Indoor-Outdoor HDR Photography and Scene Relighting

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Carnegie Mellon University

Radiance Workshop, Salt Lake City, UT, 2024

Millions of homes on the market

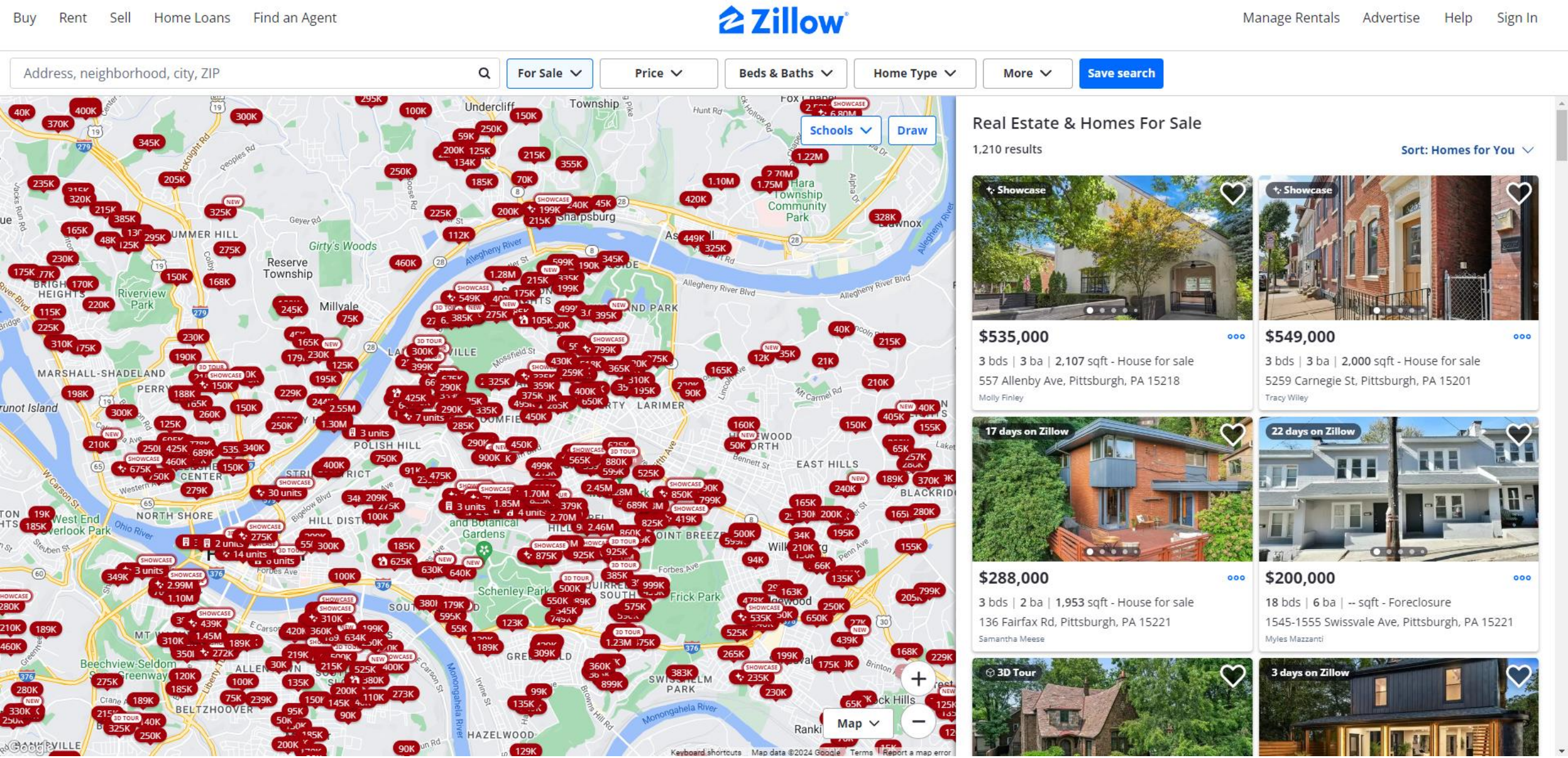


Image source: https://www.zillow.com/pittsburgh-pa/

How to virtually stage indoor spaces?

Realistic Lighting

Automatic Process

Image source: https://www.zillow.com/homedetails/408-Battery-Dr-S-Mc-Donald-PA-15057/59857693_zpid/

Virtual Home Staging

Input

Indoor Image

Outdoor Image

Photometric Calibration

Output

Virtual Rendered Scene

Inverse Rendering

Ji, Guanzhou, Azadeh O. Sawyer, and Srinivasa G. Narasimhan. "Virtual Home Staging: Inverse Rendering and Editing an Indoor Panorama under Natural Illumination." International Symposium on Visual Computing, 2023.
Ji, Guanzhou, Azadeh O. Sawyer, and Srinivasa G. Narasimhan. "Virtual Home Staging and Relighting from a Single Panorama under Natural Illumination.“, Journal of Machine Vision and Application, 2024.

Virtual Staging

Changing Light

Changing Light

Outline

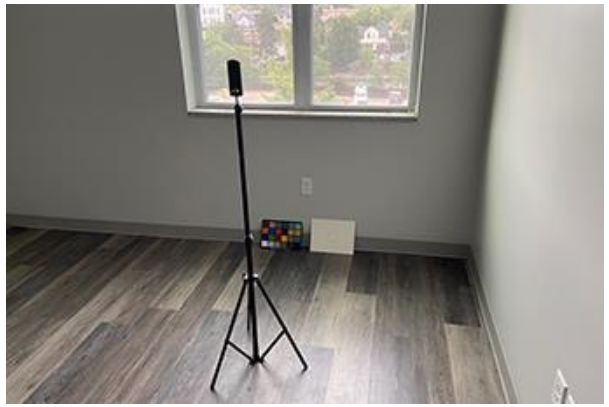
- indoor-outdoor HDR photography

- inverse rendering for scene relighting

- applications for scene editing

Indoor-Outdoor HDR Photography

360° Panorama



Indoor Scene

Ricoh Theta Z1

Luminance meter

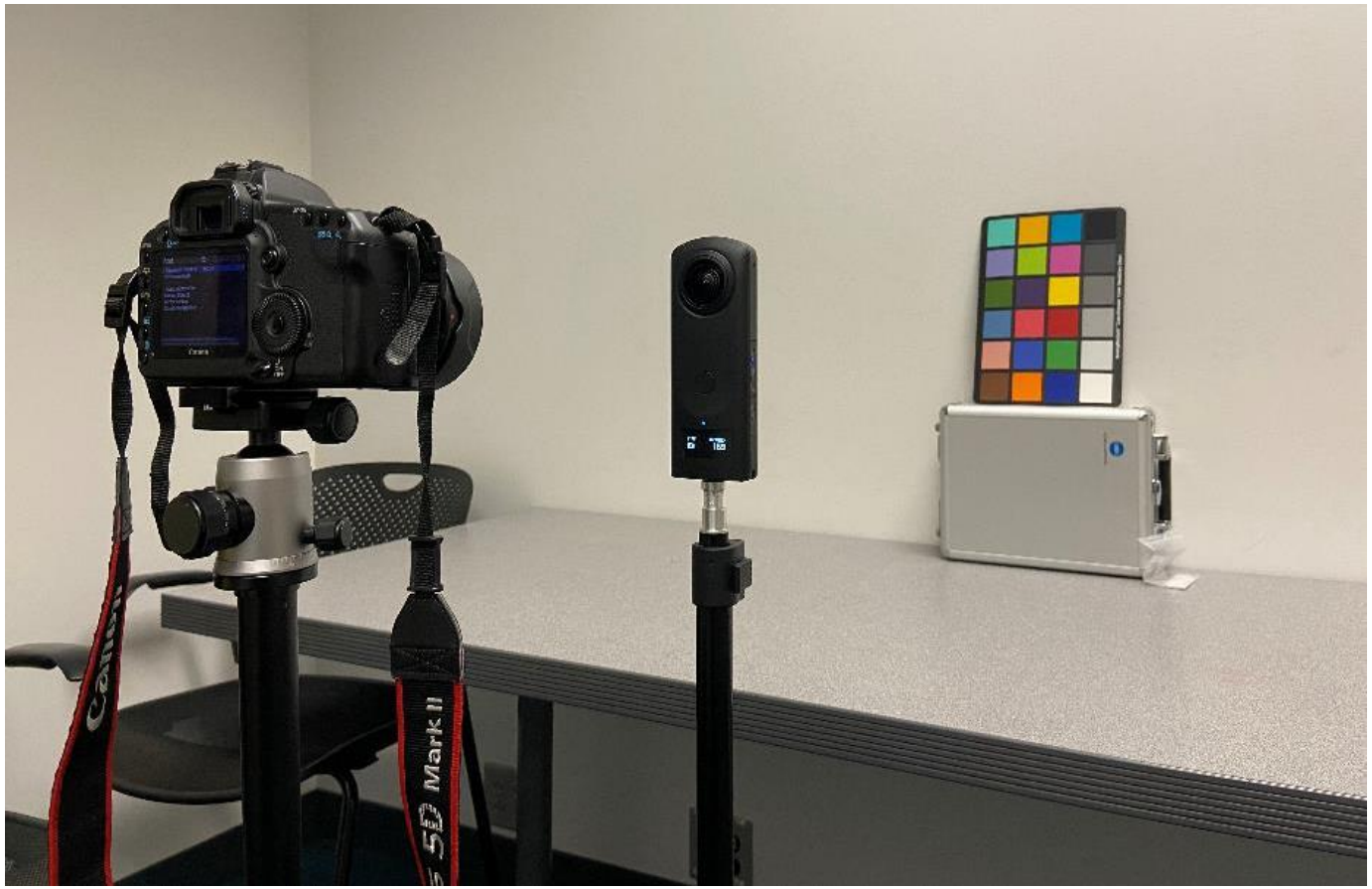
Outdoor Scene

Fisheye Lens

Canon 6D

180° Fisheye

Indoor-Outdoor HDR Calibration

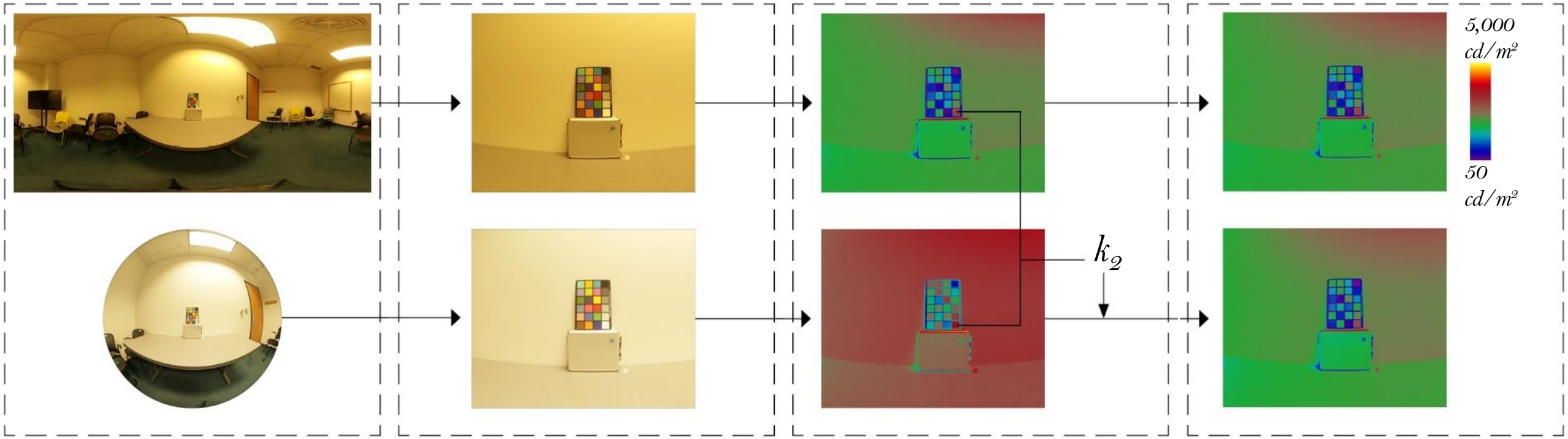


Camera set-up with the same camera settings as data collection

Ricoh Theta Z1

Canon 6D w/ Fisheye Lens

Indoor-Outdoor HDR Calibration



$$L_{outdoor} = k_1 * k_2 * (0.2127 * R + 0.7151 * G + 0.0722 * B)$$

k_1 is from the luminance measurement from indoor scene
k_2 is a constant when camera settings stay the same
R, G, and B are three color channels

Post-Processing

Indoor

Photometric Calibration

Outdoor

Vignetting Correction

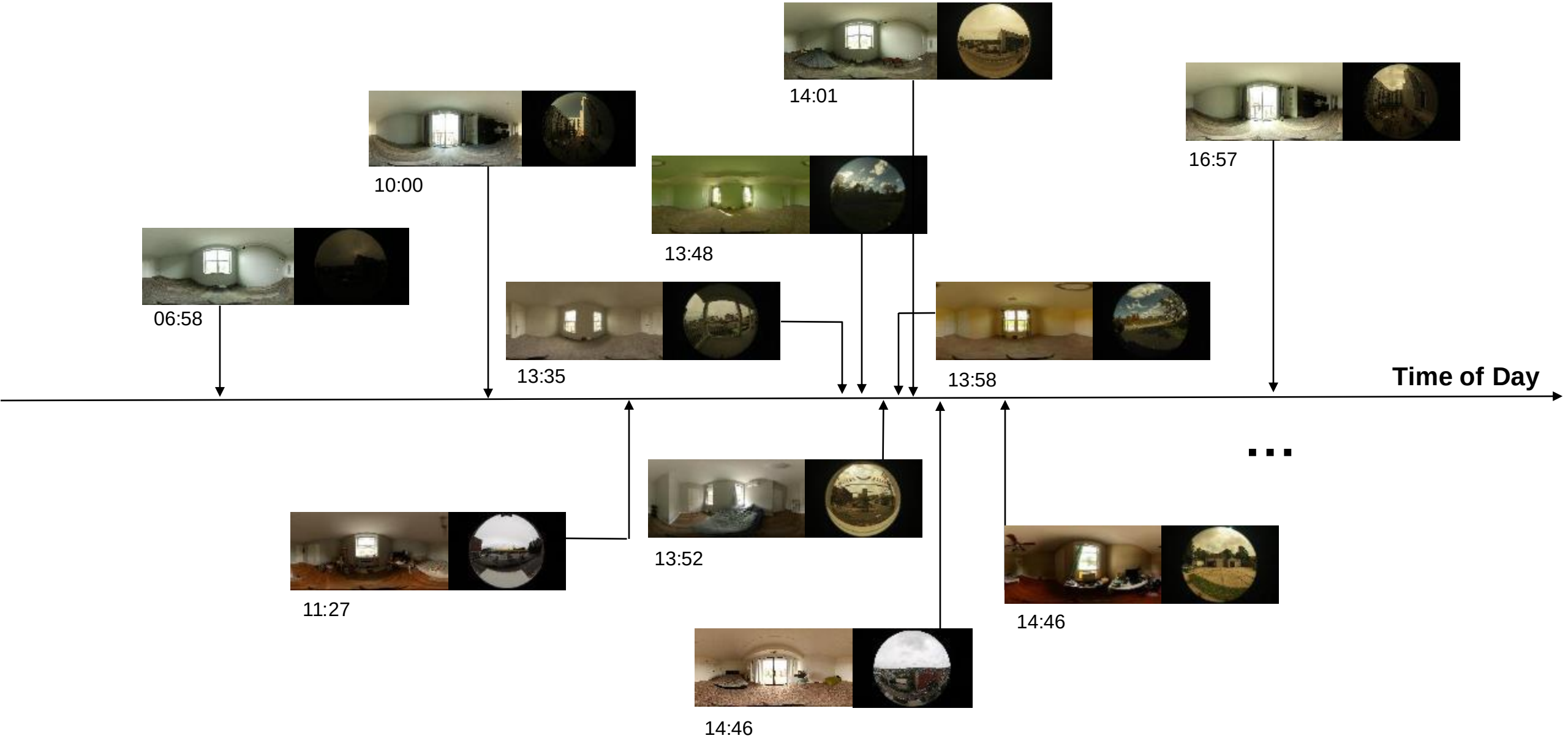
Equidistant Correction

Color Correction

Photometric Calibration

DAYLIGHT 6500

Data Collection



Calibrated HDR Dataset

137 Scenes, 10 months (Oct. 2022 – Jul.2023), Pittsburgh

Method 1

Indoor Scene

Ricoh Theta Z1

$1,160

Luminance meter

~$5,000

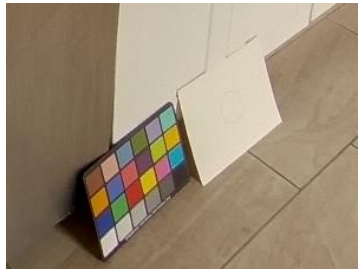
Outdoor Scene

Fisheye Lens

$1,249

Canon 6D

$1,125



White Board

Color Checker*

Method 2

Indoor Scene

Outdoor Scene

Ricoh Theta Z1

$1,160

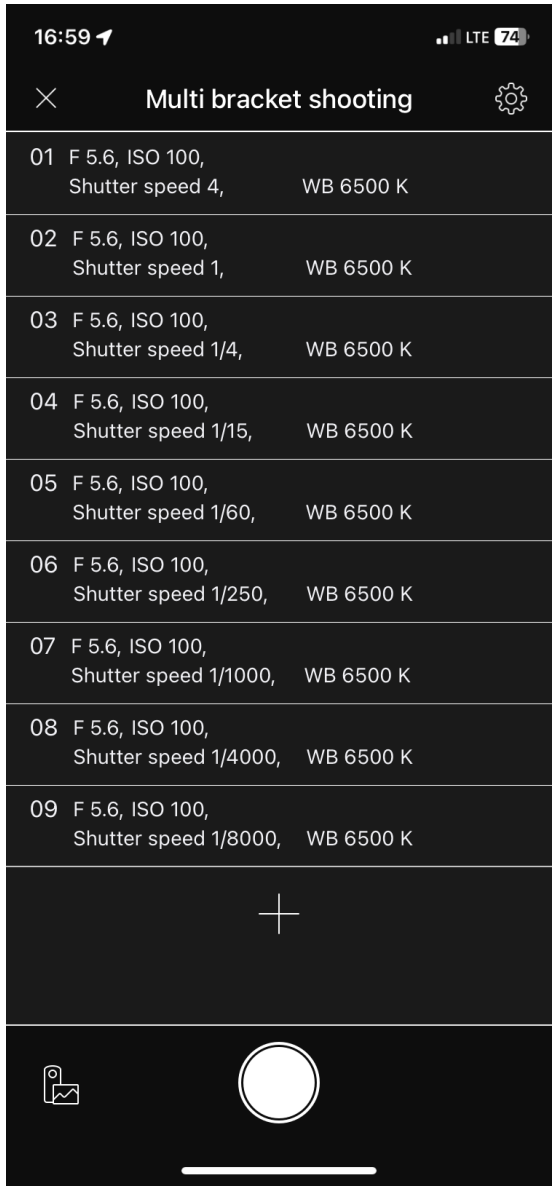
Light meter

~$30

Color Checker*

*The color checker is just in case it is needed for future research

Indoor-Outdoor HDR Panoramas



Ricoh Theta Z1

Indoor

Outdoor

Outdoor Photography

Ricoh Theta Z1

Low-Rise Building

Operable Window

Non-Operable Window

High-Rise Building

Non-Operable Window

Balcony

Pano-Pano HDR Dataset

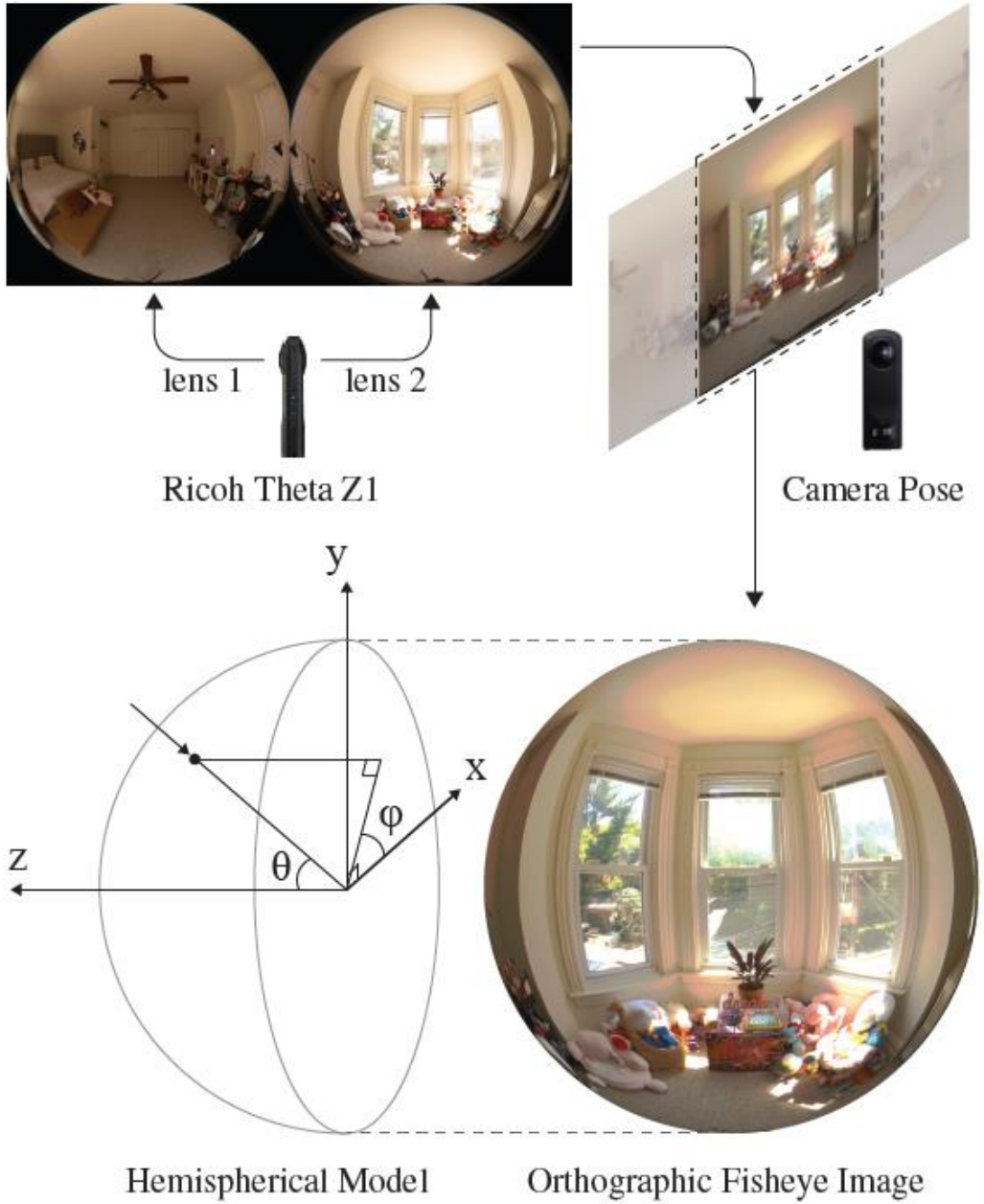
Indoor Panoramas

Outdoor Panoramas

141 paired indoor-outdoor panoramas with photometric calibration
Feb - May, 2024

Low-Cost Photometric Calibration

Light Meter (lux), ~$30



Photometric Calibration

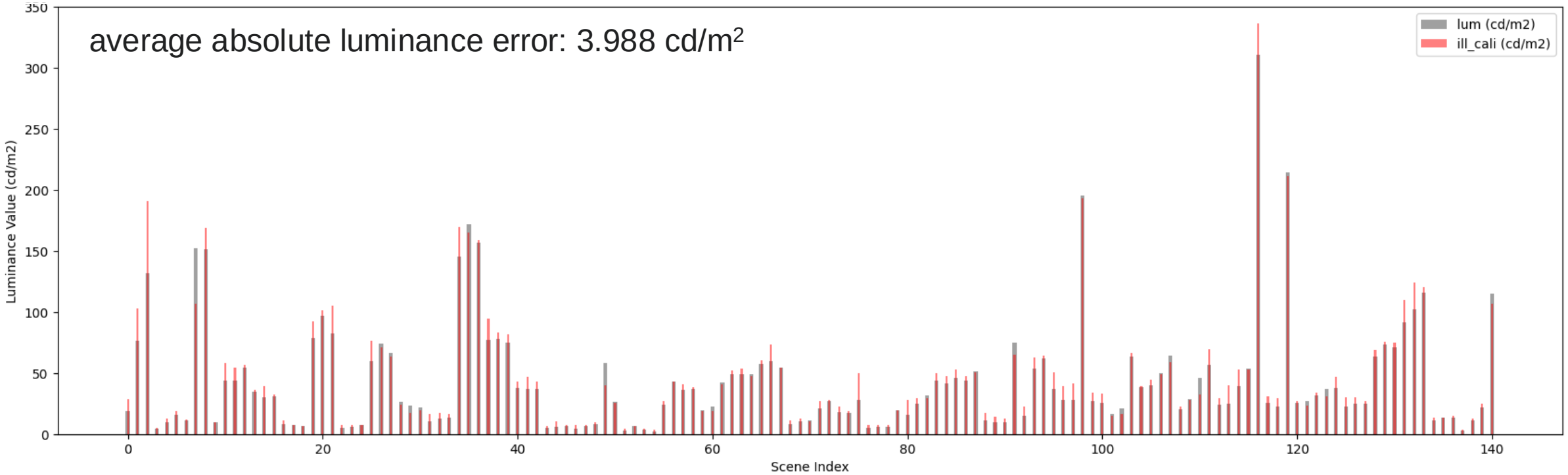
Sun at noon: 1.6×10^9 cd/m^2
Computer Screen: 50-300 cd/m^2


White Board


Luminance Meter
~$5,000

VS

Light Meter
~$30



Outline

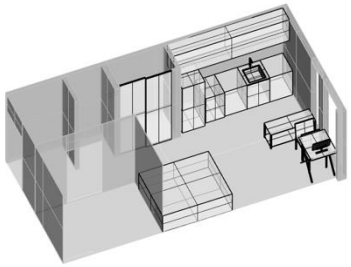
- indoor-outdoor HDR photography

- inverse rendering for scene relighting

- applications for scene editing

Standard Workflow

3D Layout



Detailed Modeling

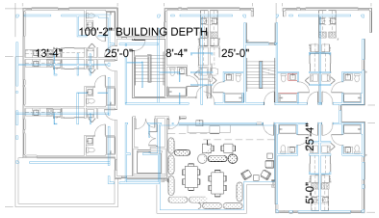
AUTODESK AUTOCAD

AUTODESK 3DS MAX

AUTODESK REVIT

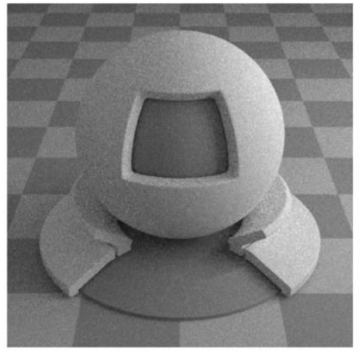
Rhinoceros

SketchUp



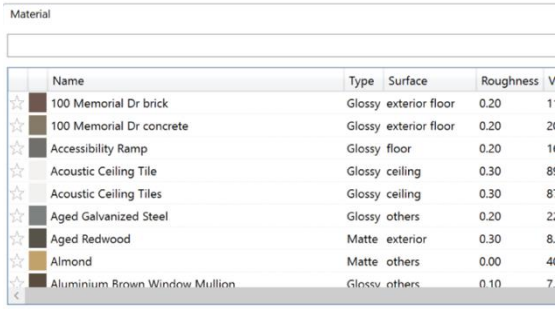
Existing Floor Plan

Materials



Wall LM83

Type	Matte
Reflectance	50.00 %
Specular	0.00 %
Diffuse	50.00 %
R	0.500
G	0.500
B	0.500
Roughness	0.000
Measurement Type	Standard
Credit	IES LM-83



Material

Name	Type	Surface	Roughness
100 Memorial Dr brick	Glossy	exterior floor	0.20
100 Memorial Dr concrete	Glossy	exterior floor	0.20
Accessibility Ramp	Glossy	floor	0.20
Acoustic Ceiling Tile	Glossy	ceiling	0.30
Acoustic Ceiling Tiles	Glossy	ceiling	0.30
Aged Galvanized Steel	Glossy	others	0.20
Aged Redwood	Matte	exterior	0.30
Almond	Matte	others	0.00
Aluminium Brown Window Mullion	Glossy	others	0.10

Existing Material Library

Outdoor Light

Standard Sky Model

GPS location
Sky Condition (clear, overcast, and immediate)
Image Resolution

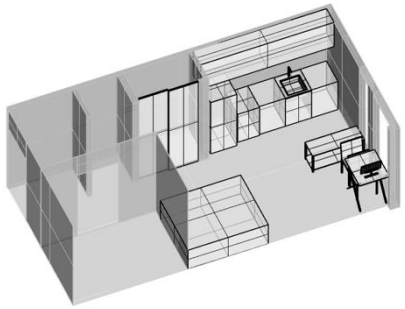
Time: several days
Input: manual modeling

Time: several minutes
Input: approximated materials

Time: several minutes
Input: approximated sky model

Standard Workflow

3D Layout



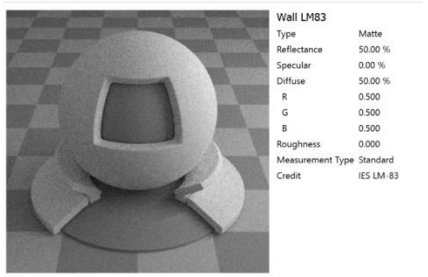
Detailed Modeling

Time: several days

Time: several hours

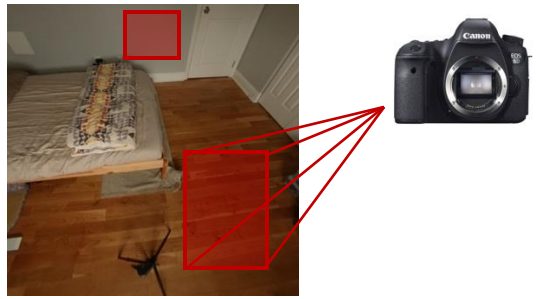
Zillow 3D Home® app

Material/Texture



Existing Material Library

Time: several minutes



Time: several hours

Outdoor Light

Standard Sky Model

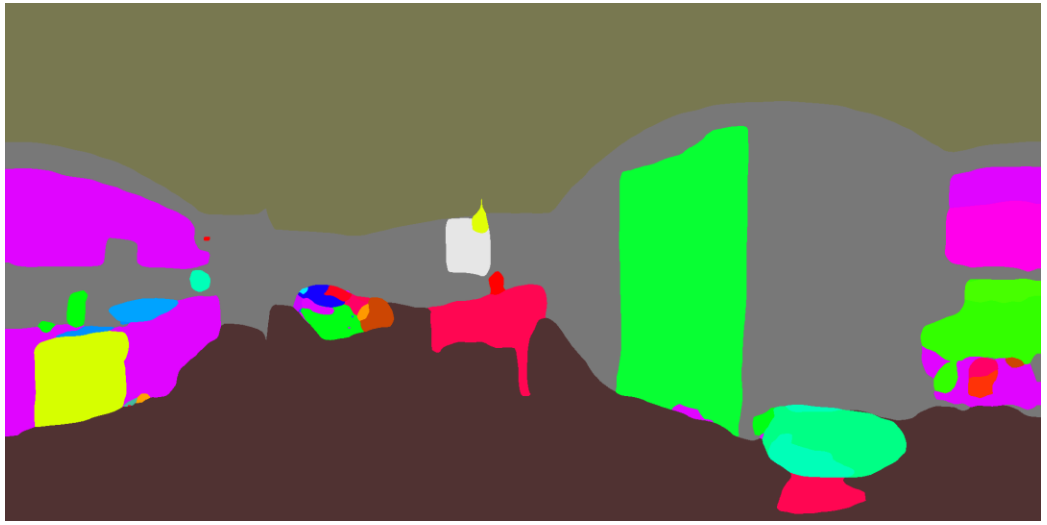
Time: several minutes

Time: several hours

Field Measurement

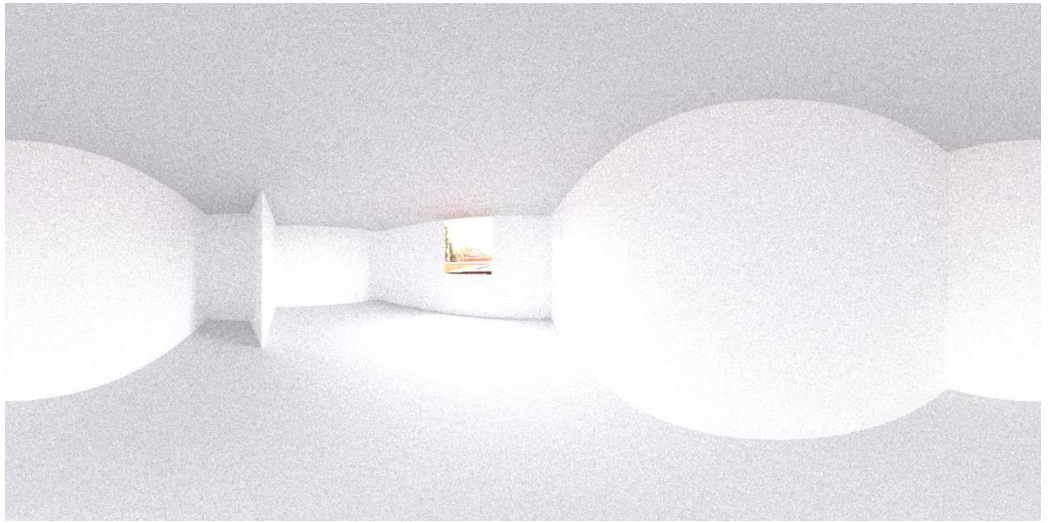
What a single image can tell us?

Input RGB Panorama



Semantic Map

Layout Estimation



Shading Layer

Inverse Rendering

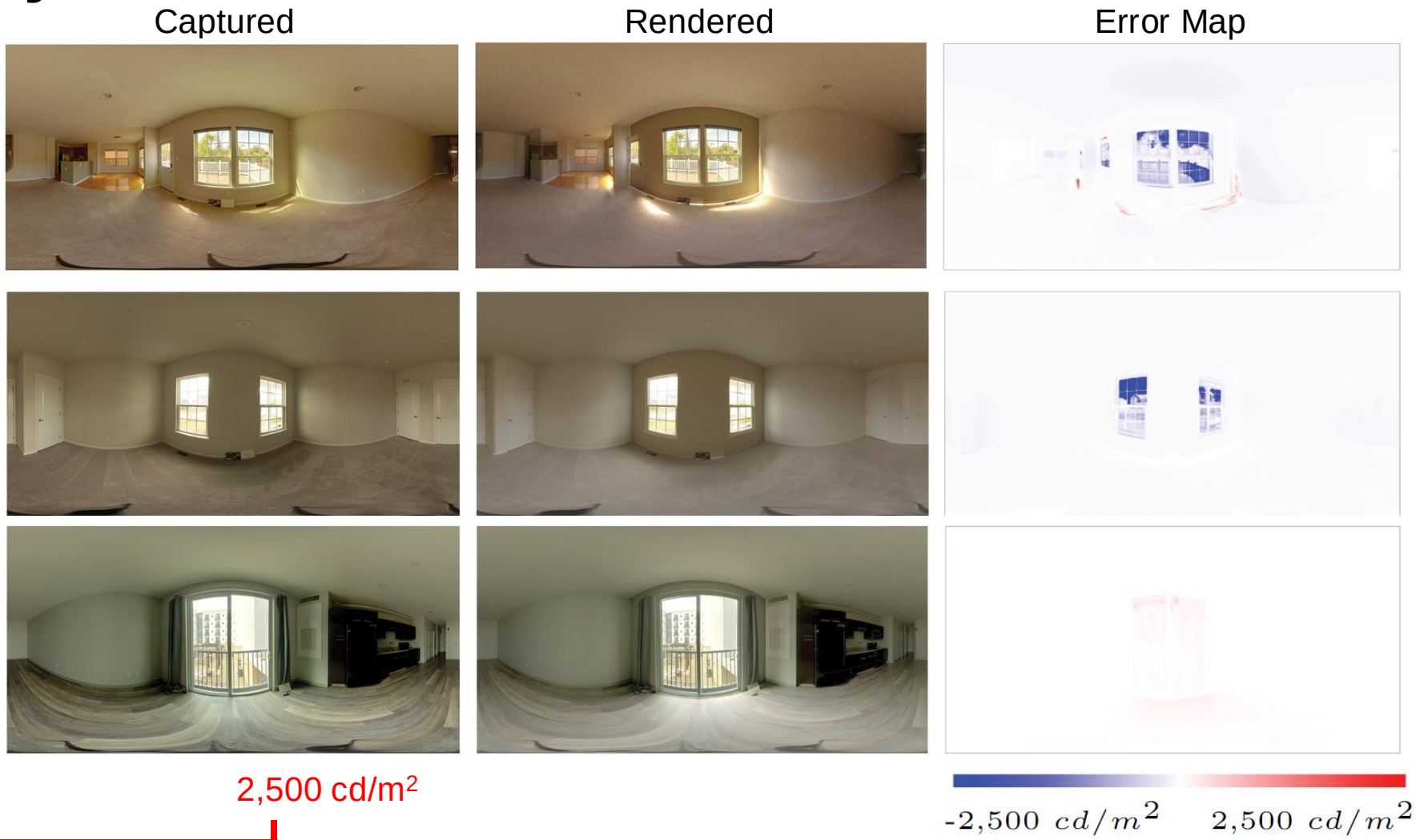
Input:

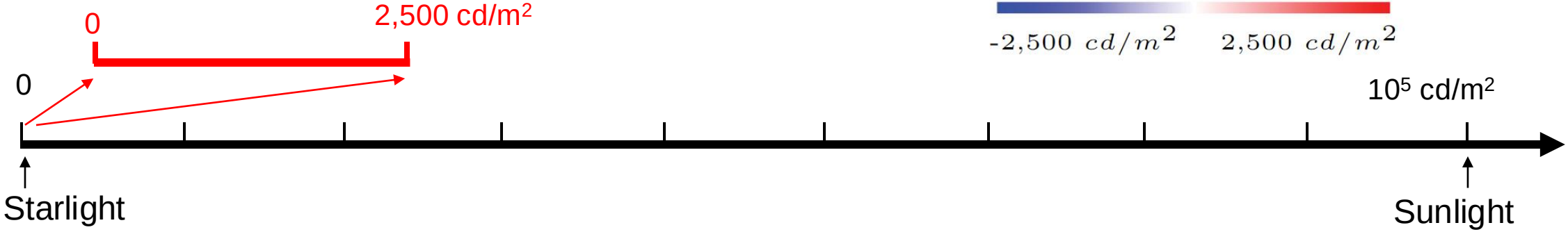
Estimating:
3D Floor Layout
Reflectance Property
Spatially-varying Light

Editing:
New Floor Layout
New Materials
New Light

Output:

Error Analysis





Outline

- indoor-outdoor HDR photography

- inverse rendering for scene relighting

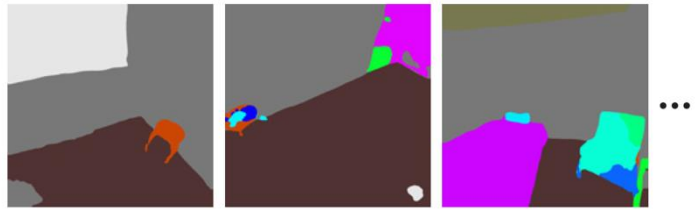
- applications for scene editing

Furniture Removal

Furniture Detection in Panorama

Input Panorama

2D Perspectives



Semantic Segmentation

Furniture Objects

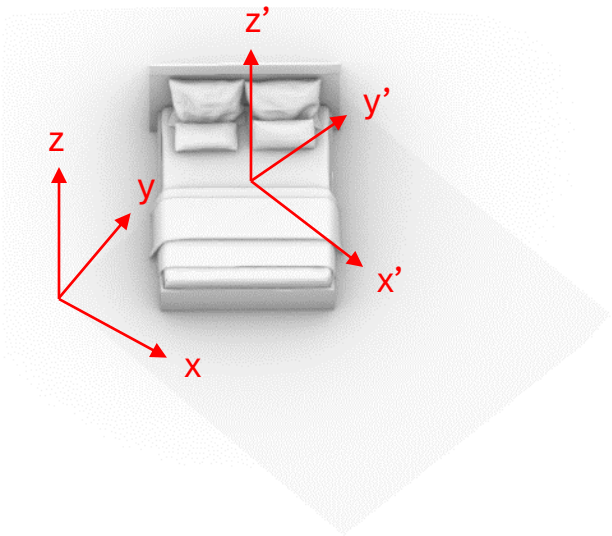
Furniture Layout

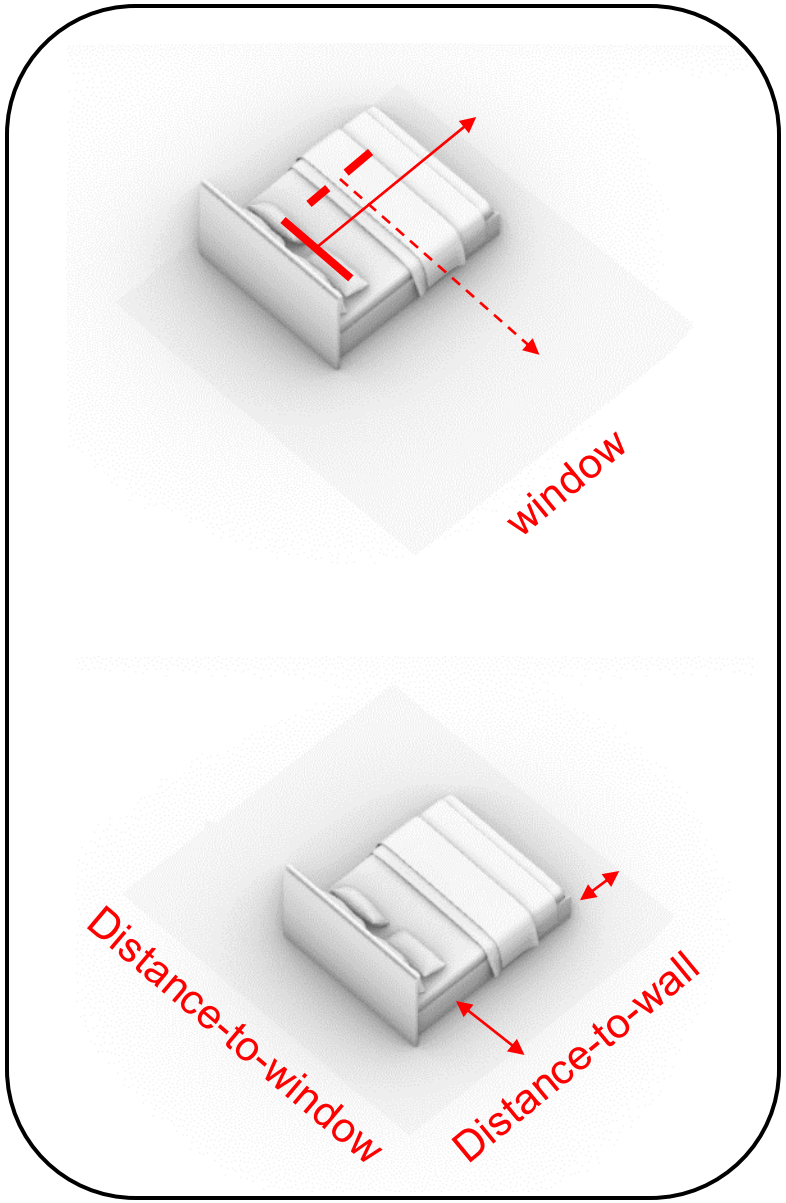
Furniture Layout

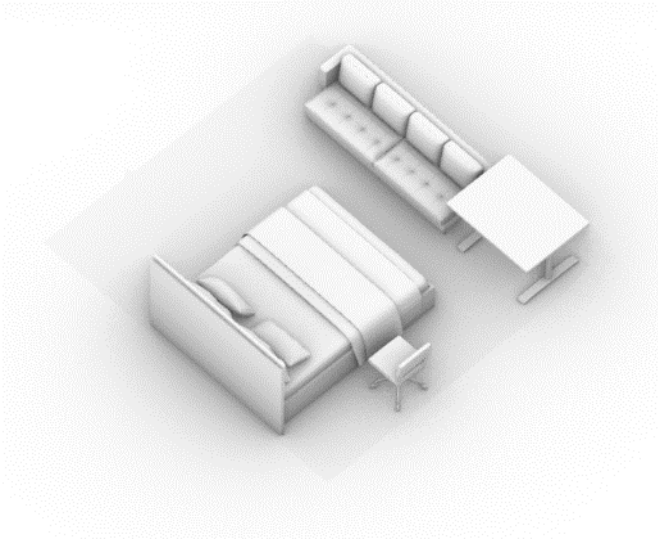
Inputs:
Furniture Objects
Floor Mesh

Parameters:
Orientation
Location

Outputs:
Adjusted Furniture Objects







Virtual Staging

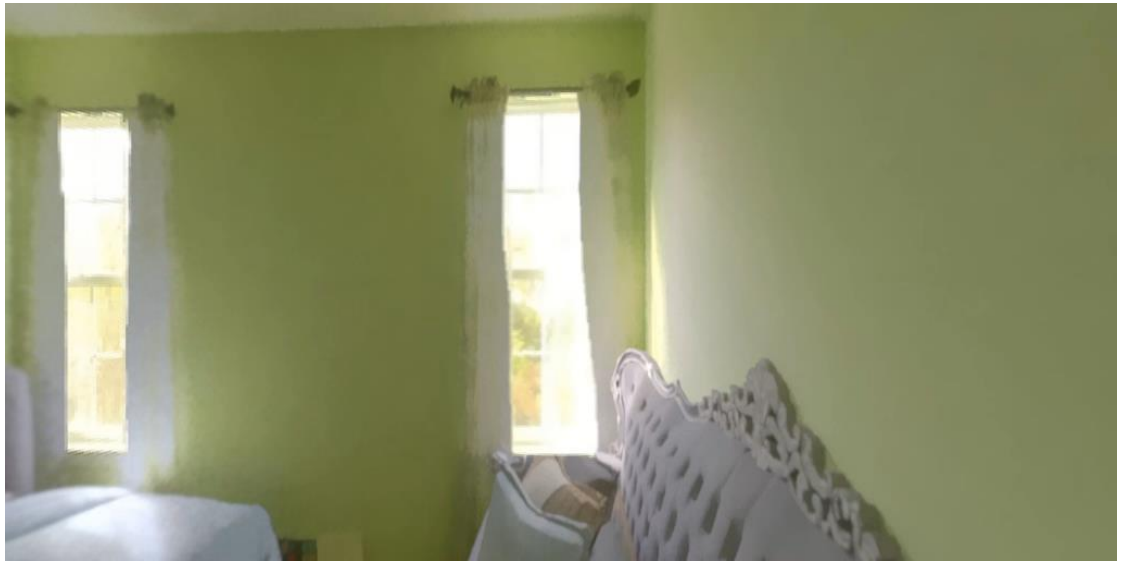
Changing Indoor Textures/Positions

Virtual Staging

Changing Indoor Position

Rendered Panorama

Position 2: 2D Perspective



Position 1: 2D Perspective

Position 3: 2D Perspective

View to Outdoor Scene

Indoor Scene 1

Indoor Scene 2

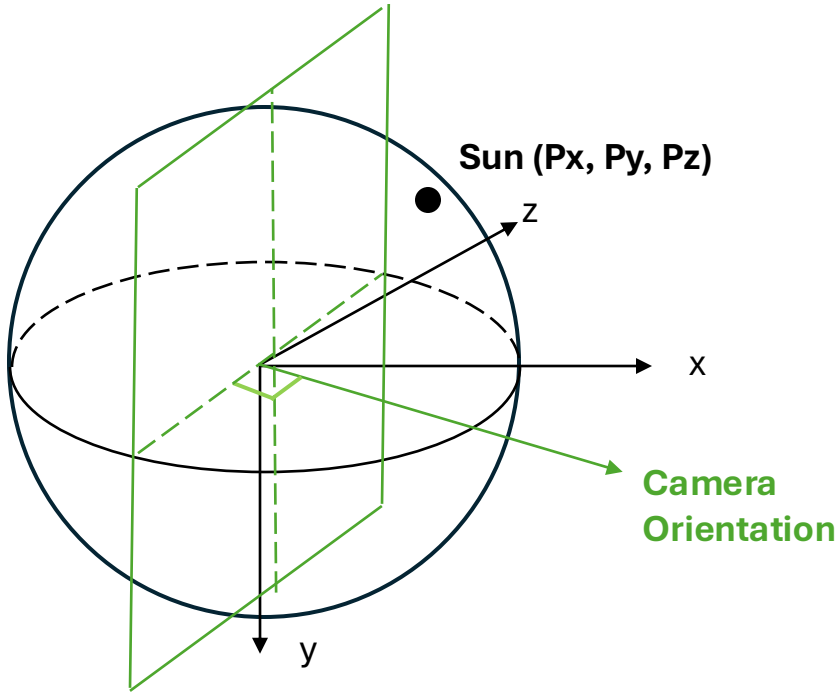
Outdoor Scene 1

Outdoor Scene 2

Editing Outdoor Images

captured 180 fisheye

360 Equirectangular



Editing Outdoor Images

theta (azimuth): 194.07
phi (altitude): 40.31

captured: 2022-10-14,13:49

theta (azimuth): 227.8
phi (altitude): 28.2

annotation for new sun

Estimating Outdoor Images

Scene 1

Scene 2

Scene 3

Rendered with Captured Outdoor Image

Rendered with Edited Outdoor Images

Rendered with Captured Outdoor Image

Rendered with Edited Outdoor Images

Removing Sun from Outdoor Image

captured: 10-14,14:30

Rendered Scene

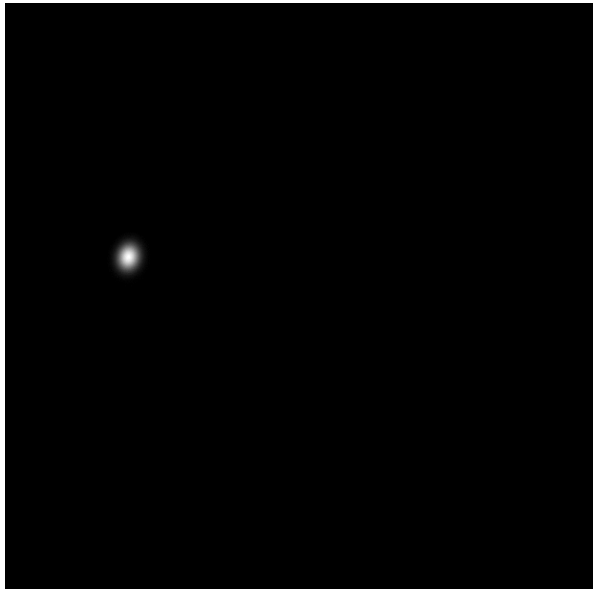
edited: 10-14,14:30 no sun

Rendered Scene

Adding Sun on the Outdoor Image

Captured Outdoor Image

Virtual Rendered Scene



Virtual Sun Mask

Virtual Rendered Scenes

Natural Illumination

Electrical Light (6336K)

Electrical Light in the Evening

Electrical Light (6336K)

Electrical Light (2660K)

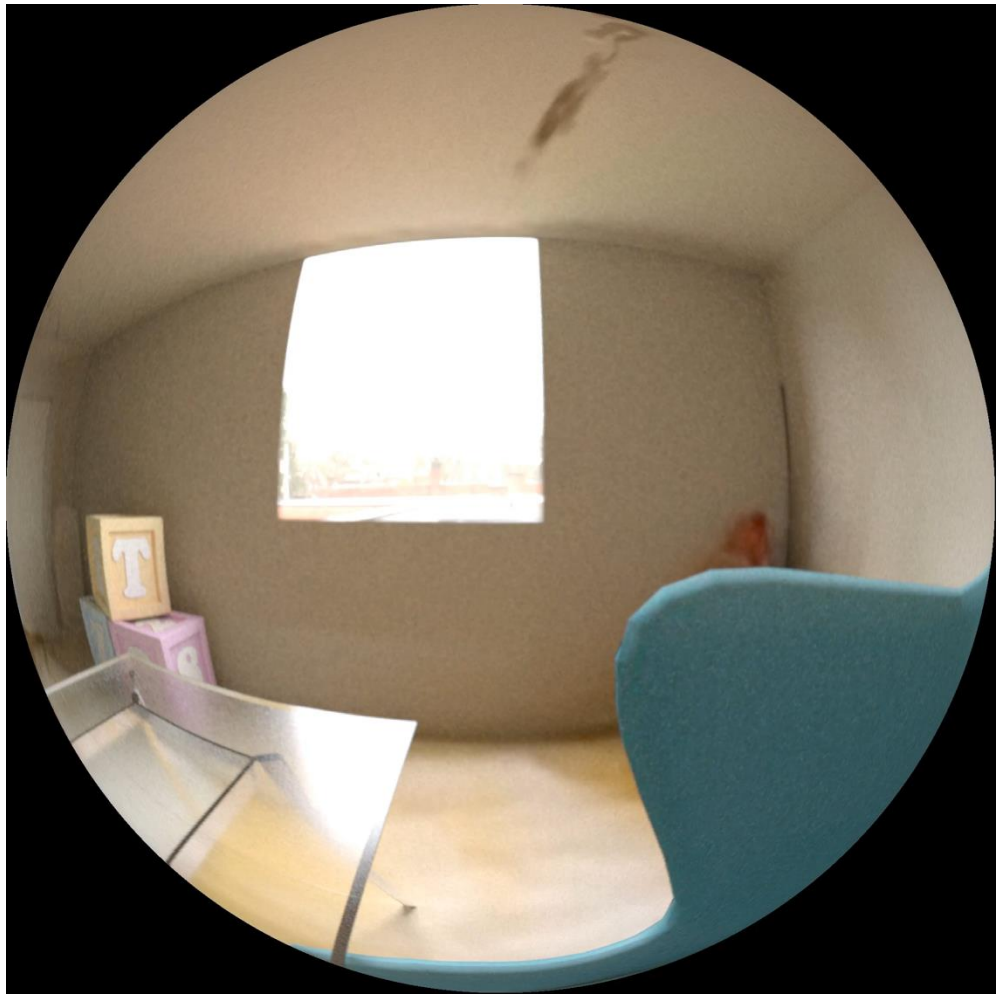
Electrical Light in the Evening

Kitchen Remodeling

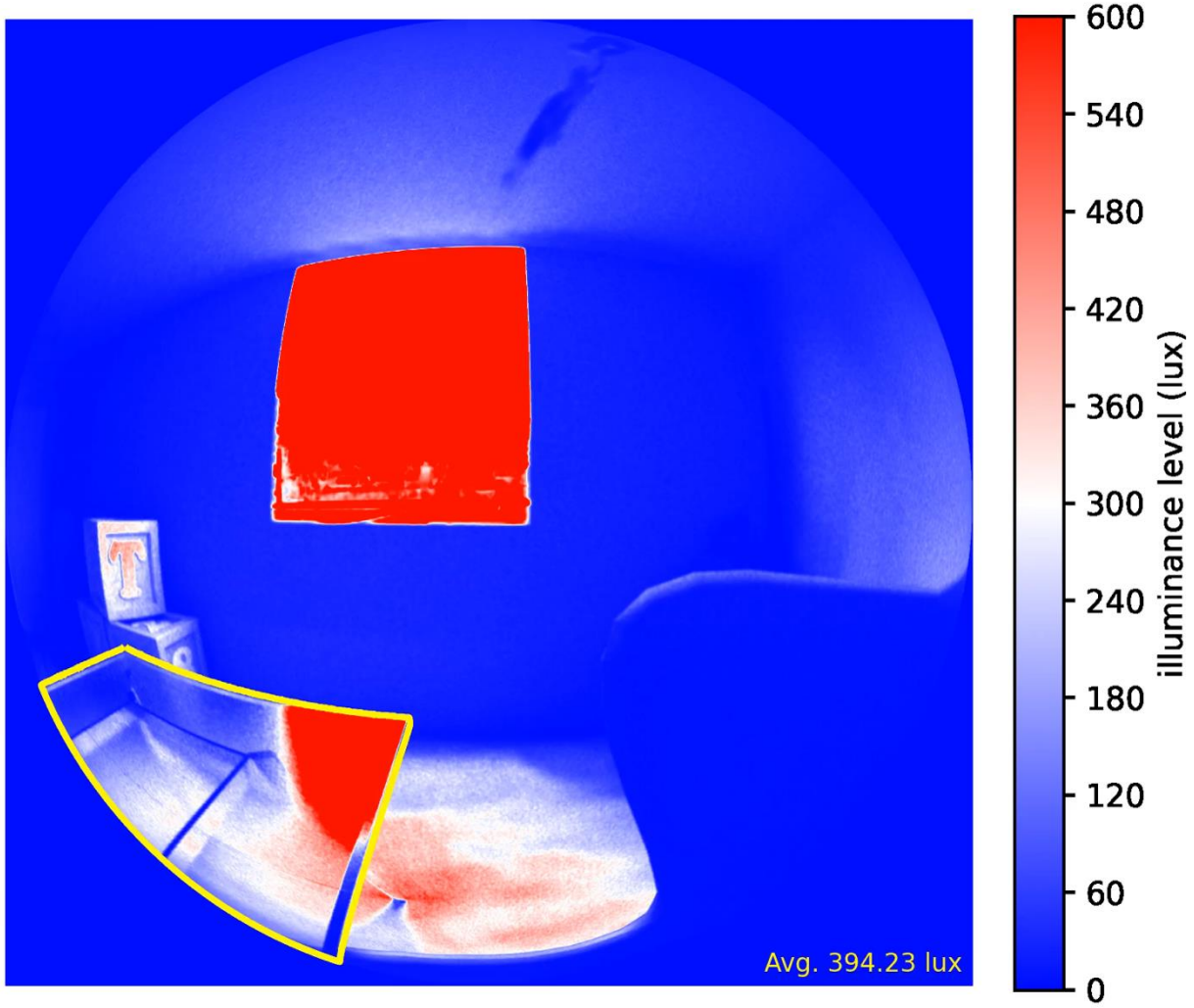
Kitchen Remodeling

Illuminance Map

Indoor Task Lighting

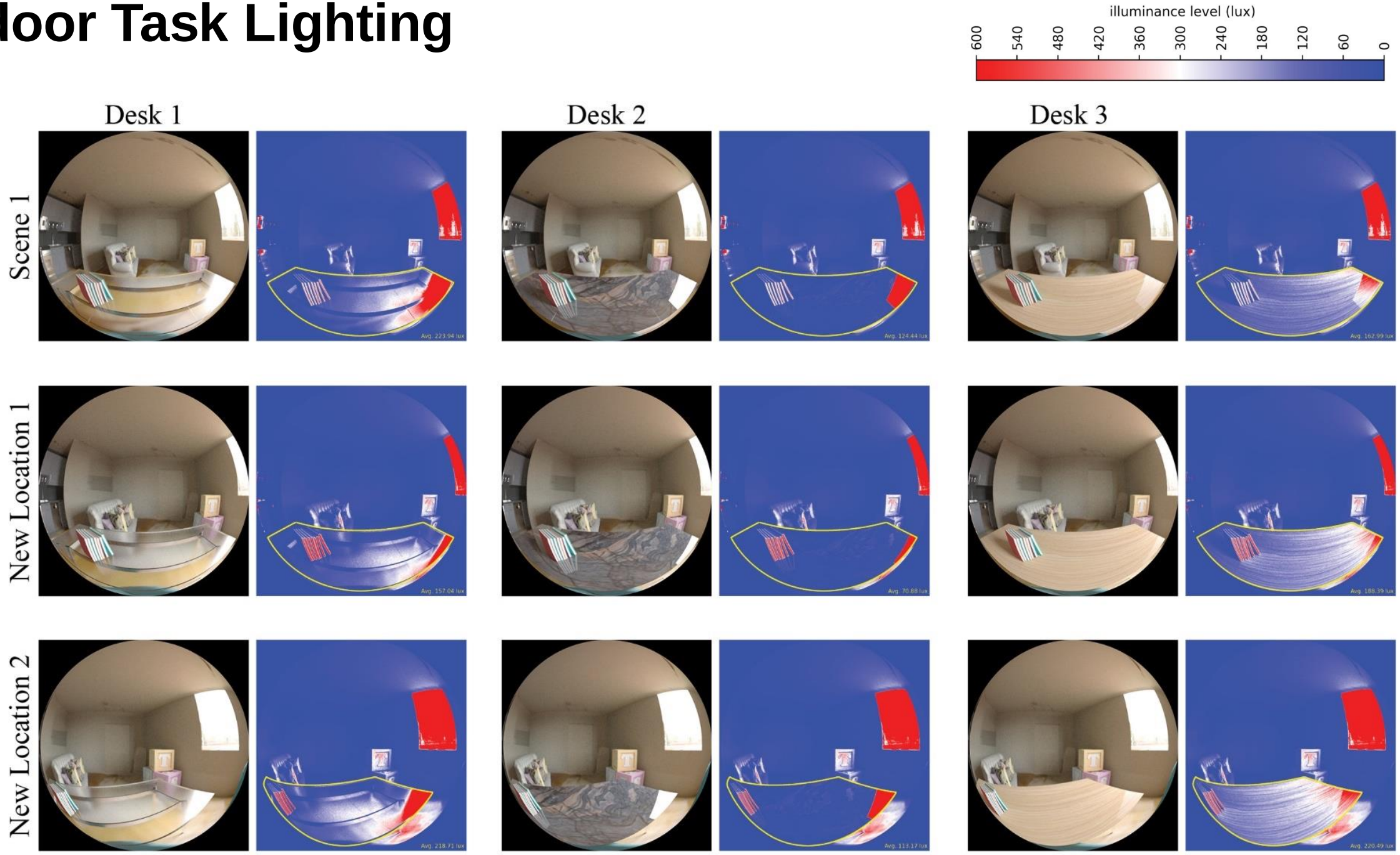


Virtual Rendered Scene

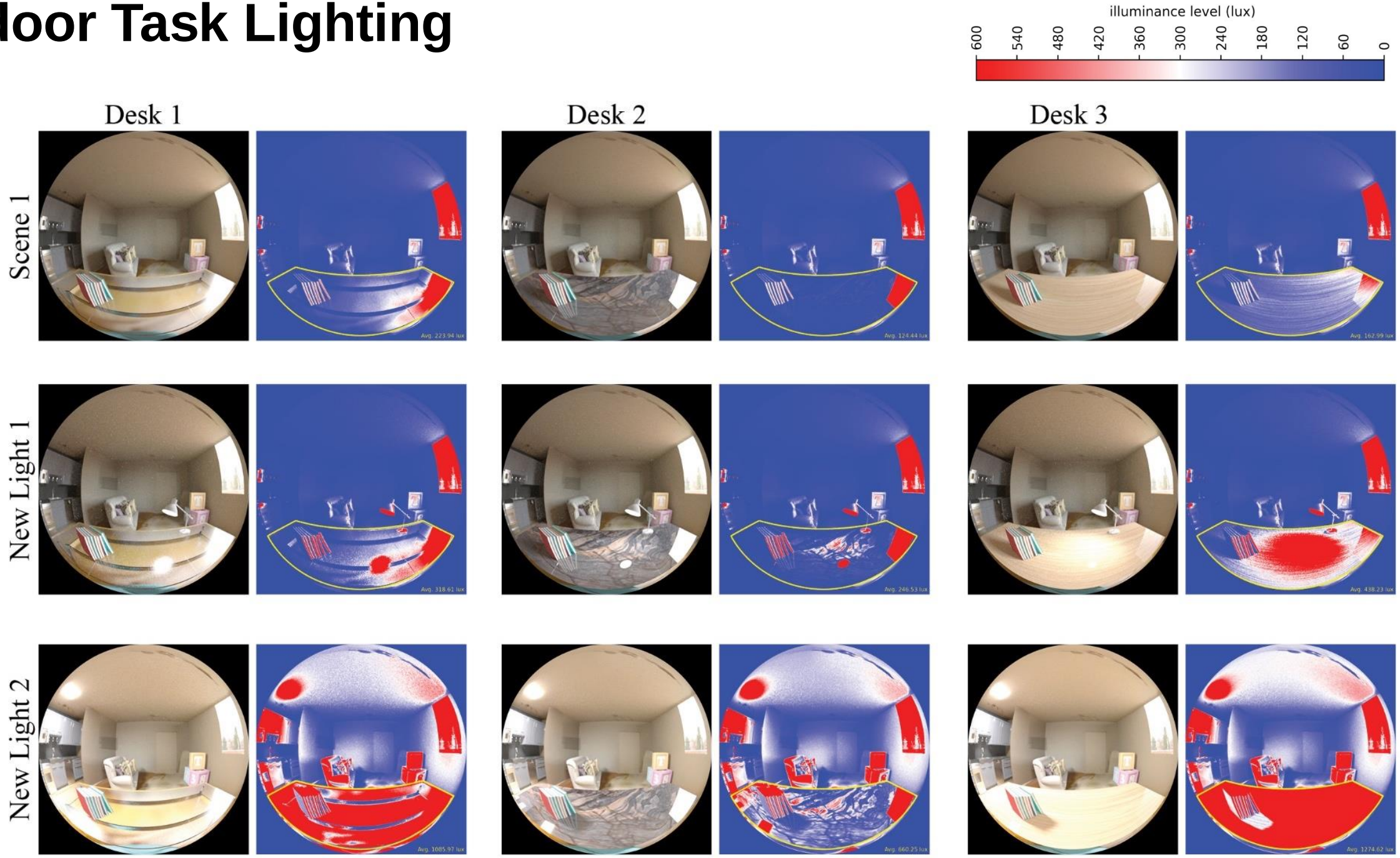


Reading (300lux) on the task surface (desk)

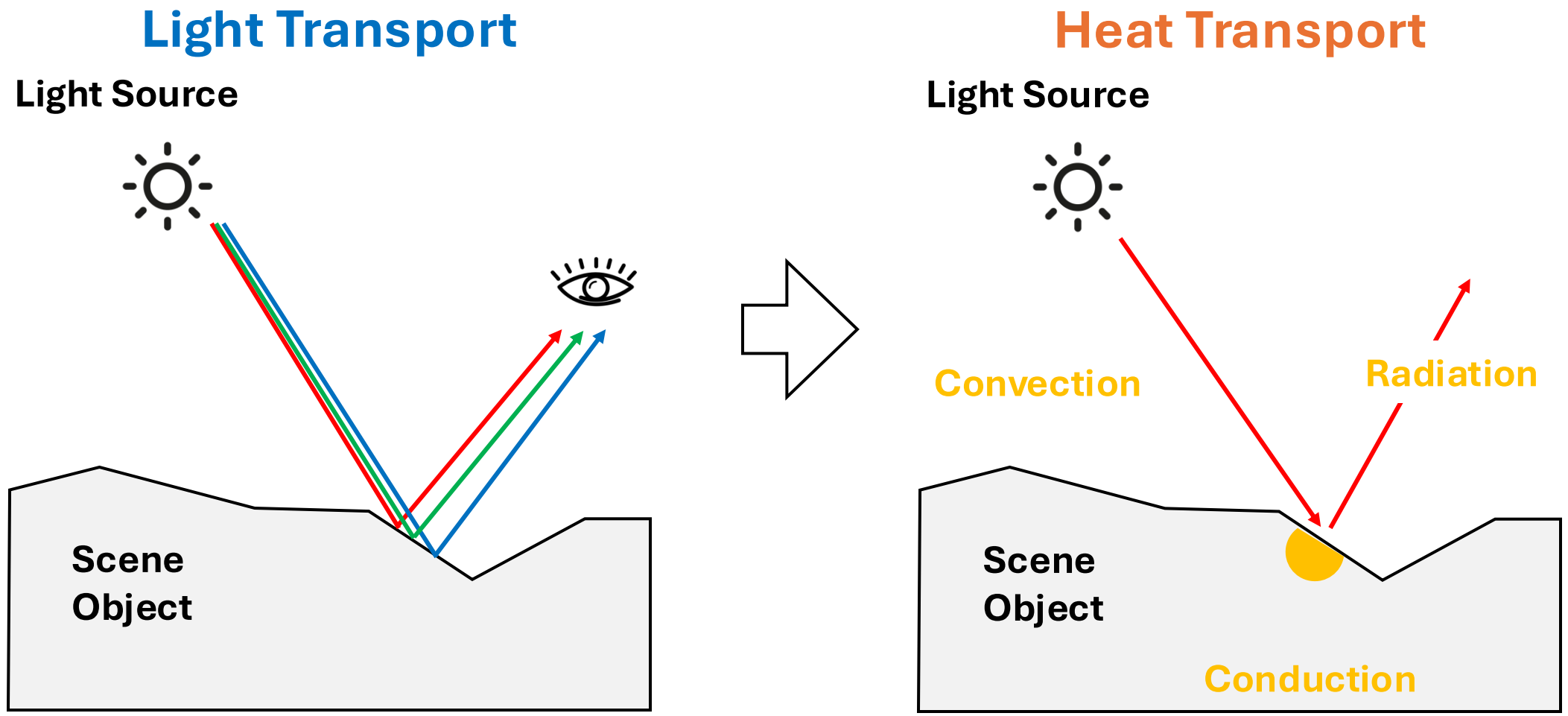
Indoor Task Lighting



Indoor Task Lighting



Ongoing Work: estimating heat map



Summary

Input

Indoor Image

Outdoor Image

several minutes

Output

Calibrated HDR Dataset

137 paired indoor-outdoor Images

141 paired indoor-outdoor panoramas

*each scene is annotated with room orientation, luminance value, and illuminance value

For more information:

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cs.cmu.edu/~ILIM/virtual_home_staging