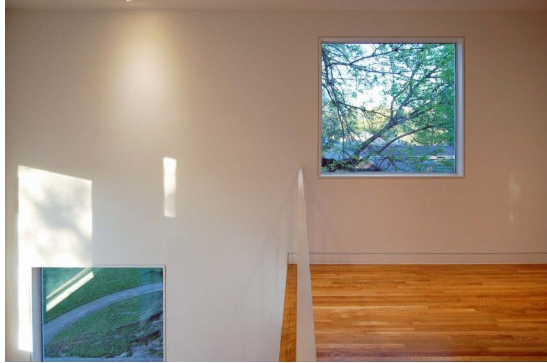# Window View Satisfaction Evaluation in Residential Buildings Using Machine Learning and Data
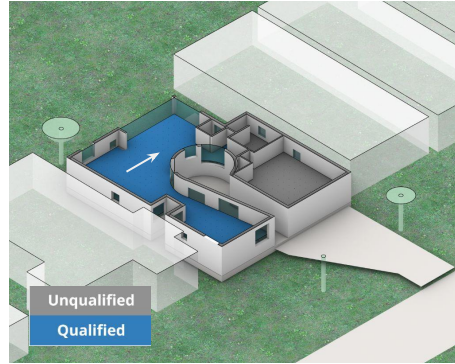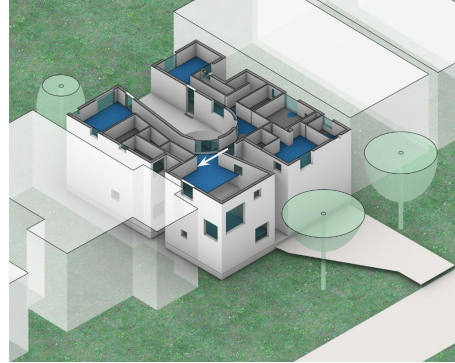
Jaeha Kim , Katharina Kral , Timur Dogan , Cornell University
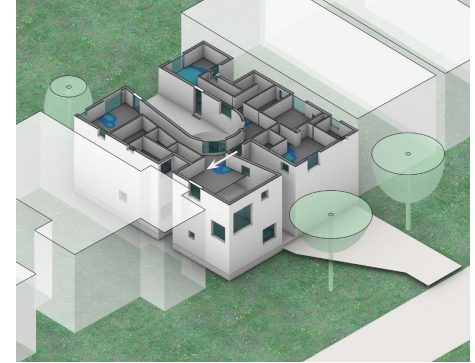
Application of LEED v4.1 and EN17037 (Climate Studio)

Existing View Evaluation Metrics

Actual View

LEED

EN17037

Unqualified / Qualified

Fail / Minimum / Medium / High

El House, Houston, TX, Designed by WW Architecture
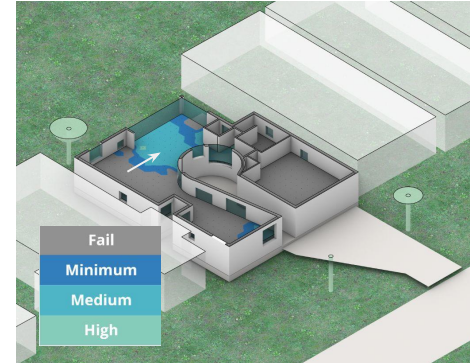
View Quality Metrics and Occupant Satisfaction

Existing Research

A window view quality assessment framework
Ko et al. (2021)

$$VQI = \underline{V_{content}} \cdot V_{access} \cdot V_{clarity}$$

$$V_{content} = L_{sky} + L_{landscape} \cdot wf_{ct.dis.} + L_{ground} \cdot wf_{movement} + L_{nature} \cdot wf_{nature}$$

View Quality = 1
$V_{content}$ =1; all three layers and nature
V_{access} = 1; high access
$V_{clarity}$ = 1; high clarity

View Quality = 0.75
$V_{content}$ = 0.75; 2 layers and nature
V_{access} = 1; high access
$V_{clarity}$ = 1; high clarity

View Quality = 0.375
$V_{content}$ = 0.75; 2 layers and nature
V_{access} = 0.5; minimum access
$V_{clarity}$ = 1; high clarity

View Quality = 0.375
$V_{content}$ = 0.75; 2 layers and nature
V_{access} = 1; high access
$V_{clarity}$ = 0.5; minimum clarity

View Quality = 0.125
$V_{content}$ = 0.5; 2 layers
V_{access} = 0.5; minimum access
$V_{clarity}$ = 0.5; minimum clarity

View Quality = 0.125
$V_{content}$ = 0.25; 1 layer (sky only)
V_{access} = 0.5; minimum access
$V_{clarity}$ = 1; high clarity

View Quality = 0
One of the variables is 0
(below minimum threshold)

$V_{content} = 0$ $V_{access} = 0$ $V_{clarity} = 0$

Evaluation of the effect of landscape distance seen in window views on visual satisfaction
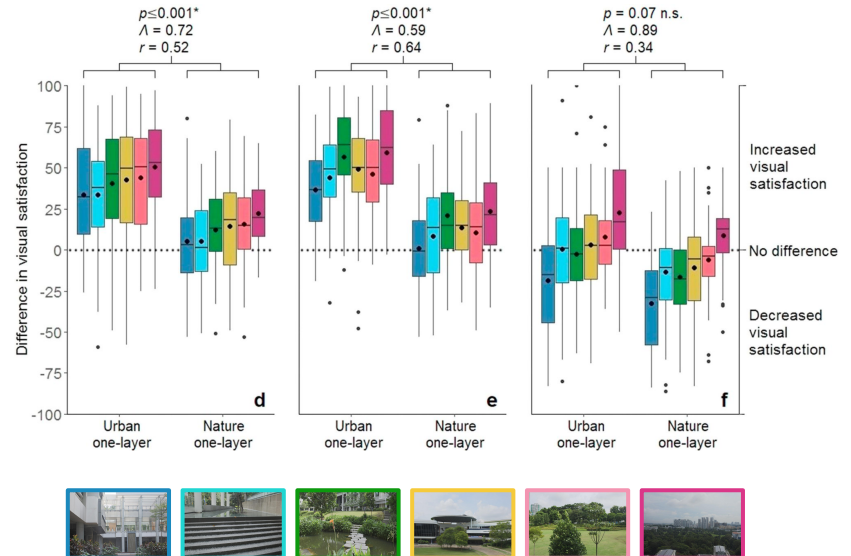*Kent et al. (2021)*

MANOVA online survey result on 6 view images (n = 91)

P value: t-test result for statistical significance
Λ (Wilk's Lambda): the percentage of variance in dependent variables not explained by differences independent variables
r (effect size): agreement degree with each other cross two experimental conditions

Comparison of View Quality Index with Occupant Satisfaction
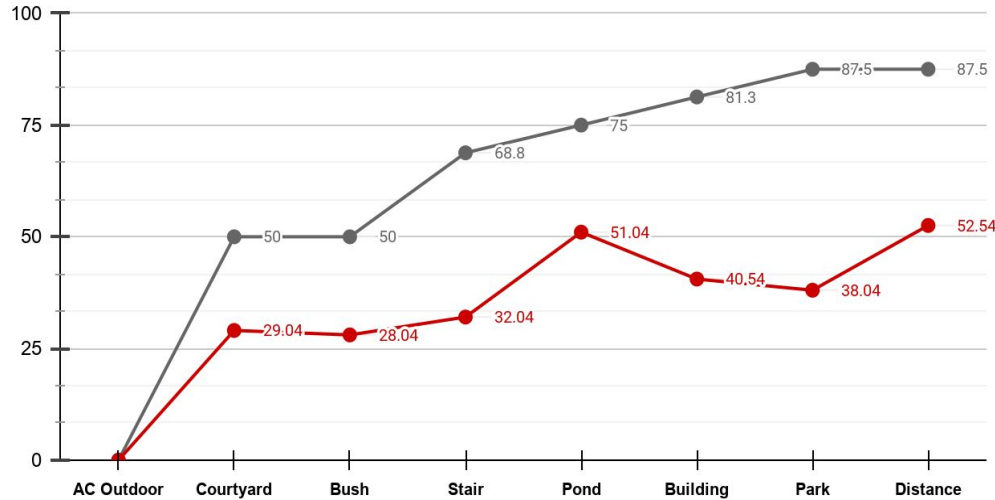
$$VQI = V_{content} \cdot V_{access} \cdot V_{clarity}$$

$V_{content} = L_{sky} + L_{landscape} \cdot wf_{ct.dis.} + L_{ground} \cdot wf_{movement} + L_{nature} \cdot wf_{nature}$

with

$L_{sky}, L_{landscape}, L_{ground}, L_{nature} = \begin{cases} 0.25 \; if \; present \; in \; the \; scene \\ 0 \; if \; absent \; in \; the \; scene \end{cases}$

$wf_{ct.dis.} = \begin{cases} 1 \; if \; 50 \; m < Content \; distance \\ 0.75 \; if \; 20 \; m < Content \; distance \; \leq 50 \; m \\ 0.5 \; if \; 6 \; m < Content \; distance \; \leq 20 \; m \\ 0 \; if \; Content \; distance \; \leq 6 \; m \end{cases}$ except preferred features (see Section 3.1),

$wf_{movement} = \begin{cases} 1 \; if \; distant \; dynamic \; feature(s)(> 6 \; m) \; is \; present \; in \; the \; scene \\ 0.5 \; if \; no \; dynamic \; feature(s)(\leq 6 \; m) \; is \; present \; in \; the \; scene \\ 0 \; if \; nearby \; dynamic \; feature(s)(\leq 6 \; m) \; is \; present \; in \; the \; scene \end{cases}$,

$wf_{nature} = \begin{cases} 1 \; if \; \% \; of \; natural \; features \; in \; the \; scene > 50 \; \% \\ 0.75 \; if \; 25 \; \% < \% \; of \; natural \; features \; in \; the \; scene \leq 50 \; \% \\ 0.5 \; if \; \% \; of \; natural \; features \; in \; the \; scene \leq 25 \; \% \\ 0 \; if \; no \; natural \; feature \; in \; the \; scene \end{cases}$

$V_{access} = \begin{cases} 1 \; if \; \alpha_{view} \geq \alpha_{saturation} \\ y \; if \; \alpha_{min} < \alpha_{view} < \alpha_{saturation} \; with \; y = \frac{1}{2} \left(\frac{\alpha_{view}}{\alpha_{saturation} - \alpha_{min}} \right) \\ 0.5 \; if \; \alpha_{view} = \alpha_{min} \\ 0 \; if \; \alpha_{view} < \alpha_{min} \end{cases}$

$V_{clarity} = \begin{cases} 1 \; if \; \beta_{clarity} \geq \beta_{saturation} \\ y \; if \; \beta_{min} < \beta_{clarity} < \beta_{saturation} \; with \; y = \frac{1}{2} \left(\frac{\beta_{clarity}}{\beta_{saturation} - \beta_{min}} \right) \\ 0.5 \; if \; \beta_{clarity} = \beta_{min} \\ 0 \; if \; \beta_{clarity} < \beta_{min} \end{cases}$

Legend:
- View Content Framework
- Survey Result

Chart data (x-axis: AC Outdoor, Courtyard, Bush, Stair, Pond, Building, Park, Distance):

View Content Framework: 0, 50, 50, 68.8, 75, 81.3, 87.5, 87.5

Survey Result: 0, 29.04, 28.04, 32.04, 51.04, 40.54, 38.04, 52.54

When looking at the window view, please rate the following your degree of satisfaction based on the criteria "Visual Content"

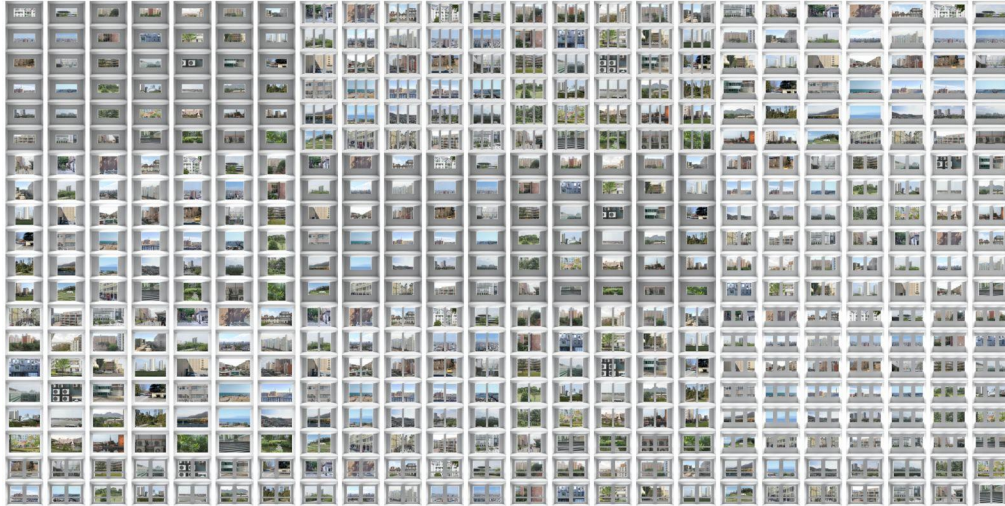Very dissatisfied | Dissatisfied | Somewhat dissatisfied | Neither satisfied nor dissatisfied | Somewhat satisfied | Satisfied | Very satisfied

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Expert System Data Collection (Label)

987 Different Window Views Evaluation with 240 Participants

↕

23 existing studies used an average of **five** view scenarios,
while only three studies used an average of **112** view scenarios.

| Unsatisfactory | | | | | Neither of them | | | | Satisfactory |
| -5 | -4 | -3 | -2 | -1 | 0 | 1 | 2 | 3 | 4 | 5 |

View Content

View Access

Privacy

Overall Rating

Permutation Feature Importance

WindowAreaSum | -0.114232

BuildingClosestDist | -0.081761

FloorHeights | -0.071684

EquipmentPtsCountRatio| -0.059538

TreeClosestDist | -0.044441

WaterPtsCountRatio | -0.038019

TreePtsCountRatio | -0.037109

SkyPtsCountRatio | -0.033924

ParkingLotClosestDist| -0.031622

Z1PtsCountRatio | 0.018565

ContextWindowPtsCountRatio| -0.017601

BuildingPtsCountRatio| -0.012330

WaterClosestDist | -0.011655

Z3PtsCountRatio | 0.010880

RoadPtsCountRatio | -0.008237

EquipmentClosestDist| -0.007951

LandmarkPtsCountRatio| -0.007194

ContextWindowClosestDist| -0.006741

ElementNumber | -0.006587

SidewalkPtsCountRatio| -0.005666

RoadClosestDist | -0.002915

Z4PtsCountRatio | 0.002381

SidewalkClosestDist | 0.002316

Z2PtsCountRatio | -0.001712

InteriorClosestDist | 0.001388

GrassClosestDist | -0.001383

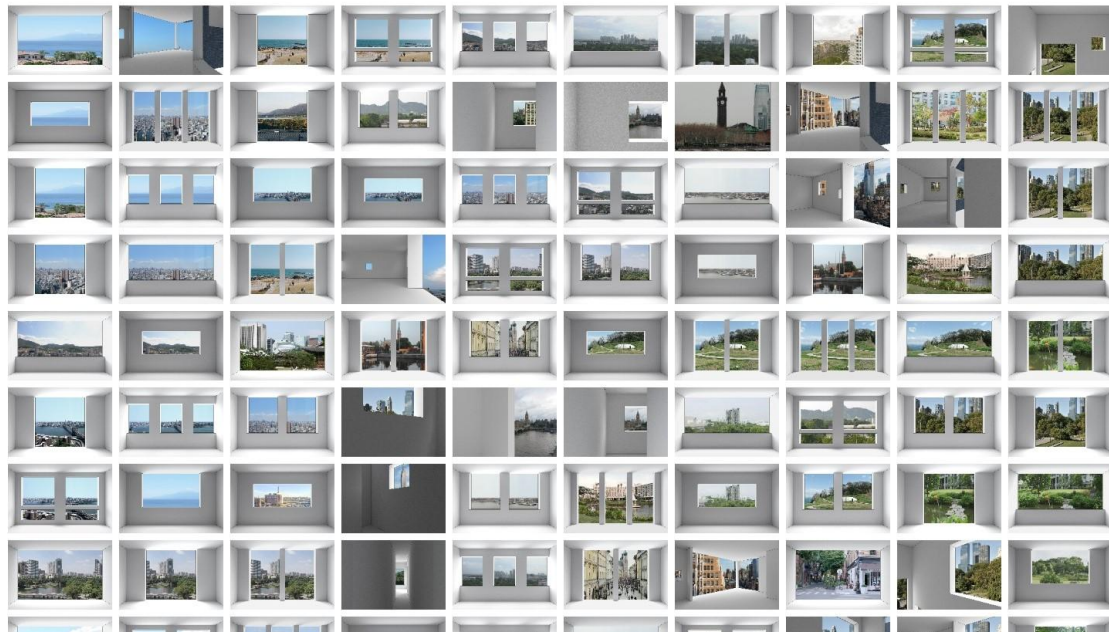ParkingLotPtsCountRatio| -0.000758

GrassPtsCountRatio | -0.000711

InteriorPtsCountRatio| 0.000000

LandmarkClosestDist | 0.000000

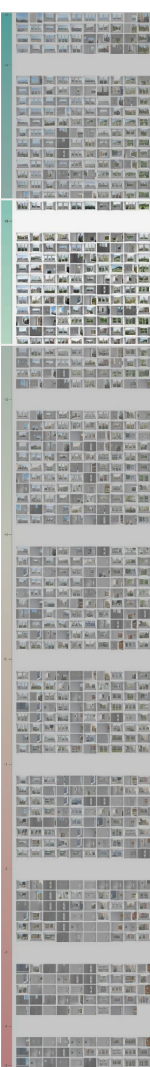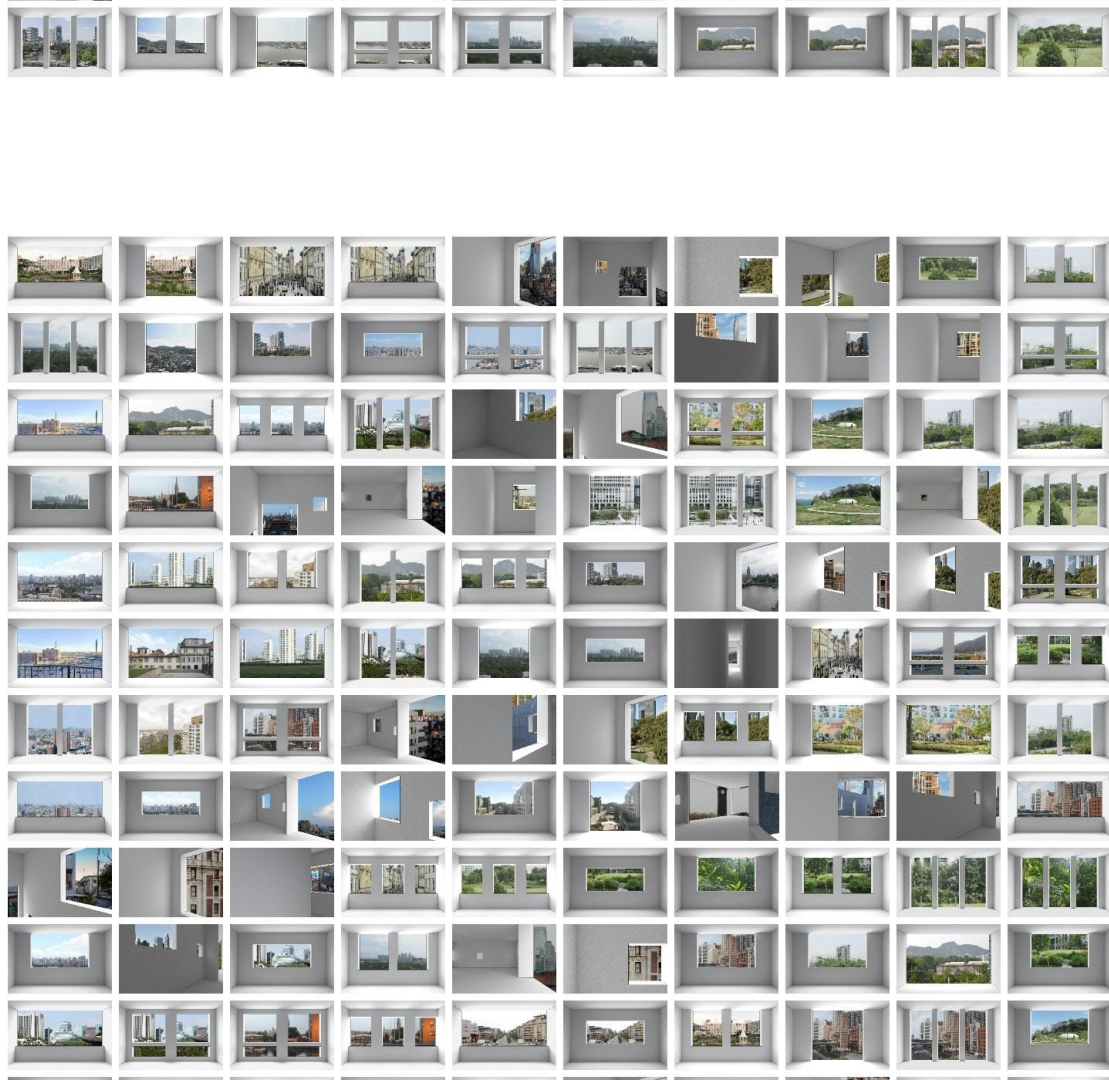+5

+4

**View Satisfaction Survey Result_Content**

Permutation Feature Importance

WindowAreaSum | -0.114232

BuildingClosestDist | -0.081761

FloorHeights | -0.071684

EquipmentPtsCountRatio| -0.059538

TreeClosestDist | -0.044441

WaterPtsCountRatio | -0.038019

TreePtsCountRatio | -0.037109

SkyPtsCountRatio | -0.033924

ParkingLotClosestDist| -0.031622

Z1PtsCountRatio | 0.018565

ContextWindowPtsCountRatio| -0.017601

BuildingPtsCountRatio| -0.012330

WaterClosestDist | -0.011655

Z3PtsCountRatio | 0.010880

RoadPtsCountRatio | -0.008237

EquipmentClosestDist| -0.007951

LandmarkPtsCountRatio| -0.007194

ContextWindowClosestDist| -0.006741

ElementNumber | -0.006587

SidewalkPtsCountRatio| -0.005666

RoadClosestDist | -0.002915

Z4PtsCountRatio | 0.002381

SidewalkClosestDist | 0.002316

Z2PtsCountRatio | -0.001712

InteriorClosestDist | 0.001388

GrassClosestDist | -0.001383

ParkingLotPtsCountRatio| -0.000758

GrassPtsCountRatio | -0.000711

InteriorPtsCountRatio| 0.000000

LandmarkClosestDist | 0.000000

+3

Feature Data Collection by Raytracing
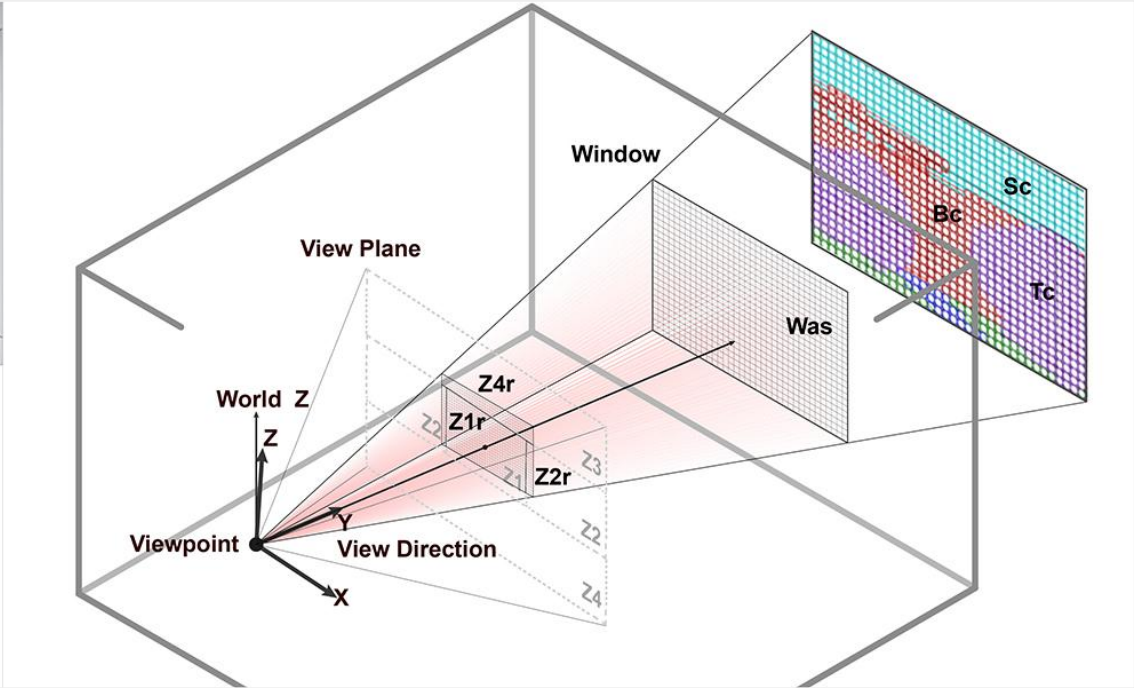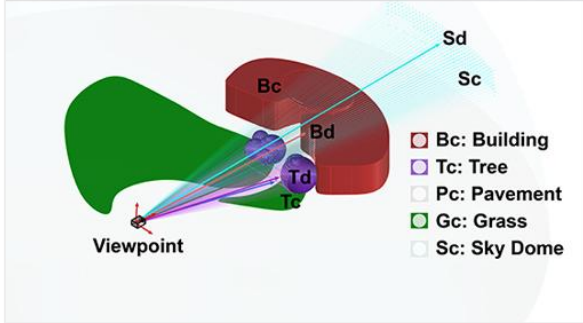
31 Features Window Size(1), Window Composition(4), View Content Visible Area(12), Distance to Visible Objects(12), Additional Parameters(2)
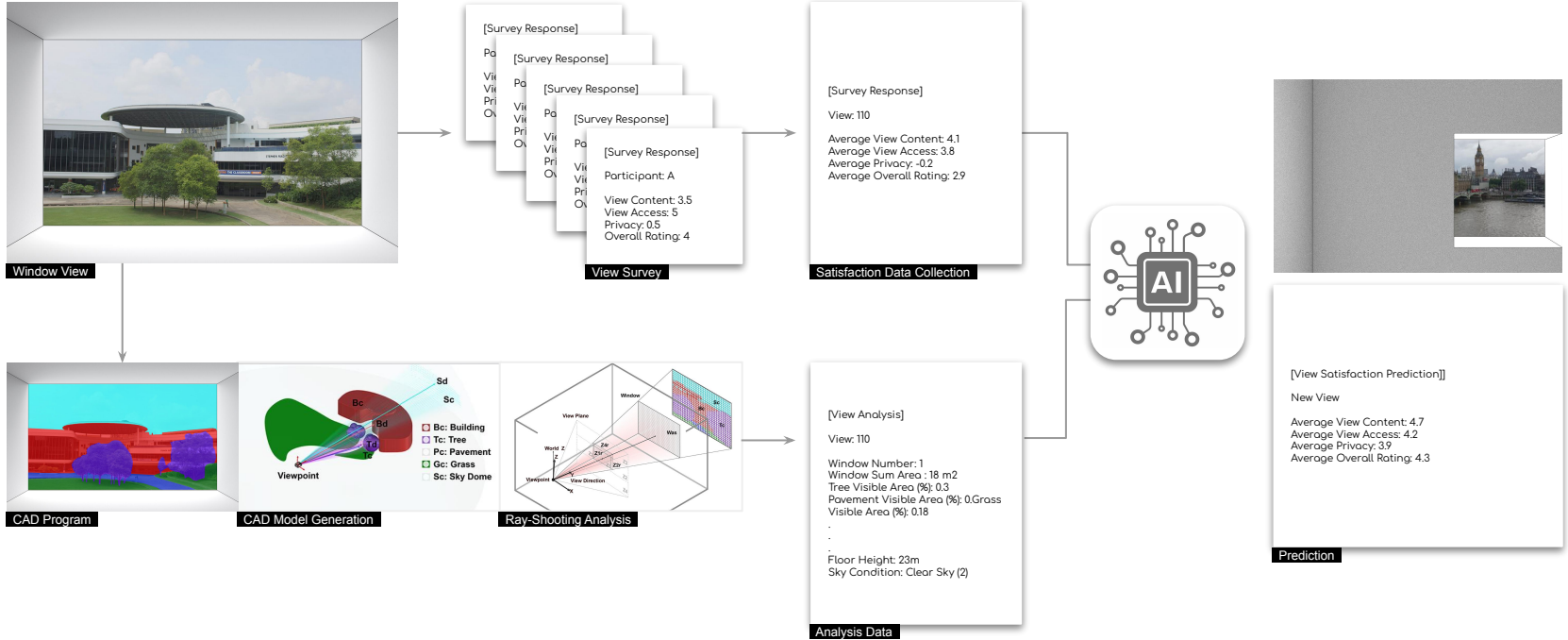
3D Model Generation for Raytracing

Material ID

Building	Interior
	Exterior
	Glazing (Window)
Context_Object	Context_Building
	Context_Window
	Equipment
	Landmark
Pavement	Sidewalk
	Road
	Parking Lot
Nature	Tree
	Grass
	Water

77 Environments X **10~27** Window Shapes = **987** Selected View Scenarios

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Machine Learning Process to Create View Satisfaction Predictor

Data + Machine Learning

Window View

[Survey Response]

[Survey Response]

[Survey Response]

[Survey Response]

[Survey Response]

Participant: A

View Content: 3.5
View Access: 5
Privacy: 0.5
Overall Rating: 4

View Survey

[Survey Response]

View: 110

Average View Content: 4.1
Average View Access: 3.8
Average Privacy: -0.2
Average Overall Rating: 2.9

Satisfaction Data Collection

CAD Program

Bc: Building
Tc: Tree
Pc: Pavement
Gc: Grass
Sc: Sky Dome

Viewpoint

CAD Model Generation

Ray-Shooting Analysis

[View Analysis]

View: 110

Window Number: 1
Window Sum Area : 18 m2
Tree Visible Area (%): 0.3
Pavement Visible Area (%): 0.Grass
Visible Area (%): 0.18
.
.
.
Floor Height: 23m
Sky Condition: Clear Sky (2)

Analysis Data

AI

[View Satisfaction Prediction]]

New View

Average View Content: 4.7
Average View Access: 4.2
Average Privacy: 3.9
Average Overall Rating: 4.3

Prediction

Comparison between Framework(Ko et al), ML Prediction, and Survey

Seemingly similar images but having different view content satisfactions

Fidelity Comparison

View Content Satisfaction

+5.0
+2.5
0
-2.5
-5.0

⬛ **View Content Framework Score (Ko et al. 2021)**
⬛ **View Content Satisfaction Prediction**
⬛ **View Content Satisfaction Survey Result**

$MAE_{Framework} = 2.03$ $RMSE_{Framework} = 2.32$
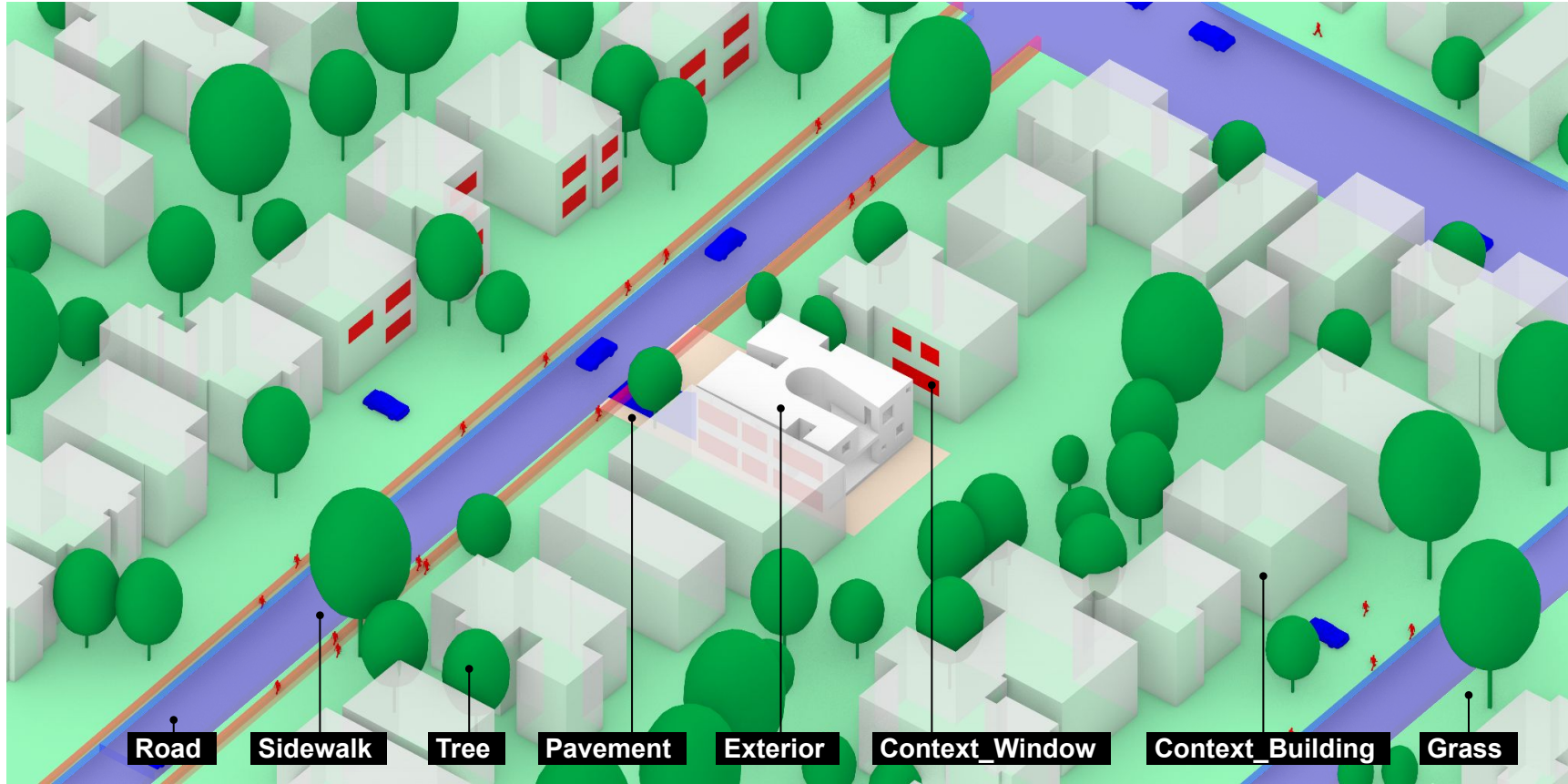$MAE_{SeEmo} = 0.76$ $RMSE_{SeEmo} = 0.91$

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Scatter Plot of the View Data Set

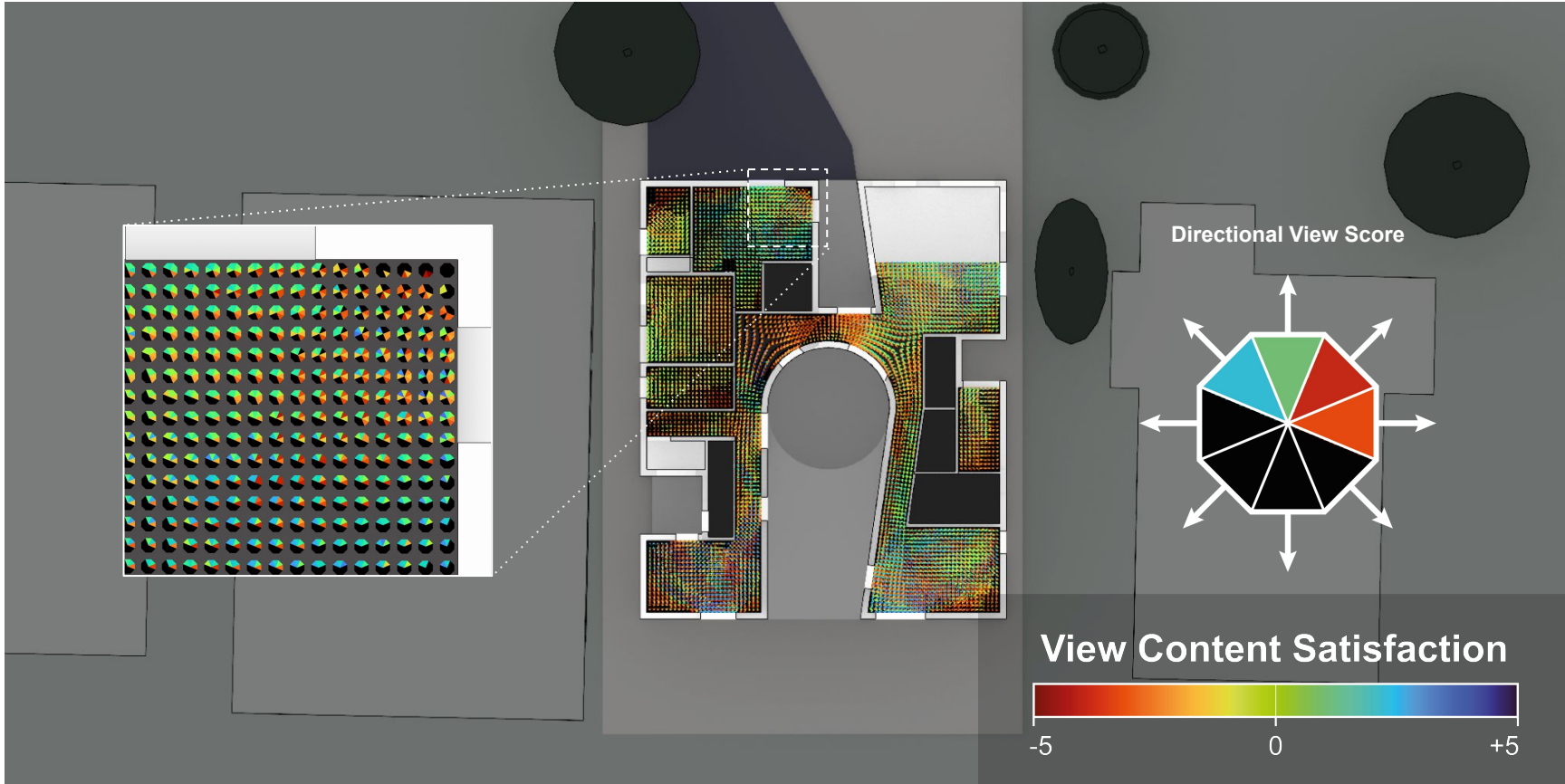Expanding Window View Scenarios
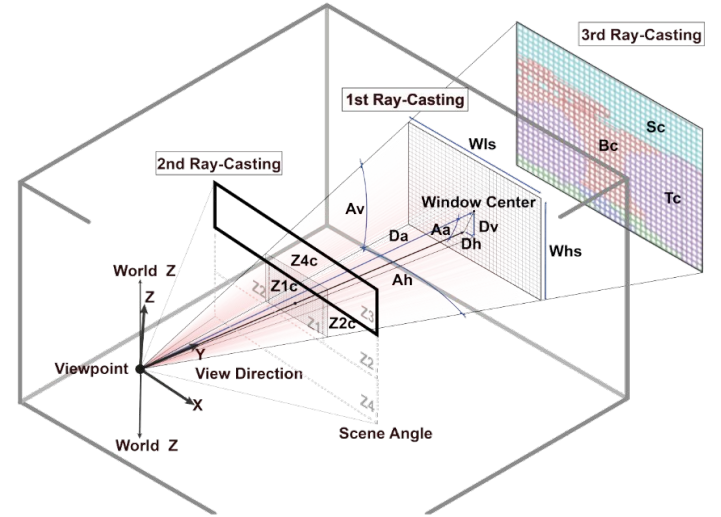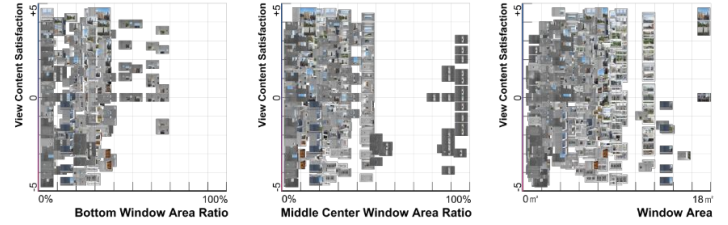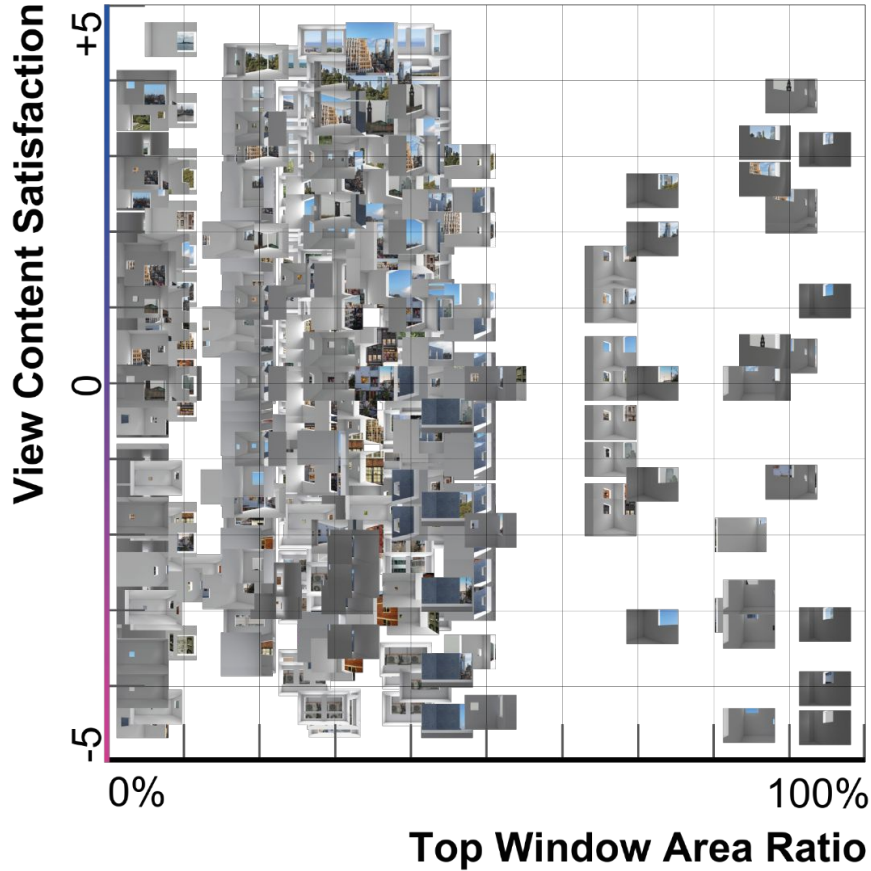
Trained ML Performance

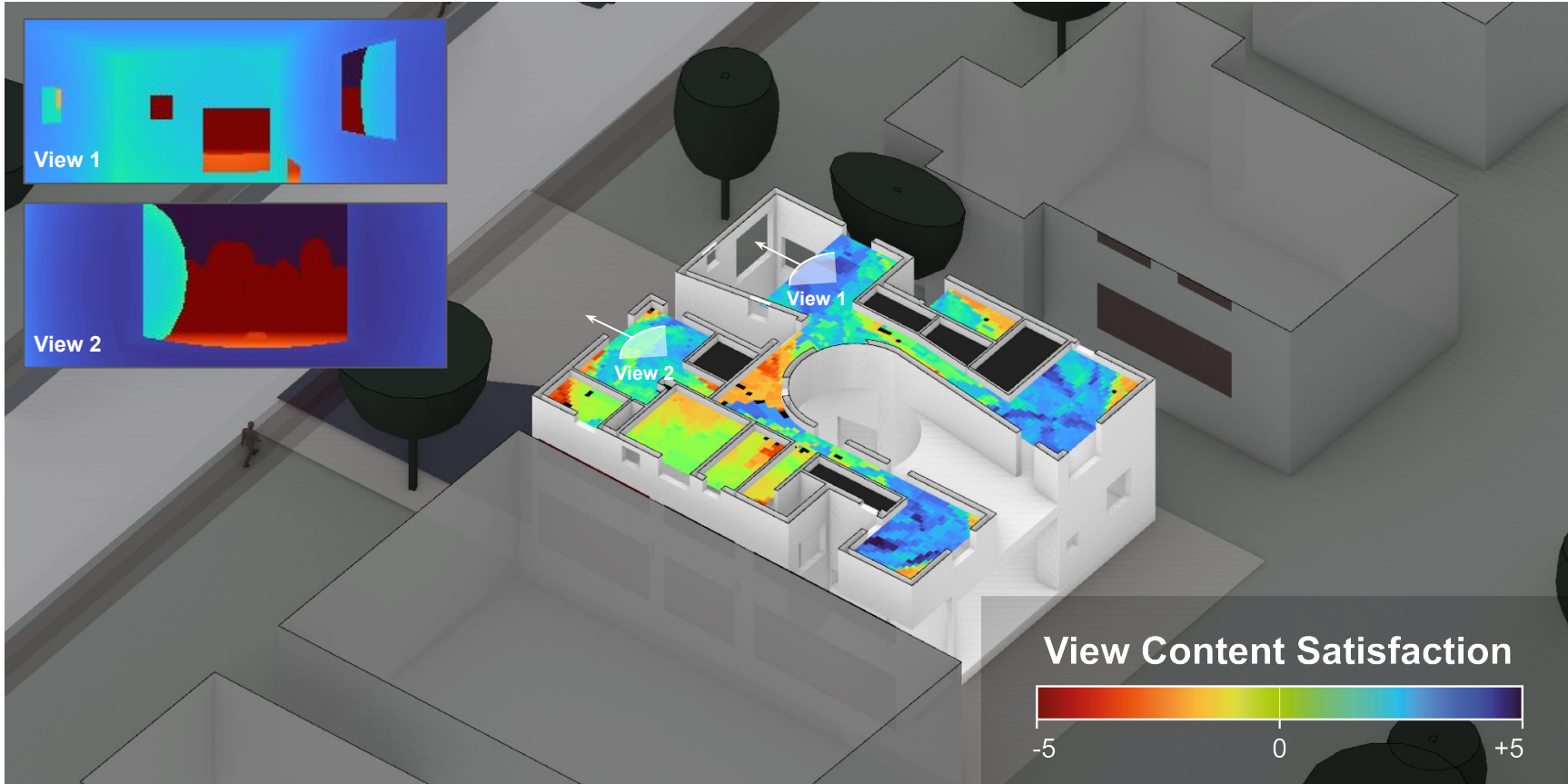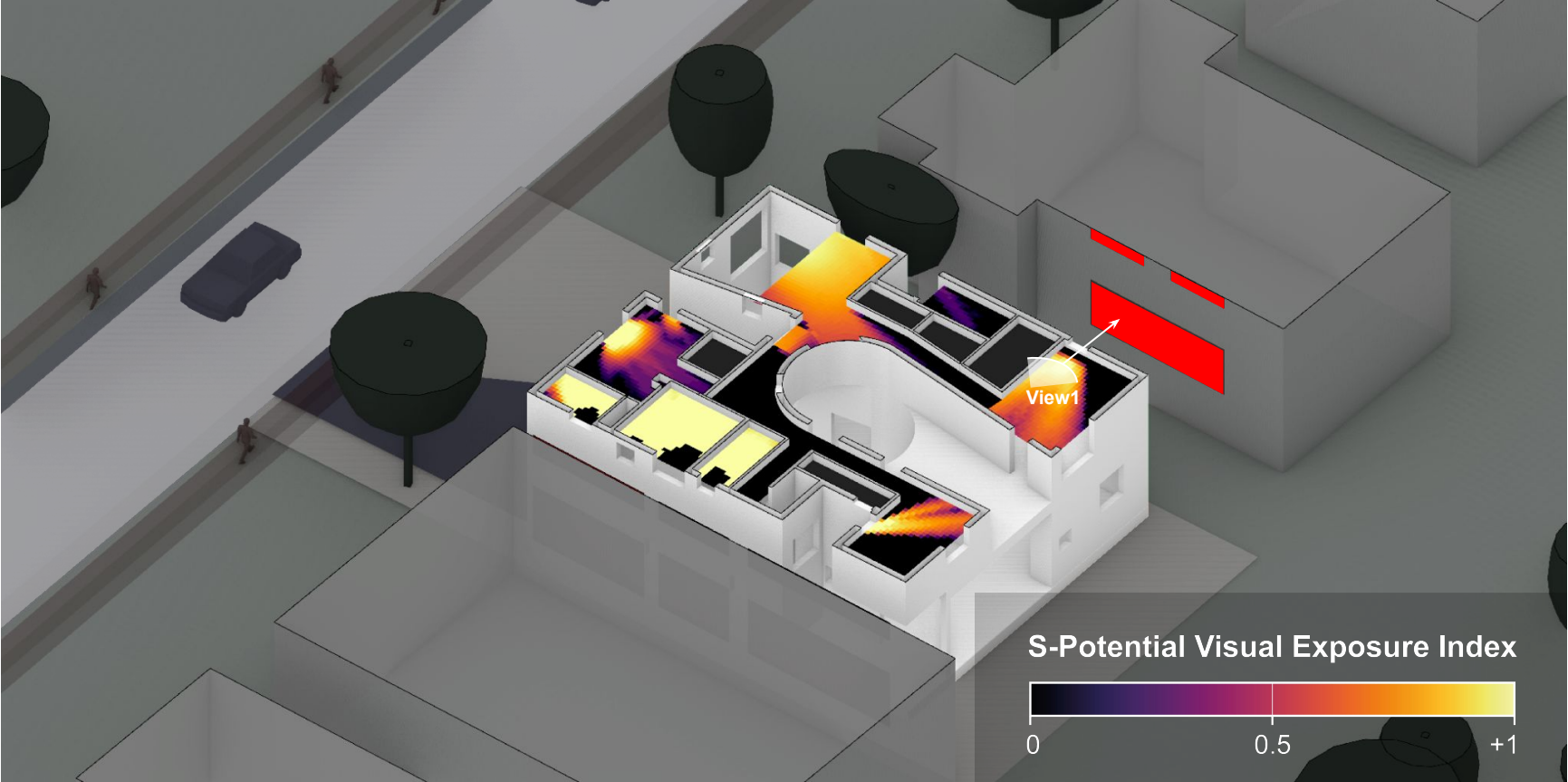|	Overall View Satisfaction	View Content Satisfaction
	ML Performance	
Prediction Accuracy	R2: 0.81 RMSE: 0.93 FastTreeRegression	R2: 0.84 RMSE: 0.90 LightGBMRegression
Permutation Feature Importance (Top 10)	WindowAreaSum Sky Visible Area BuildingDist Z1 Visible Area Equipment Visible Area FloorHeights Water Visible Area ContextWindowDist Tree Visible Area Z4 Visible Area . . .	WindowAreaSum BuildingDist FloorHeights Equipment Visible Area TreeDist Water Visible Area Tree Visible Area Sky Visible Area ParkingLotDist Z1 Visible Area . . .

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EL House, Texas (WW Architecture)

Architecture Design Application

Road Sidewalk Tree Pavement Exterior Context_Window Context_Building Grass

Satisfaction Prediction : View Content (Pie)

Architecture Design Application

Directional View Score

View Content Satisfaction

-5   0   +5

Satisfaction Prediction : View Content (Pixel)

Architecture Design Application

View 1

View 2

View 1

View 2

View Content Satisfaction

-5   0   +5

Seemo-Potential Visual Exposure Index (Pixel)

Architecture Design Application

View1

S-Potential Visual Exposure Index

0   0.5   +1

Balancing between view content satisfaction and privacy satisfaction
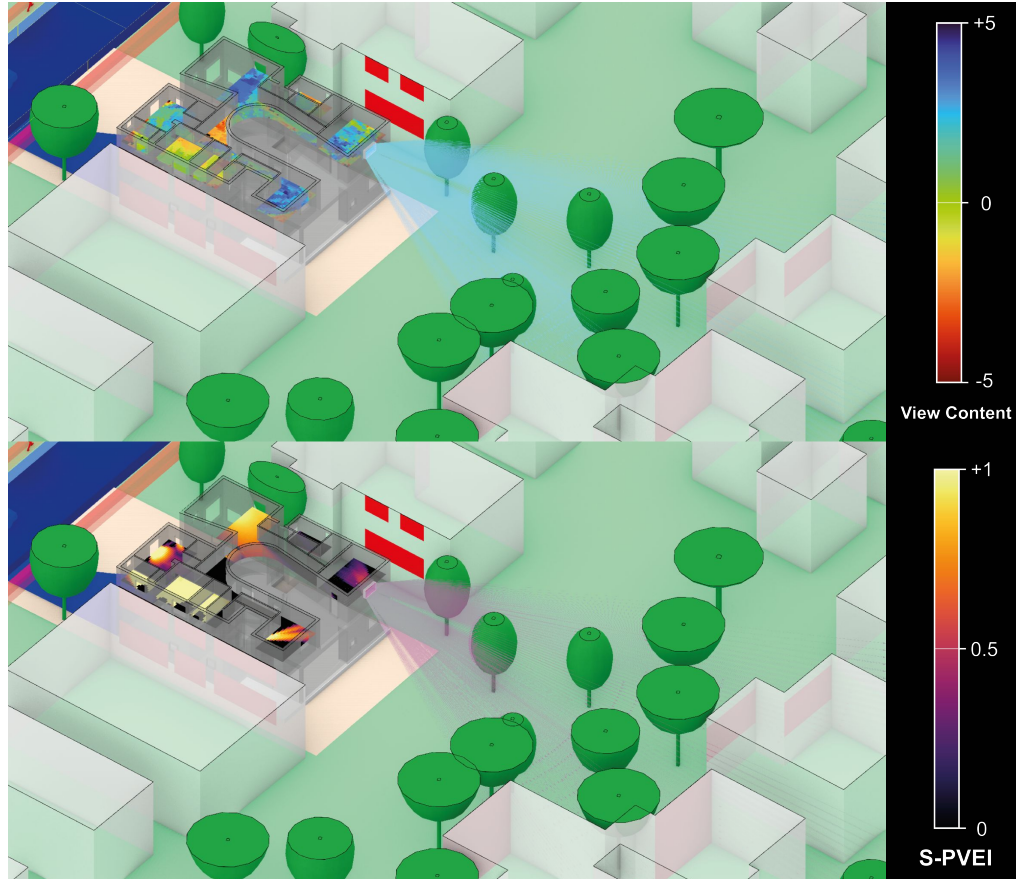
Thank you for listening

Jaeha Kim, Katharina Kral, Timur Dogan
jk2894@cornell.edu
Environmental Systems Lab / Cornell University