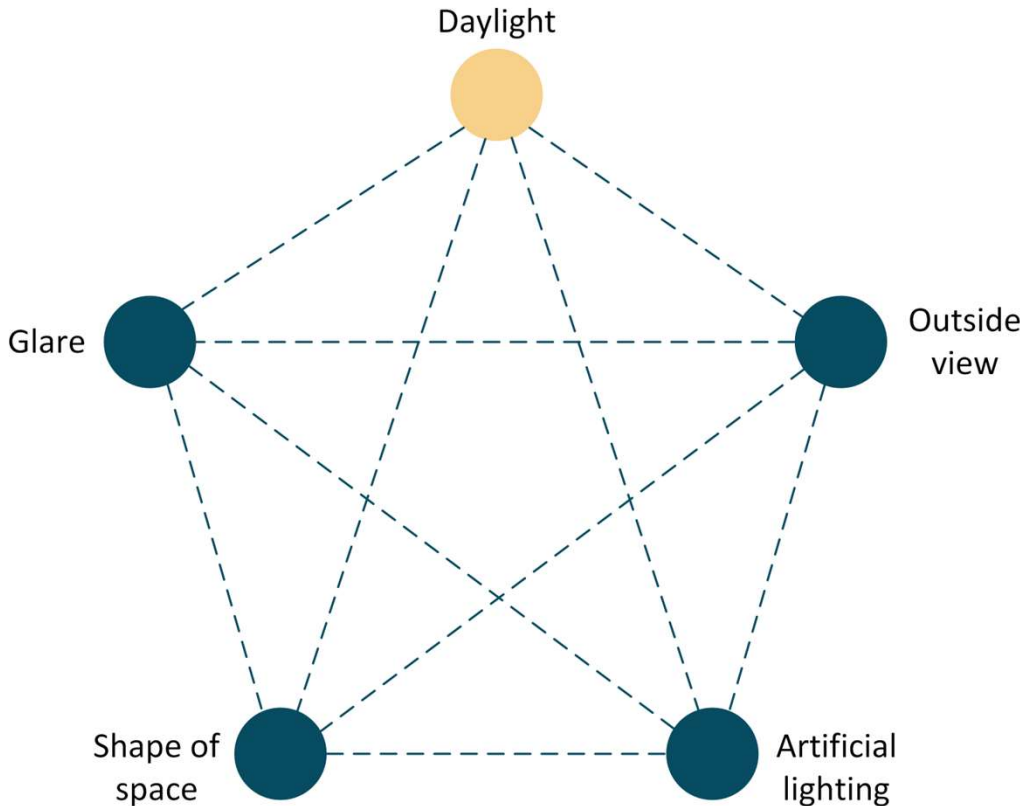
Visual comfort

A definition



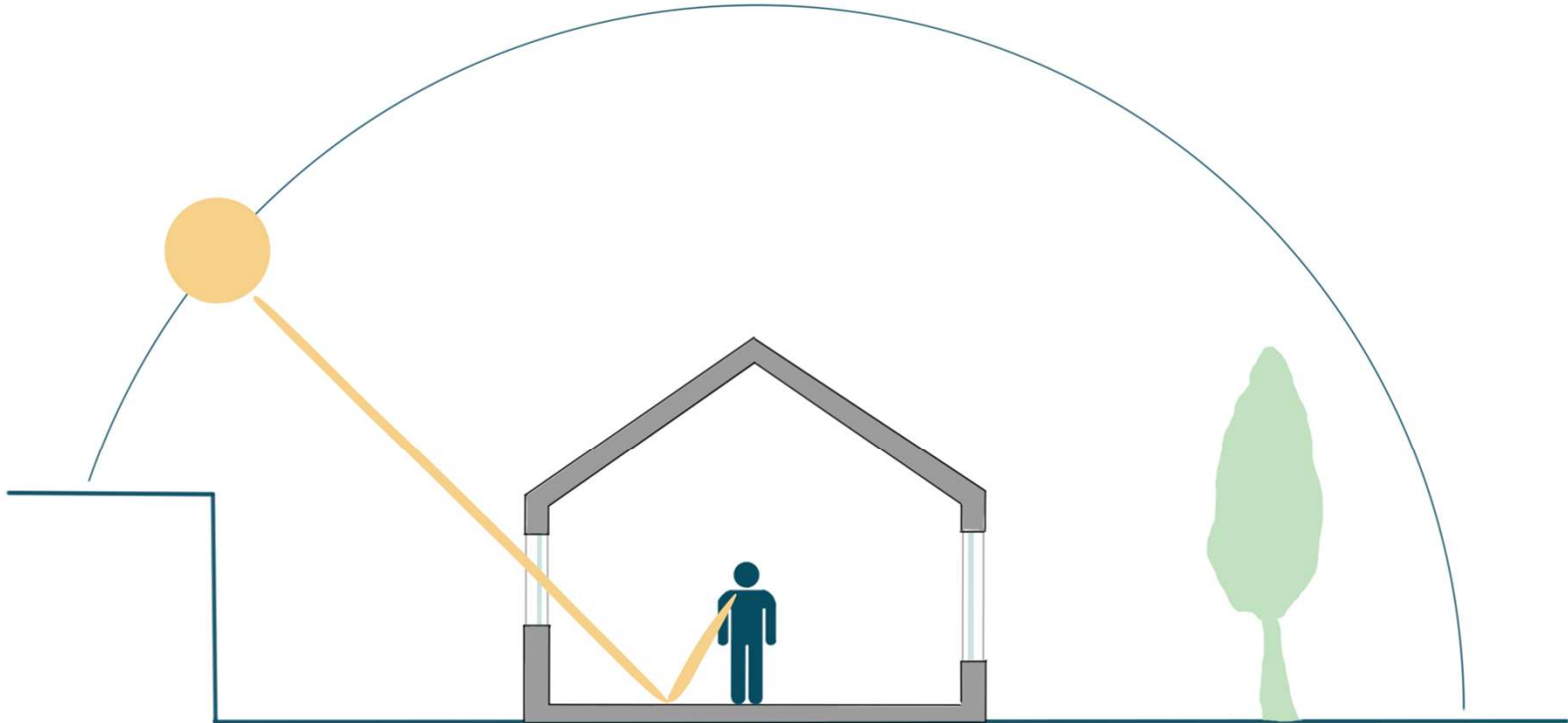
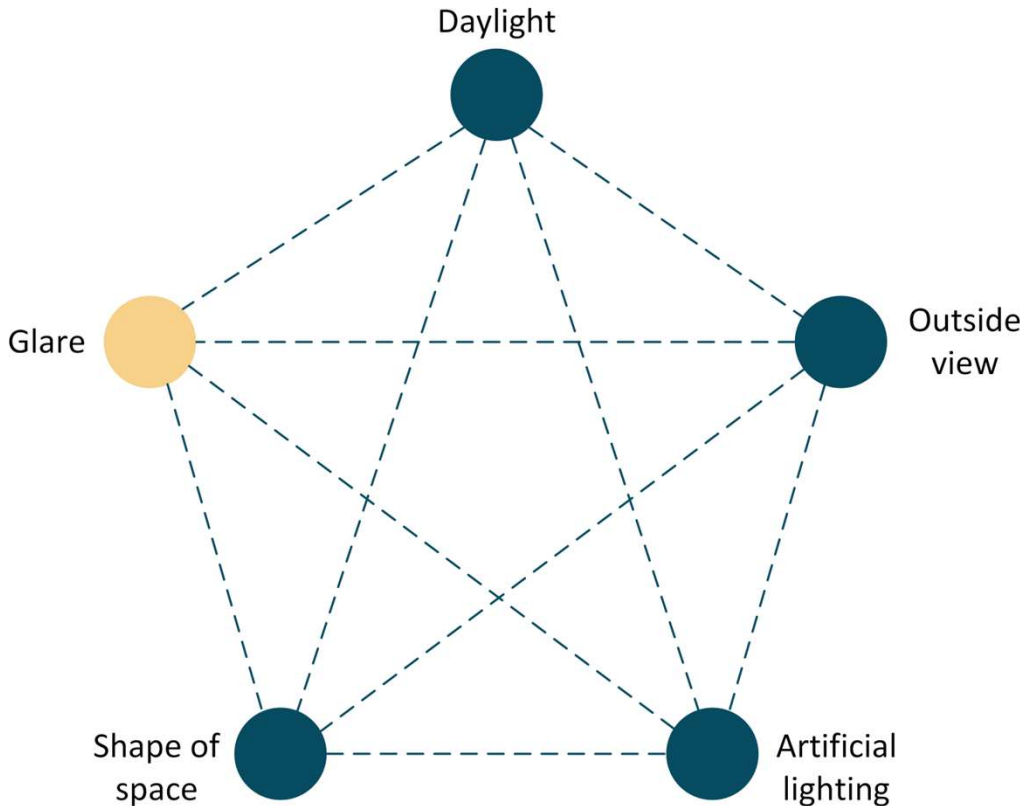
Visual comfort

A definition



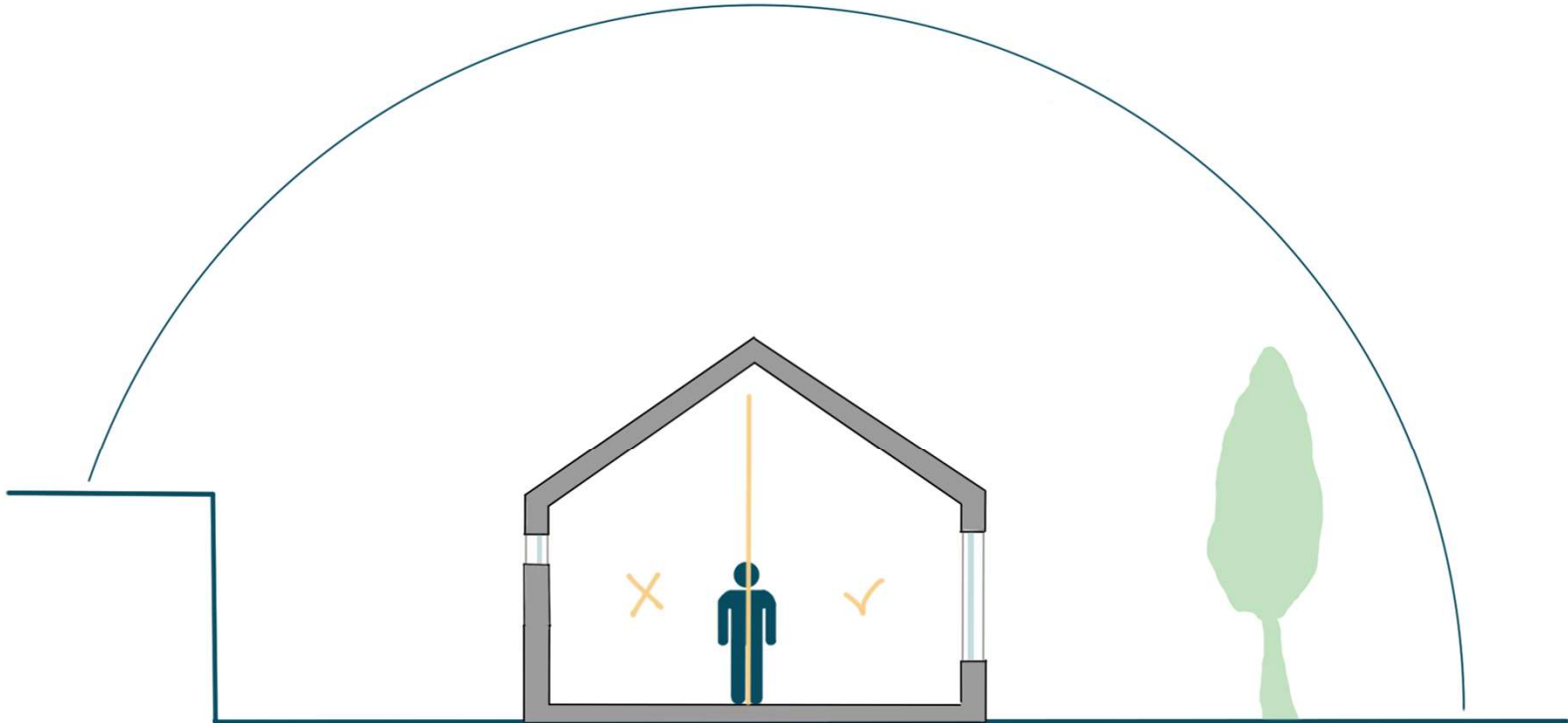
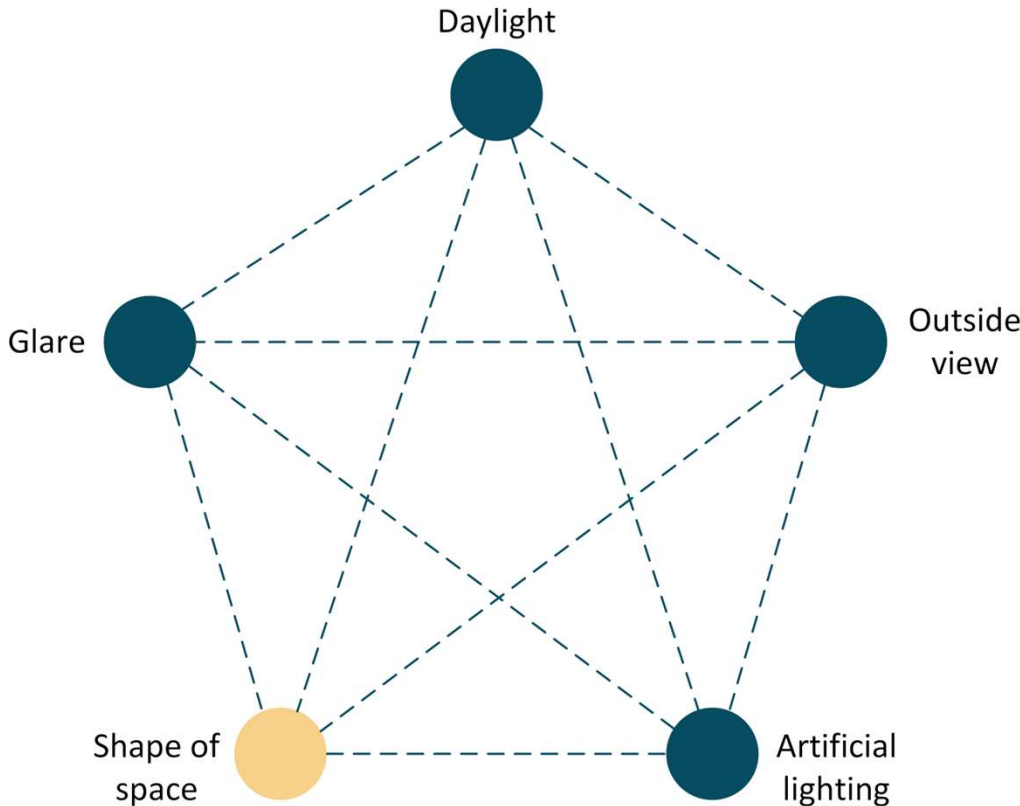
Visual comfort

A definition



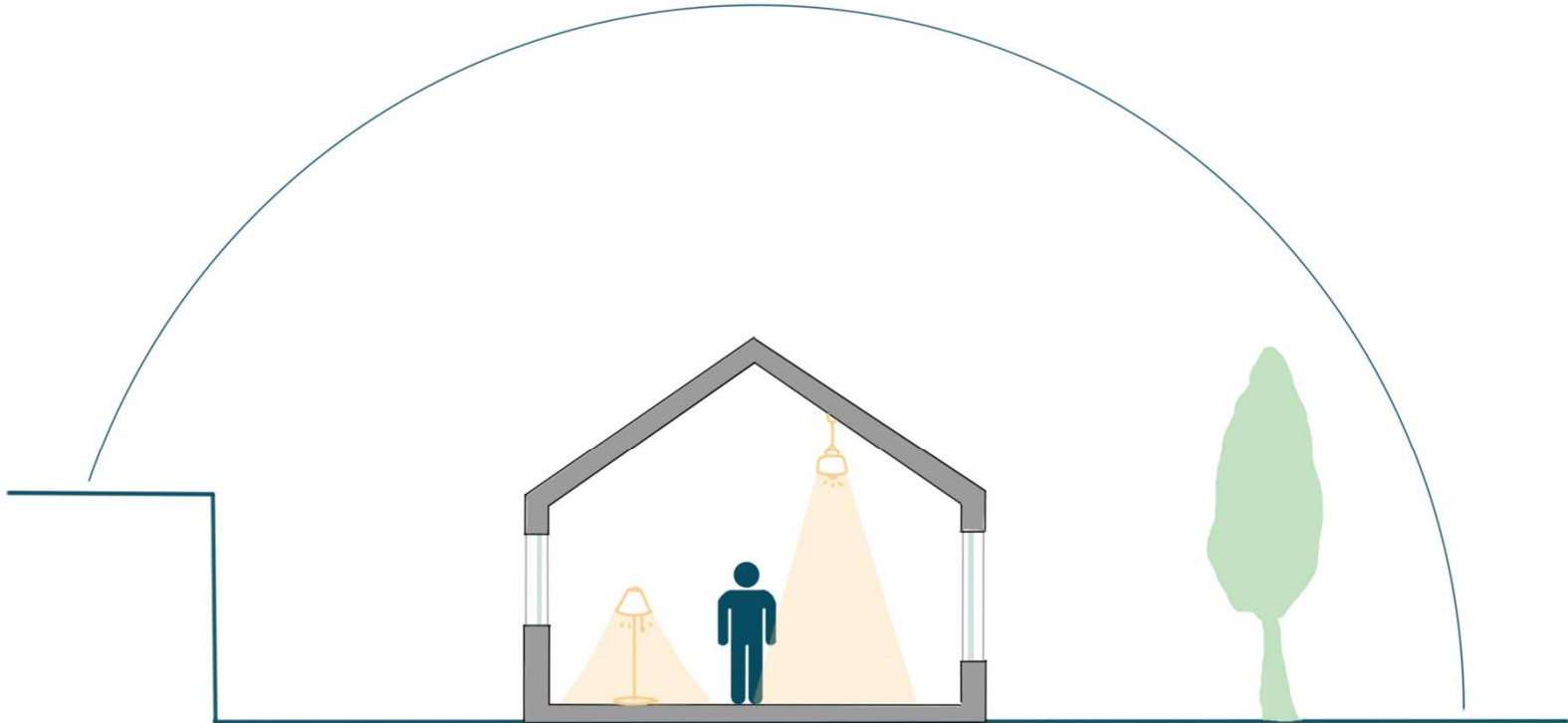
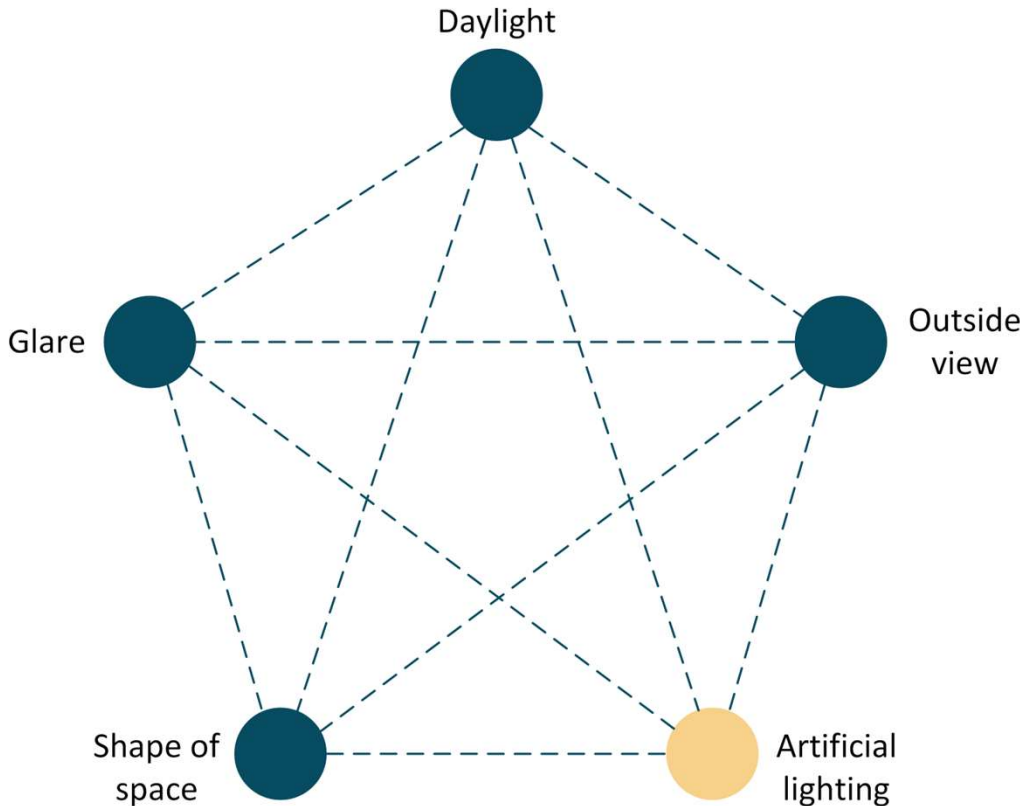
Visual comfort

A definition



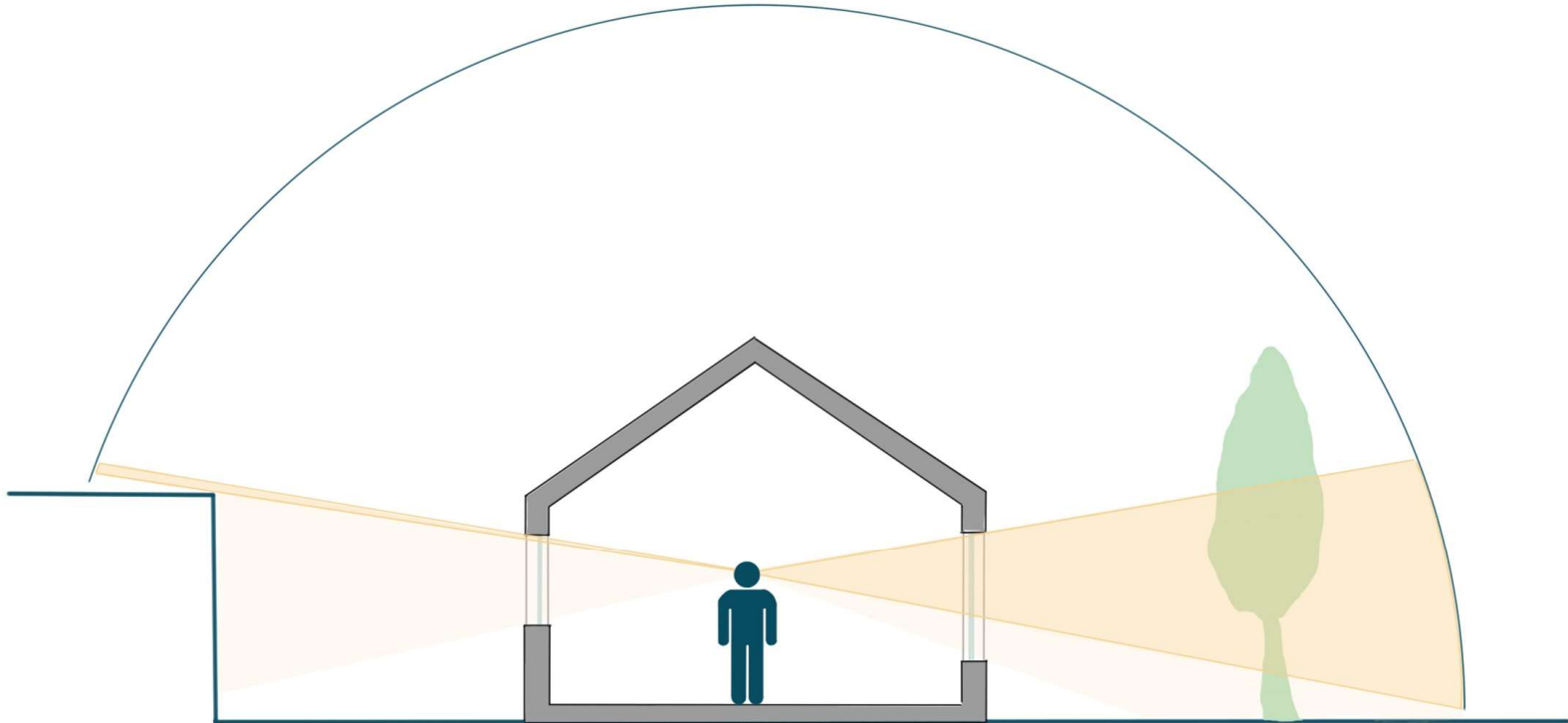
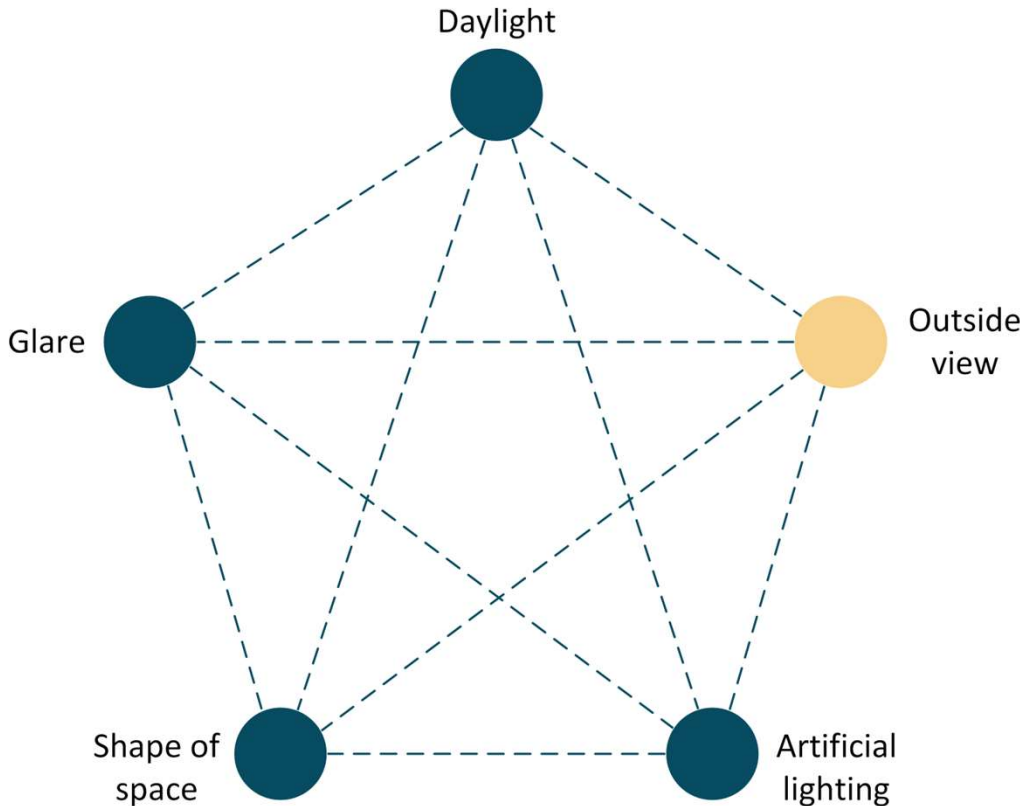
Visual comfort

A definition



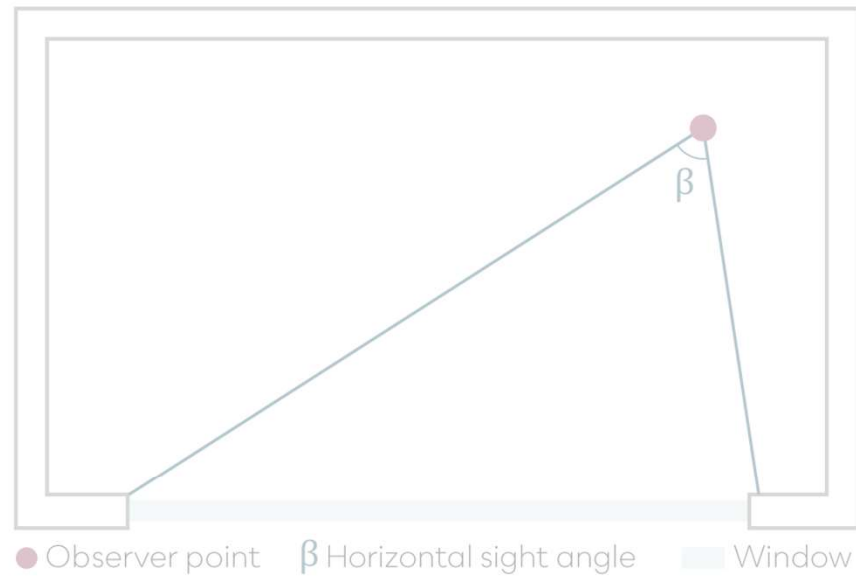
Visual comfort

A definition

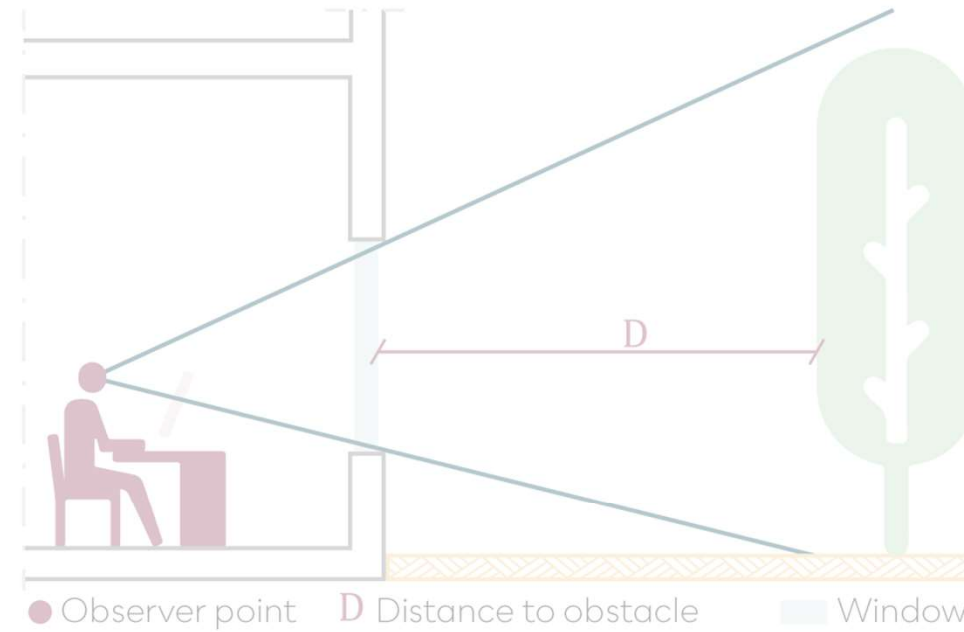


View out indicators

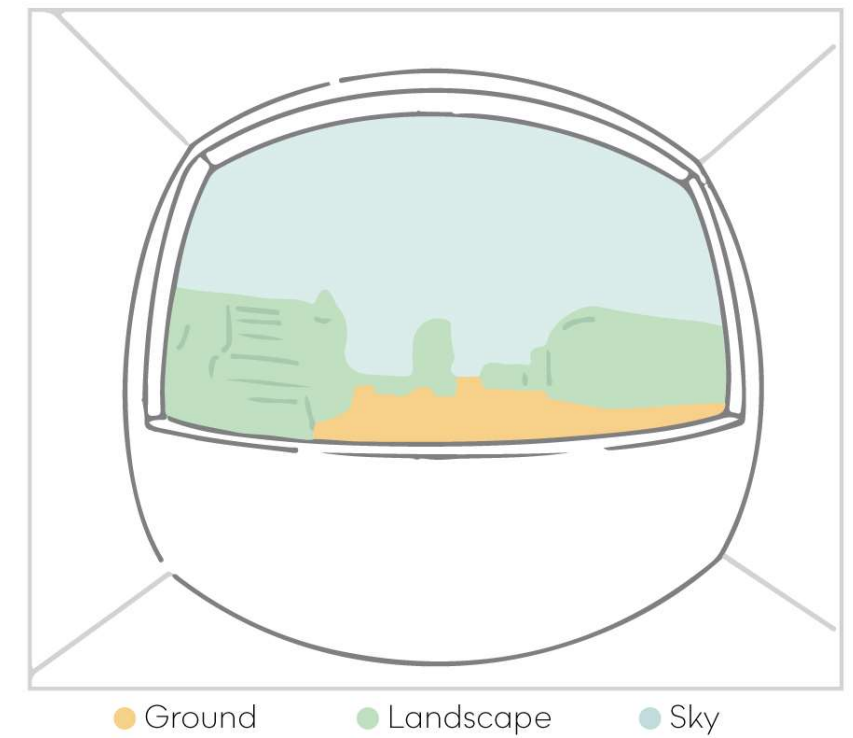
A definition



Horizontal sight angle



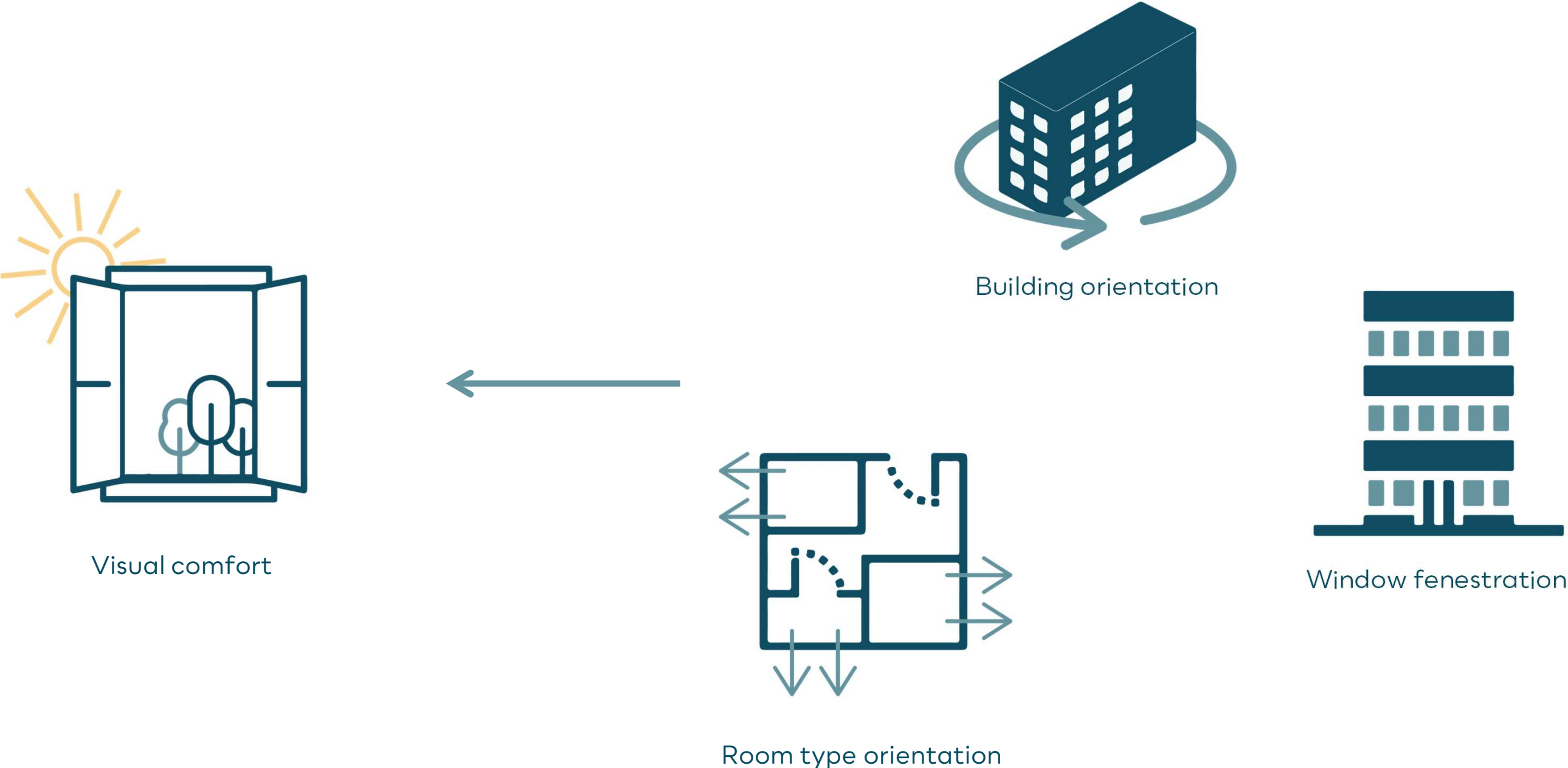
Outside distance of view / number of visible layers



View layers (fish eye-view)

Design parameters

Parameters affecting visual comfort



Optimal room orientation

Enhances solar heat-control, natural light gain, align usage timeframes, optimise sunlight availability



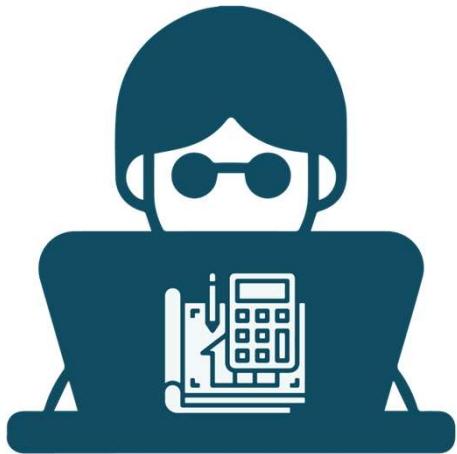
Optimal room orientation

Enhances solar heat-control, natural light gain, align usage timeframes, optimise sunlight availability



Simulations

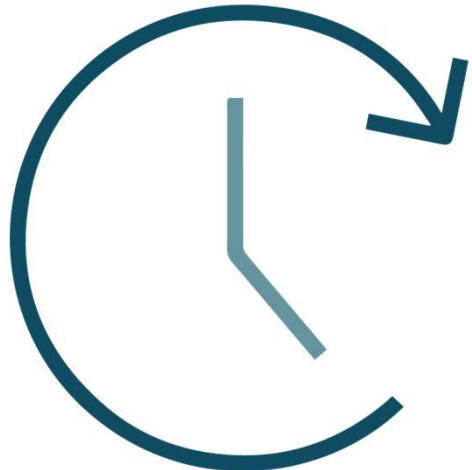
Push performance-based decisions to later stages



Simulations



Unknown input



Time consuming



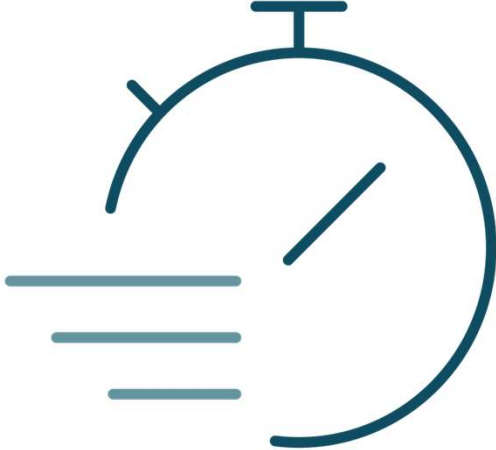
Pushed forward performance assessment

Machine learning

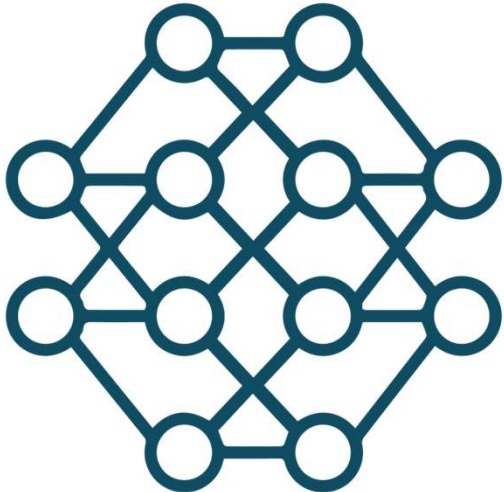
Can replace simulations



Machine learning



Quick predictions



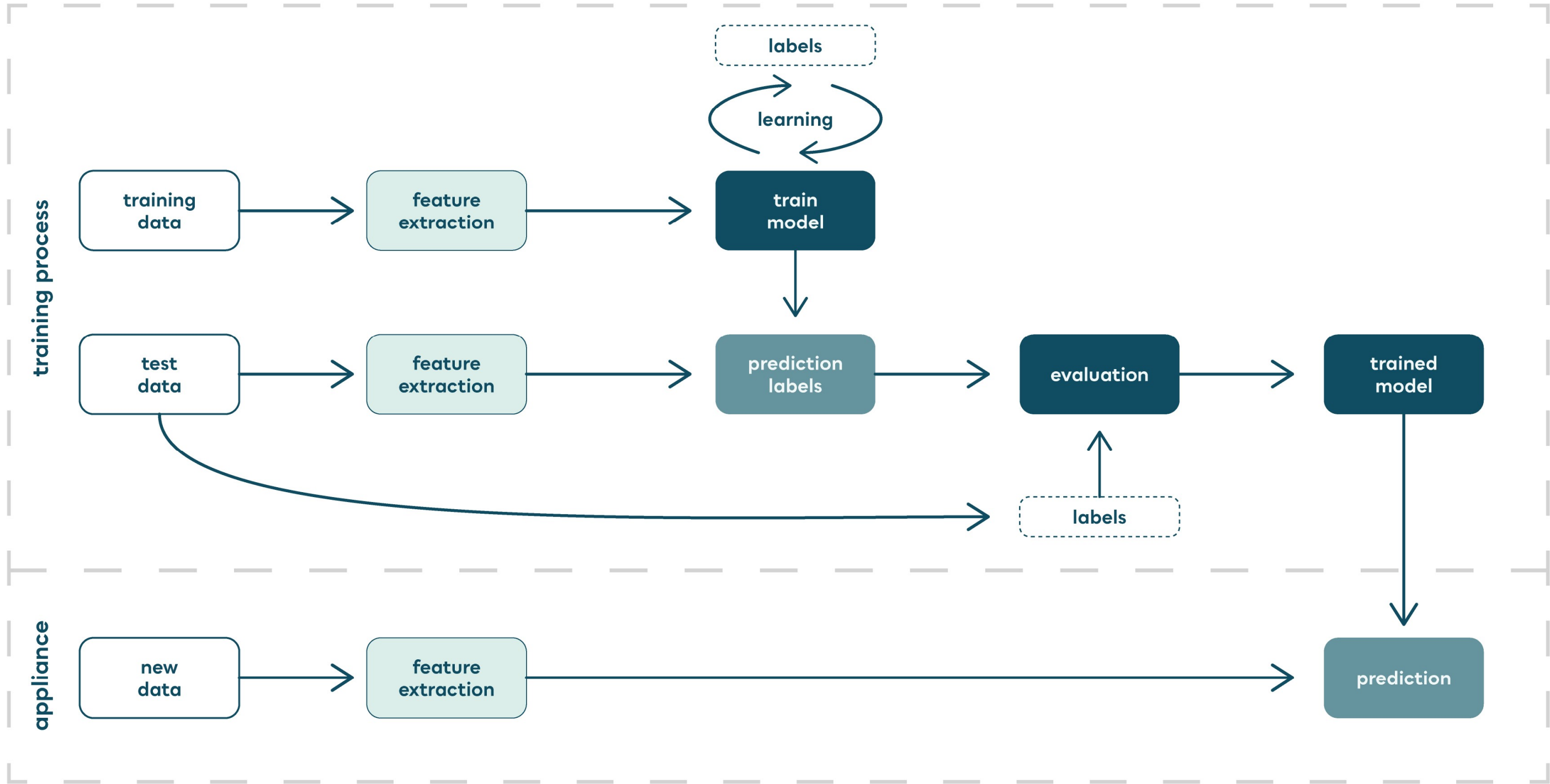
Correlated variables



Performance assessment
in the moment

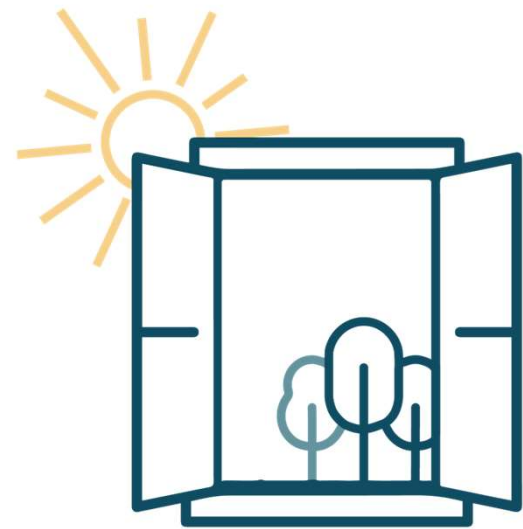
Supervised learning

A definition

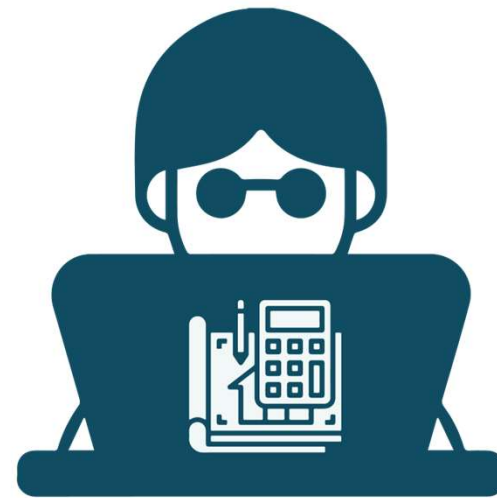


Problem statement

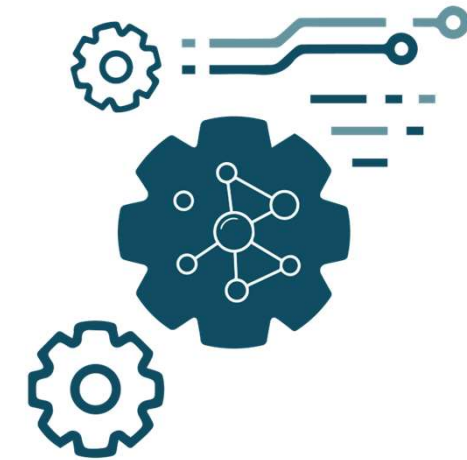
Problems and potential



Visual comfort influences occupant's well-being and the sustainability of buildings



Simulations are time consuming and require unknown input



Machine learning can make quick predictions based on correlated variables

background knowledge

Research framework

machine learning

ML design process framework

“Swiss dwellings” dataset

labels & features

ML training & performance

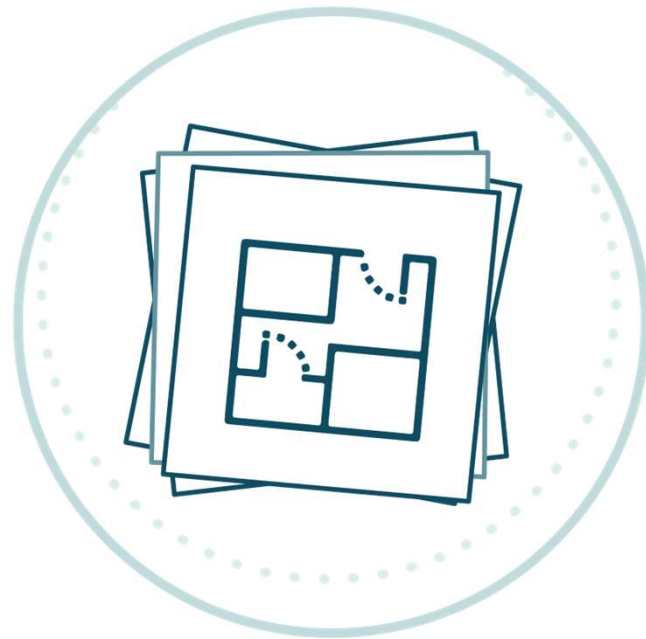
layout evaluation system

framework test

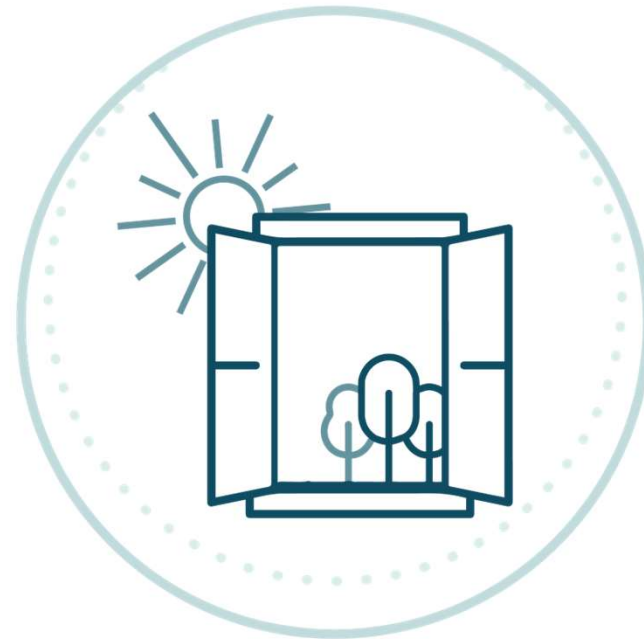
conclusion

Research gap

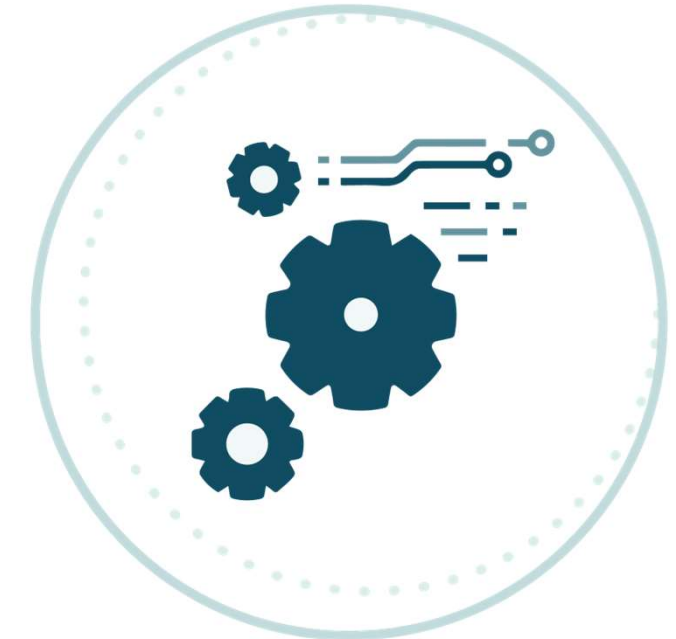
What is currently missing



Real-world dwelling layouts



Predict daylight and view quality



Adapt design process to utilize ML

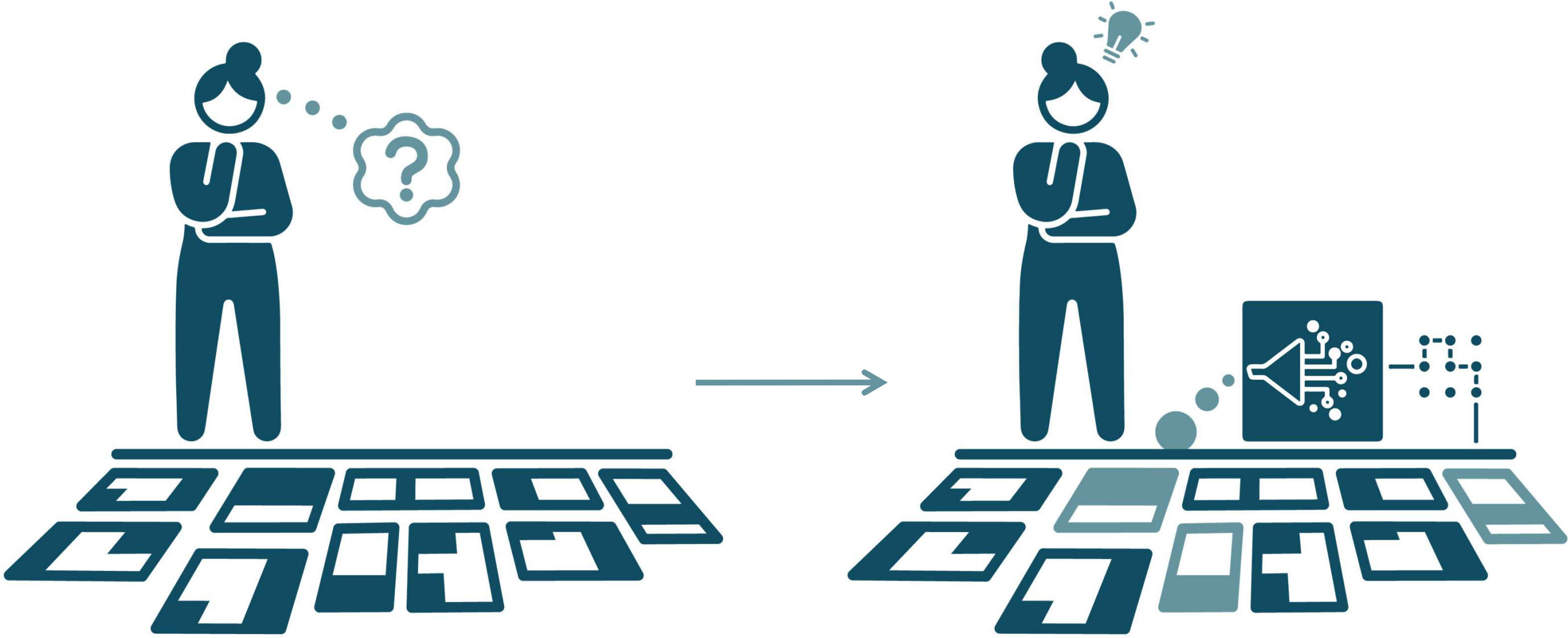
Research questions

Main research question

HOW CAN A **MACHINE LEARNING** PROCESS **SUPPORT DESIGNERS** WITH
EVALUATING AND OPTIMISING **RESIDENTIAL LAYOUTS** FOR DAYLIGHT
AND VIEW PERFORMANCE DURING THE **EARLY DESIGN PHASE?**

Objective

Method to support designers

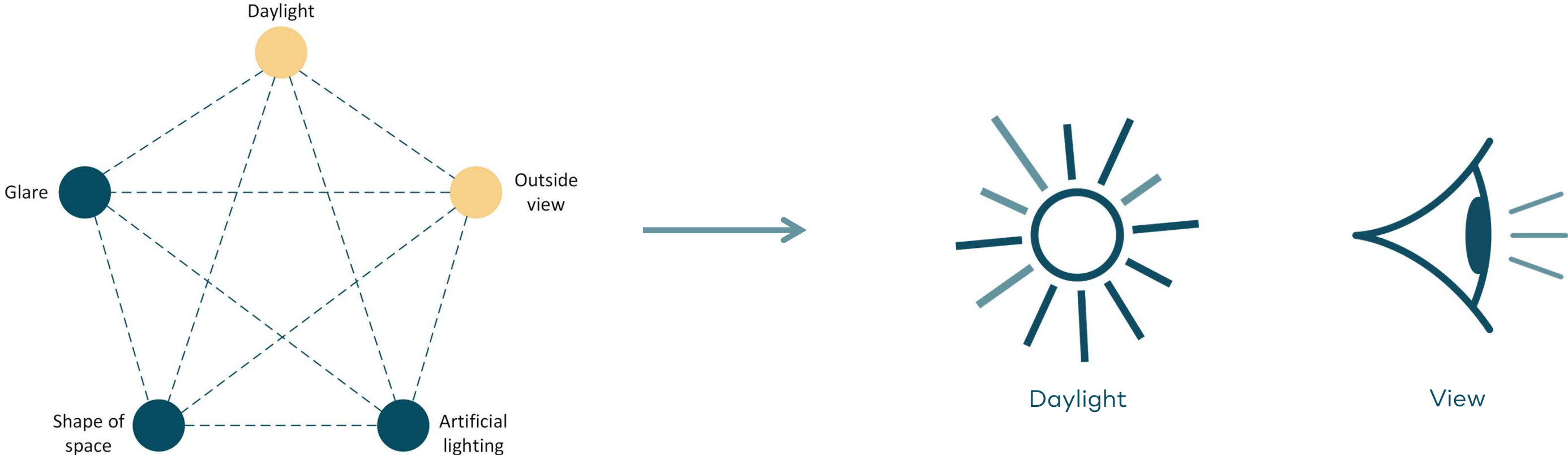


Decisions not performance based

ML process to support designers

Boundary conditions

Method with 2 labels



background knowledge

research framework

machine learning (ML)

ML design process framework

“Swiss dwellings” dataset

labels & features

ML training & performance

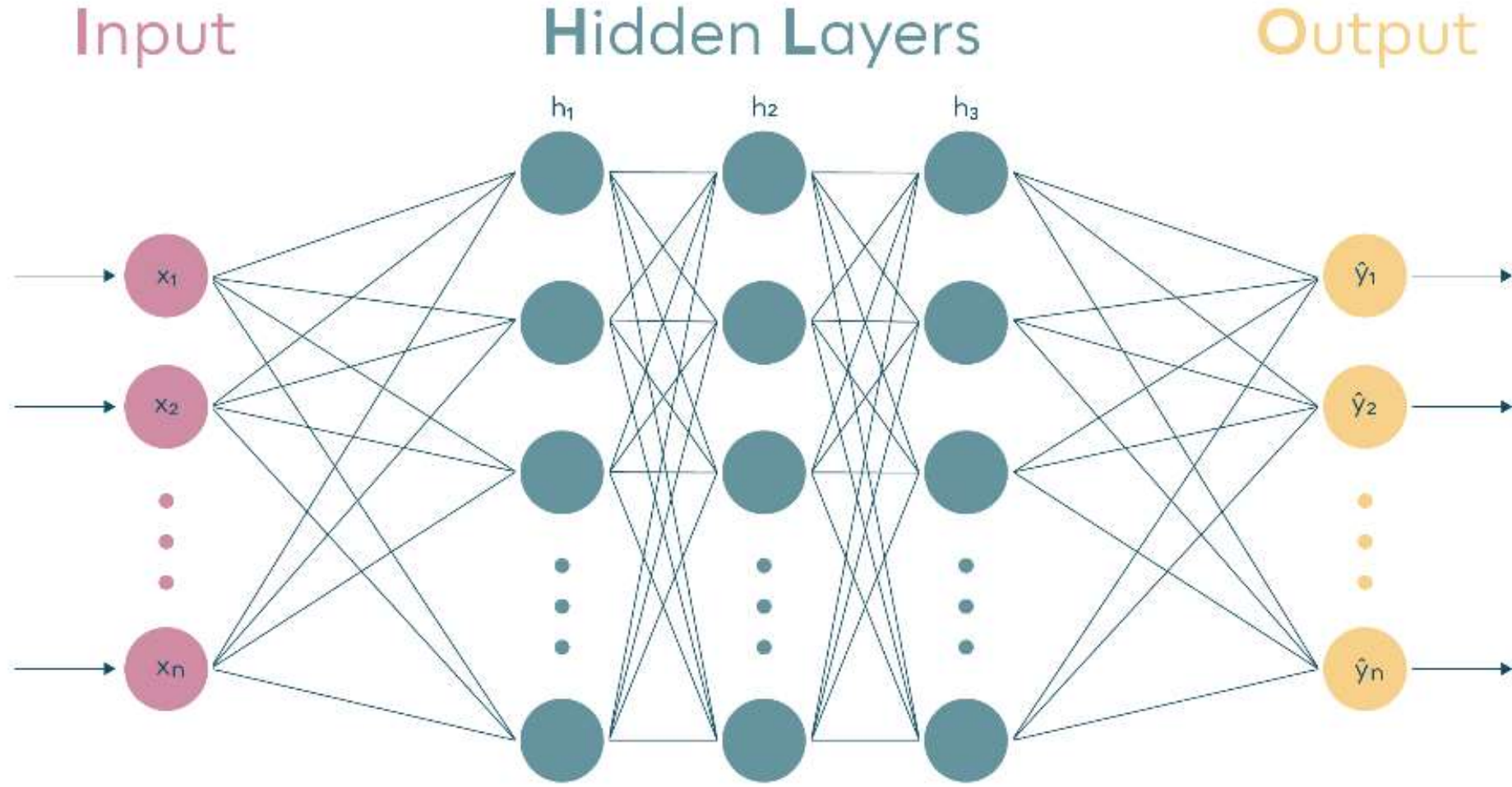
layout evaluation system

framework test

conclusion

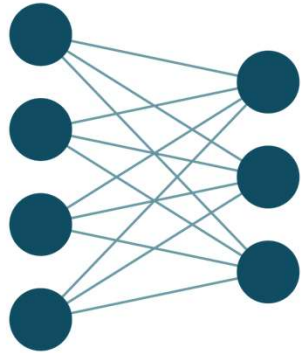
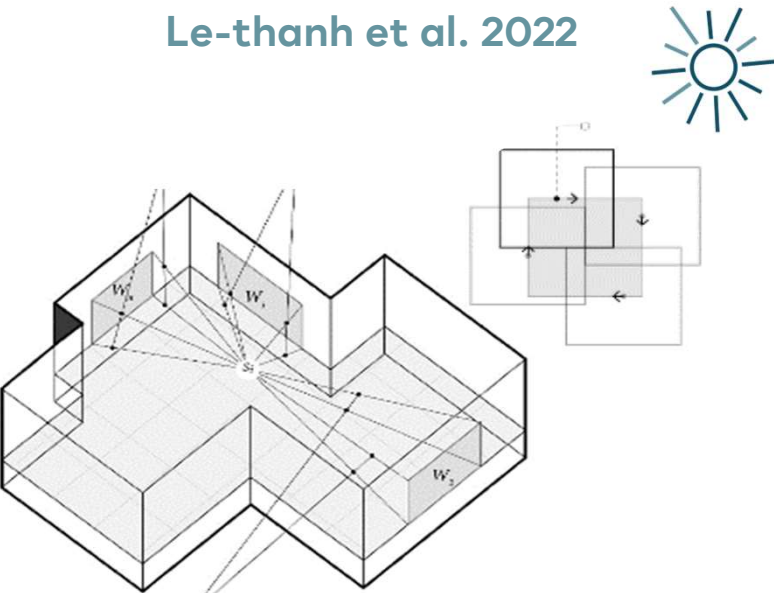
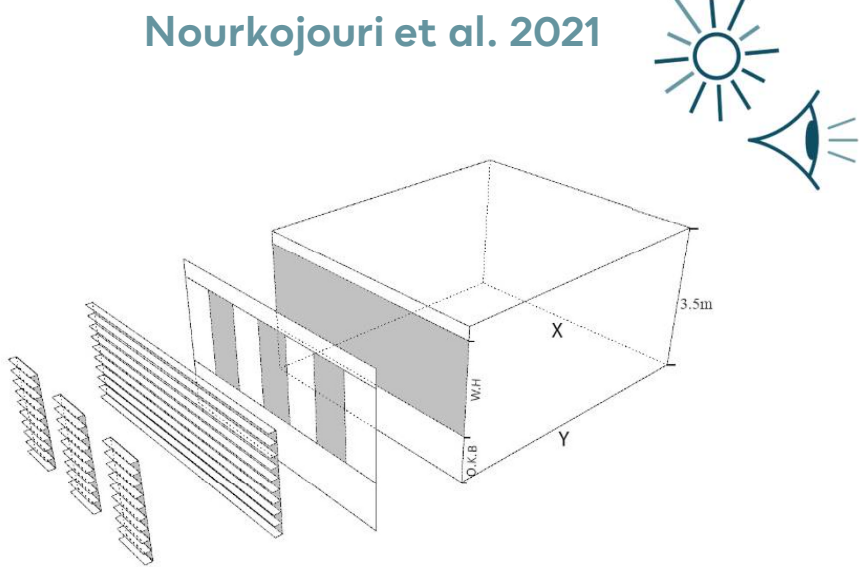
Neural networks

A definition



Relevant work ANN

Daylight & view predictions with numerical data

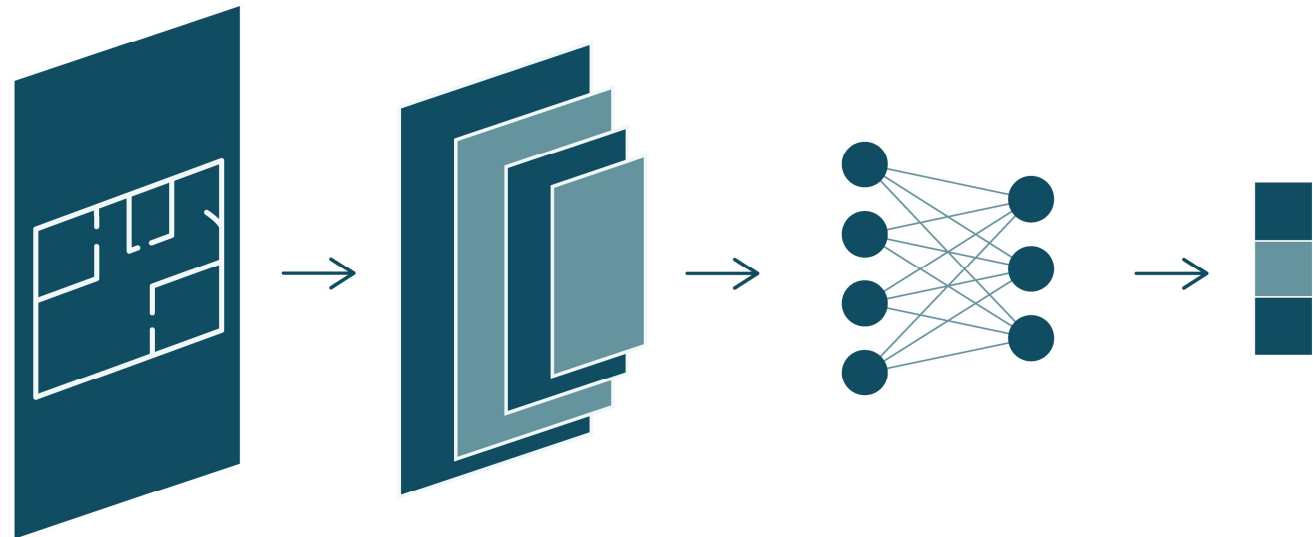


- Model: Artificial neural network (ANN)
- Labels: 3 daylight & 2 glare & 3 view
- Input: parametrically generated facade

- Model: Artificial neural network (ANN)
- Labels: 4 daylight
- Input: parametrically generated rooms

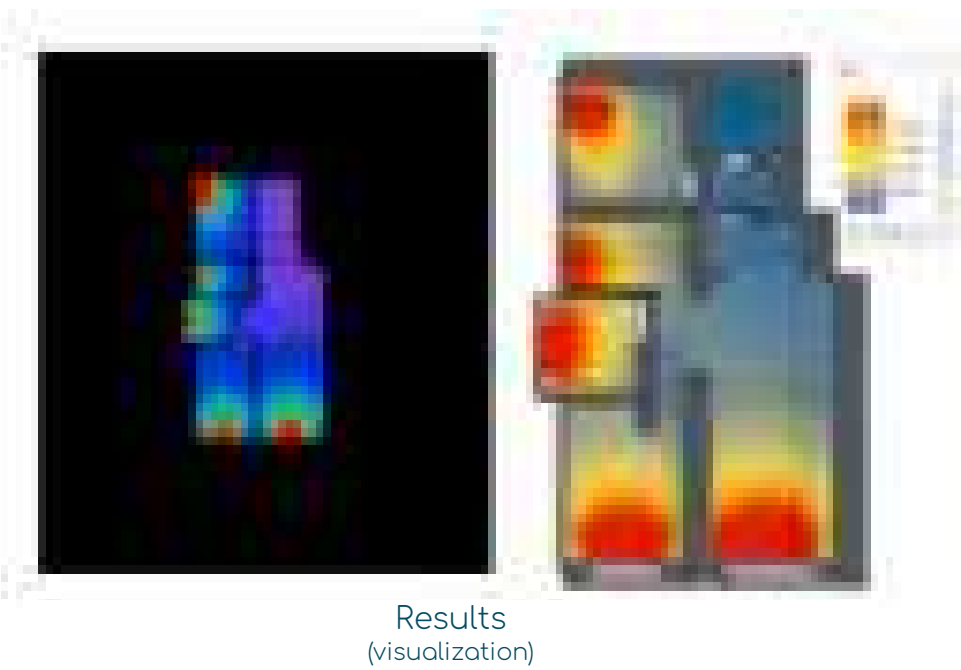
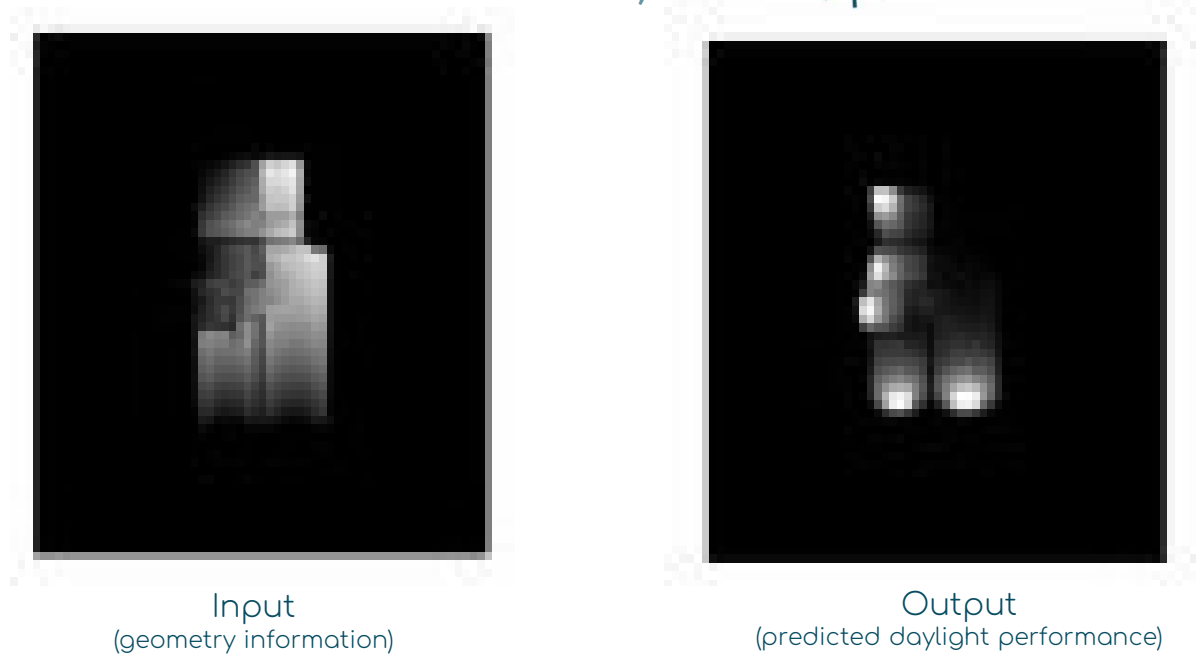
Relevant work convolutional neural network (CNN)

Daylight prediction with images



- Model: ResNet50 (CNN) and pix2pix (GAN)
- Labels: 2 daylight
- Input: real-world & generated layouts

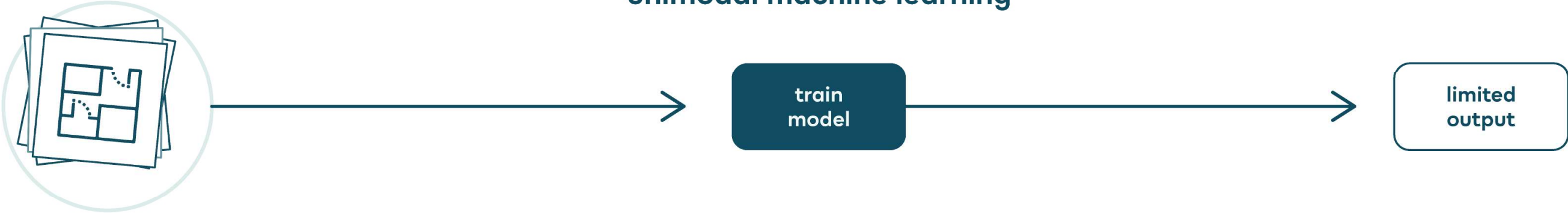
He et al., 2021 



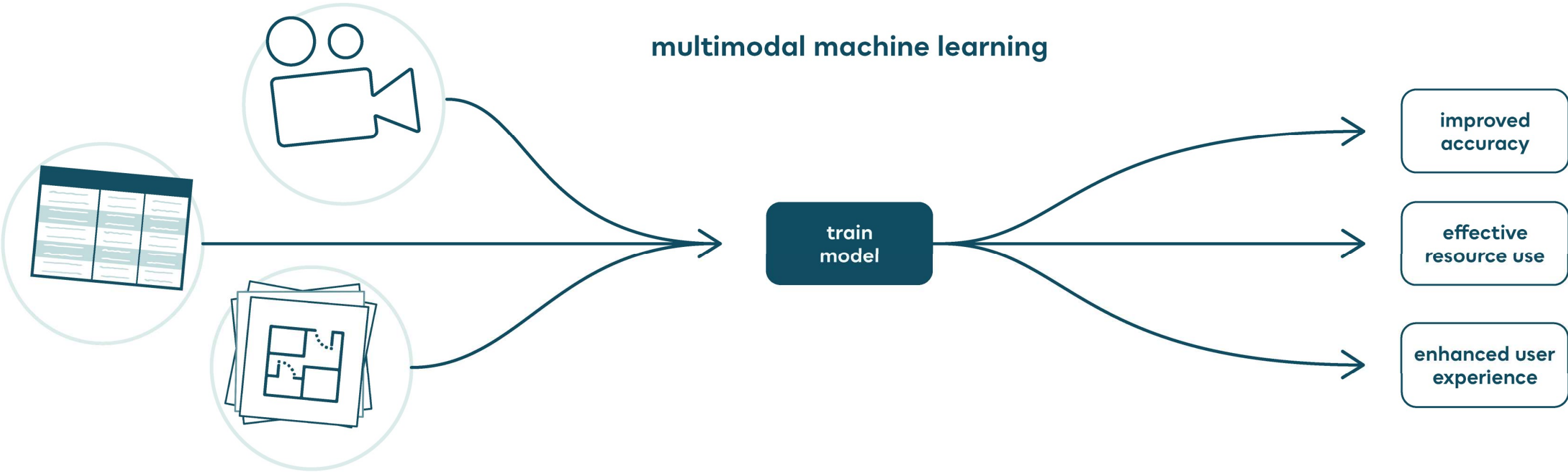
Multimodal learning

Combining different types of data streams

unimodal machine learning

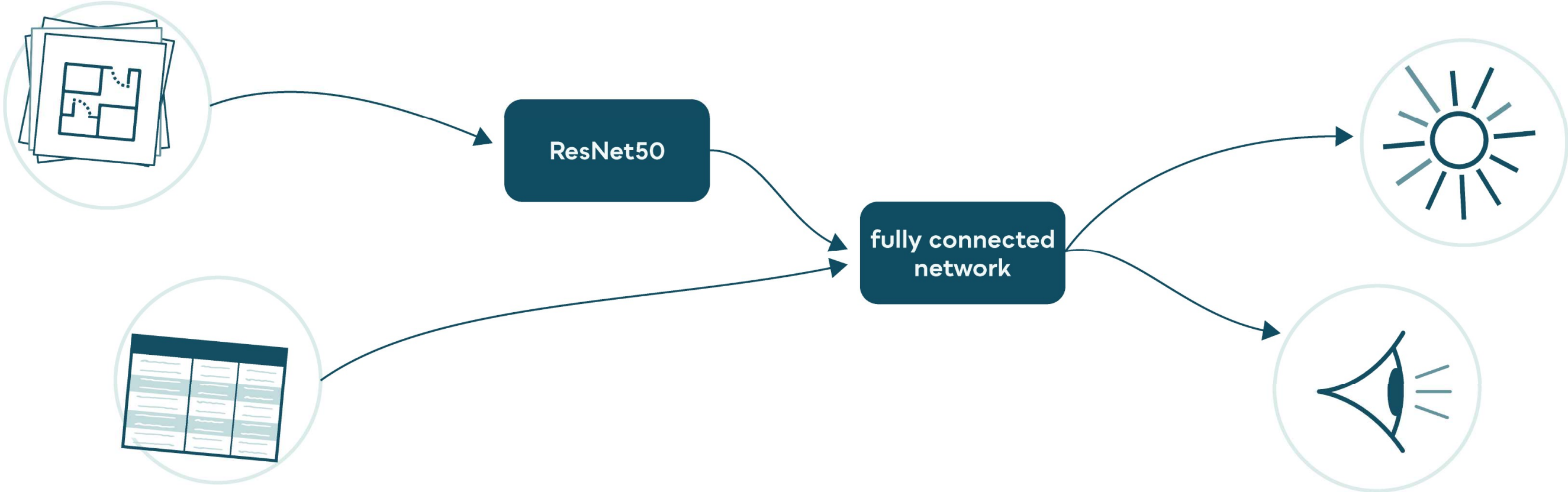


multimodal machine learning



Proposed ML model

Optimal use of data streams from dataset



background knowledge

research framework

machine learning

ML design process framework

“Swiss dwellings” dataset

labels & features

ML training & performance

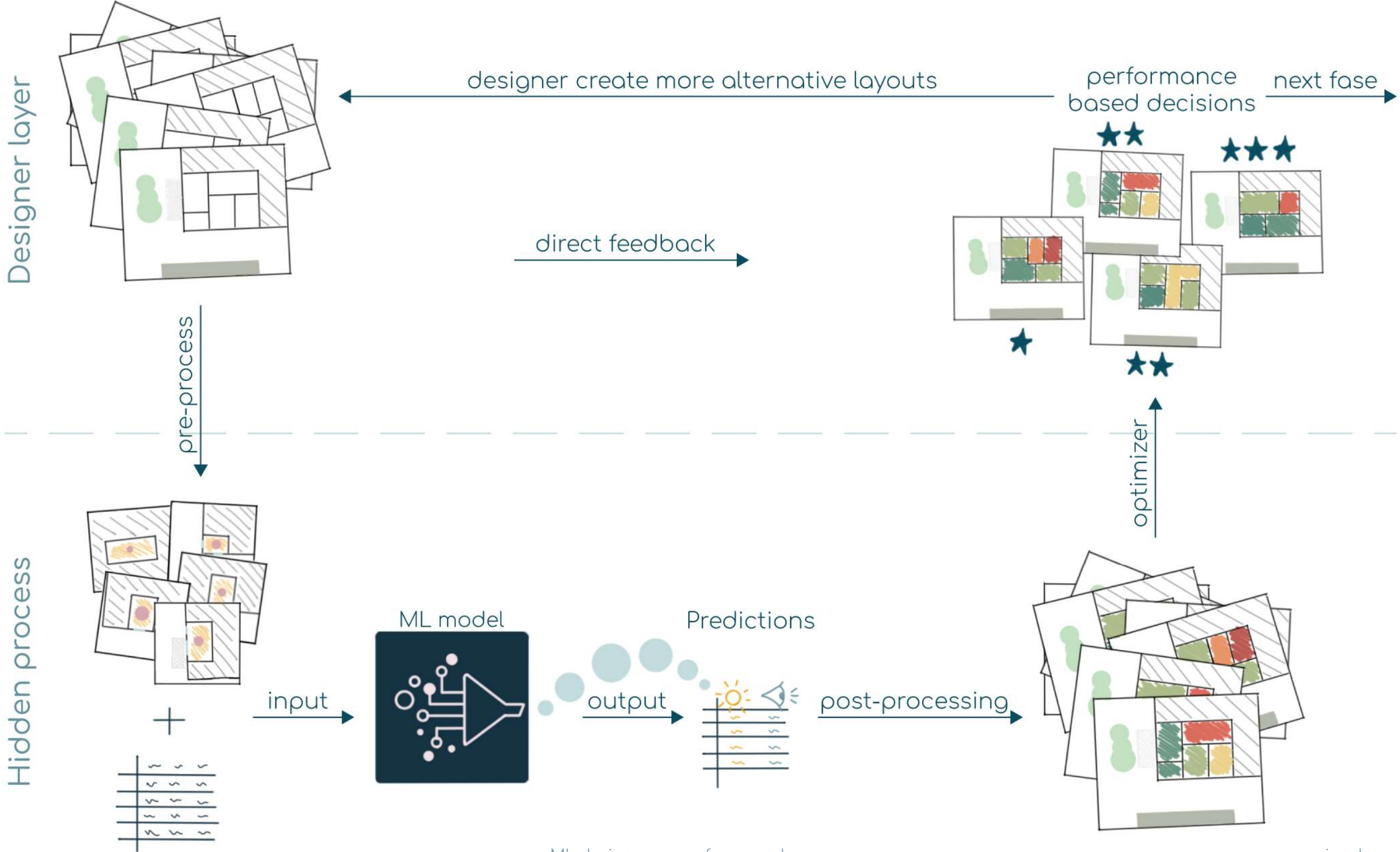
layout evaluation system

framework test

conclusion

ML design process framework

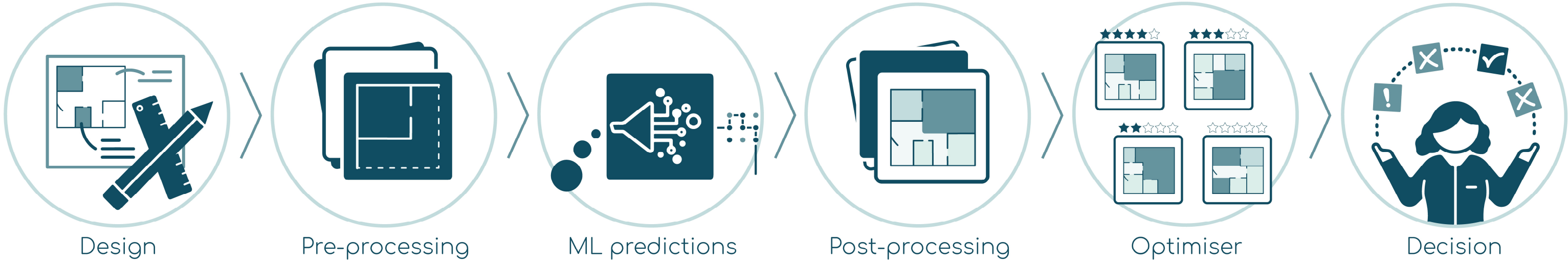
Guidance during design



ML design process framework

The implementation of ML in the design process

ML design process framework



background knowledge

research framework

machine learning

ML design process framework

“Swiss dwellings” dataset

labels & features

ML training & performance

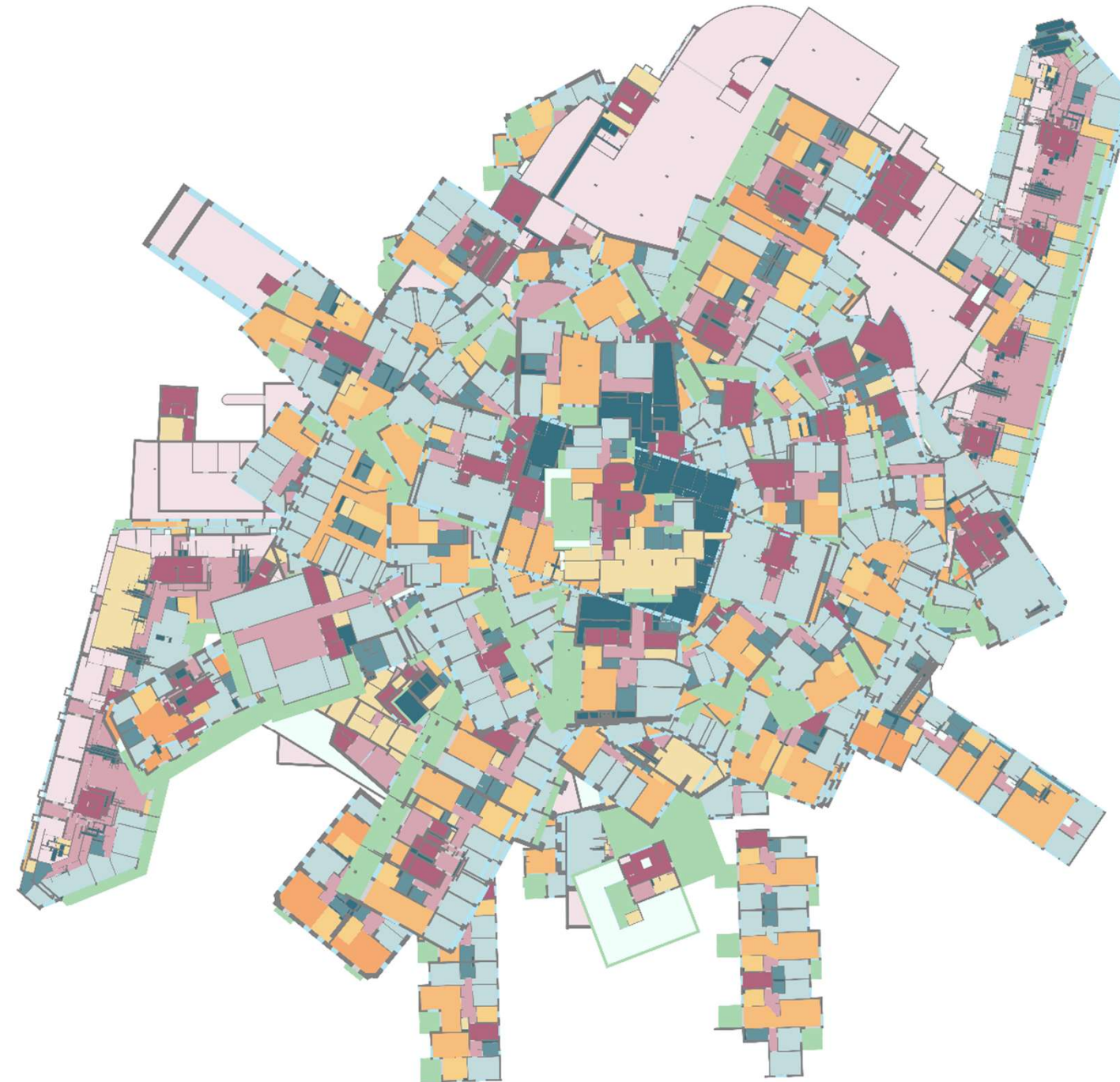
layout evaluation system

framework test

conclusion

“Swiss dwellings” dataset

An overview



"Swiss dwellings" dataset

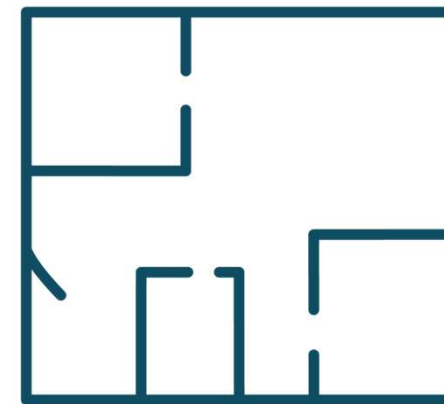
The clean numbers



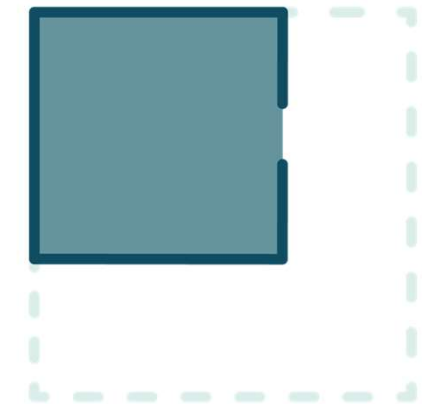
1,287 sites



2,551 buildings



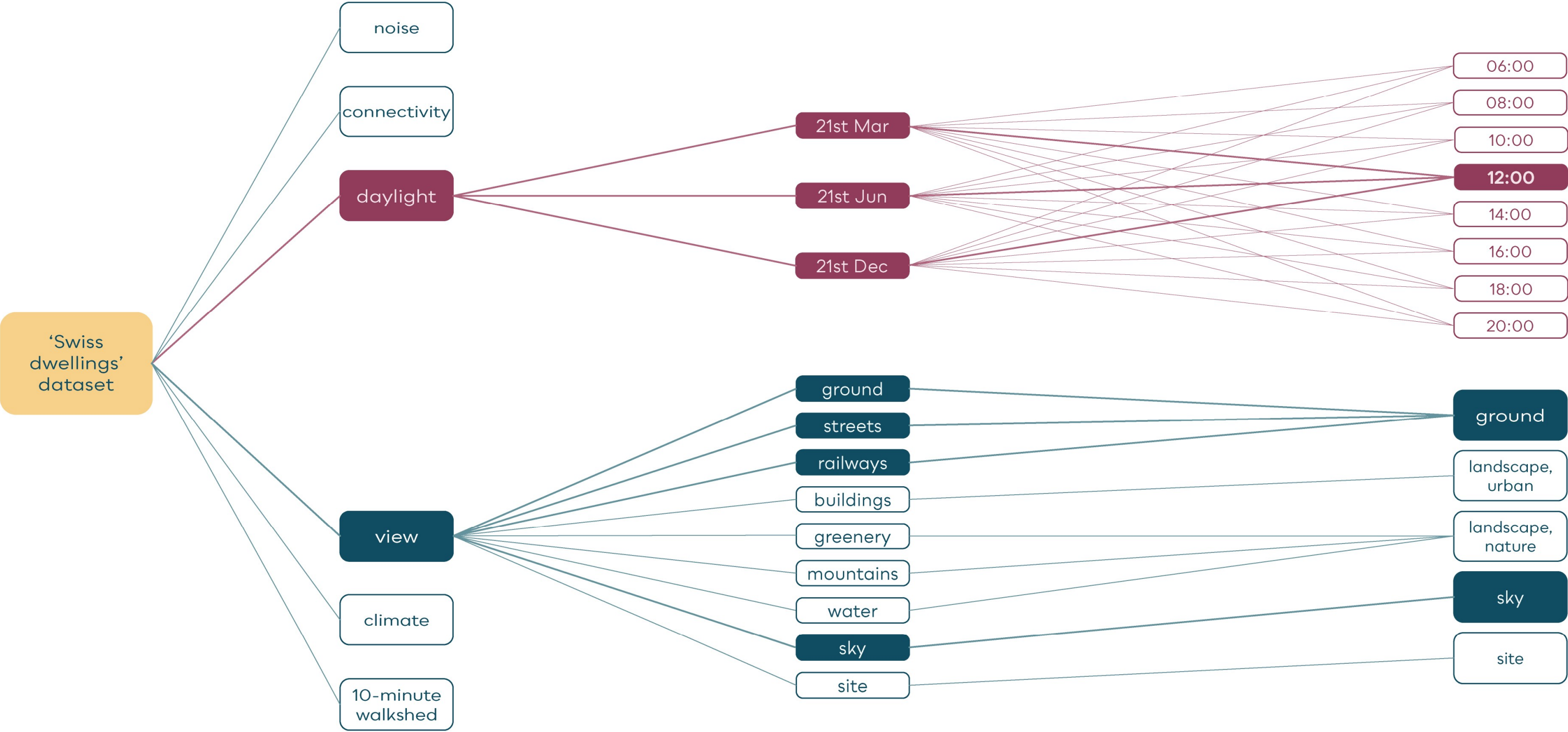
34,757 apartments



138,922 rooms

Simulation data

An overview & the focus



background knowledge

research framework

machine learning

ML design process framework

“Swiss dwellings” dataset

labels & features

ML training & performance

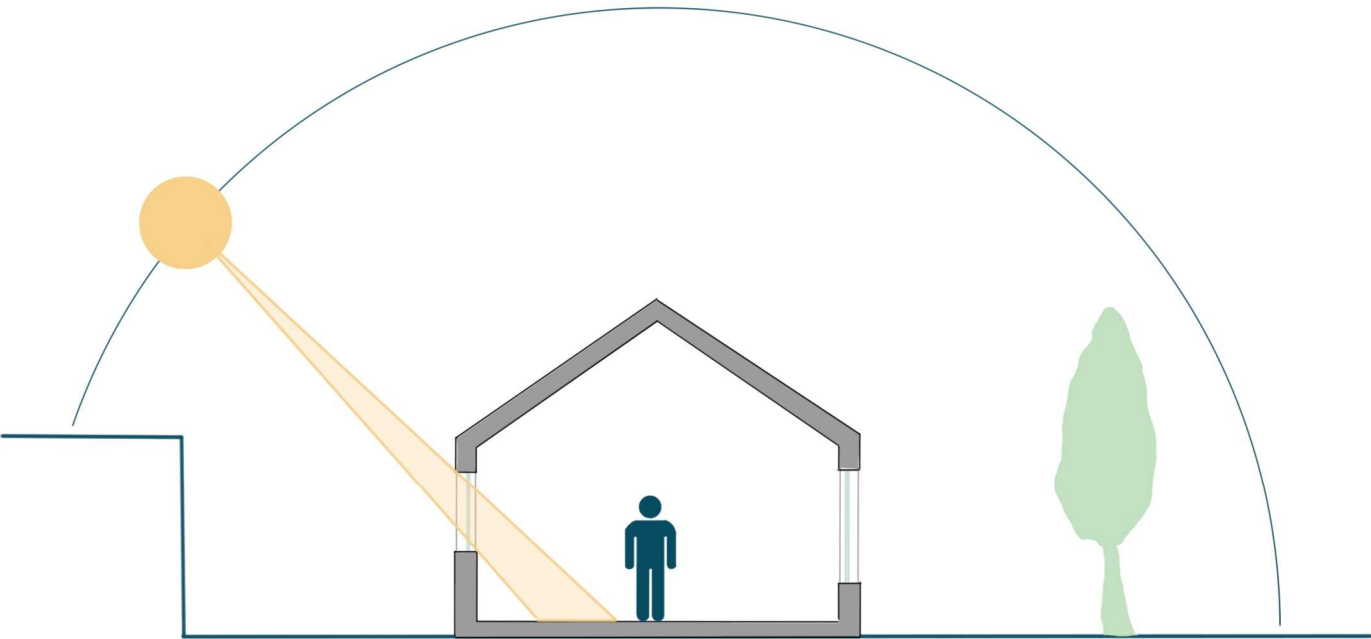
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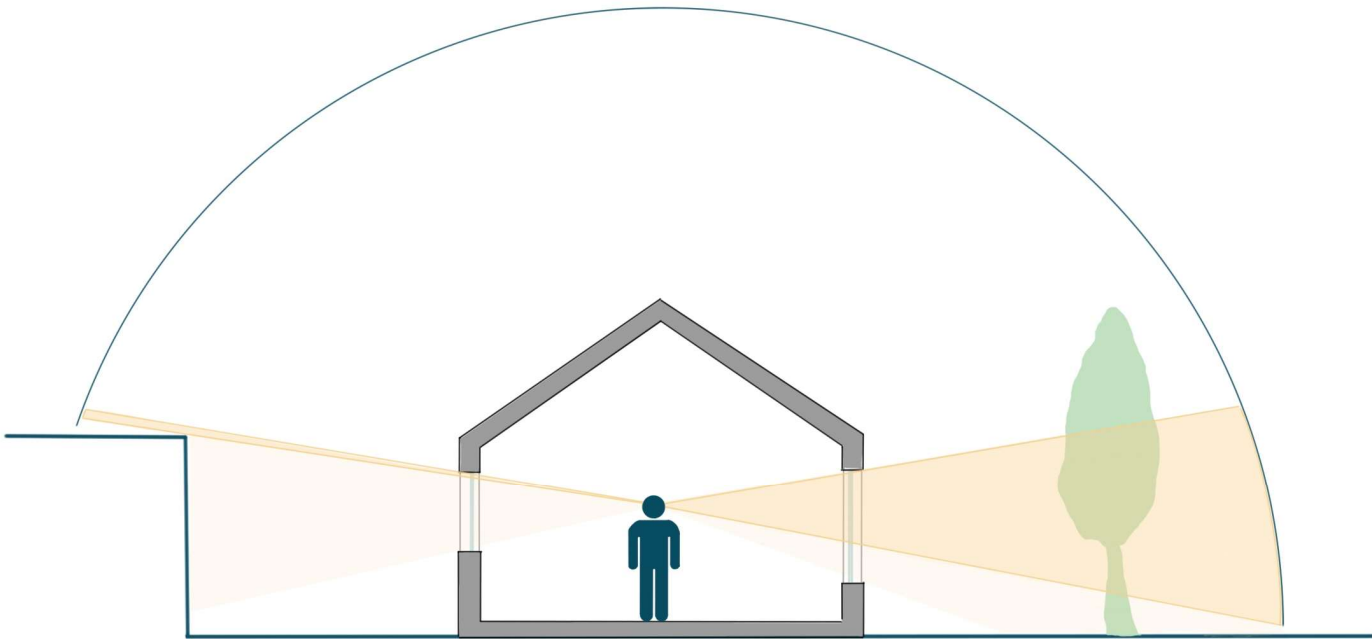
Labels

3 daylight & 2 view labels



Daylight

21st March, June & December at 12:00
(median)



View

to ground & sky
(80th percentile)

Features

A summarized overview

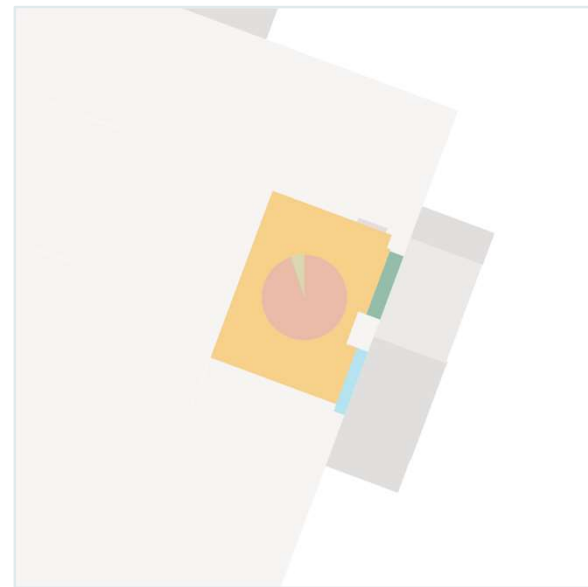
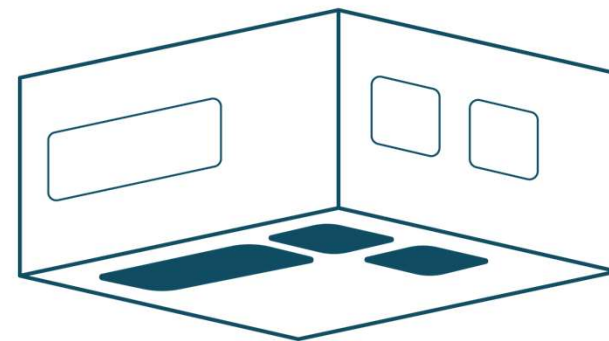
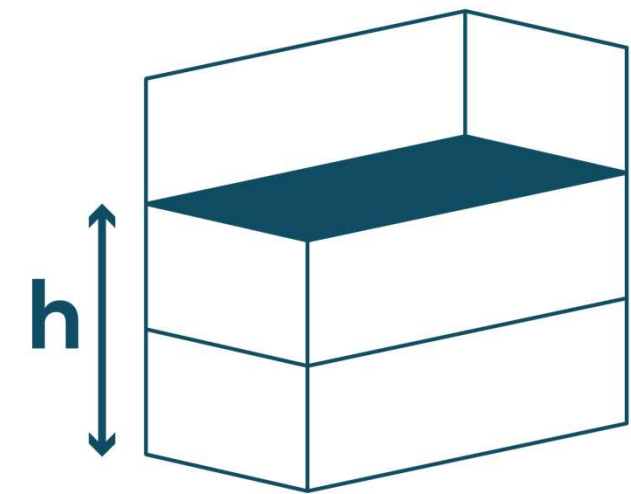


Image feature per room



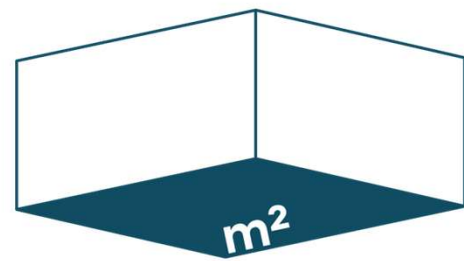
Window to floor ratio



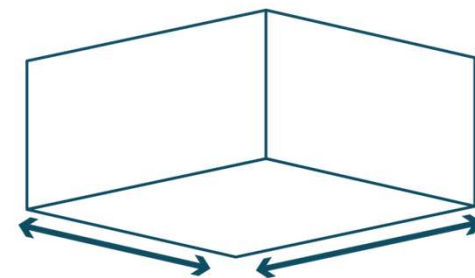
Room elevation

Features

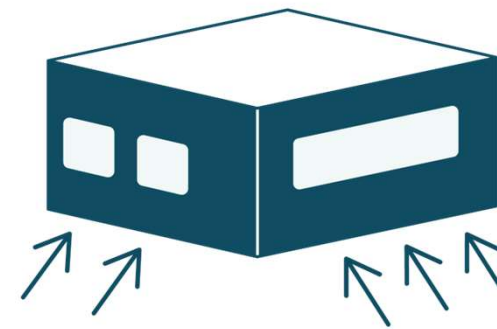
A complete overview



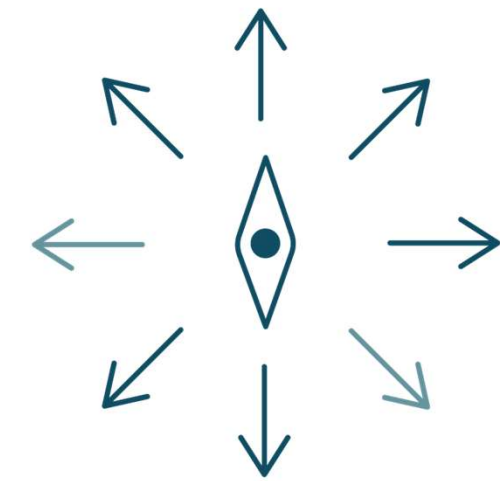
Room area



Depth to width ratio



Window distribution



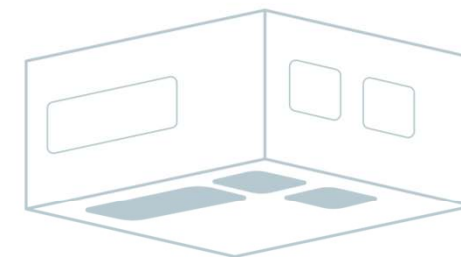
Room orientation



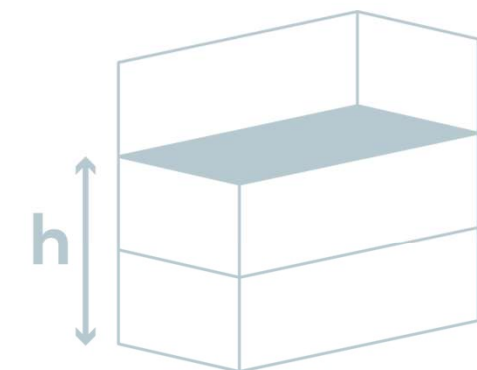
Environmental obstructions



Site obstructions



Window to floor ratio



Elevation

background knowledge

research framework

machine learning

ML design process framework

“Swiss dwellings” dataset

labels & features

ML training & performance

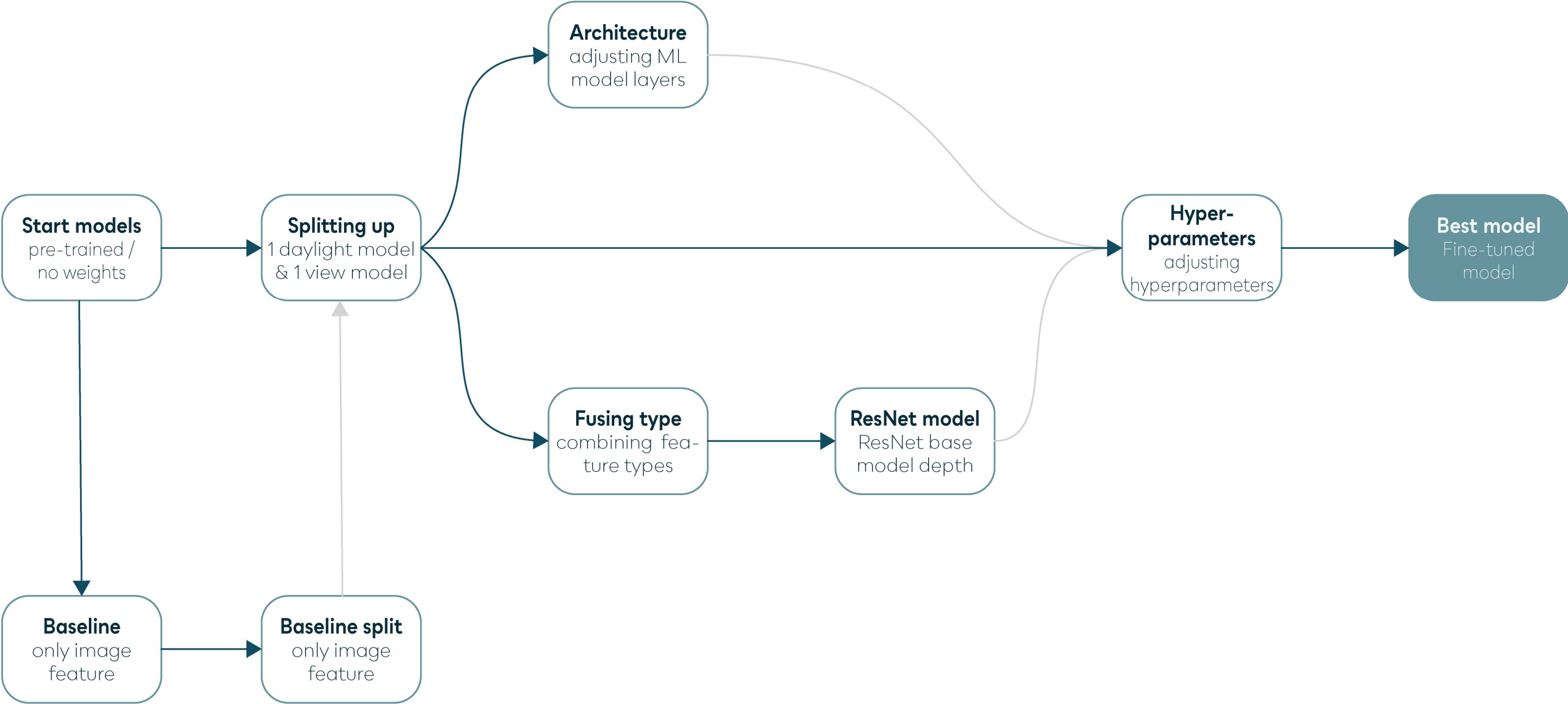
layout evaluation system

framework test

conclusion

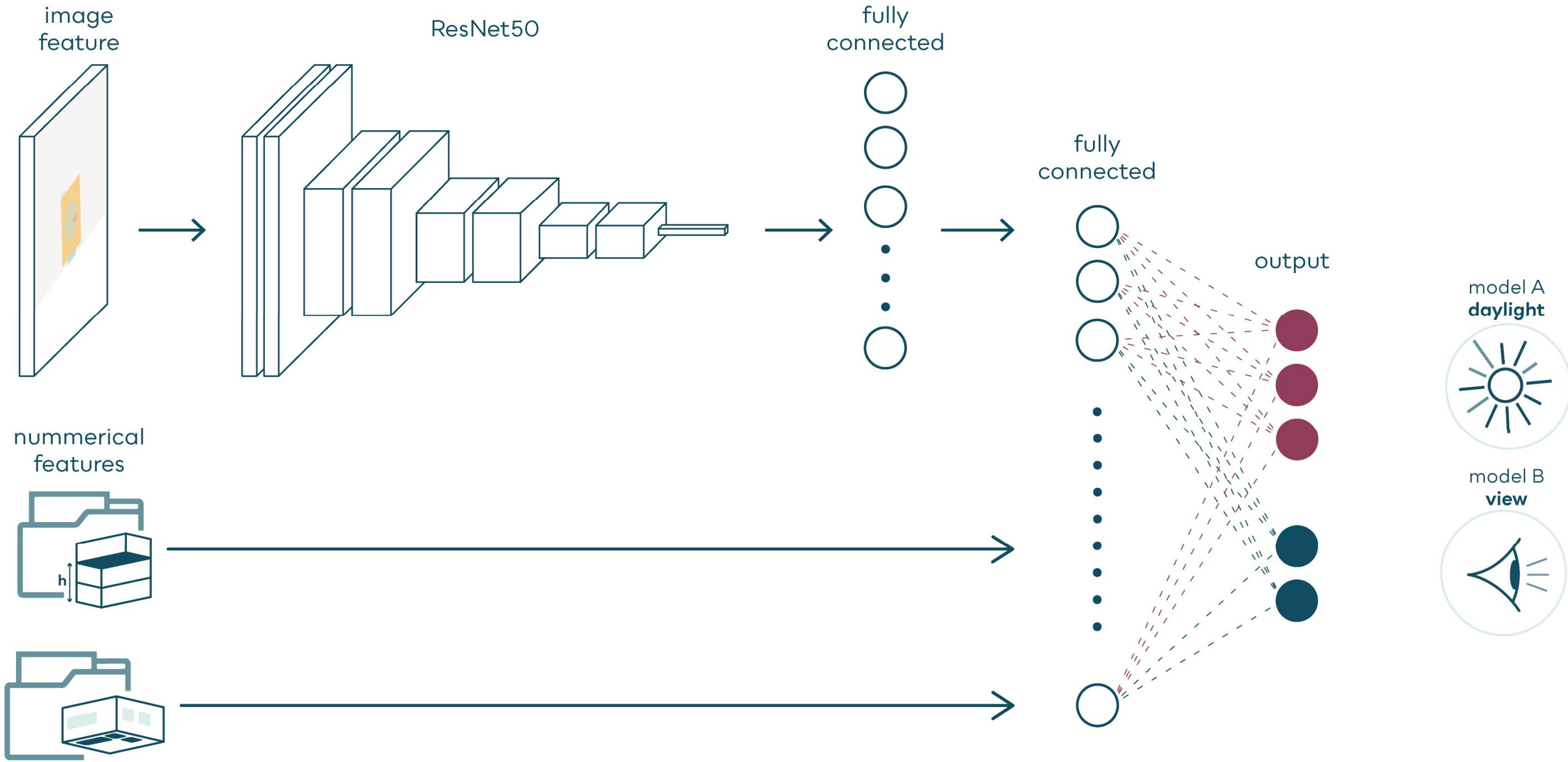
ML model experiments

Ablation studies



ML model architecture

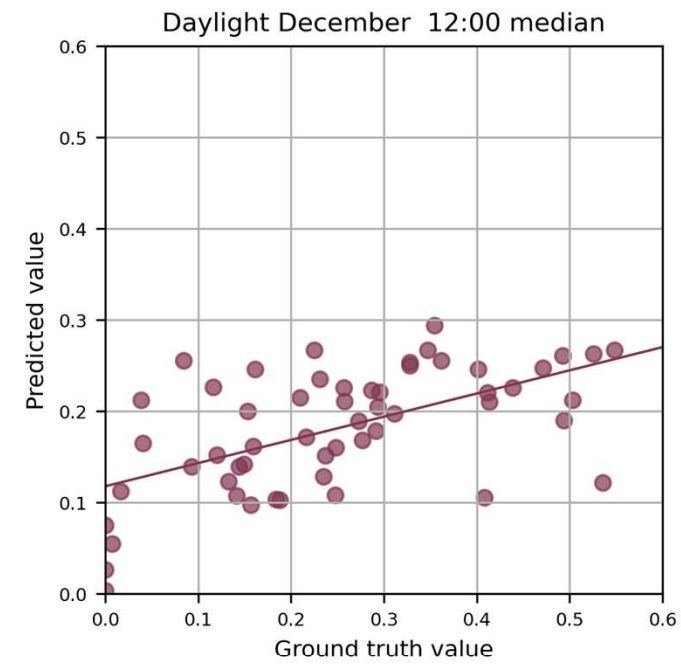
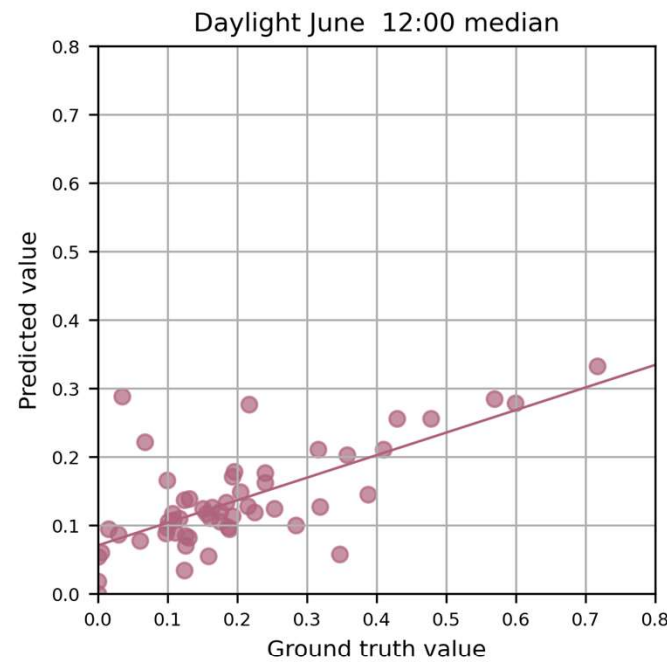
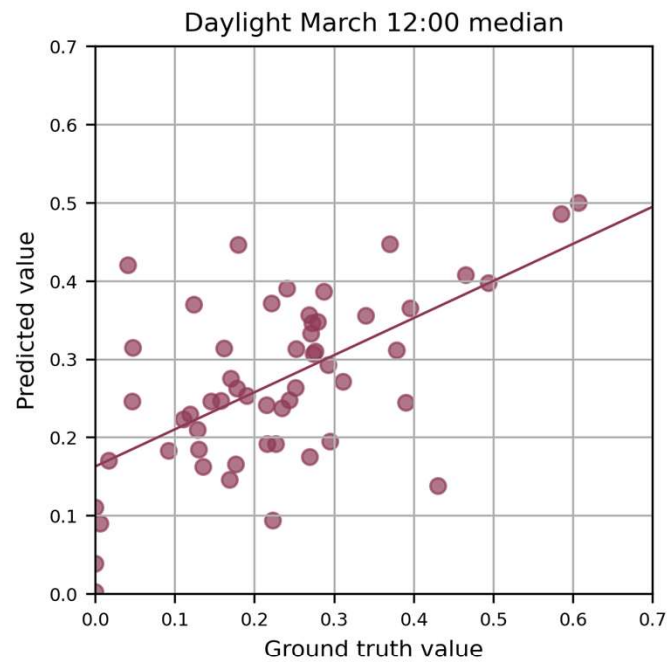
Multimodal learning: CNN + ANN



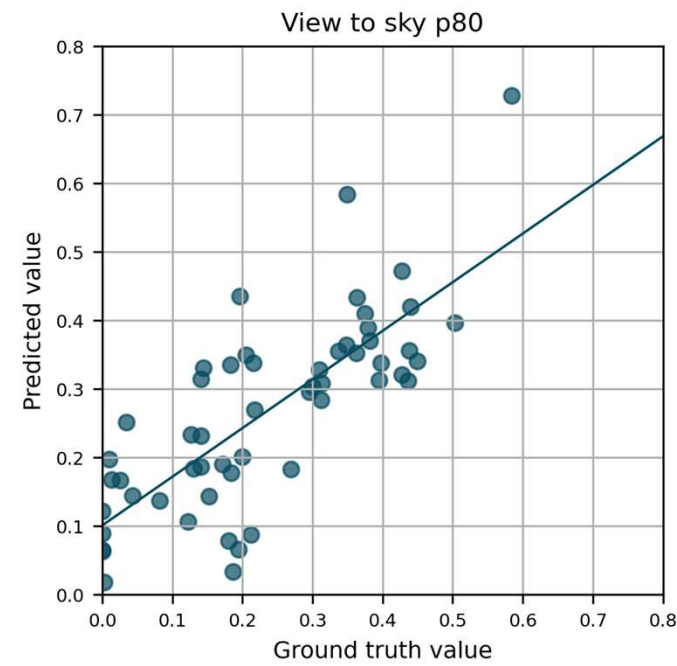
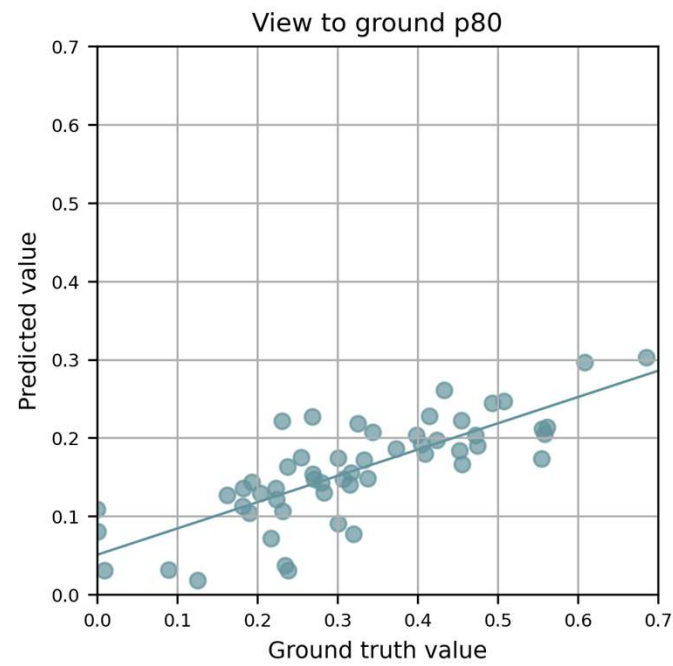
Predictions

Daylight and view value predictions

12 general apartments - daylight predictions - Model7.5A



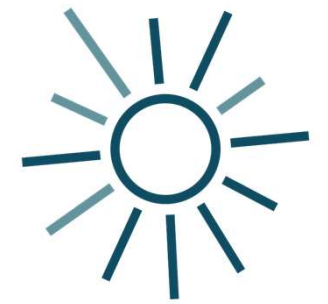
Daylight
Training MSE = 0.0008
Test MSE = 0.0047



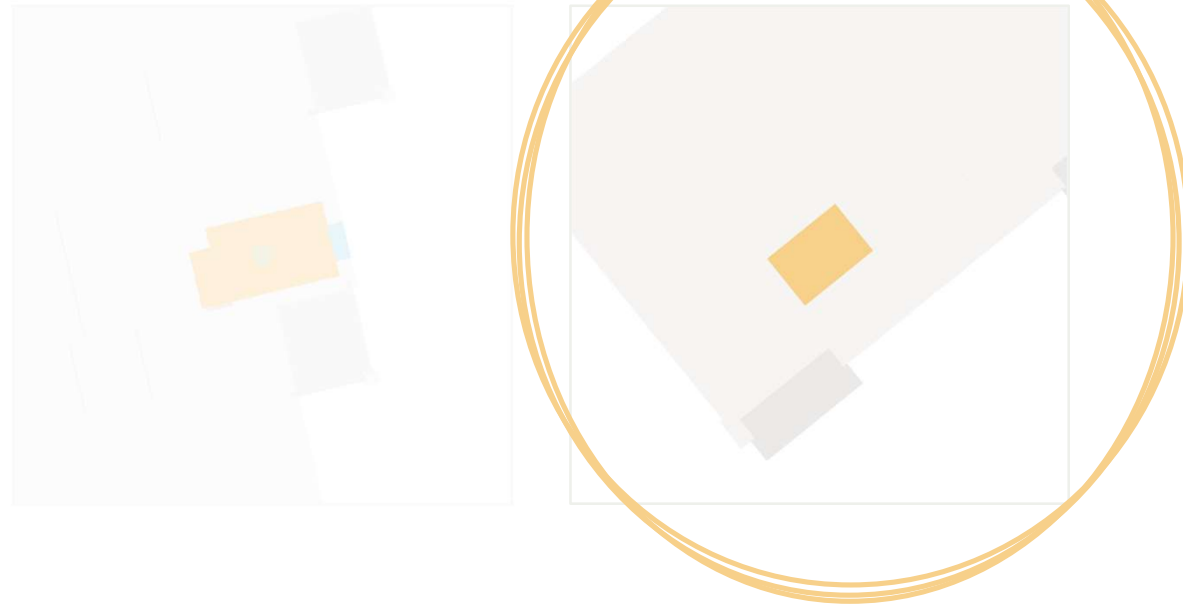
View
Training MSE = 0.0012
Test MSE = 0.0057

Daylight prediction evaluation

Room types that are over- and underpredicted



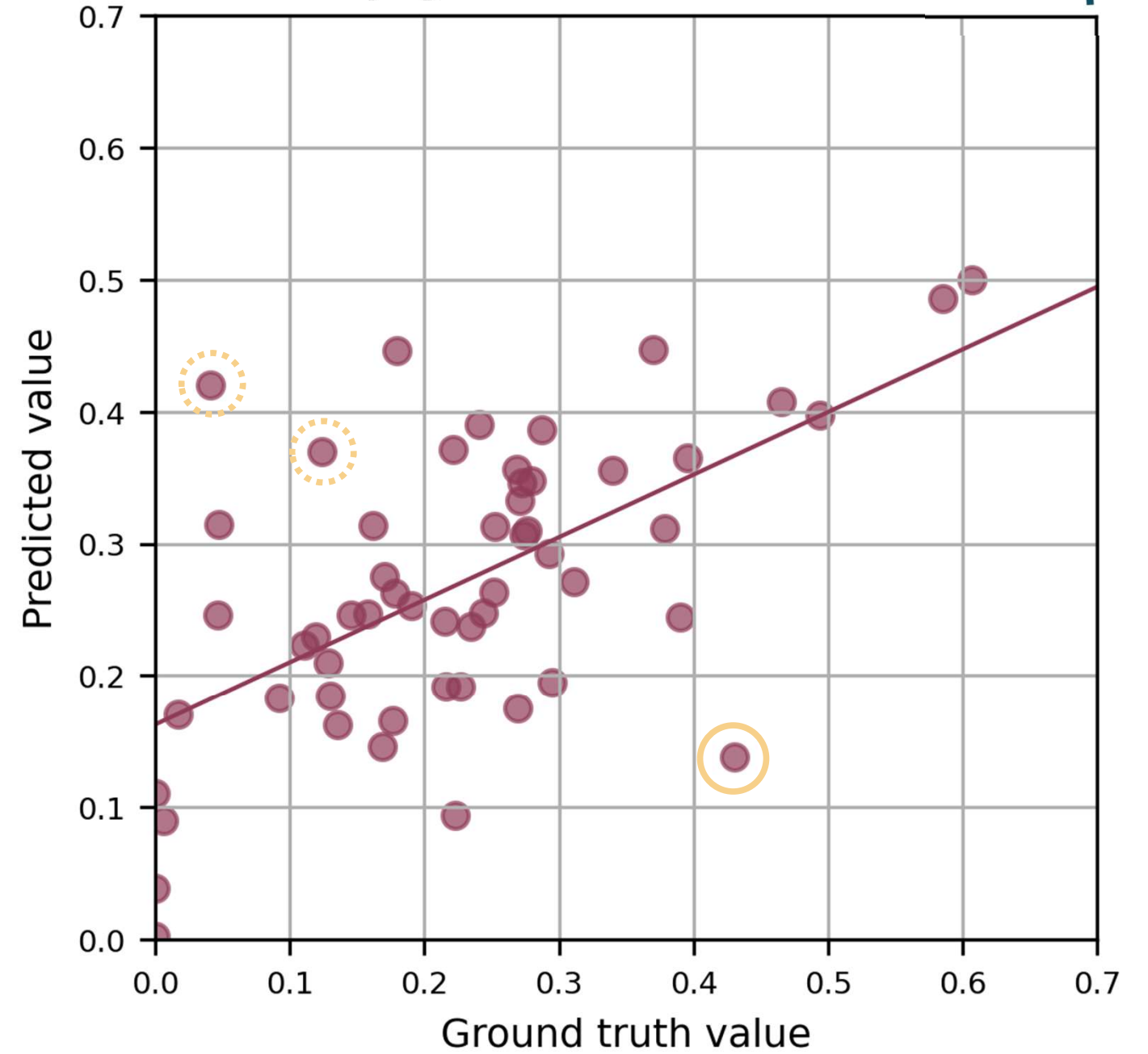
Underprediction rooms



Overprediction rooms



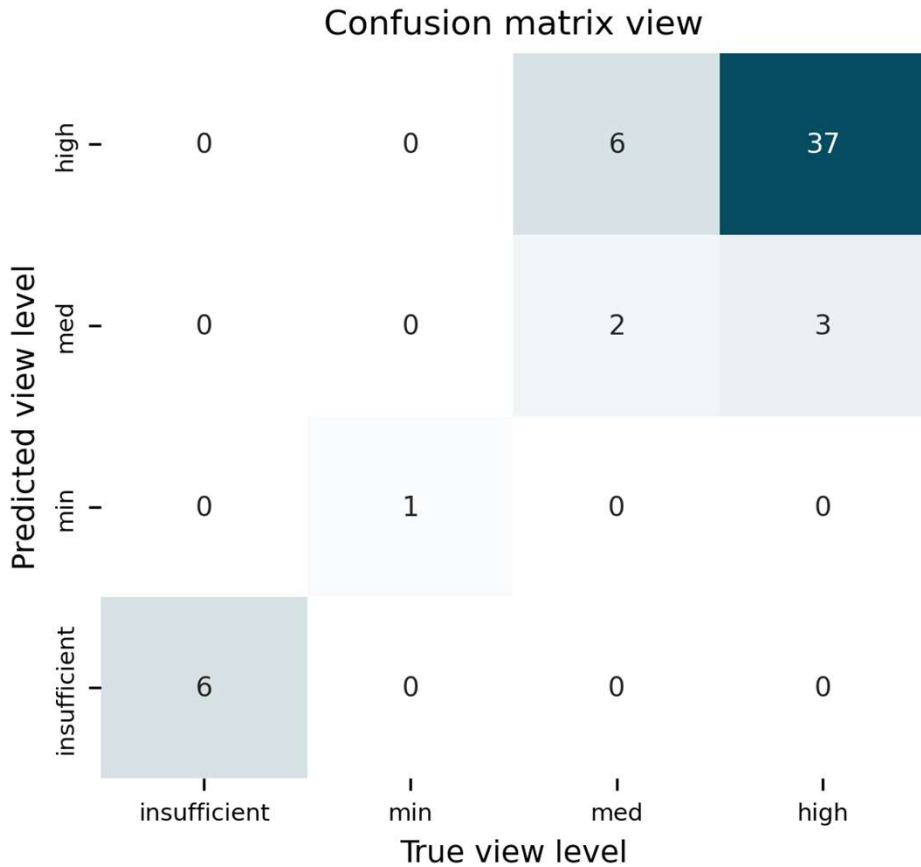
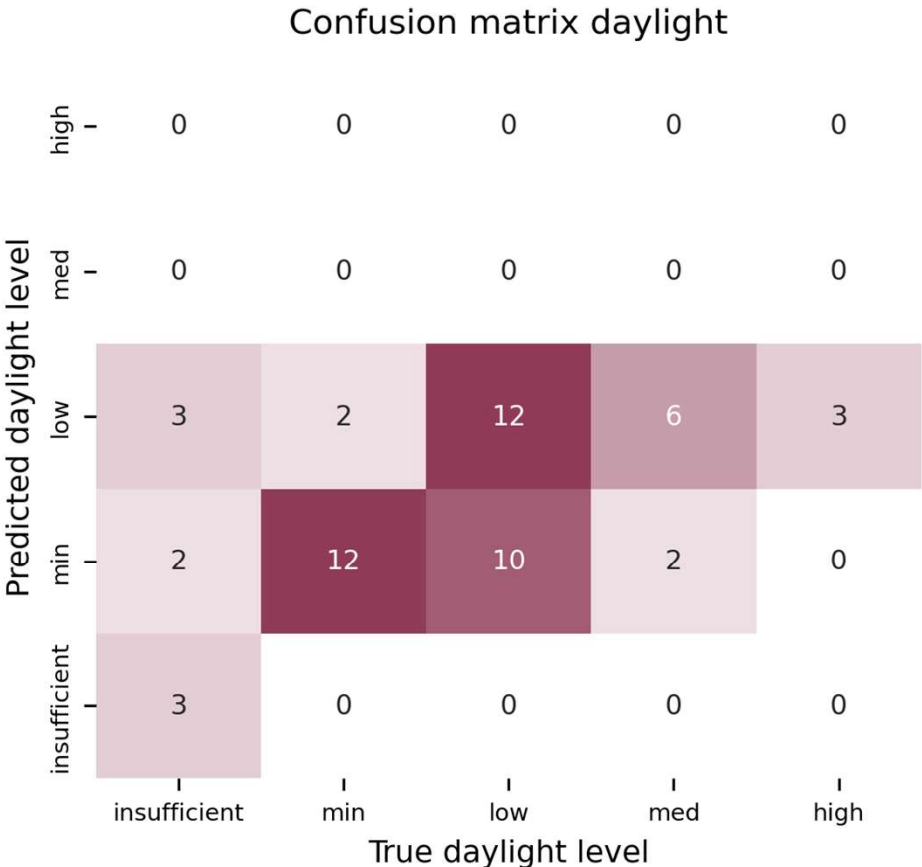
Daylight March 12:00 median



Performance translation

of the daylight and view value predictions

12 general apartments - confusion matrix - Model7.5A & Model7.5B



background knowledge

research framework

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ML design process framework

“Swiss dwellings” dataset

labels & features

ML training & performance

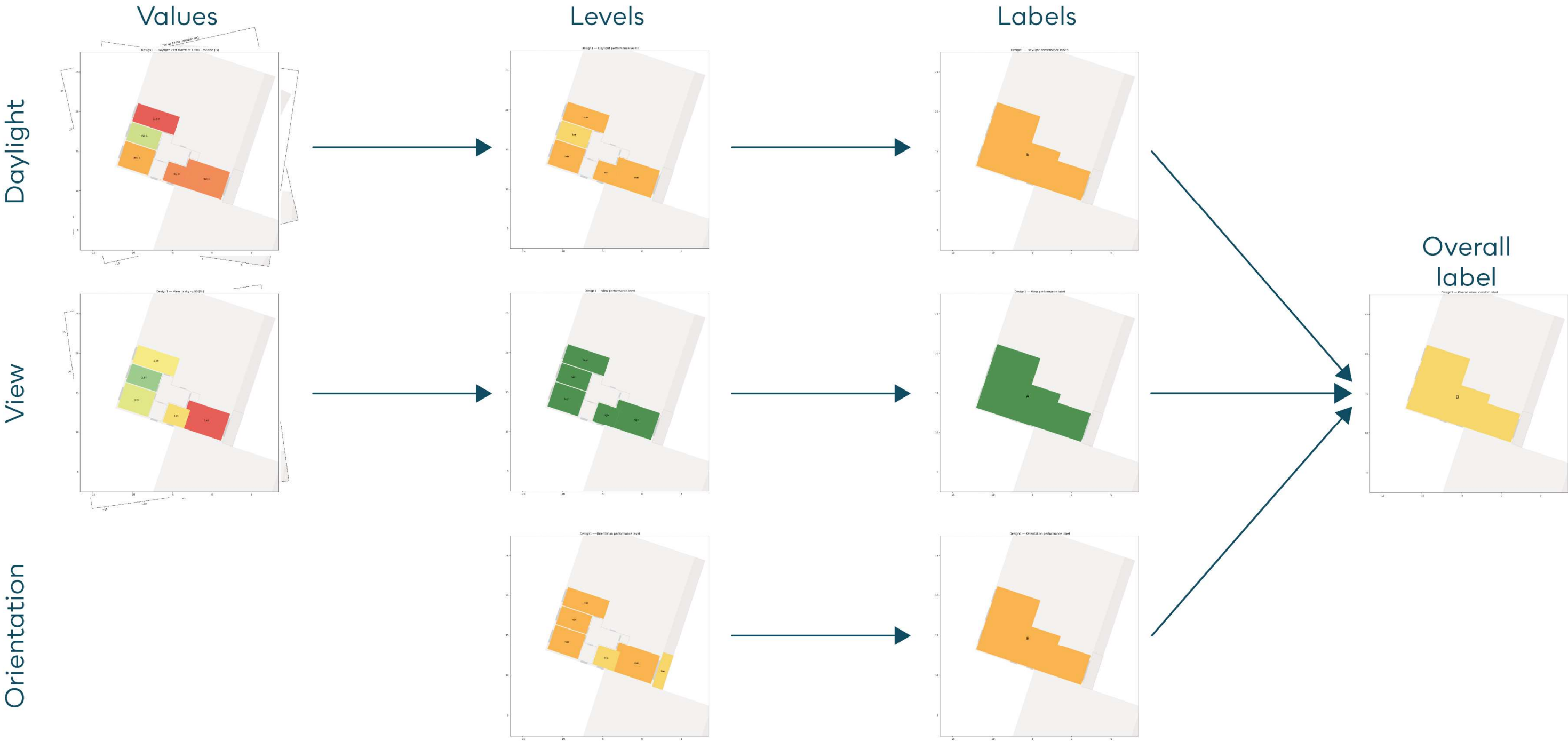
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Layout evaluation system

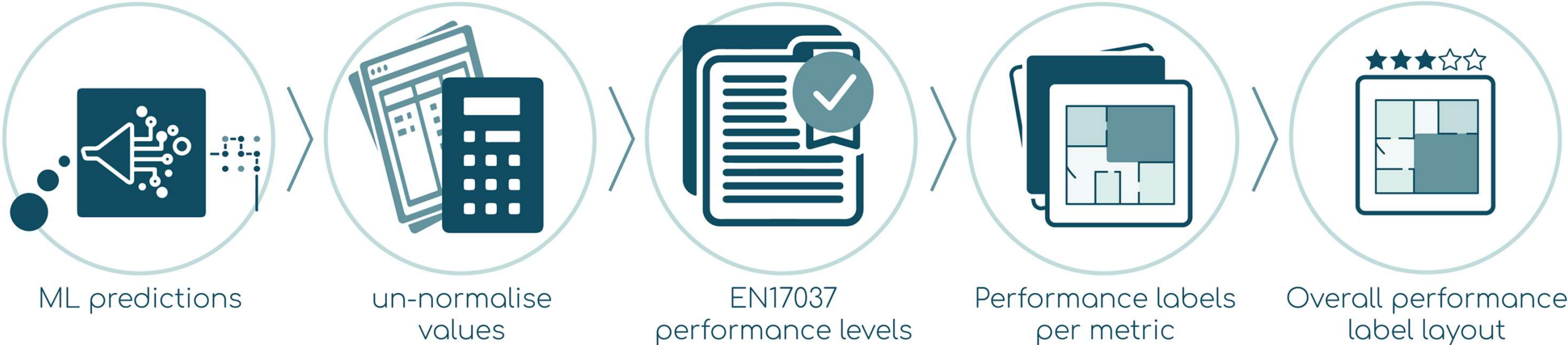
Quantifying the visual comfort of a layout



Layout evaluation system

Simplified steps

steps layout evaluation system



Unnormalising values

Normalised daylight predictions to illuminance values



21st of March, June & December

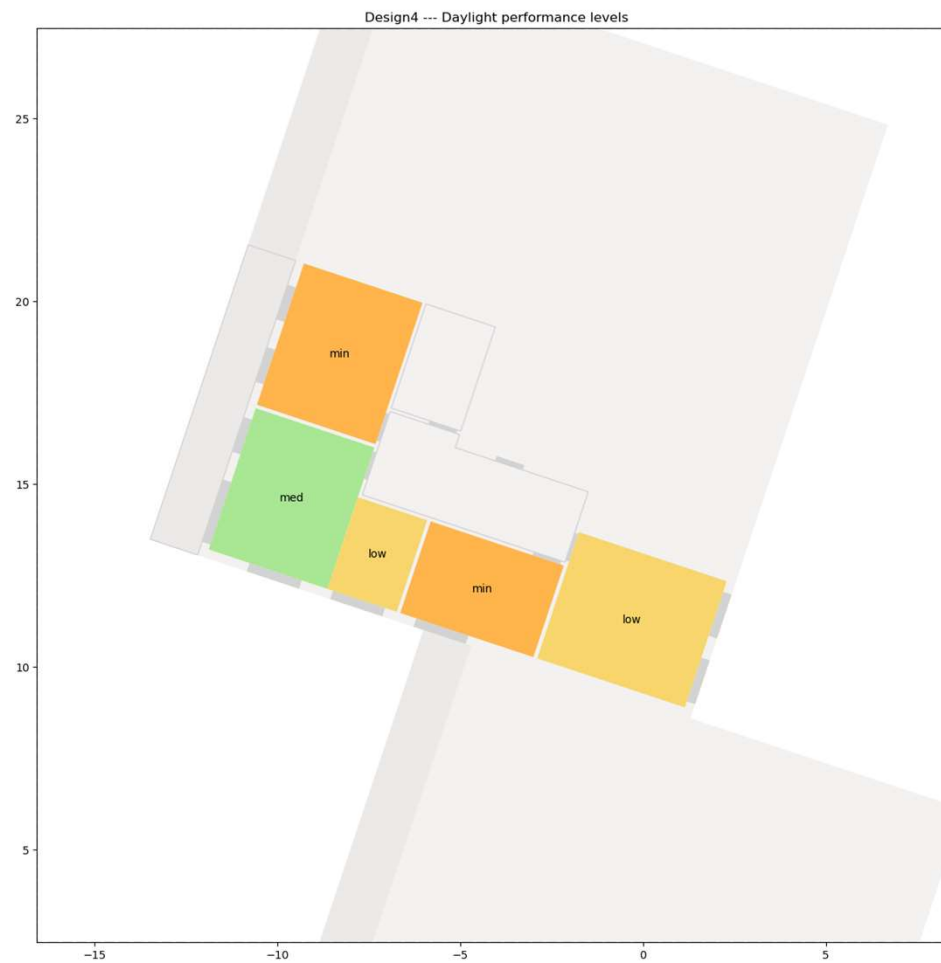
Daylight level	Target illuminance*
Insufficient	lux < min threshold
Minimum	bedroom/room: 100 lx, living room: 150 lx, kitchen: 200 lx
Low	300 lx
Medium	500 lx
High	750 lx

* For 50% of the space

Daylight apartment evaluation

Determine performance level

Find the EN17037 daylight performance level per room



Daylight performance levels

Daylight level	Target illuminance*
Insufficient	lux < min threshold
Minimum	bedroom/room: 100 lx, living room: 150 lx, kitchen: 200 lx
Low	300 lx
Medium	500 lx
High	750 lx

* For 50% of the space

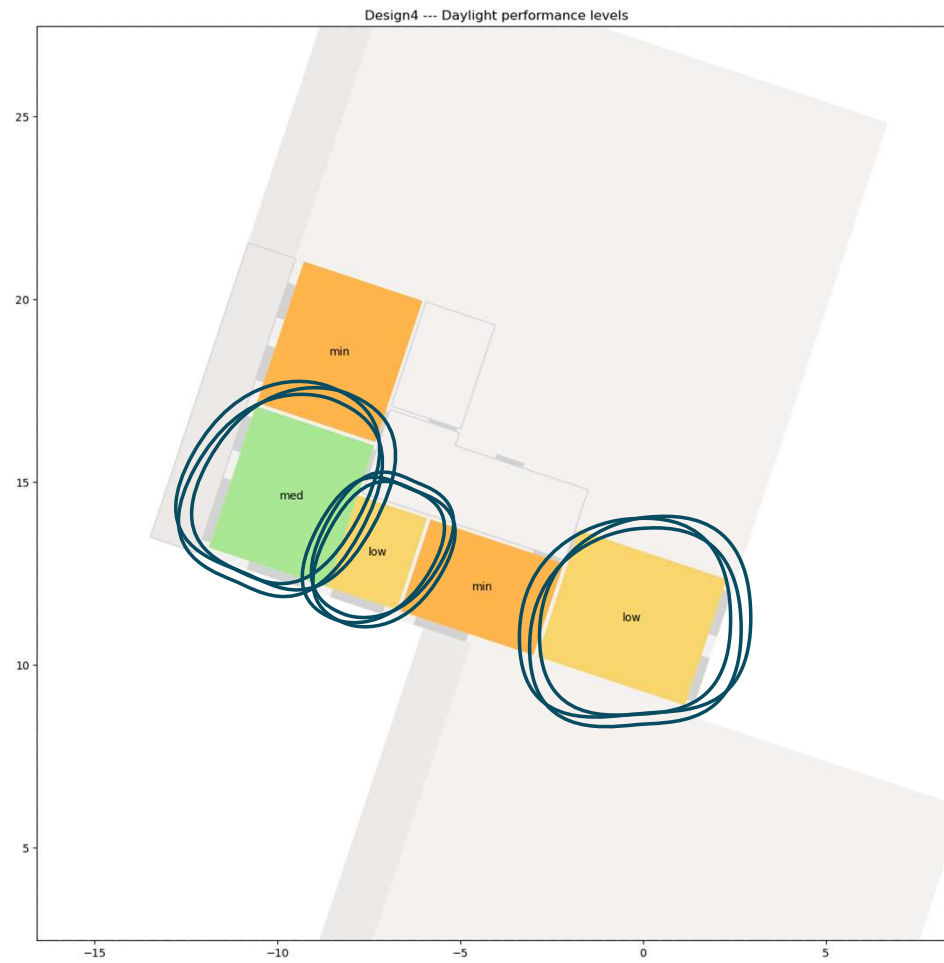
Daylight apartment evaluation

Daylight performance label

Determine performance label of layout



Min
Low
Med
High



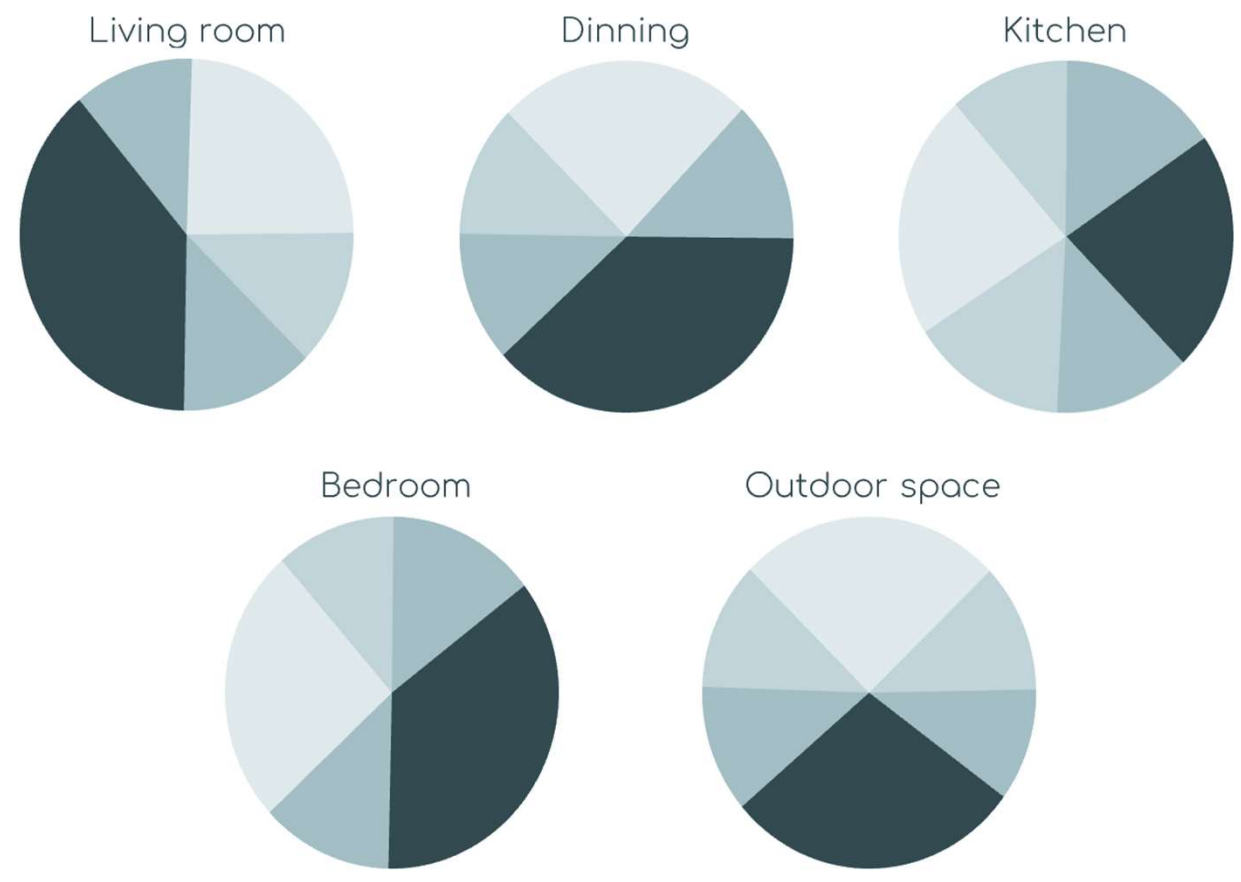
Daylight level

Daylight label	Room with the lowest daylight level	View level for 50% of the living spaces
F	Insufficient	-
E	Minimum	-
D	Minimum	Low
C	Low	Medium
B	Medium	High
A	High	-

Daylight apartment evaluation

Orientation performance level

Find orientation performance per room



Orientation room requirements per room type

Orientation label	Room with the lowest orientation level	Orientation level for 50% of the living spaces
E	Minimum	-
D	Minimum	Low
C	Low	Medium
B	Medium	High
A	High	-

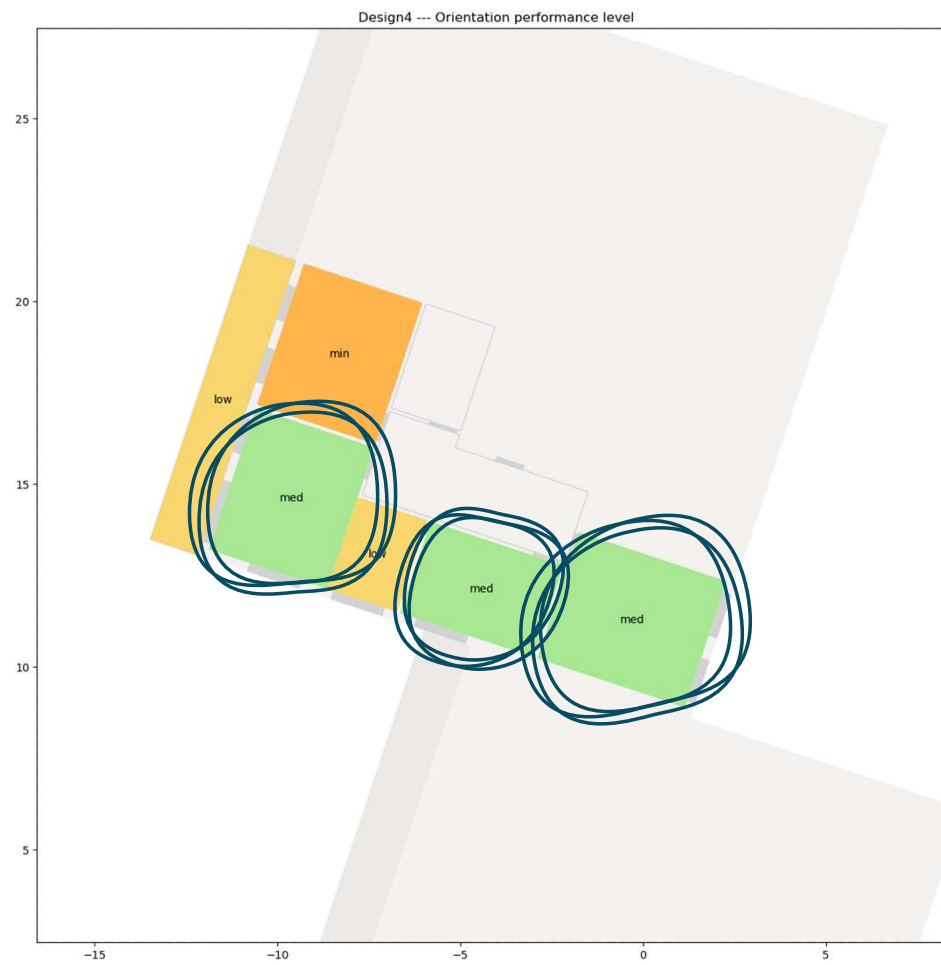
Orientation apartment evaluation

Orientation performance label

Determine performance label of layout



Min
Low
Med
High



Orientation room requirements per room type

Orientation label	Room with the lowest orientation level	Orientation level for 50% of the living spaces
E	Minimum	-
D	Minimum	Low
C	Minimum	Medium
B	Minimum	High
A	High	-

Orientation apartment evaluation

Overall visual comfort performance label

Determine overall performance label of layout



$$y_{overall} = \frac{0.4 + 0.75 + 0.6}{3} * 1 = 0.58$$

Category label	Daylight x_{day}	View x_{view}	Orientation x_{orient}
A	1	1	1
B	0.8	0.75	0.8
C	0.6	0.50	0.6
D	0.4	0.25	0.4
E	0.2	0	0.2
F	0	-	-

Apartment's aspects quality

Overall visual comfort label	Visual comfort aspect points
F	[0]
E	[0.01-0.35]
D	[0.36-0.55]
C	[0.56-0.70]
B	[0.71-0.85]
A	[0.86-1.00]

Apartment visual comfort quality

background knowledge

research framework

machine learning

ML design process framework

“Swiss dwellings” dataset

labels & features

ML training & performance

layout evaluation system

framework test

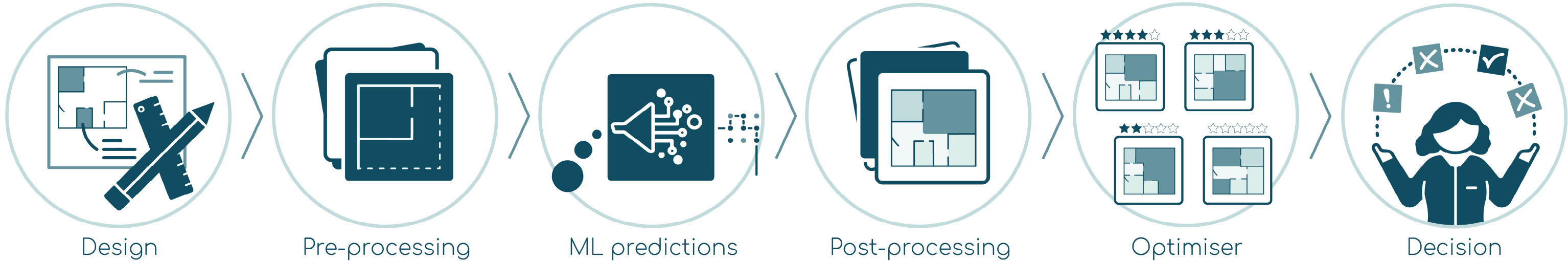
conclusion



ML design process framework

The implementation of ML in the design process

ML design process framework

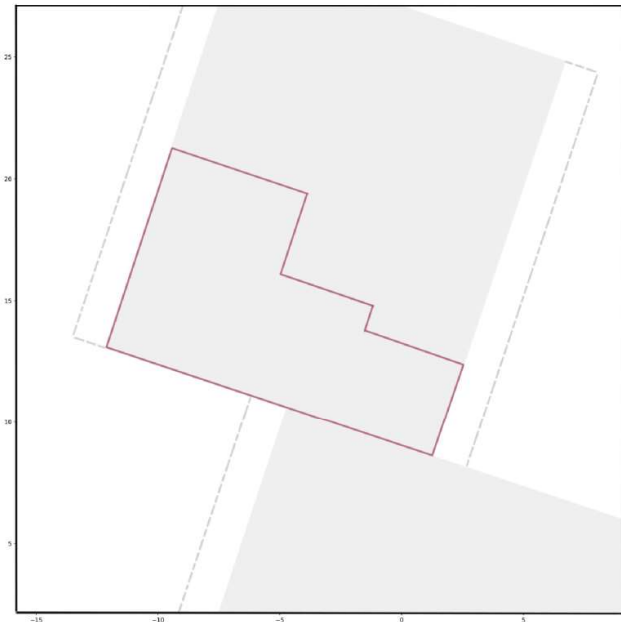


Design

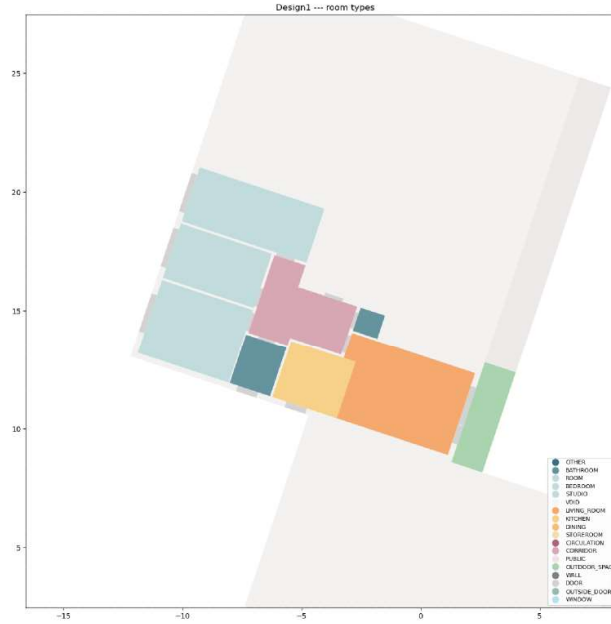
Step 1: creating layout design options



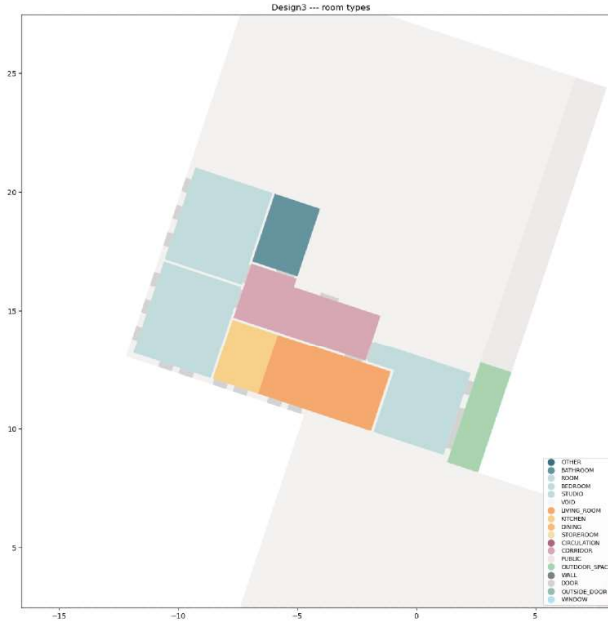
Design space



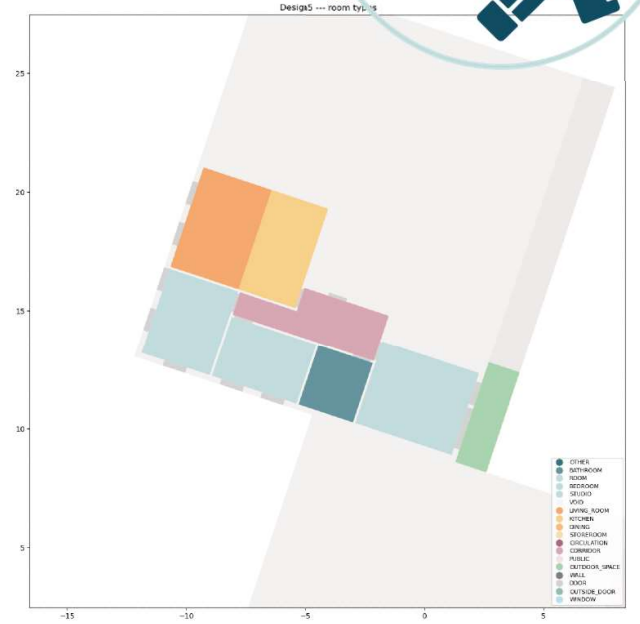
Design 1



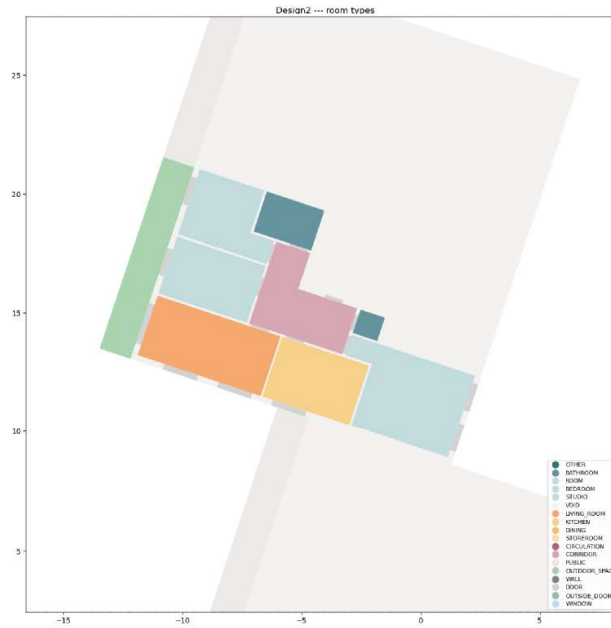
Design 3



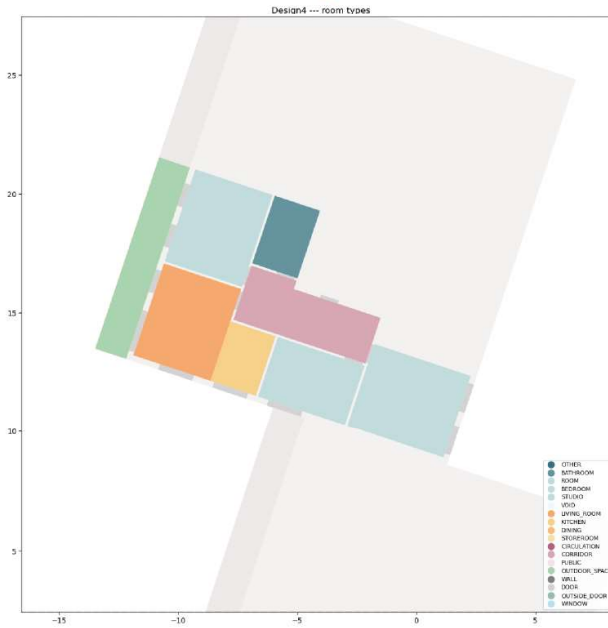
Design 5



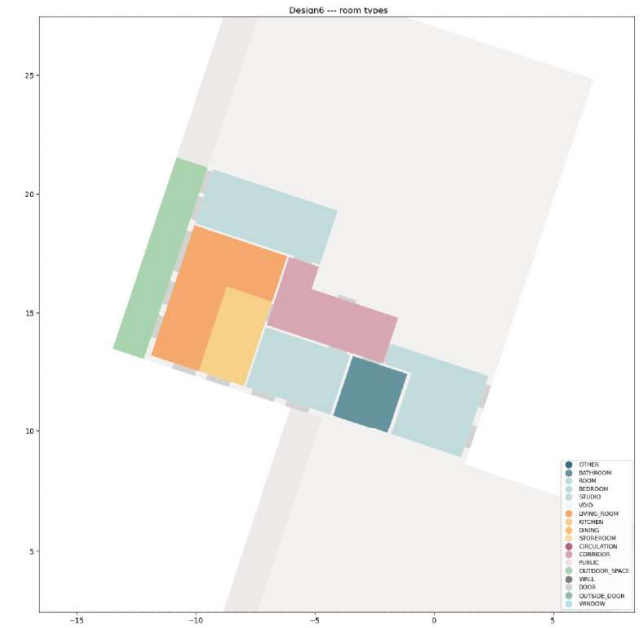
Design 2



Design 4

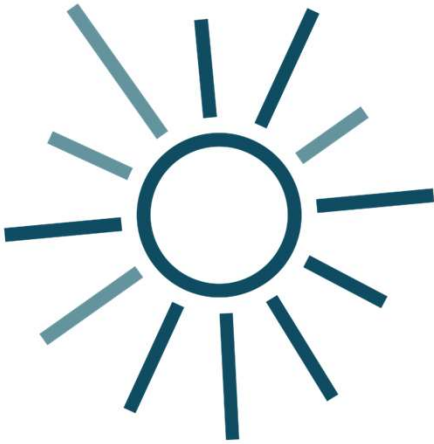
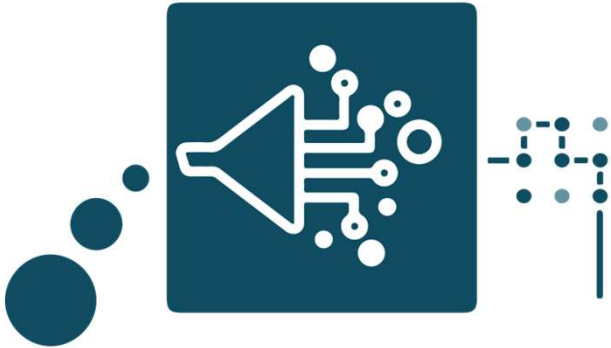
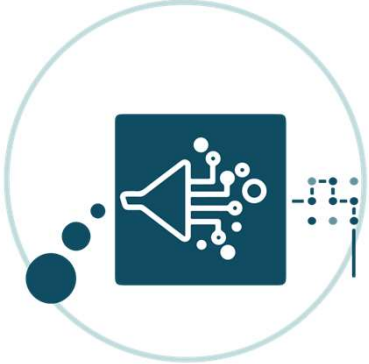


Design 6



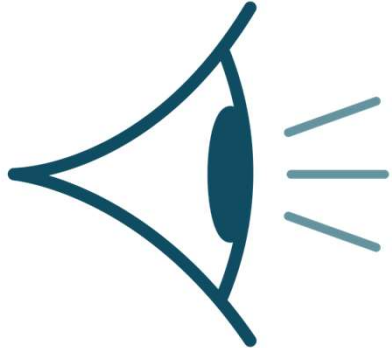
ML model predictions

Step 3: predicting daylight and view values



Daylight

21st March, June, December at 12:00,
median [lx]

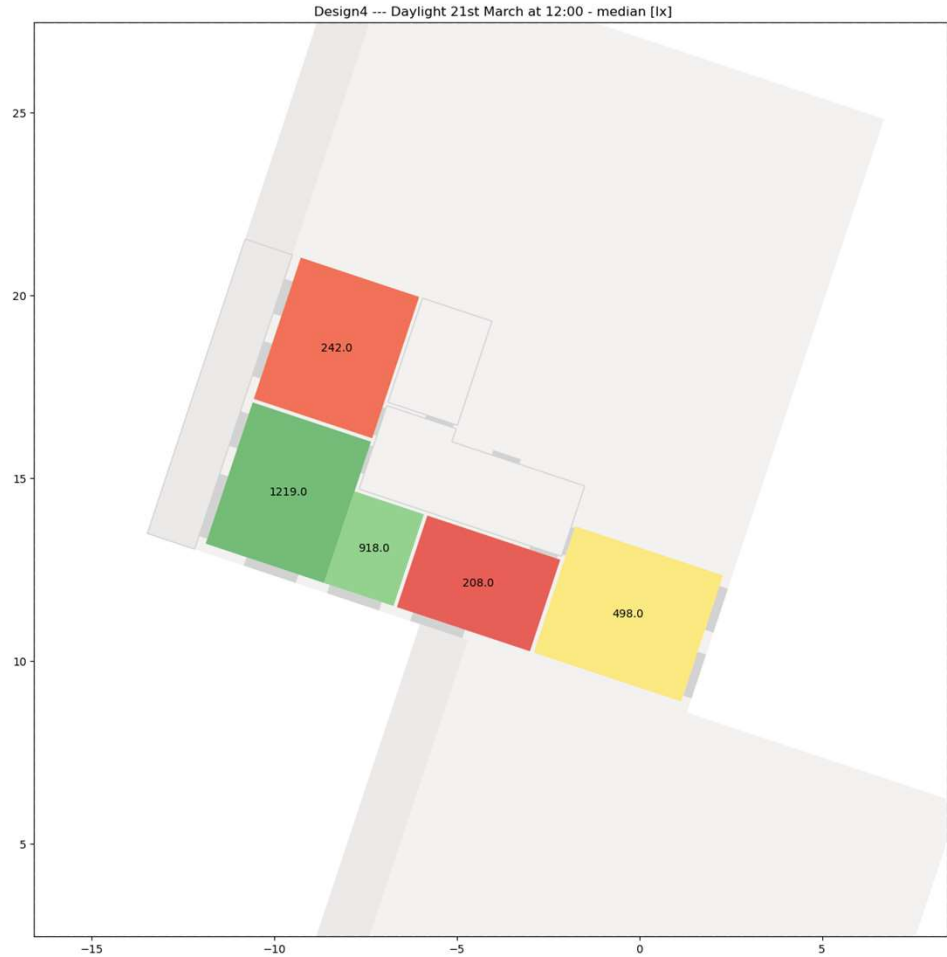
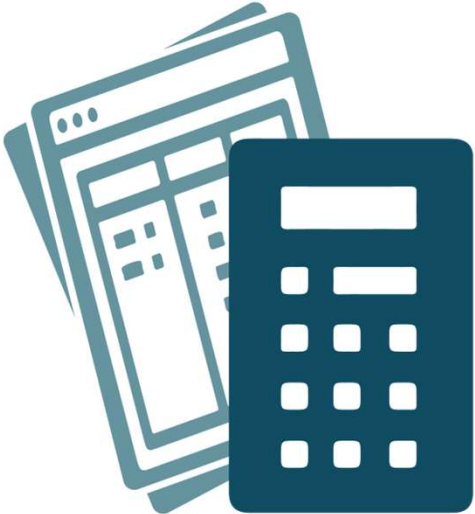


View

to ground & sky,
p80 [%]

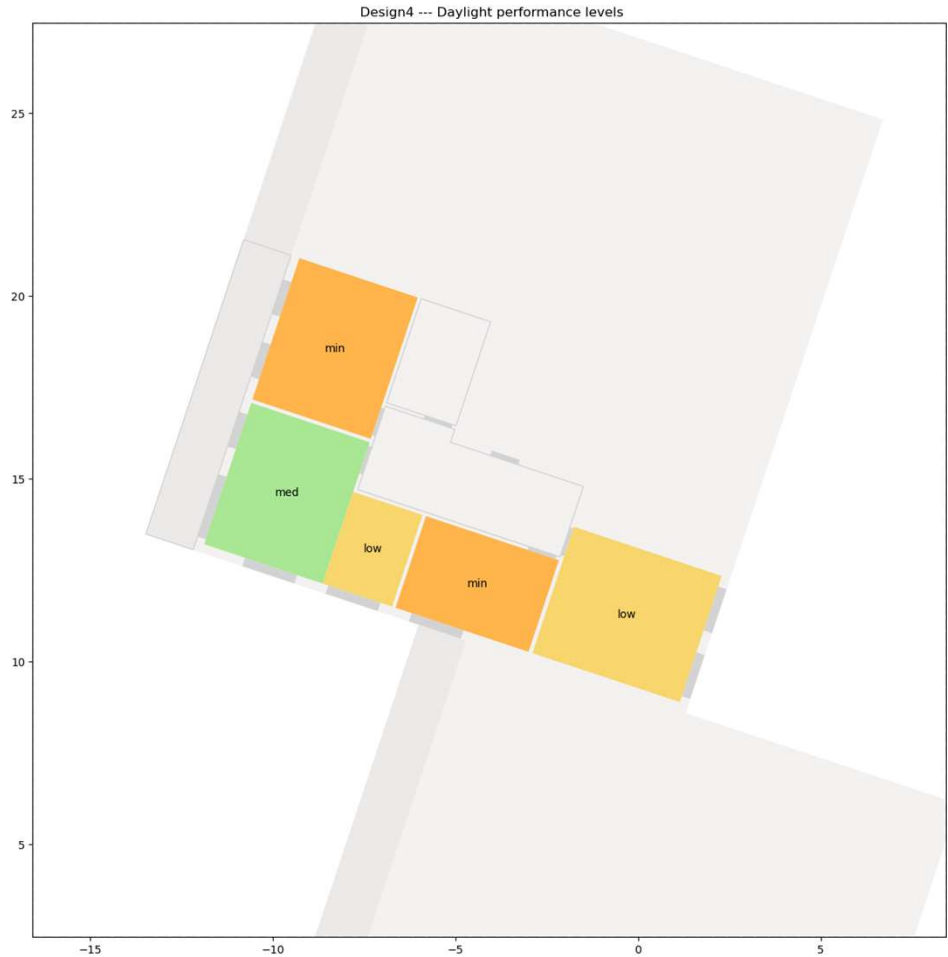
Post-processing

Step 4: visualising the predicted values on the layout designs



Daylight illuminance [lx]

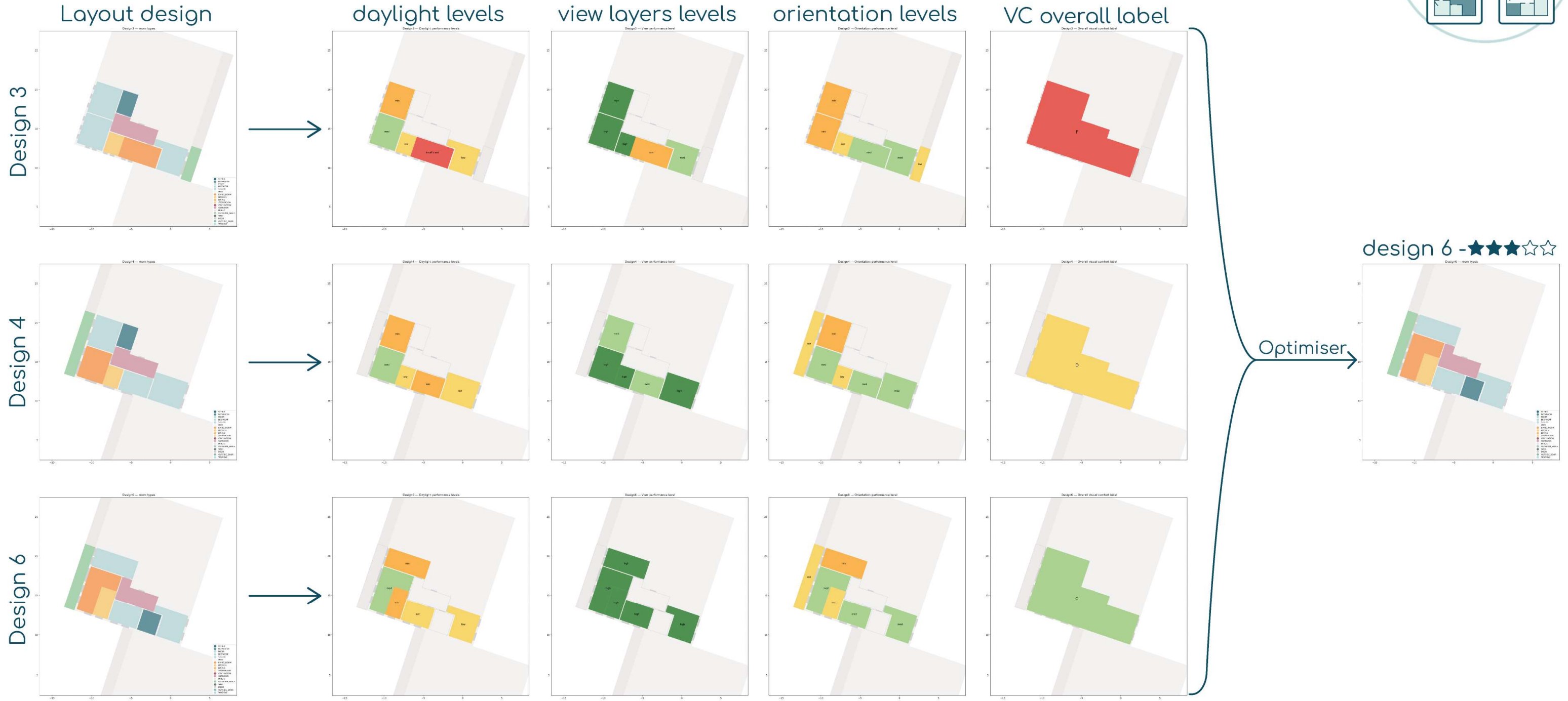
21st March 12:00



Daylight level

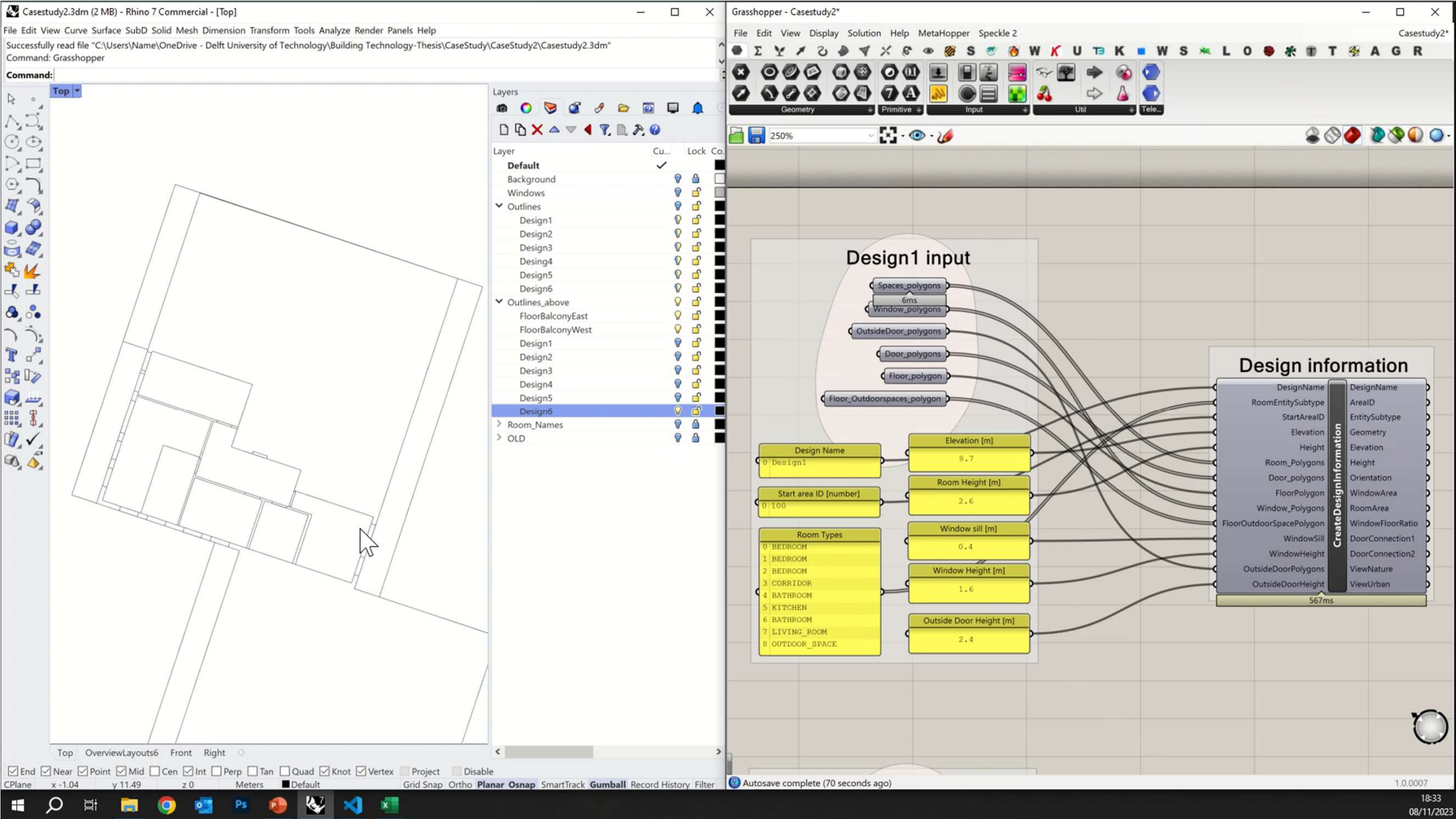
Optimiser

Step 5: find the best layout option among the selection



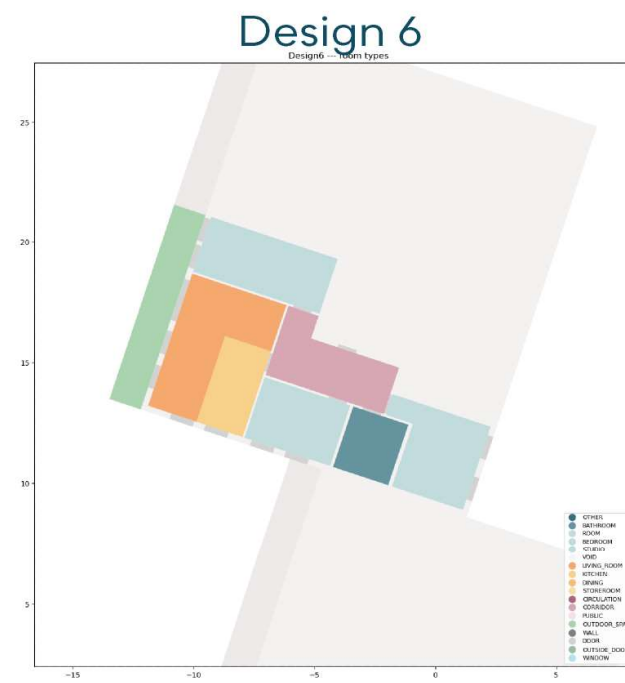
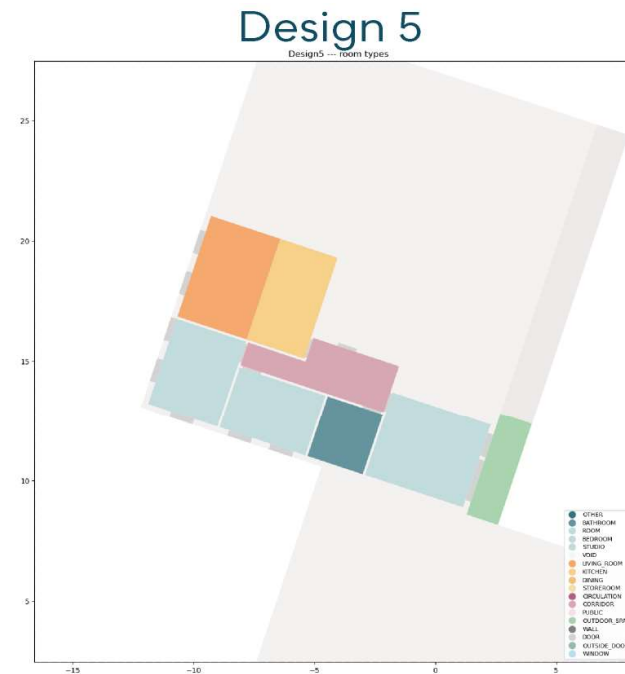
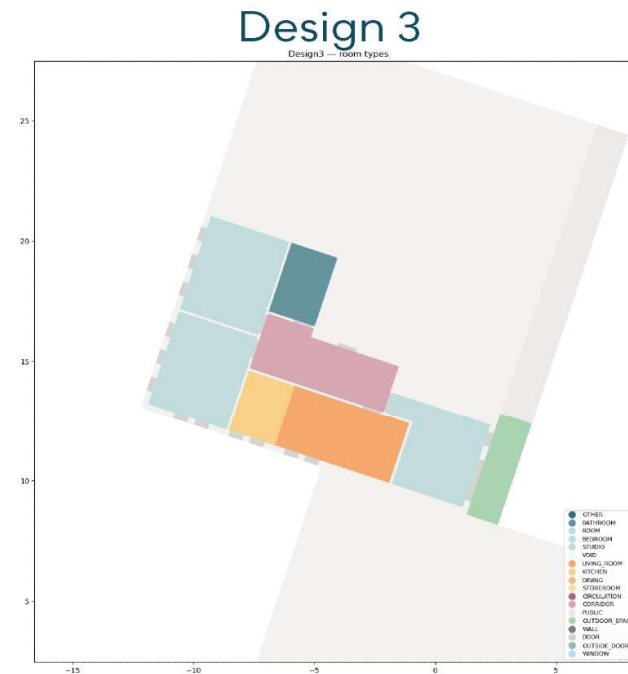
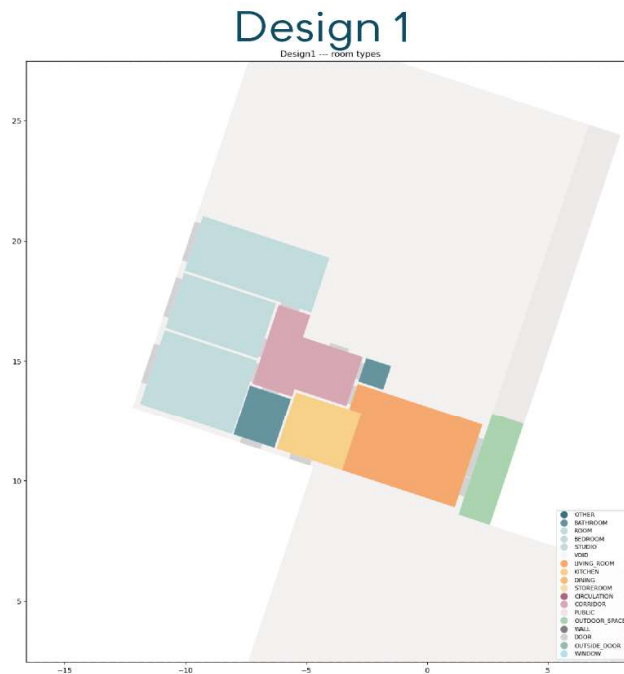
Framework to practice

Real time farmwork loop



Decision

Step 6: designer can compare layouts and make performance-based decision

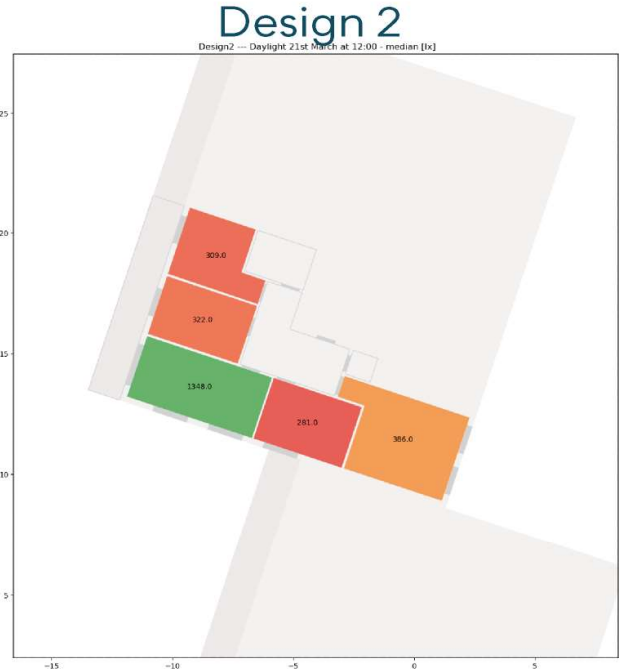
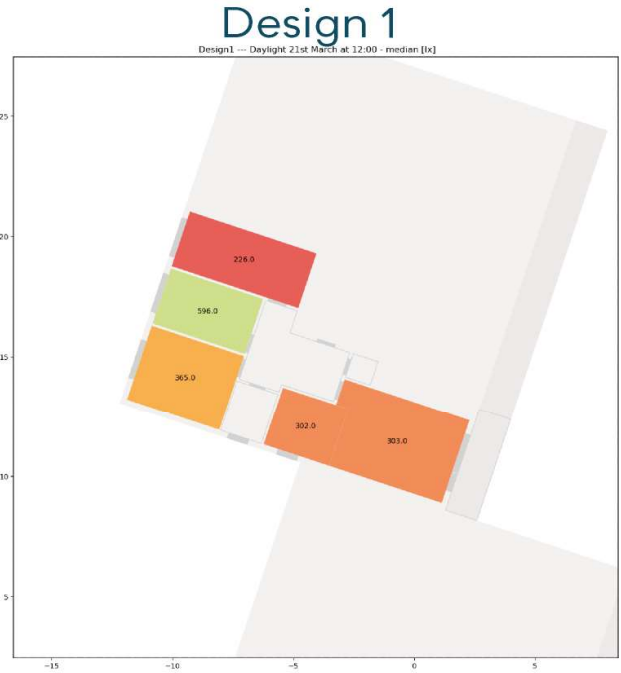


Design options

Framework test

Decision

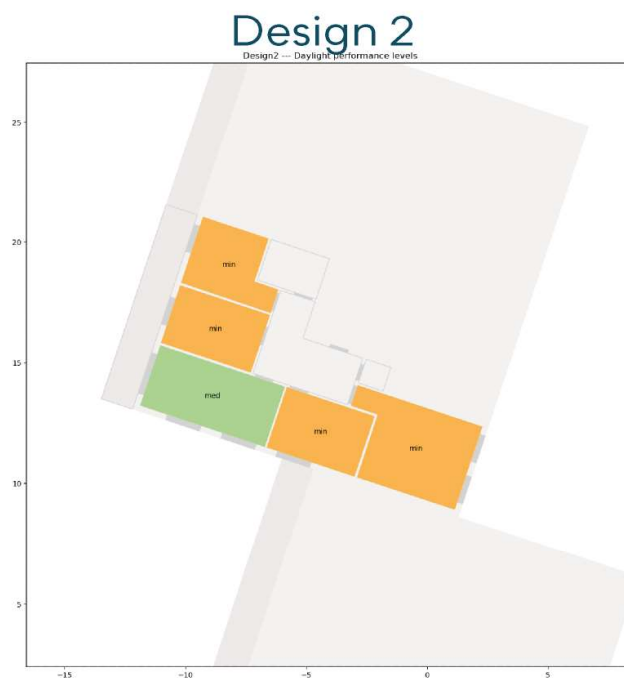
Step 6: designer can compare layouts and make performance-based decision



Daylight illuminance value, March [lx]

Decision

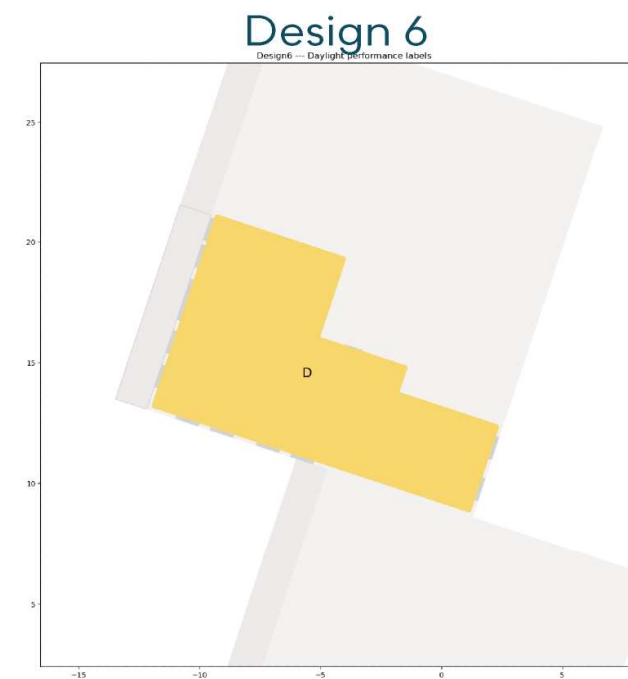
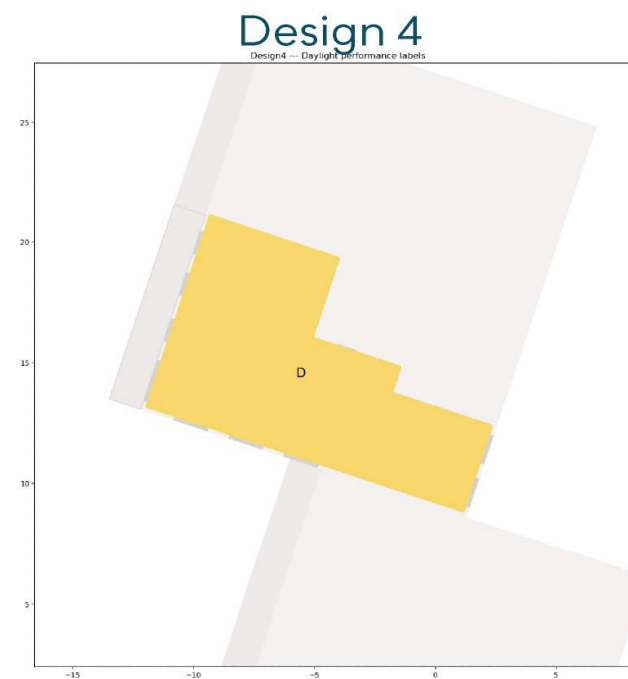
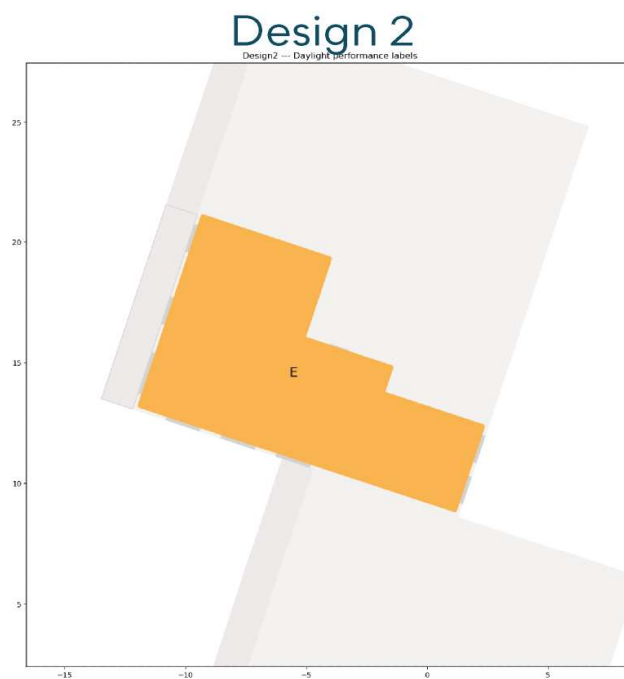
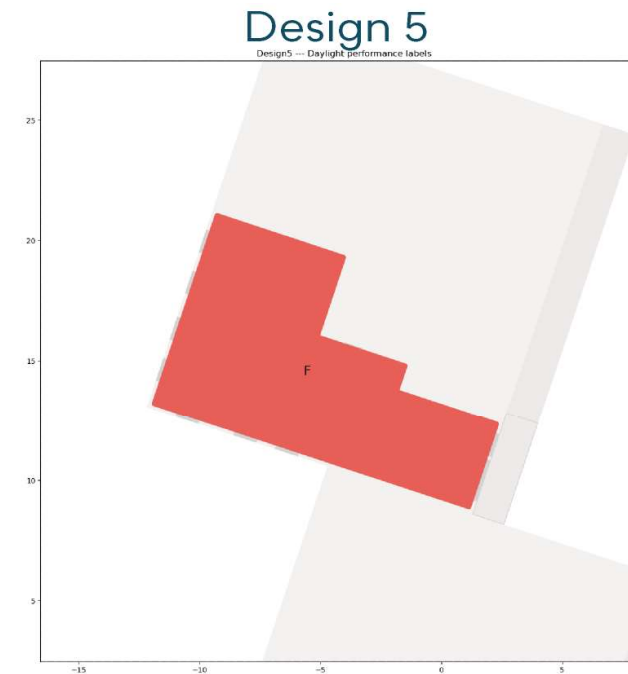
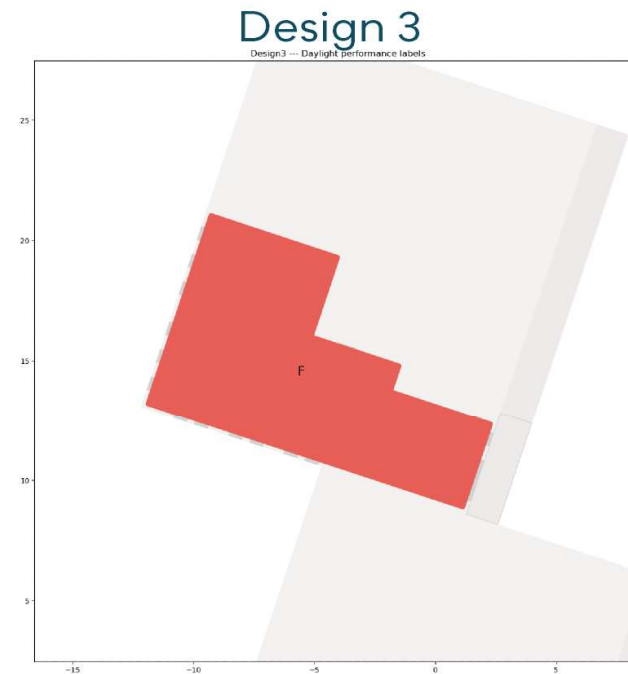
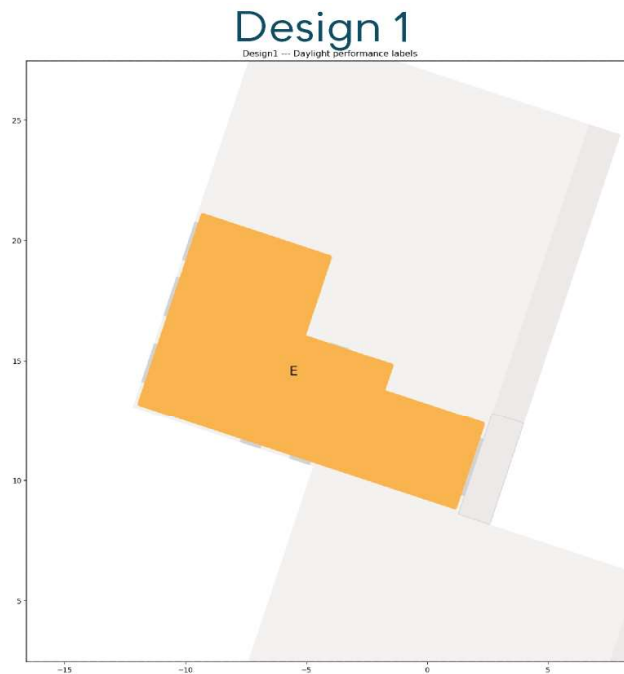
Step 6: designer can compare layouts and make performance-based decision



Daylight performance level

Decision

Step 6: designer can compare layouts and make performance-based decision

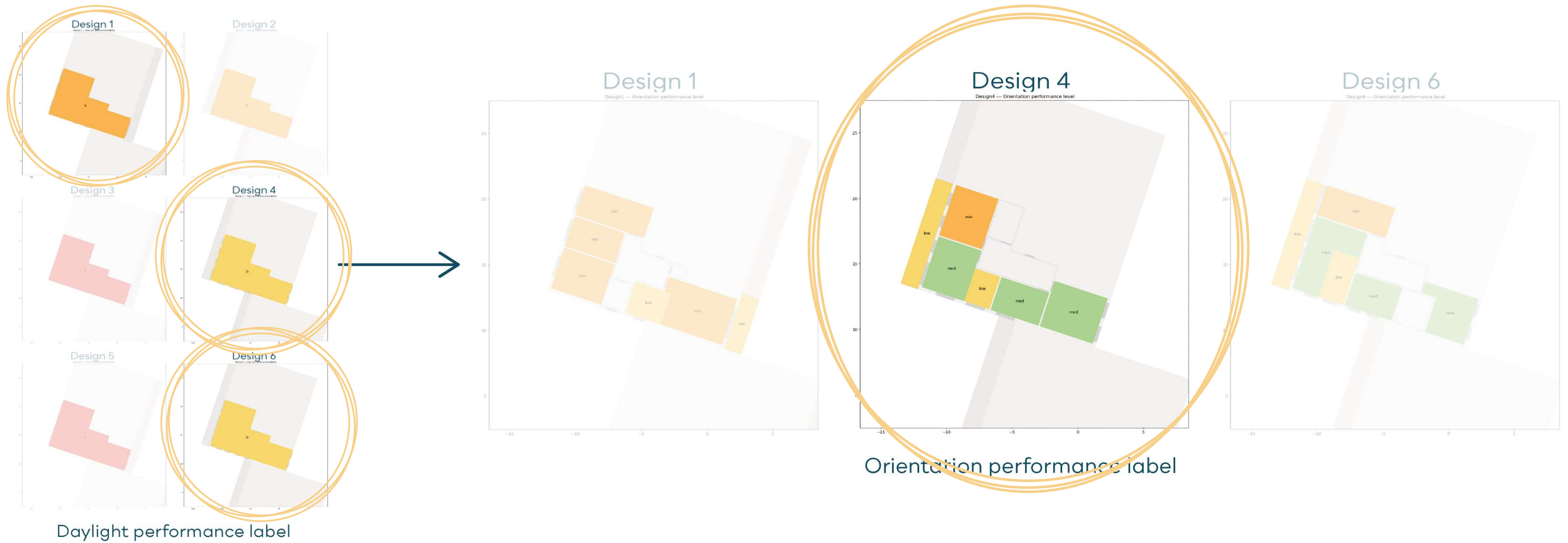


Daylight performance label

Framework test

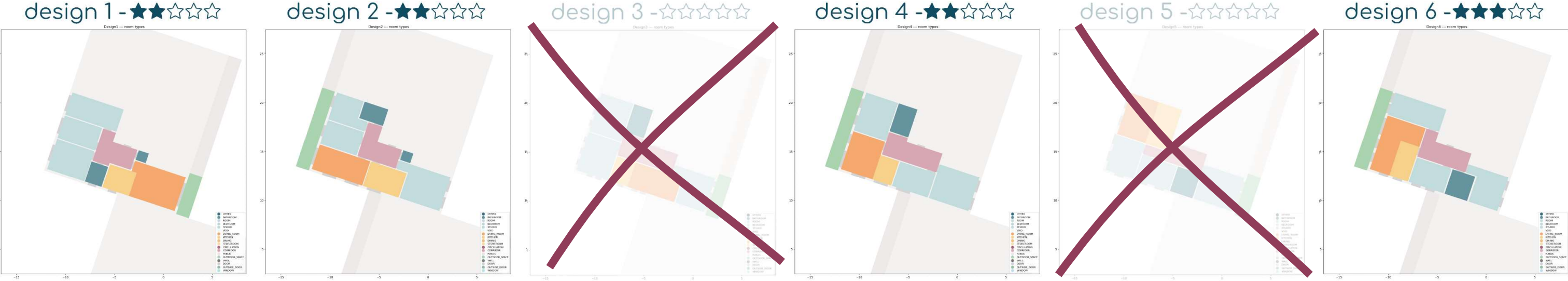
Decision

Step 6: designer can compare layouts and make performance-based decision



Decision

Step 6: designer can compare layouts and make performance-based decision



Optimiser - overall visual comfort performance label

Decision

Step 6: designer can compare layouts and make performance-based decision



Optimiser - overall visual comfort performance label

Move to next phase

background knowledge

research framework

machine learning

ML design process framework

“Swiss dwellings” dataset

labels & features

ML training & performance

layout evaluation system

framework test

conclusion



Conclusion

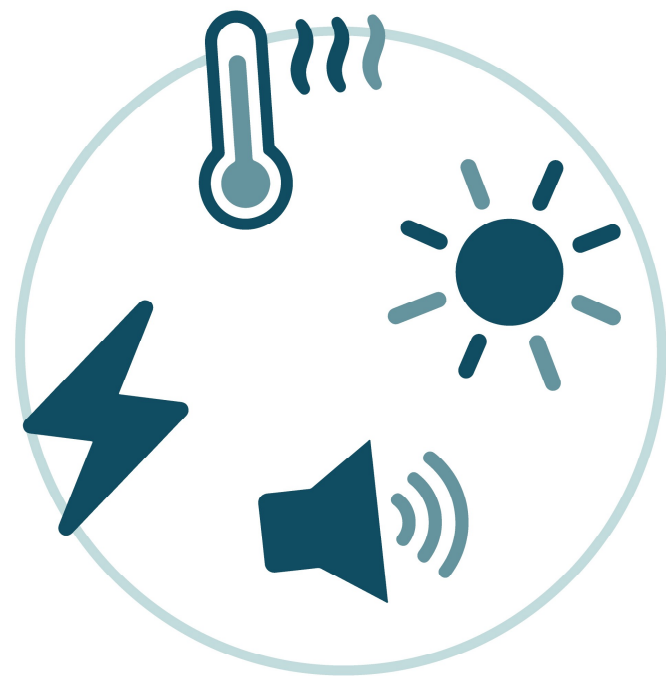
To tackle the problem

ML design process framework

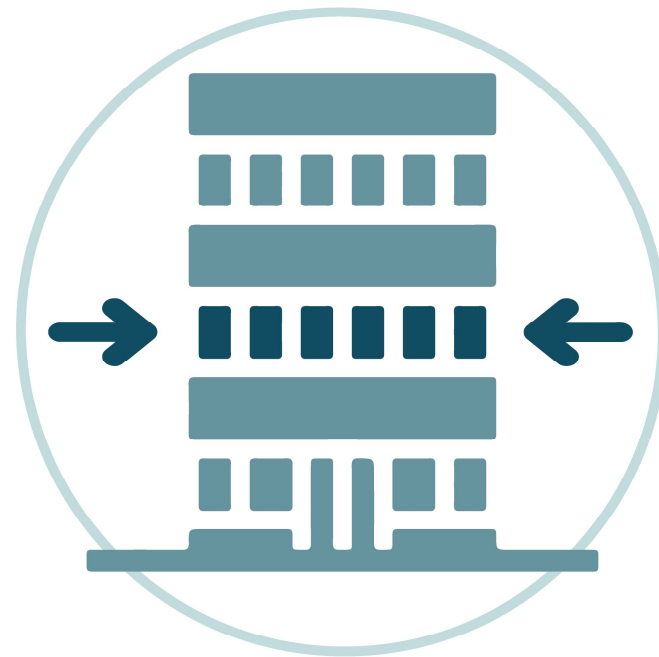


Future research

The future of “visual comfort l(AI)outs”



performance indicators



extending application size



ML layout generation

Questions

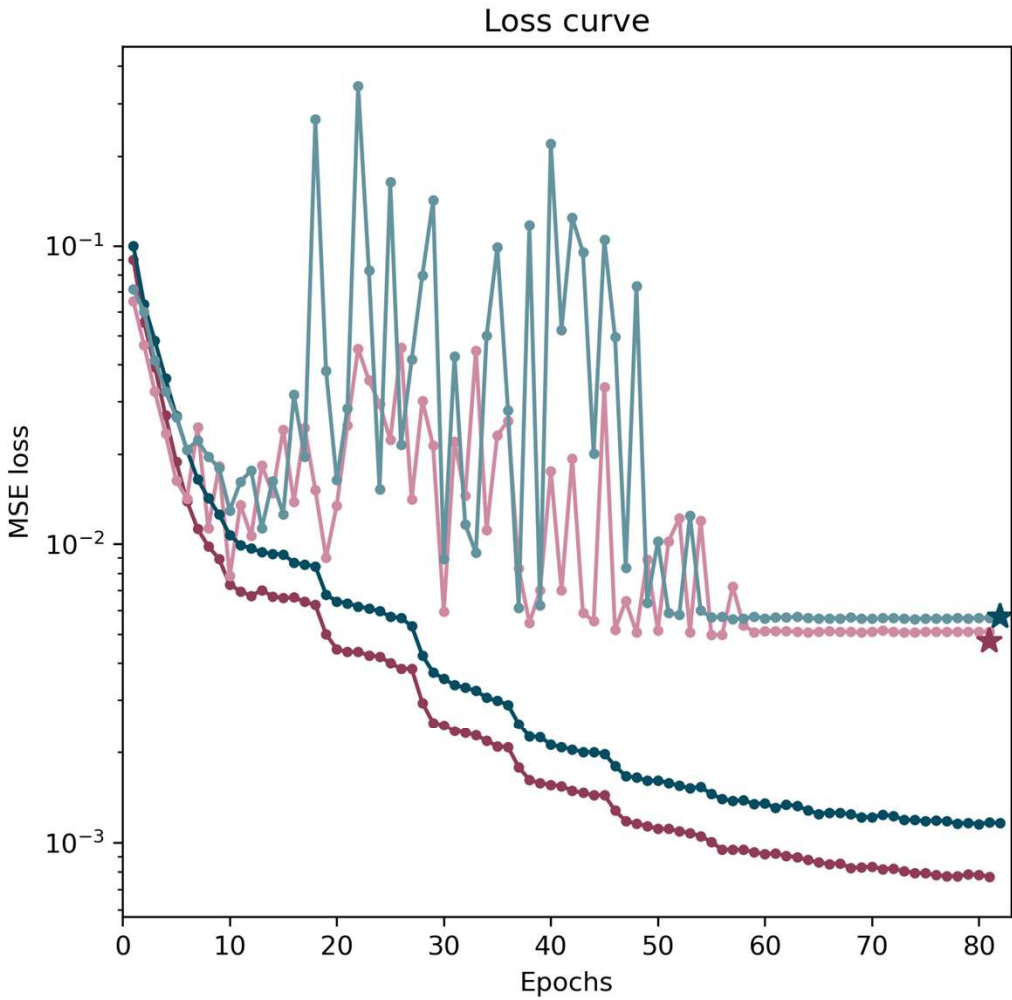
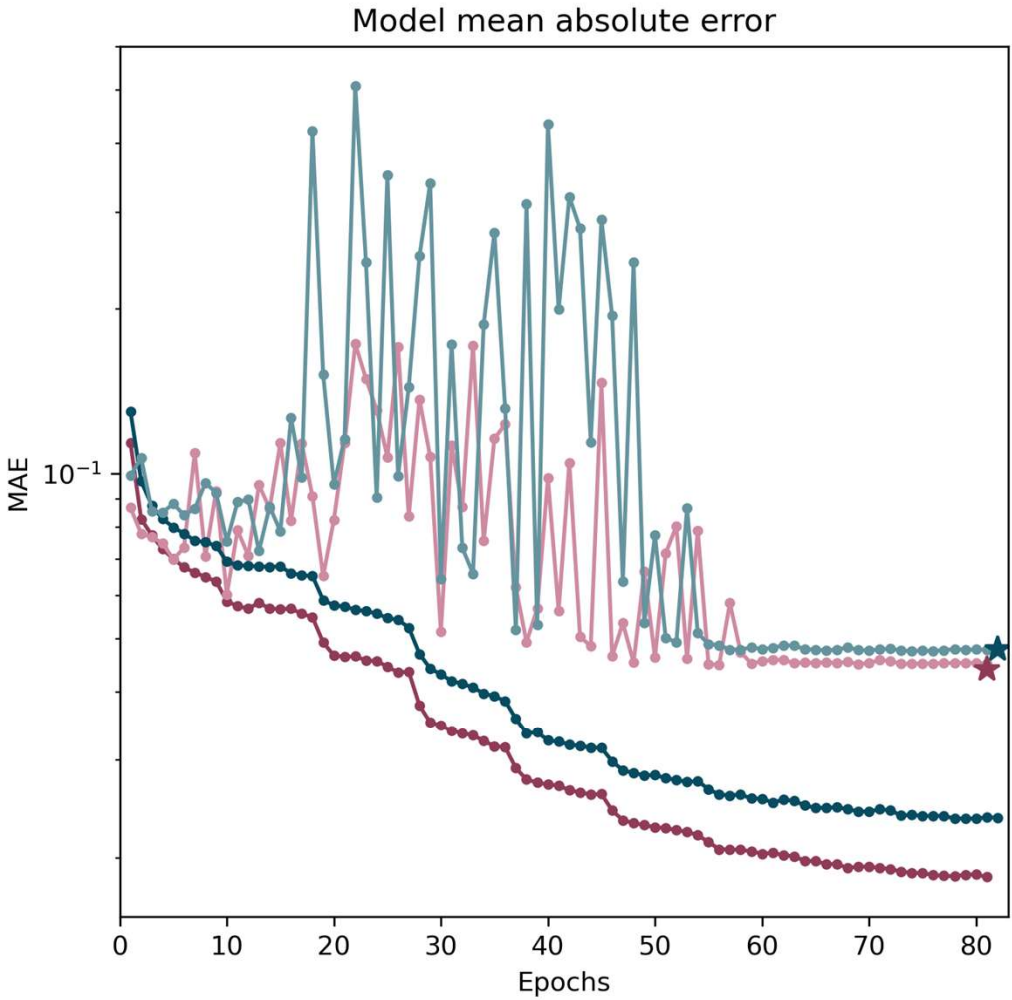


Loss curves

Model 7.5: Model 3.2 with low dropout & L2 regularization rate

Loss curves Model 7.5A & Model 7.5B

- Training (daylight)
- Training (view)
- Validation (daylight)
- Validation (view)
- ★ Test (daylight)
- ★ Test (view)



Daylight

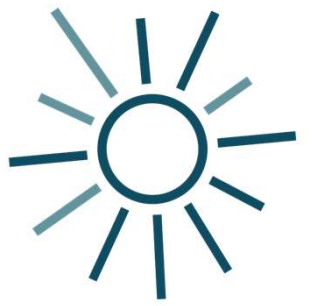
MSE = 0.0047 / MAE = 0.0440

View

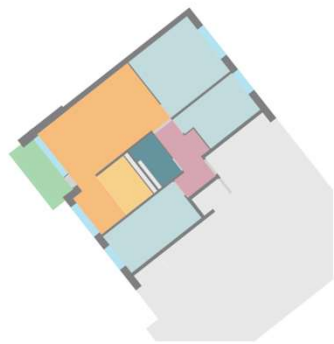
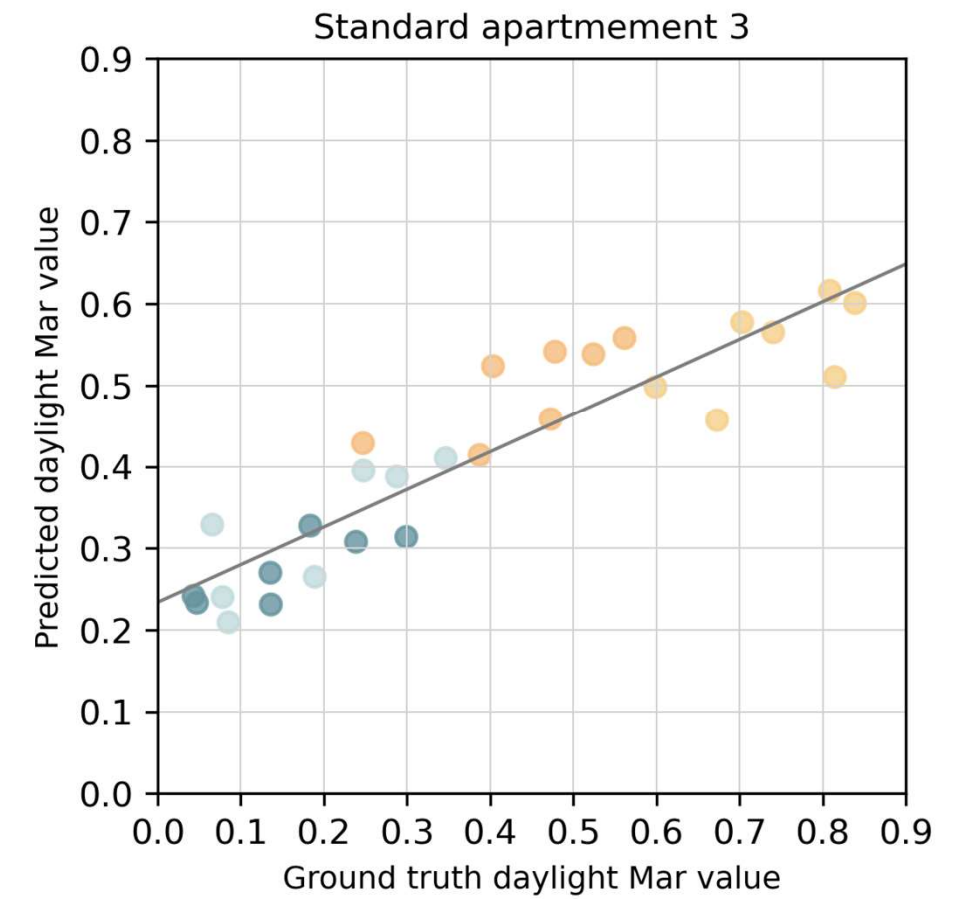
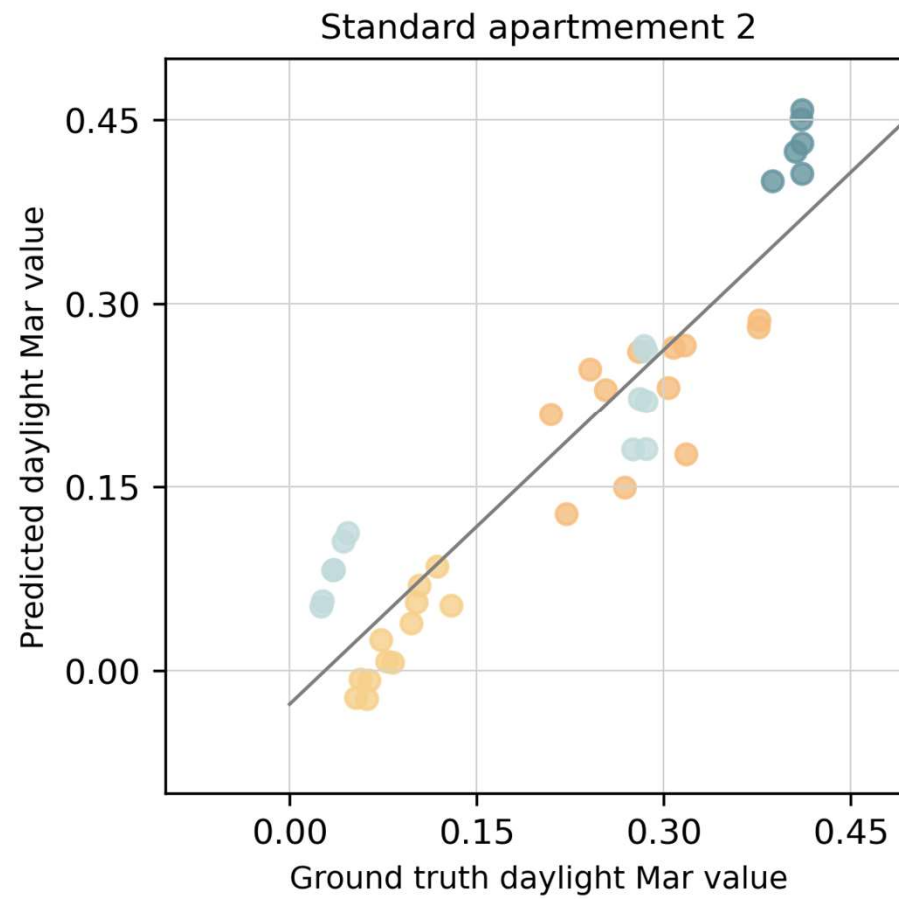
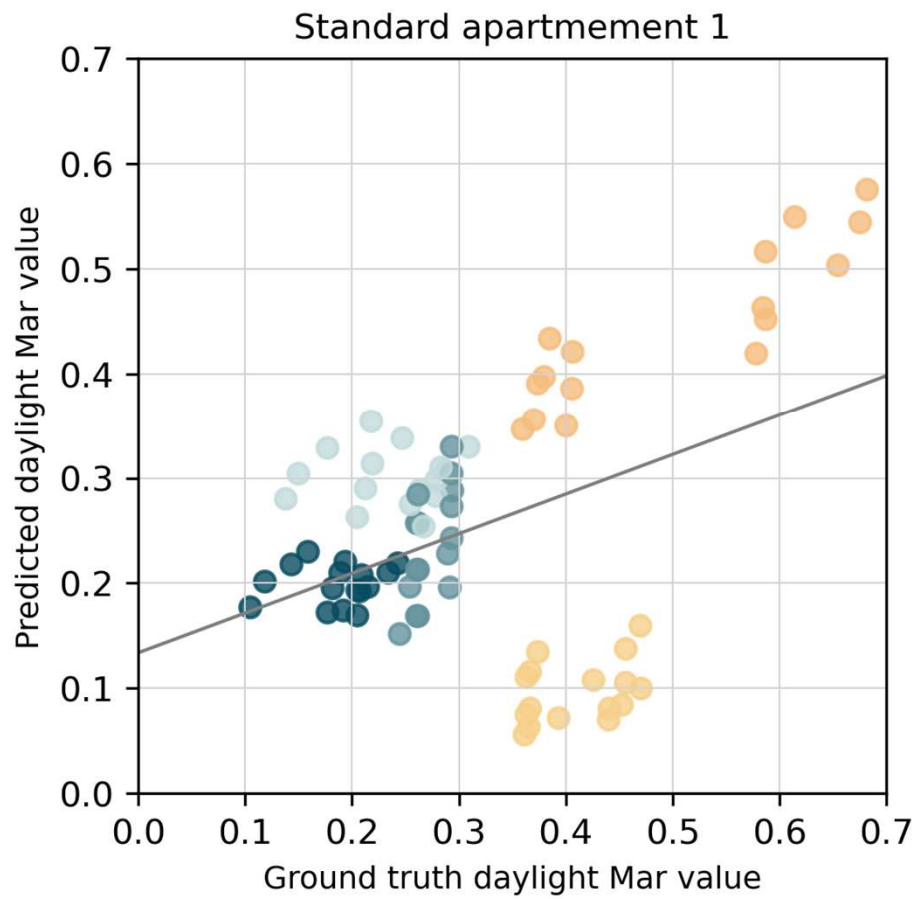
MSE = 0.0057 / MAE = 0.0478

Standard layout type prediction daylight

Prediction correlations per room type

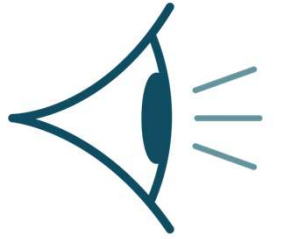


Standard apartments daylight Mar predictions - model 7.5A

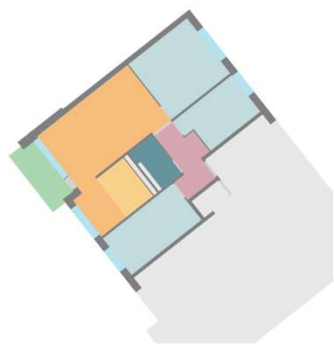
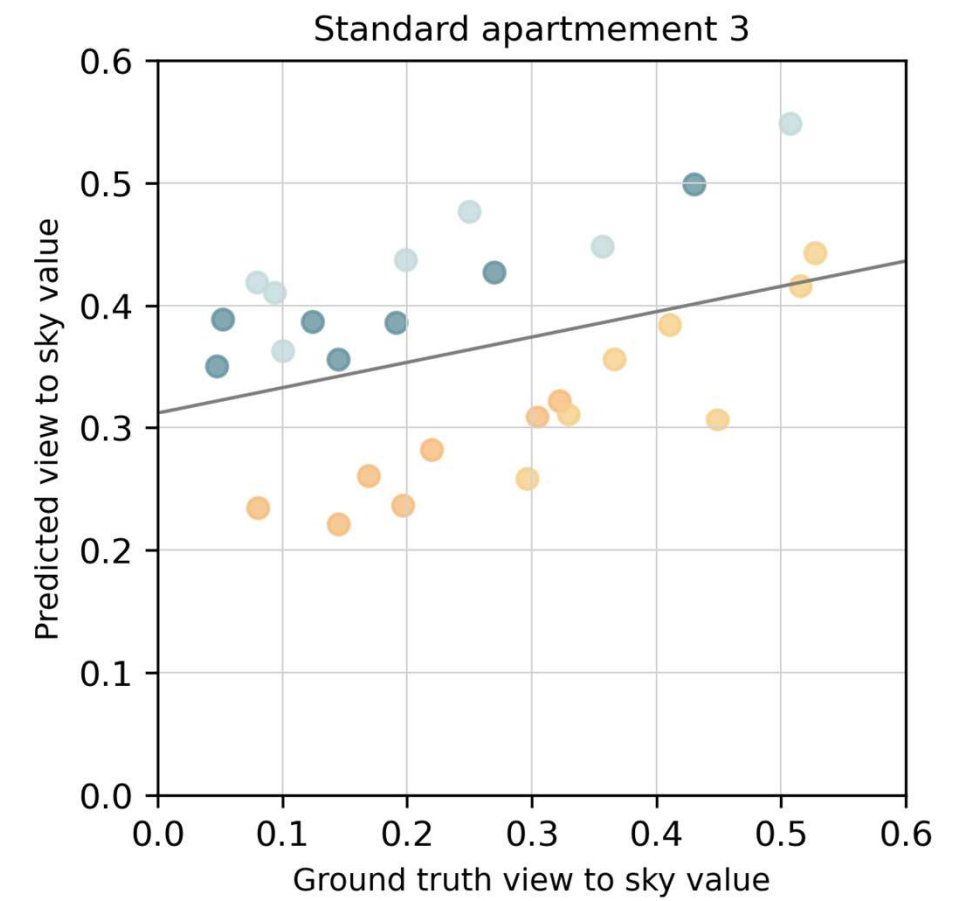
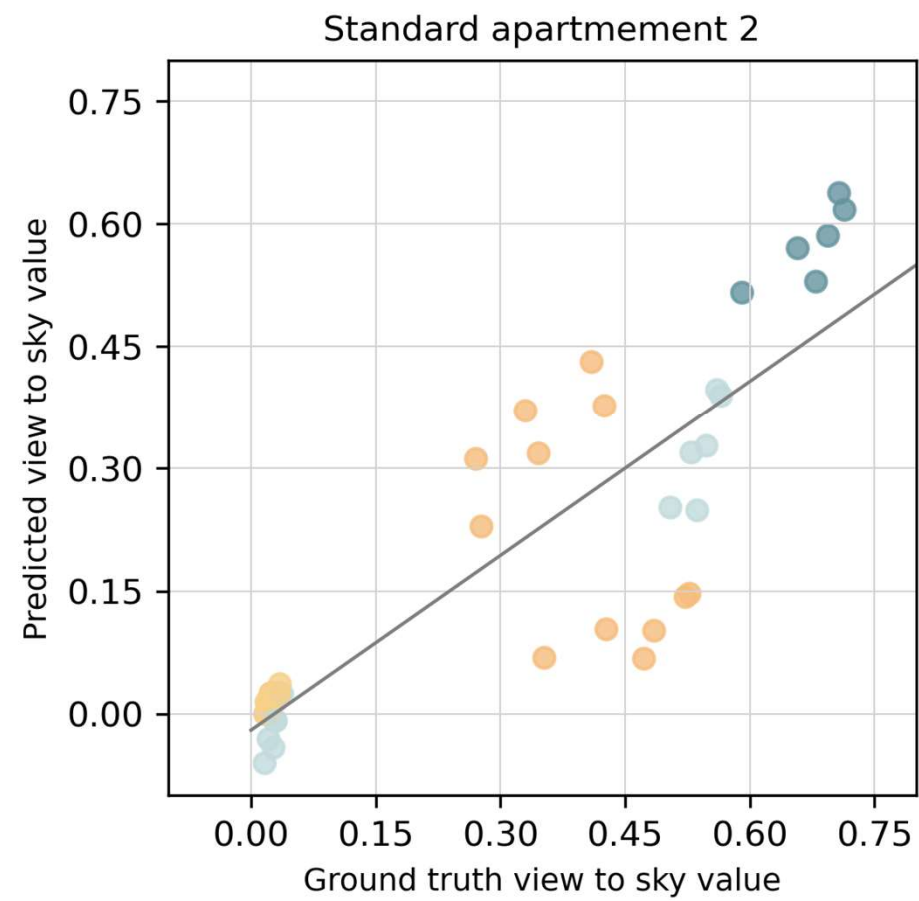
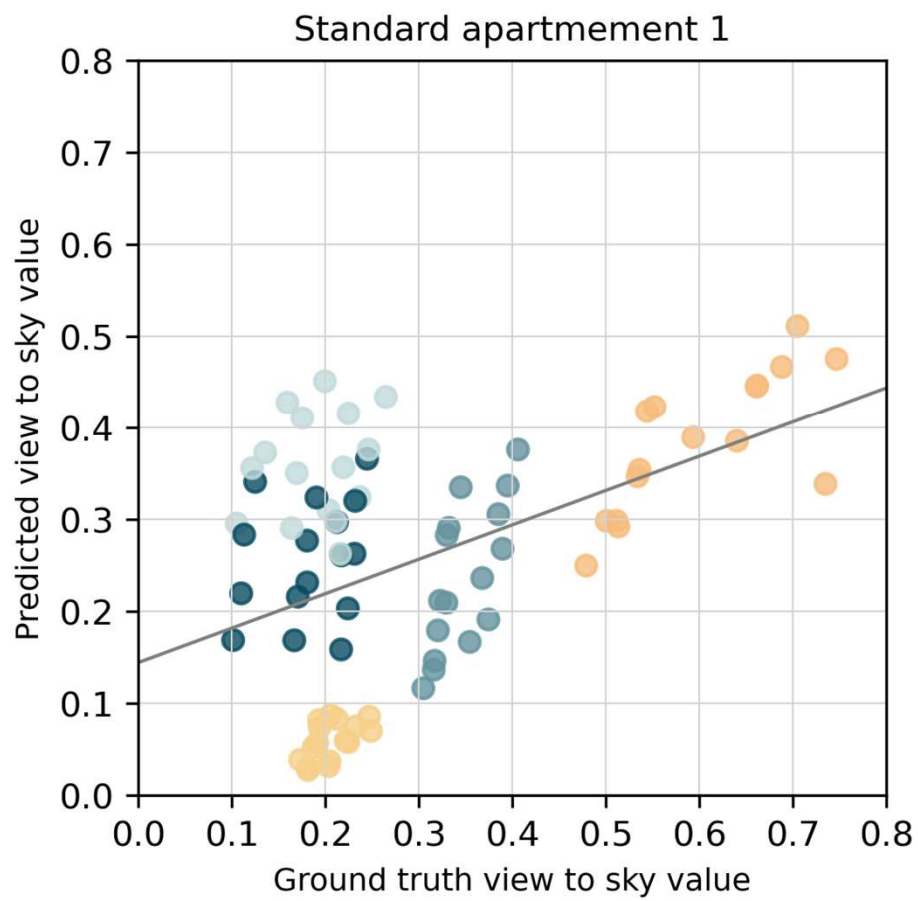


Standard layout type prediction sky view

Prediction correlations per room type

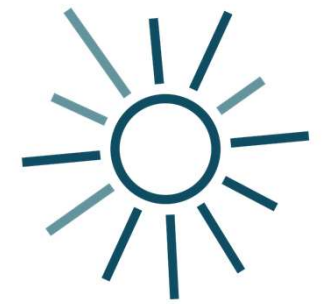


Standard apartments view to sky predictions - model 7.5B

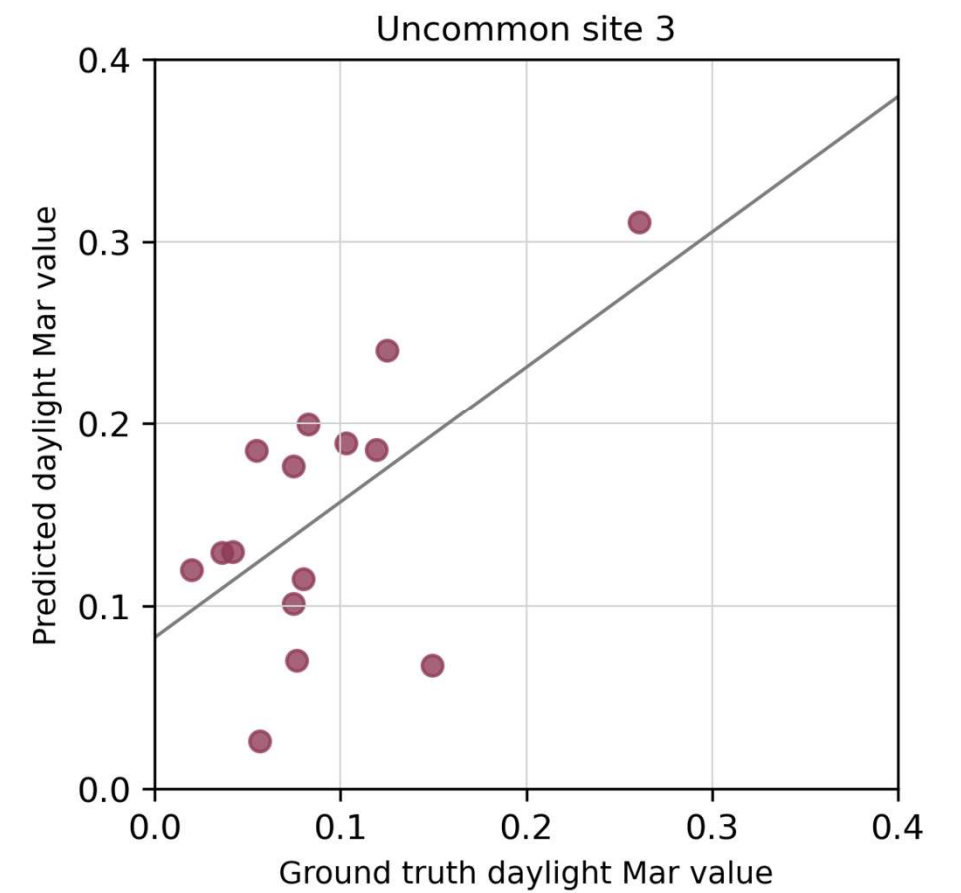
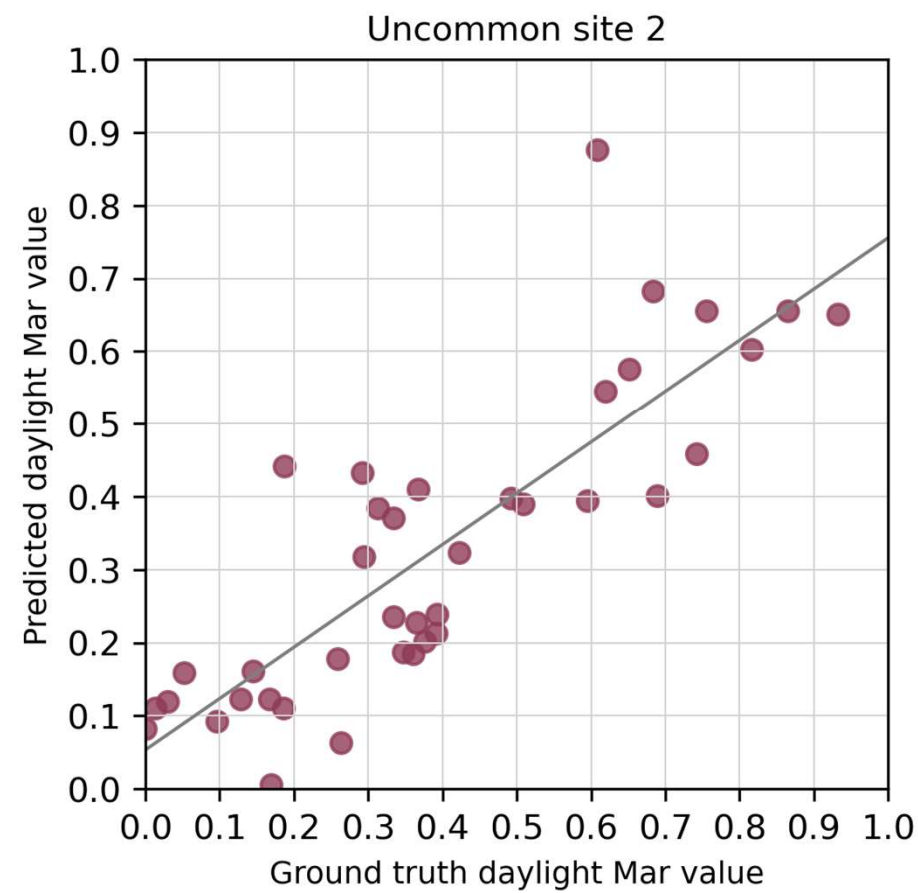
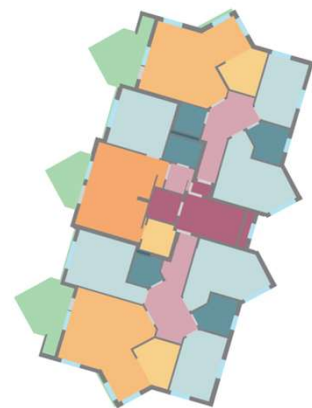
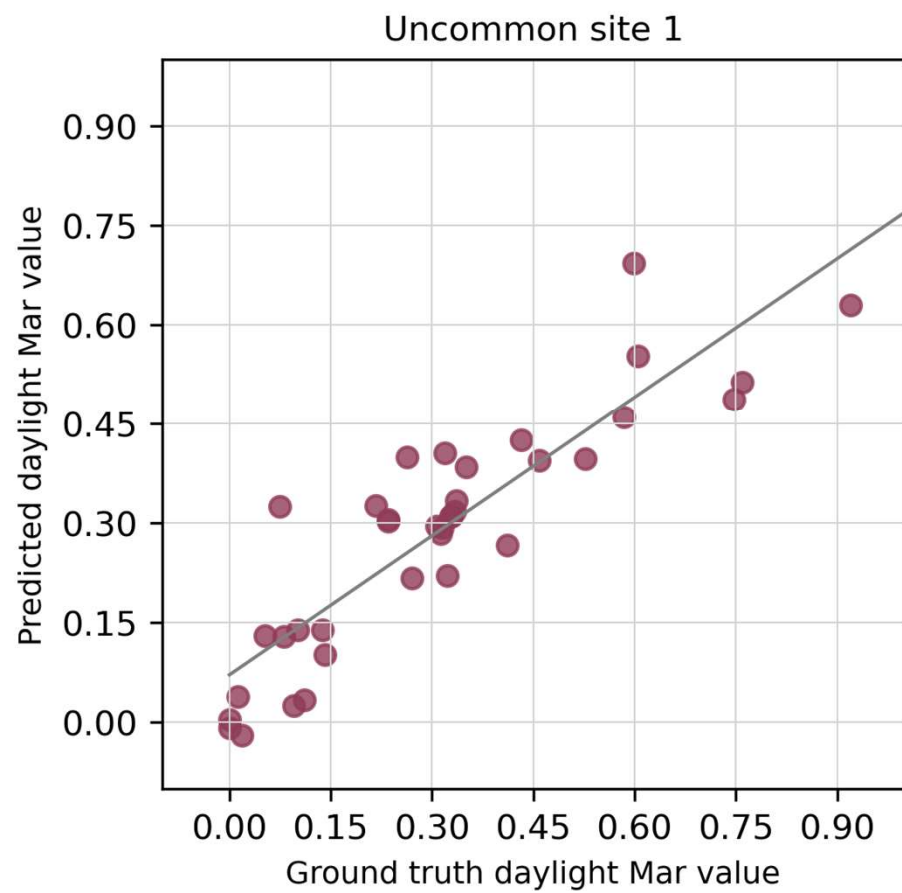


Uncommon room/building geometry prediction daylight

Prediction correlations per apartment

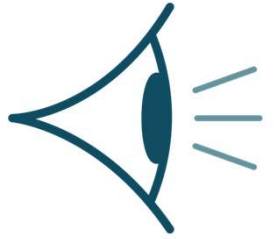


Uncommon sites daylight Mar predictions - model 7.5A

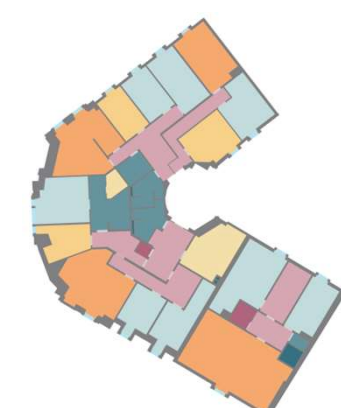
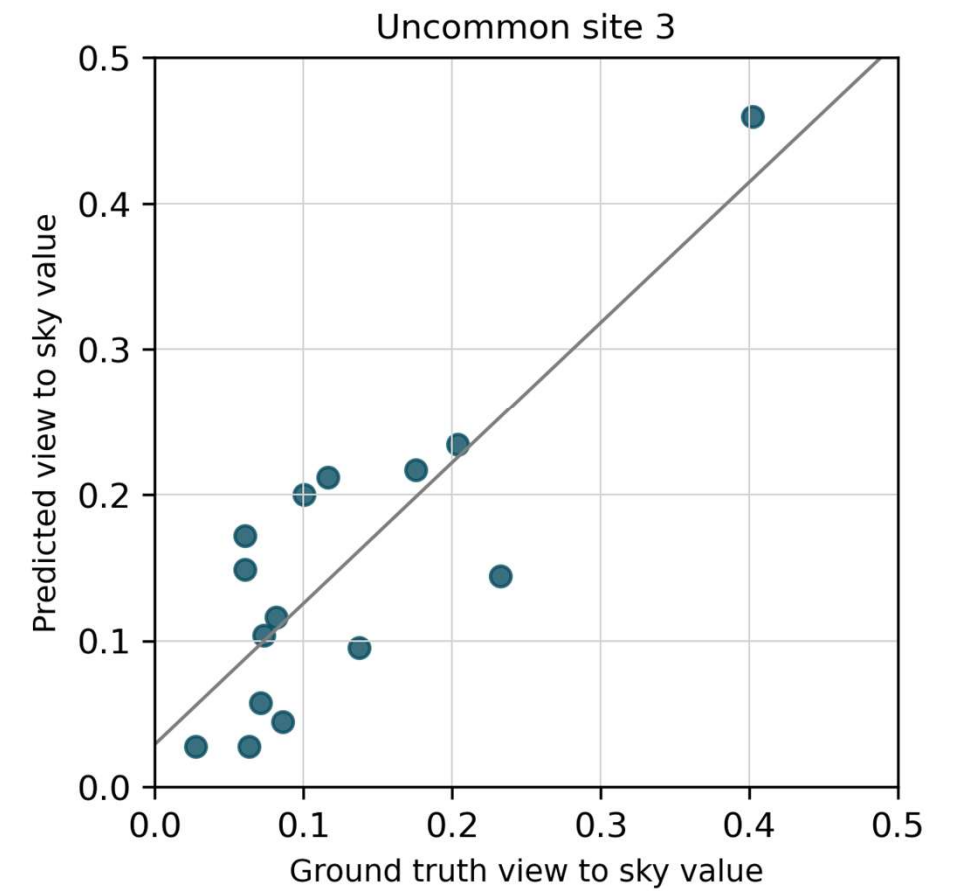
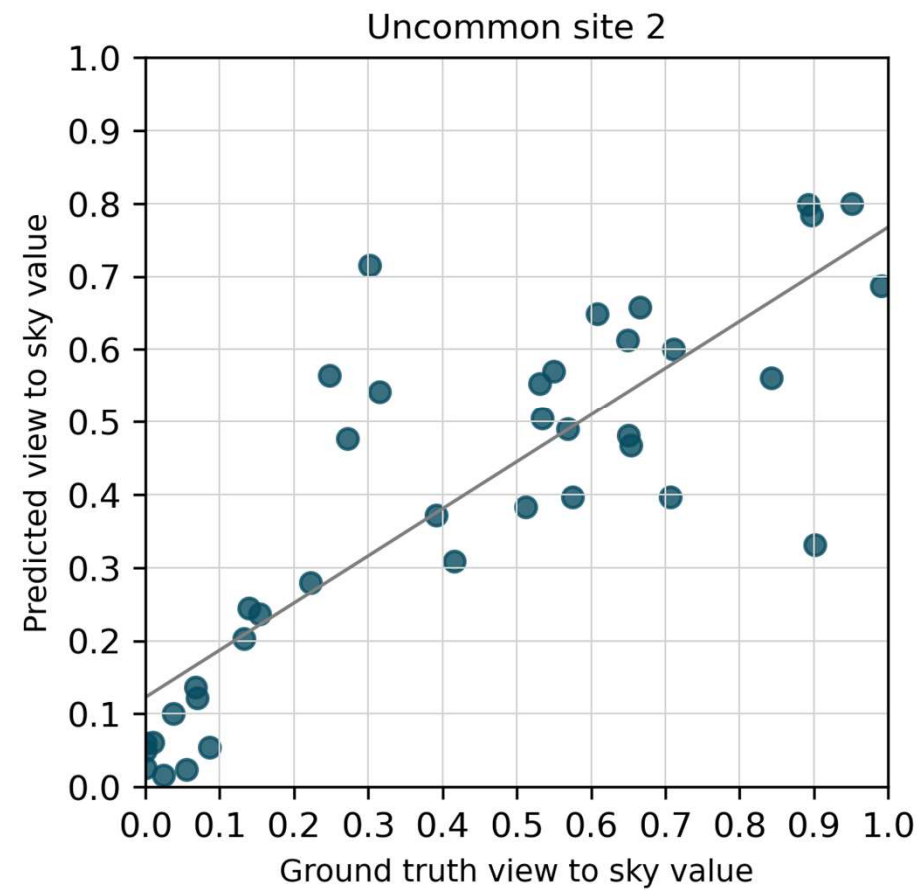
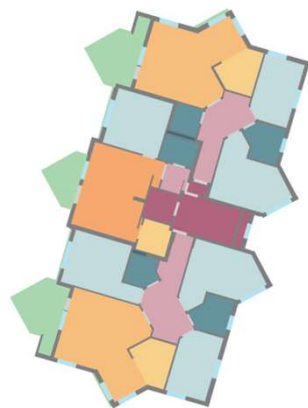
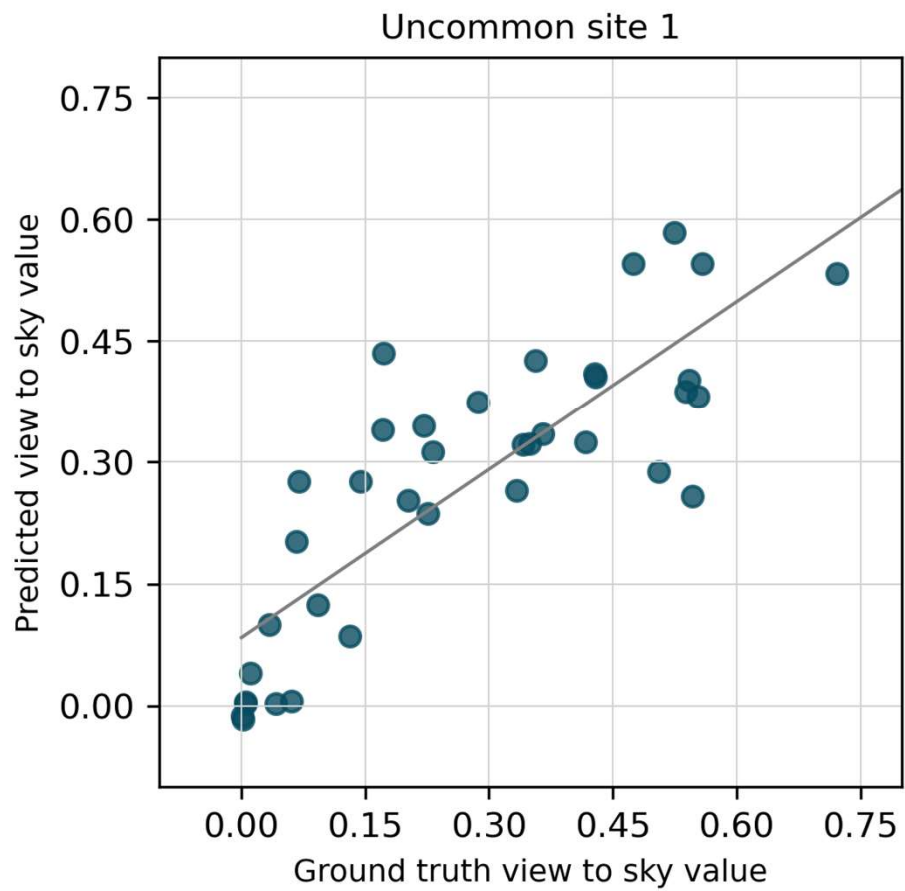


Uncommon room/building geometry prediction sky view

Prediction correlations per apartment

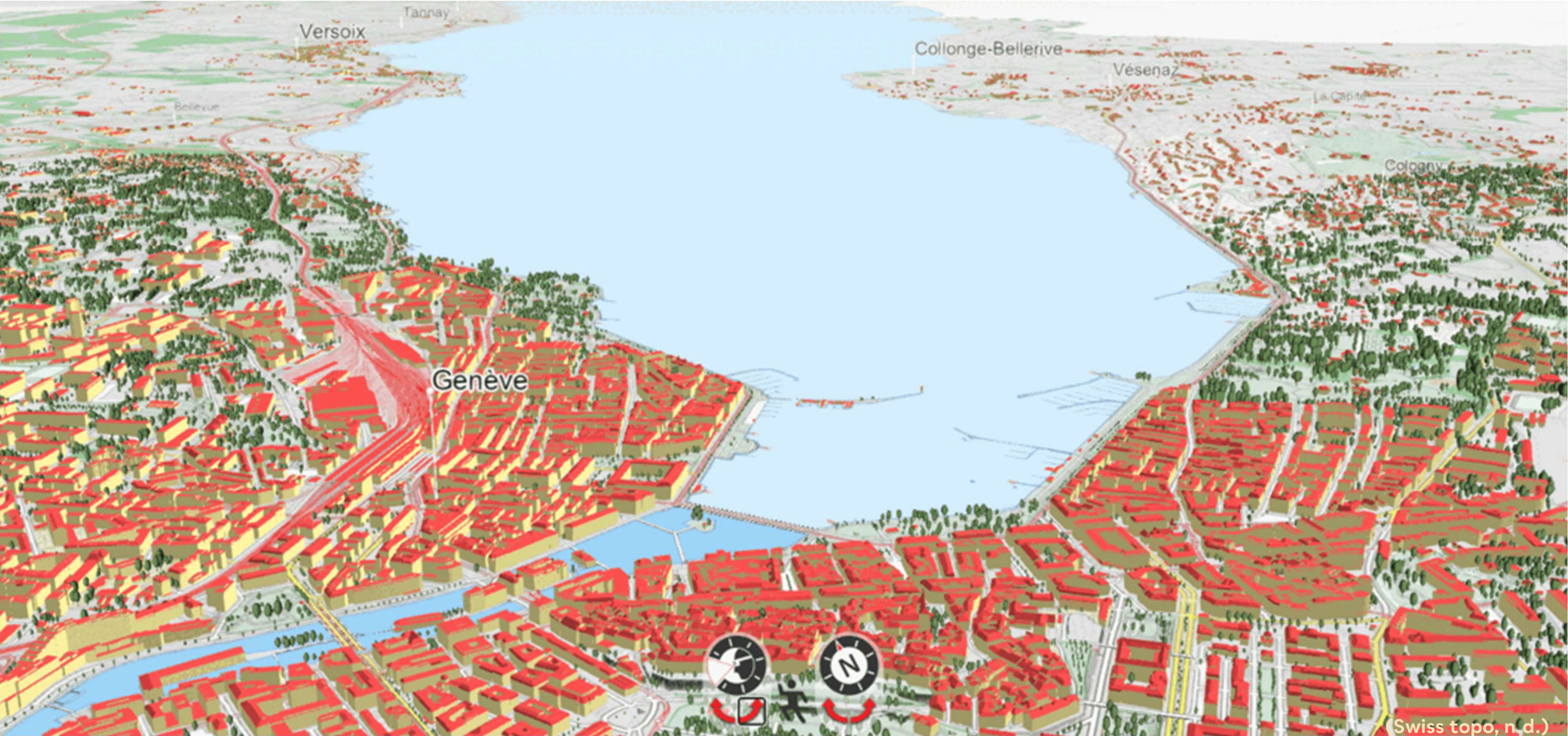


Uncommon sites view to sky predictions - model 7.5B



Swiss topo

Dataset's environment



(Swiss topo, n.d.)

Daylight evaluation

Daylight quality in rooms & apartments

Daylight level	Target illuminance*
Insufficient	lux < min threshold
Minimum	bedroom/room: 100 lx, living room: 150 lx, kitchen: 200 lx
Low	300 lx
Medium	500 lx
High	750 lx

* For 50% of the space

Daylight room requirements EN17037

Daylight label	Room with the lowest daylight level	View level for 50% of the living spaces
F	Insufficient	-
E	Minimum	-
D	Minimum	Low
C	Low	Medium
B	Medium	High
A	High	-

Daylight apartment evaluation

View layers evaluation

View quality in rooms & apartments

View level	View layers present*
Insufficient	No landscape layer
Minimum	Landscape layer
Medium	2 layers, incl. landscape layer
High	All layers

* For 75% of the space

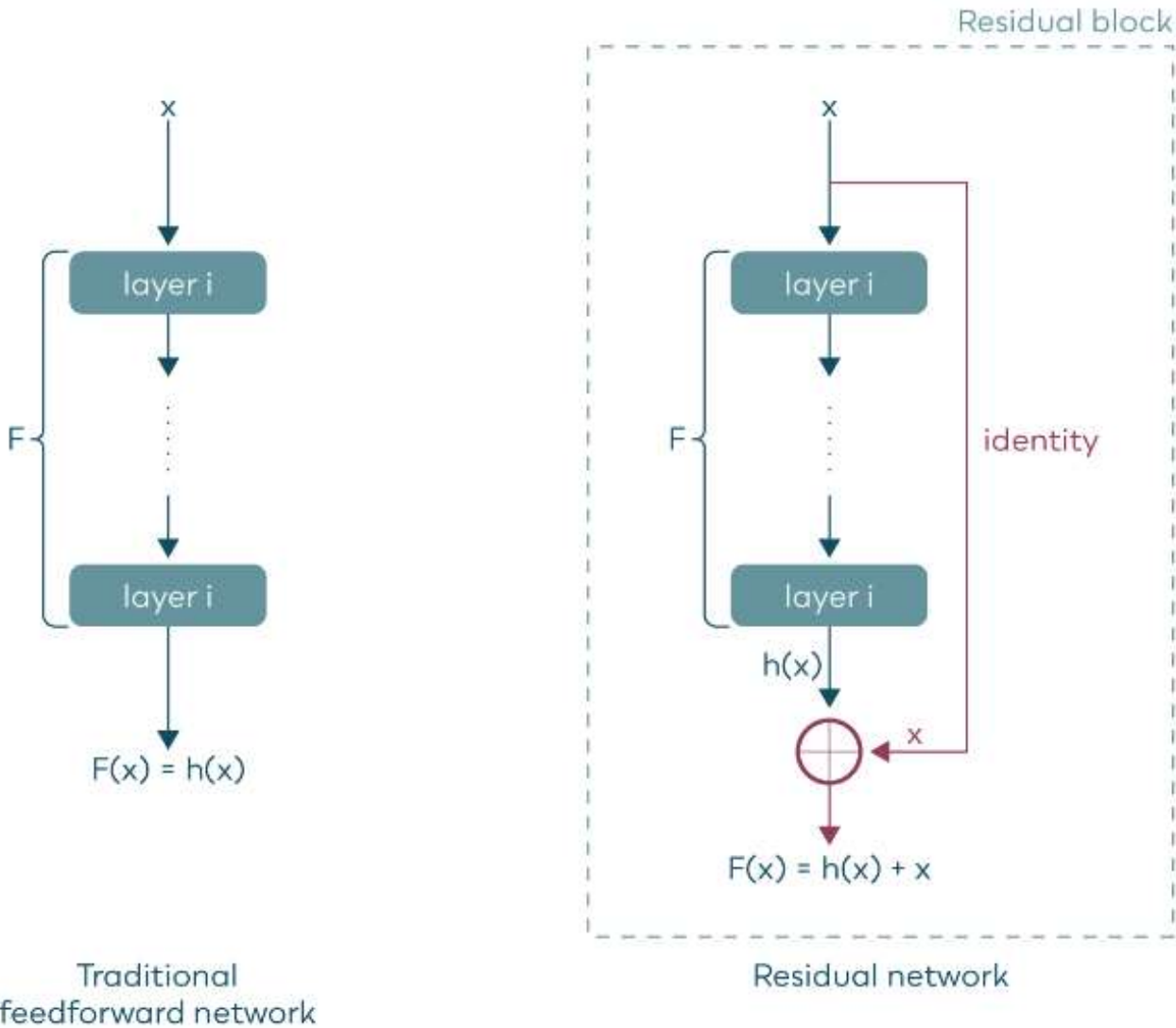
View layers room requirements EN17037

View label	Room with the lowest view level	View level for 50% of the living spaces
E	Insufficient	-
D	Minimum	-
C	Minimum	Medium
B	Medium	High
A	High	-

View quality apartment evaluation

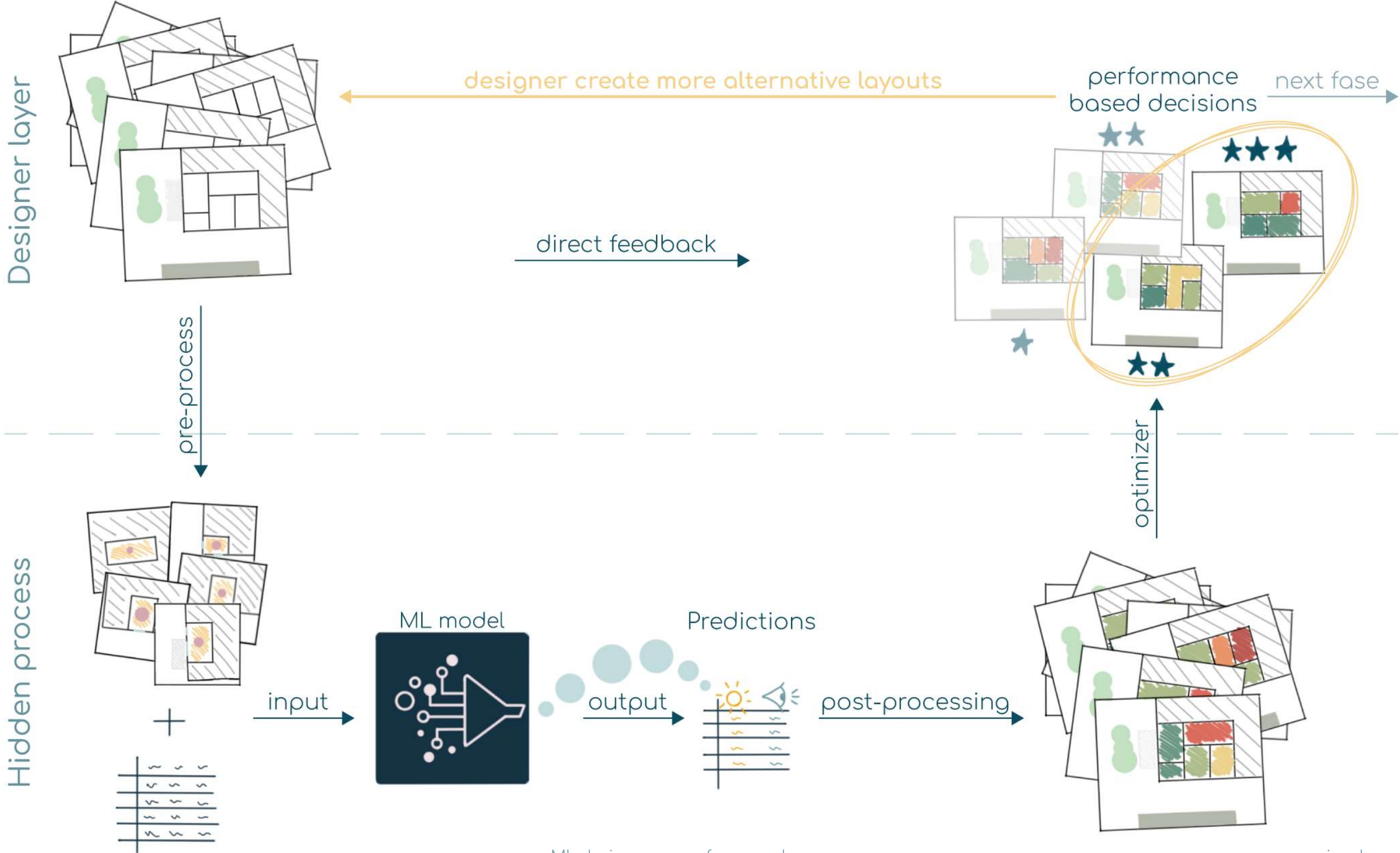
Residual networks (ResNet)

Skipping connections



ML design process framework

Guidance during design



ML design process framework

Guidance during design

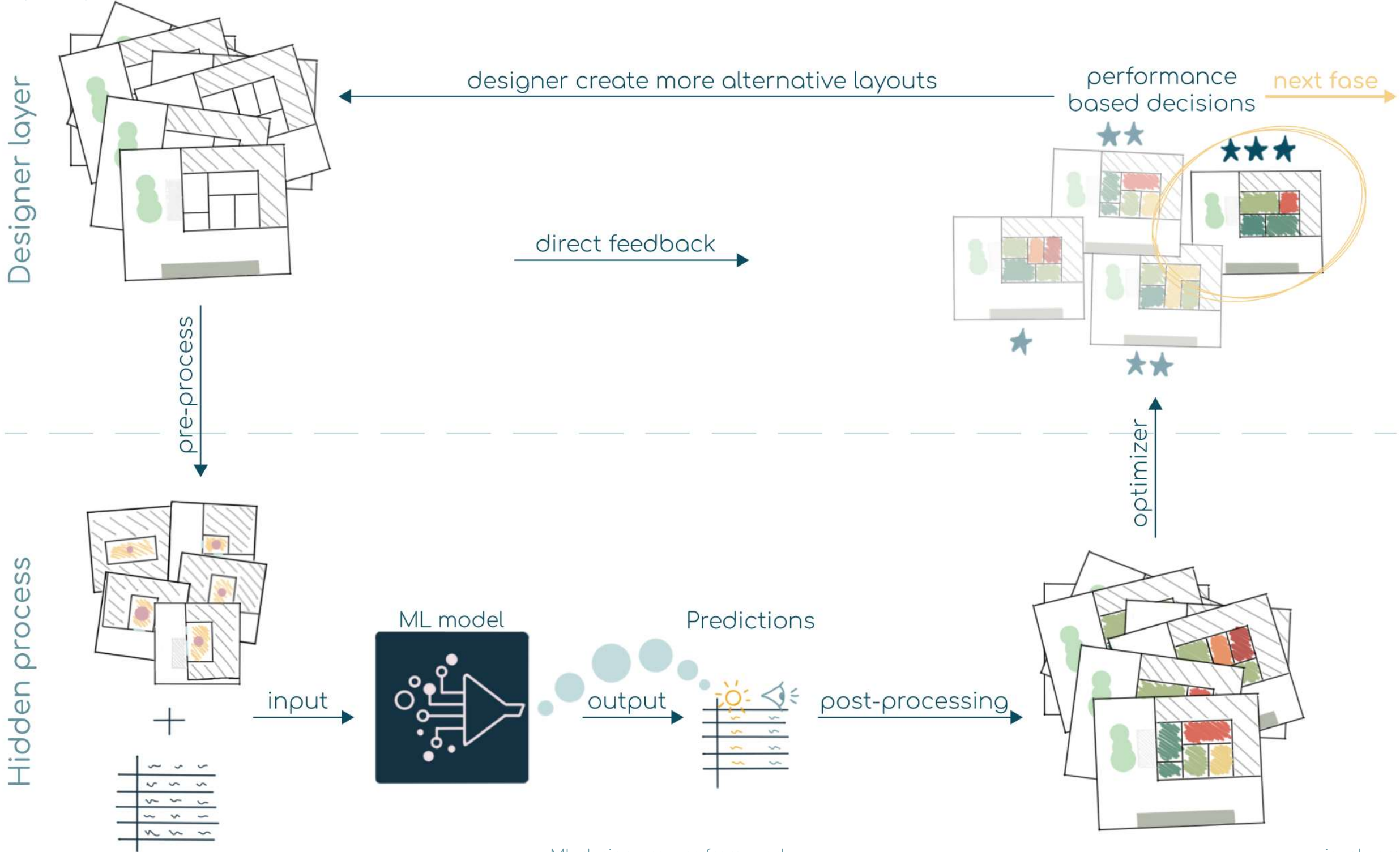
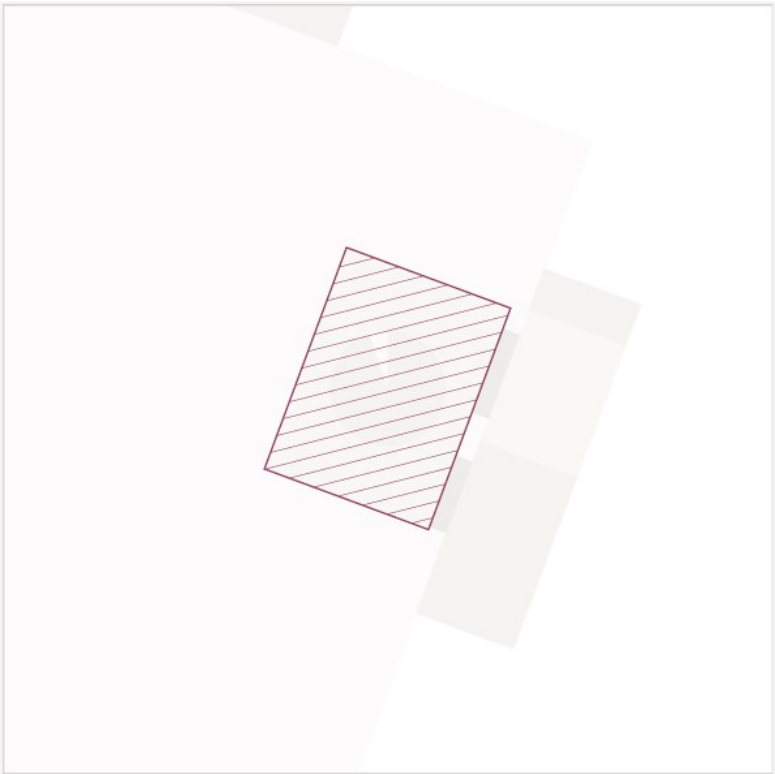
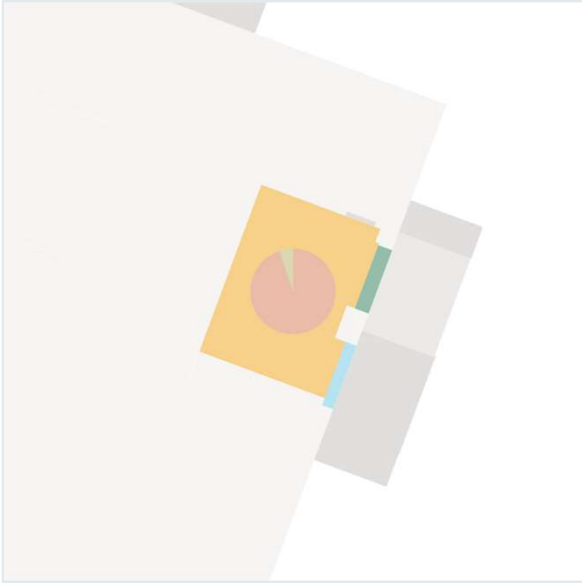
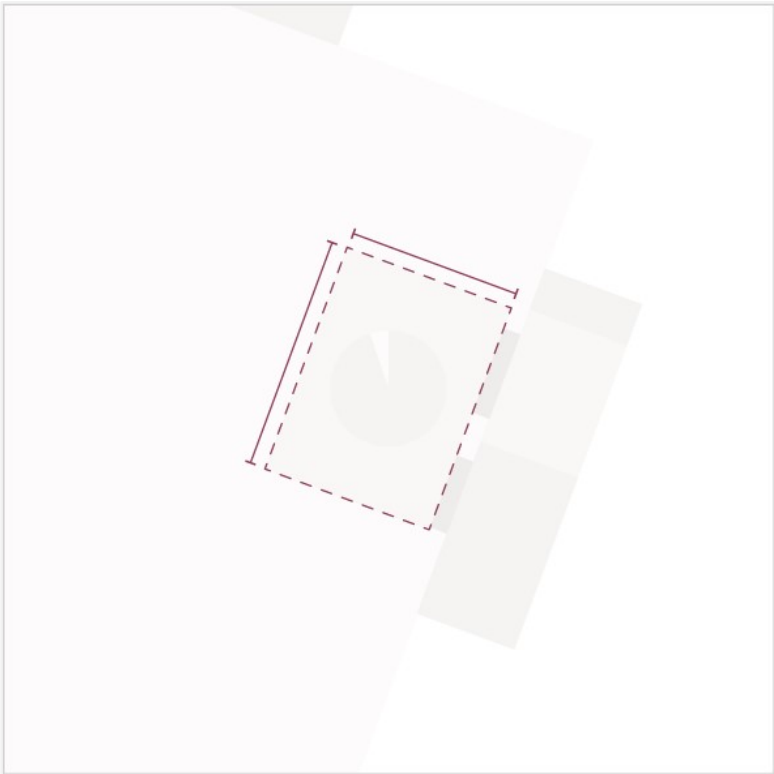


Image feature

Hidden features



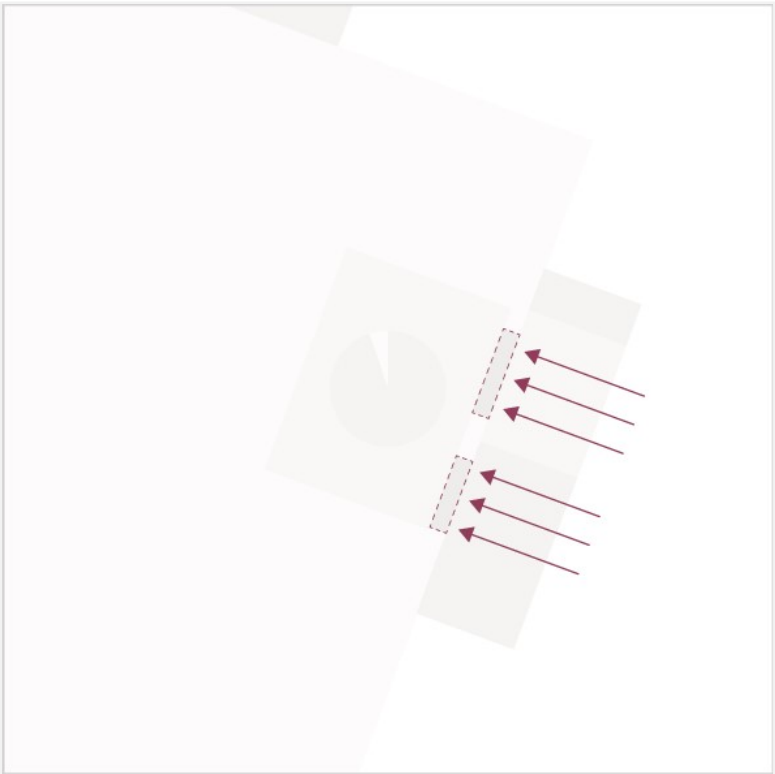
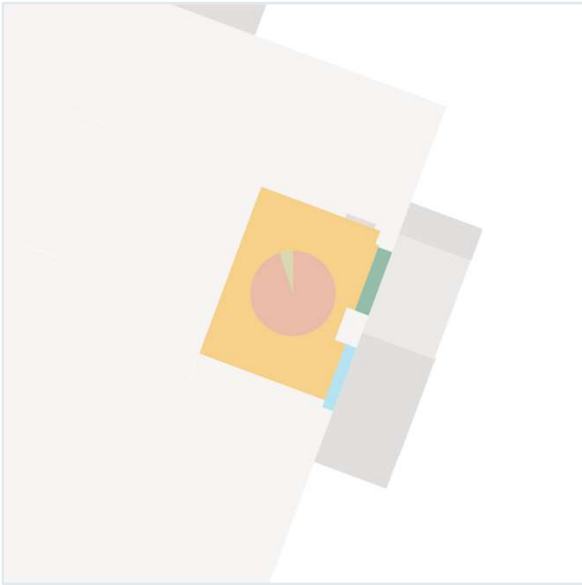
Room area



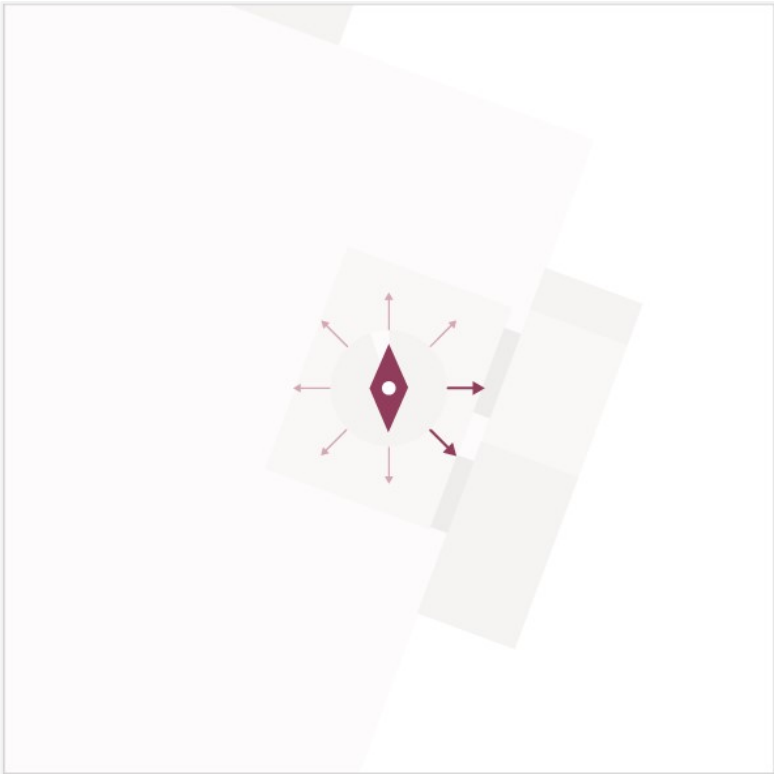
Depth to width ratio

Image feature

Hidden features



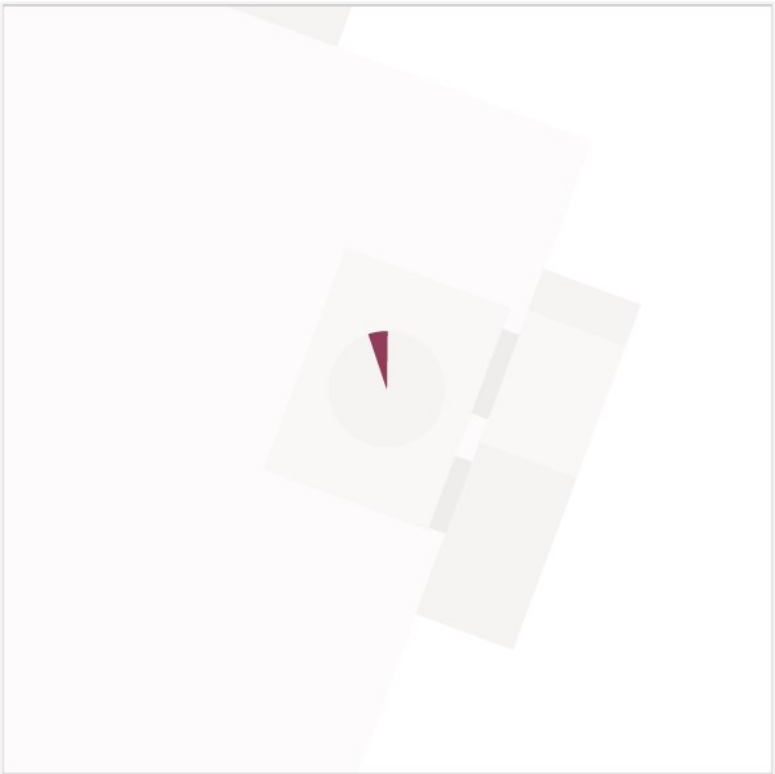
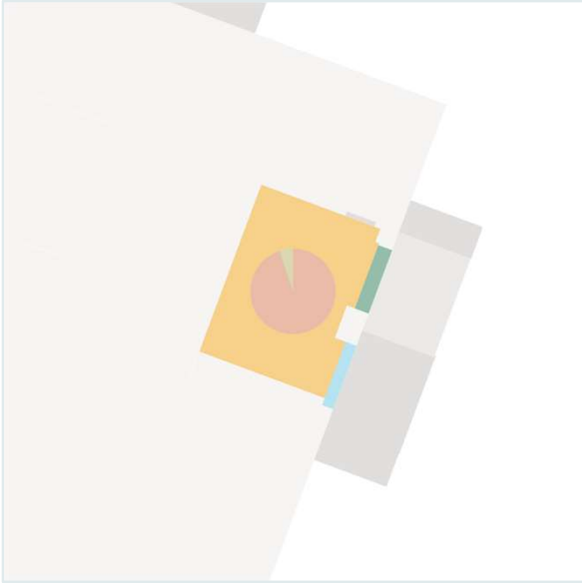
Window distribution



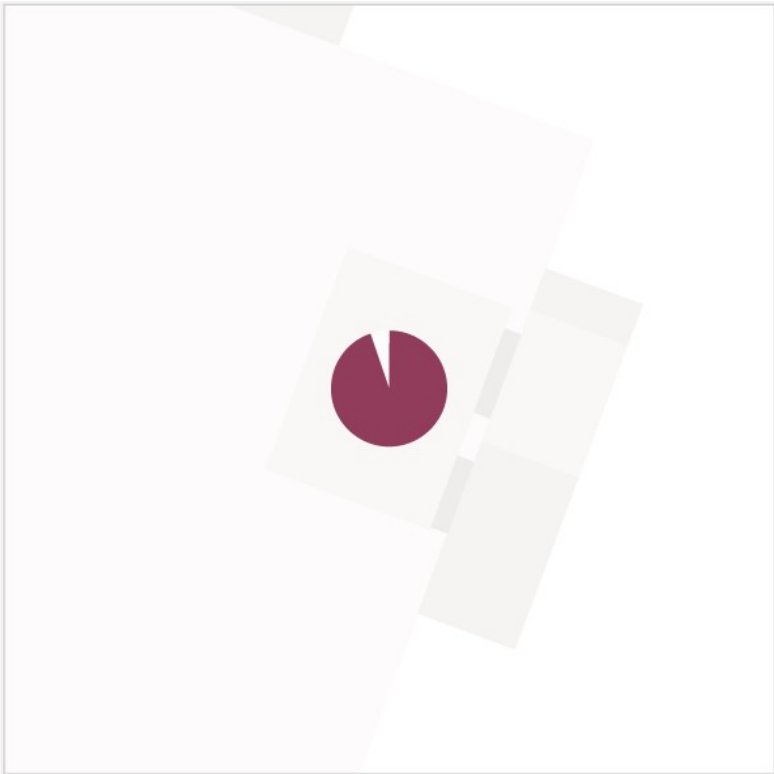
Room orientation

Image feature

Hidden features



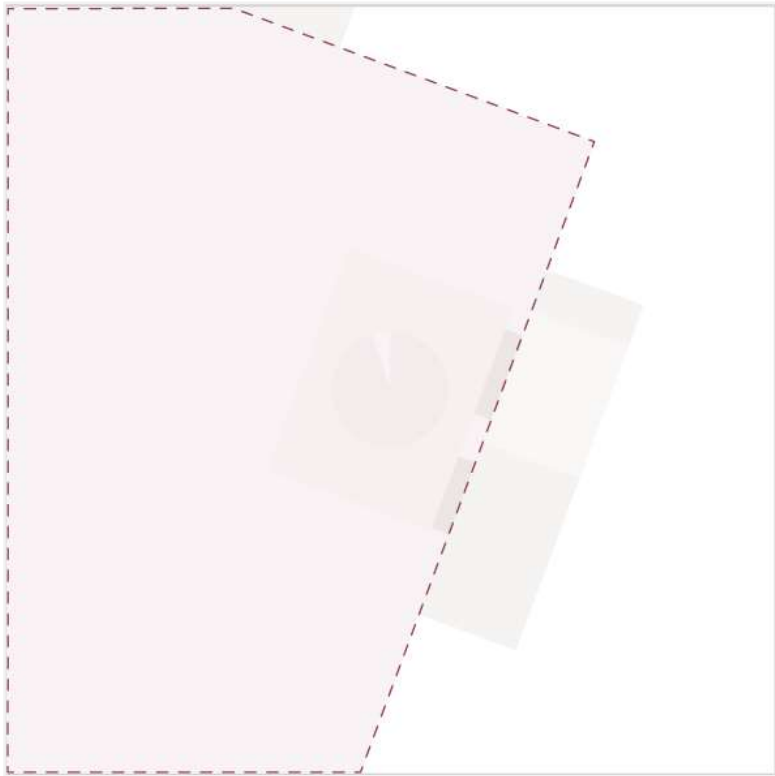
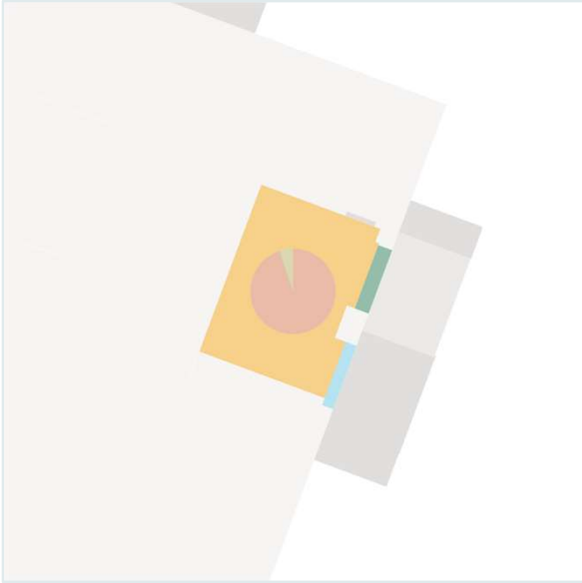
Nature obstructions



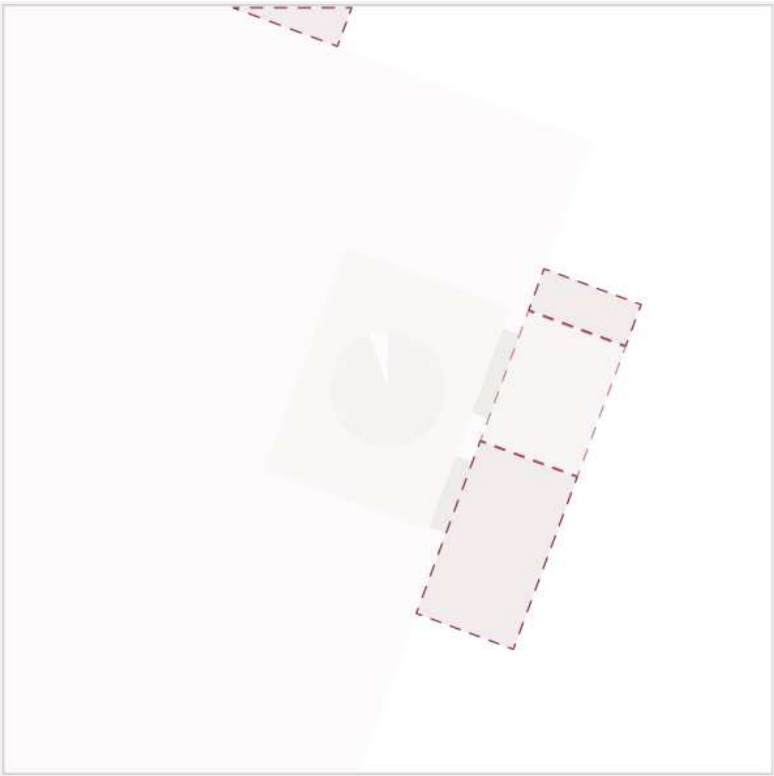
Urban obstructions

Image feature

Hidden features



Floor obstructions



Balcony / higher floor obstructions

Research questions

Sub-research questions

1. What are the guideline requirements for daylight and view quality in residential spaces?
2. How do daylight and view quality affect the overall quality of residential spaces?
3. What design parameters impact the performance of daylight and view in residential spaces?
4. What is the most appropriate machine learning model for predicting daylight and view quality in residential spaces?
5. How can a machine learning model be incorporated into the layout design process to assist designers?
6. What quantitative metrics can be utilised in the design process to evaluate and optimise residential layouts for visual comfort performance?

References

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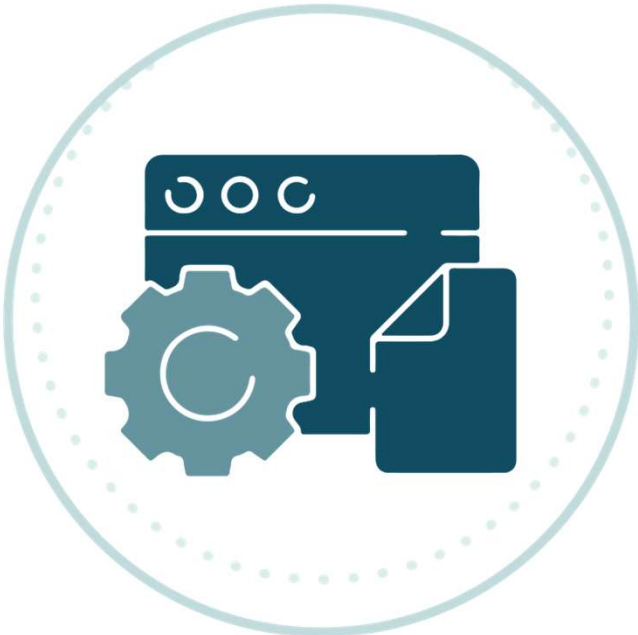
Research outline

Methodology



Discovery phase

- Literature study
- Relevant work



Development phase

- Dataset analysis & label/features
- ML process framework
- Training ML model



Evaluation phase

- Evaluate ML model
- Test ML process framework
- Conclusions