Window View Satisfaction Evaluation in Residential Buildings Using Machine Learning and Data

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Application of LEED v4.1 and EN17037 (Climate Studio)

Existing View Evaluation Metrics

El House, Houston, TX, Designed by WW Architecture
A window view quality assessment framework
Ko et al. (2021)

\[ V_{QI} = V_{content} \cdot V_{access} \cdot V_{clarity} \]

\[ V_{content} = L_{sky} + L_{landscape} \cdot W_{fatis} + L_{ground} \cdot W_{fmovement} + L_{nature} \cdot W_{fnature} \]

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)

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

**View Quality Metrics and Occupant Satisfaction**

- **Excellent**: View quality = 1
  - Visual = 0: all three layers and nature
  - Visual = 1: high access
  - Visual = 1: high clarity

- **Good**: View quality = 0.75
  - Visual = 0.75: 2 layers and nature
  - Visual = 1: high access
  - Visual = 1: high clarity

- **Sufficient**: View quality = 0.25
  - Visual = 0.25: 2 layers and nature
  - Visual = 0.5: maximum access
  - Visual = 1: high clarity

- **Insufficient**: View quality = 0
  - Visual = 0: 1 layer (sky only)
  - Visual = 0: 1 layer (sky only)
Comparison of View Quality Index with Occupant Satisfaction

Existing Research

View Content Framework

Survey Result

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

\[ VQI = V_{content} \cdot V_{access} \cdot V_{clarity} \]

\[ V_{content} = \begin{cases} 1 & \text{if Pet / Family present} \\ 0.5 & \text{if Grandparents present} \\ 0.25 & \text{if present in the scene} \end{cases} \]

\[ V_{access} = \begin{cases} 1 & \text{if Ground Level} \\ 0.5 & \text{if 1-2 Stories} \\ 0.25 & \text{if 3+ Stories} \end{cases} \]

\[ V_{clarity} = \begin{cases} 1 & \text{if % Natural Features > 50%} \\ 0.5 & \text{if % Natural Features < 50%} \end{cases} \]
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.
View Satisfaction Survey Results

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
- ZZPtsCountRatio = -0.001712
- InteriorClosestDist = 0.001388
- GrassClosestDist = -0.001383
- ParkingLotPtsCountRatio = -0.000758
- GrassPtsCountRatio = -0.000711
- InteriorPtsCountRatio = 0.000000
- LandmarkClosestDist = 0.000000
Permutation Feature Importance

WindowAreaSum | -0.114232
BuildingClosestDist | -0.081761
FloorHeights | -0.071684
EquipmentPtsCountRatio| -0.059538
TreeClosestDist | -0.044441
WoodPtsCountRatio | -0.038019
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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
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

![3D Models]

- Interior
- Exterior
- Glazing (Window)
- Context_Building
- Context_Window
- Equipment
- Landmark
- Sidewalk
- Road
- Parking Lot
- Tree
- Grass
- Water

77 Environments X 10–27 Window Shapes = 987 Selected View Scenarios
Machine Learning Process to Create View Satisfaction Predictor

[Survey Response]
Participant: A
View Content: 3.5
View Access: 5
Privacy: 0.5
Overall Rating: 4

[Survey Response]
Participant: A
View Content: 3.5
View Access: 5
Privacy: 0.5
Overall Rating: 4

[Survey Response]
Participant: A
View Content: 3.5
View Access: 5
Privacy: 0.5
Overall Rating: 4

[Survey Response]
Participant: A
View Content: 3.5
View Access: 5
Privacy: 0.5
Overall Rating: 4

[View Analysis]
View: 110
Average View Content: 4.1
Average View Access: 3.8
Average Privacy: 0.2
Average Overall Rating: 2.9

[View Analysis]
View: 110
Window Number: 1
Window Sum Area: 18 m²
Tree Visible Area (%): 0.3
Roof Visible Area (%): 0.1
Grass Visible Area (%): 0.18

Floor Height: 23m
Sky Condition: Clear Sky (2)

[View Satisfaction Prediction]
New View
Average View Content: 4.7
Average View Access: 4.2
Average Privacy: 3.9
Average Overall Rating: 4.3

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

Seemingly similar images but having different view content satisfactions

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

\[
\begin{align*}
\text{MAE}_{\text{Framework}} &= 2.03 & \text{RMSE}_{\text{Framework}} &= 2.32 \\
\text{MAE}_{\text{SeEmo}} &= 0.76 & \text{RMSE}_{\text{SeEmo}} &= 0.91
\end{align*}
\]
Scatter Plot of the View Data Set

Expanding Window View Scenarios

View Content Satisfaction

Top Window Area Ratio

Bottom Window Area Ratio

Middle Center Window Area Ratio

Window Area

1st Ray-Casting

2nd Ray-Casting

3rd Ray-Casting

World Z

Viewpoint

View Direction

Scene Angle

100%

0%

0

+5

-5

0
## Trained ML Performance

<table>
<thead>
<tr>
<th>ML Performance</th>
<th>Overall View Satisfaction</th>
<th>View Content Satisfaction</th>
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| **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 |
EL House, Texas (WW Architecture)
Satisfaction Prediction: View Content (Pie)
Satisfaction Prediction : View Content (Pixel)
Seemo-Potential Visual Exposure Index (Pixel)
Balancing between view content satisfaction and privacy satisfaction
Thank you for listening

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