Quantifying Materials in Lighting Simulations

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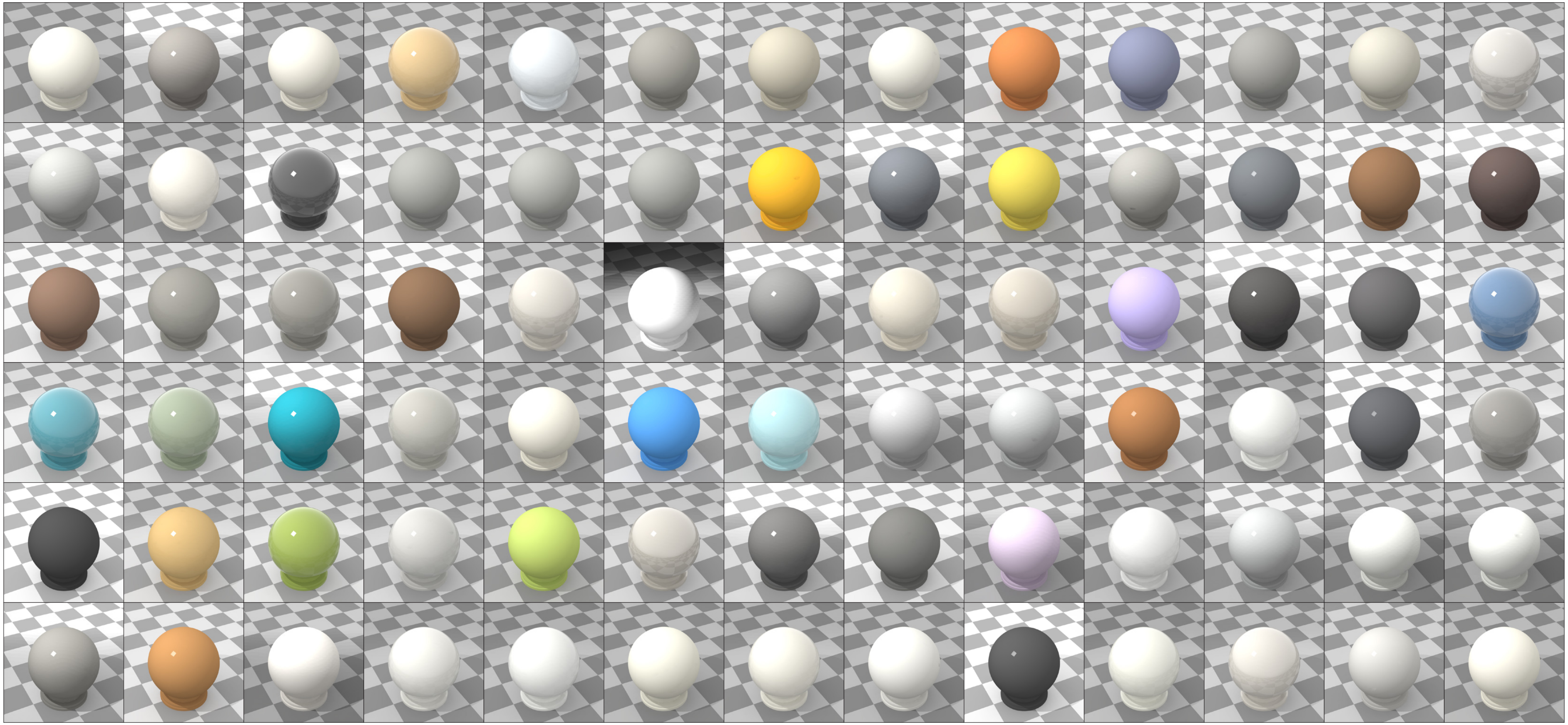

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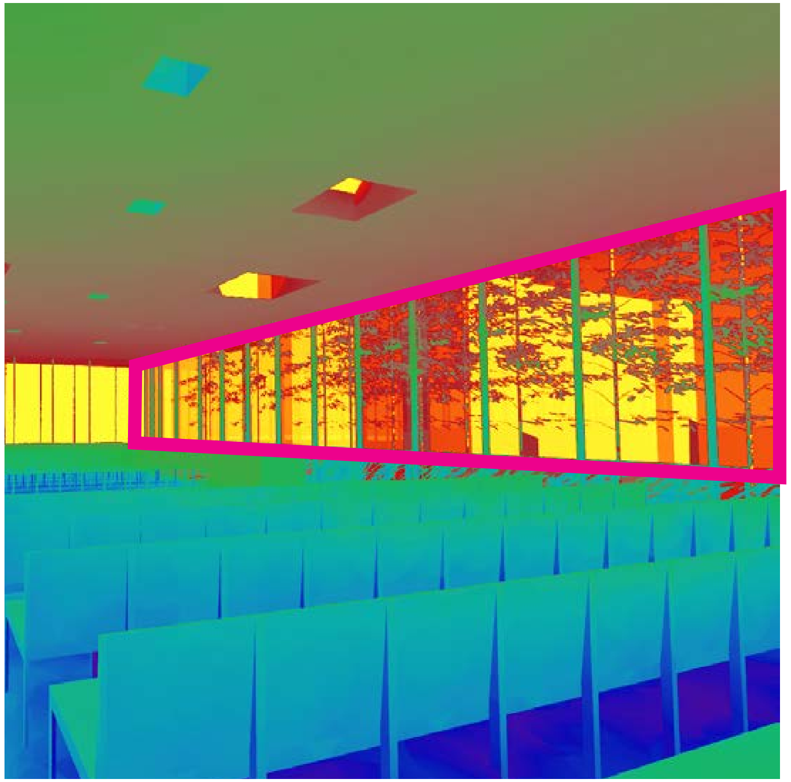
Today we are sharing two projects



Measuring and including foliage in Radiance simulations

Importance of realistic material properties for simulation

Modeling trees in Radiance: Discussions

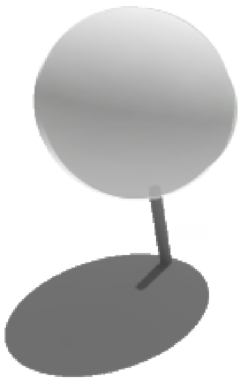
Modelling trees in Radiance: Discussions

"If you want to model your tree as a sphere (on a stick?) with a certain transmittance, ***the "trans" material*** *type should suit your purpose. Parameter setting is a bit tricky, but since you don't have any reflection or scattering to consider, simply set values according to your transmittance T "*

- Greg Ward

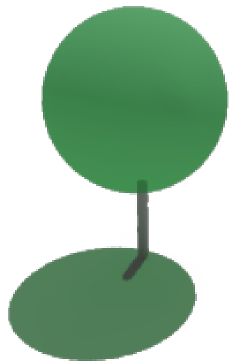
"…. if Joe is then using spheres for modelling the trees geometry, then ***the void percentage must be set to the square root of the tree canopy transmittance*** *since a ray "transmitted" by the tree will always intersect twice with the sphere!*

- Compagnon Raphaël



```
void trans tree_trans_only
0
0
7 1 1 1 0 0 0.45 1
```

19 % transmittance
55.3% reflectance



```
void trans tree_trans_reflect
0
0
7 0.28 0.7 0.37 0 0 0.8 1
```

19 % transmittance
11.3% reflectance

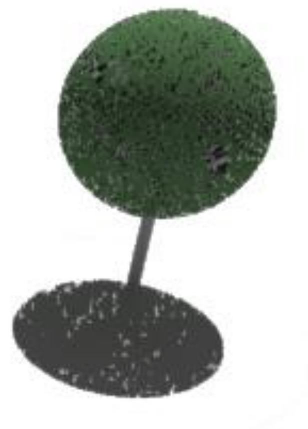
Modelling trees in Radiance: Discussions

“ *I ended up using a mixture between* ***VOID and a Plastic material****, on which I* ***varied the percentage of "Void"...*** *I am not sure, maybe that trick would also help modelling trees. Am I correct? Is, what I did, legally from the physical laws of lighting?* “

- Germán

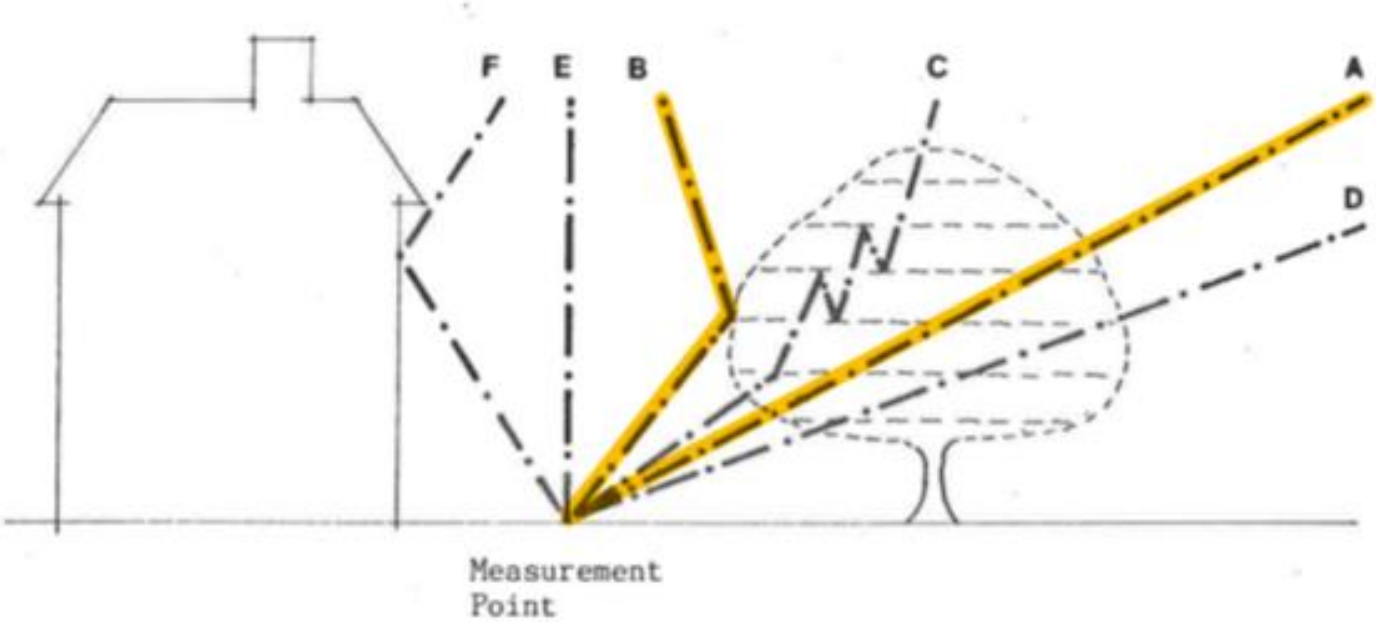
“.. Can we imagine the tree object modeled in this way as a ***hollowed sphere whose surface is composed of a texture with an "alternating void and plastic"*** *pattern, and the inside of the* ***sphere is filled with a lump of "mysterious" fog*** *...?*

- Joe Smith



Light transmission through trees

Light transmission through trees



McKennan, G. (1988). *Light Attenuation by Trees*.

A: **Transmission of light through the gaps in the tree crown.**

B: **Light reflected from the surface of the crown (15 – 20%)**

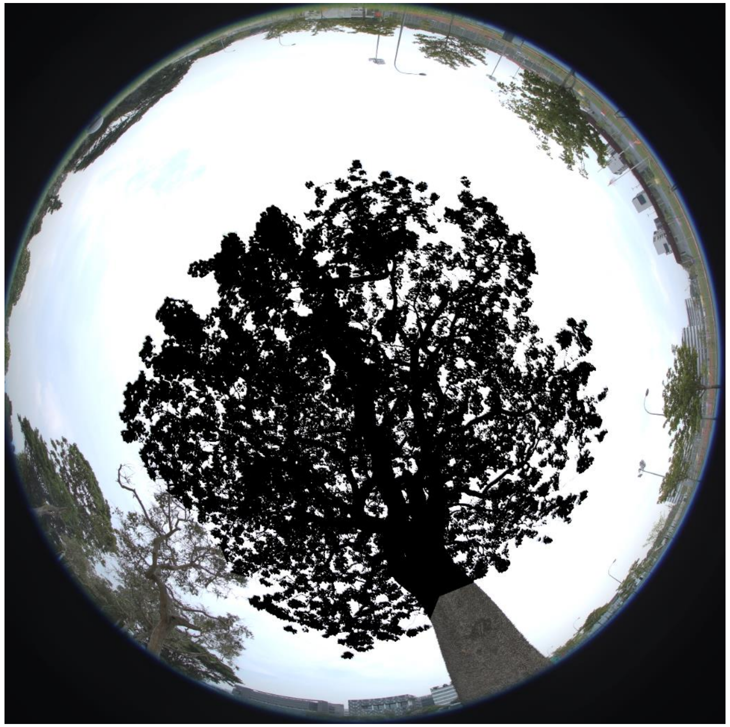
C: Internal reflection within the crown

D: Light transmitted through the leaves

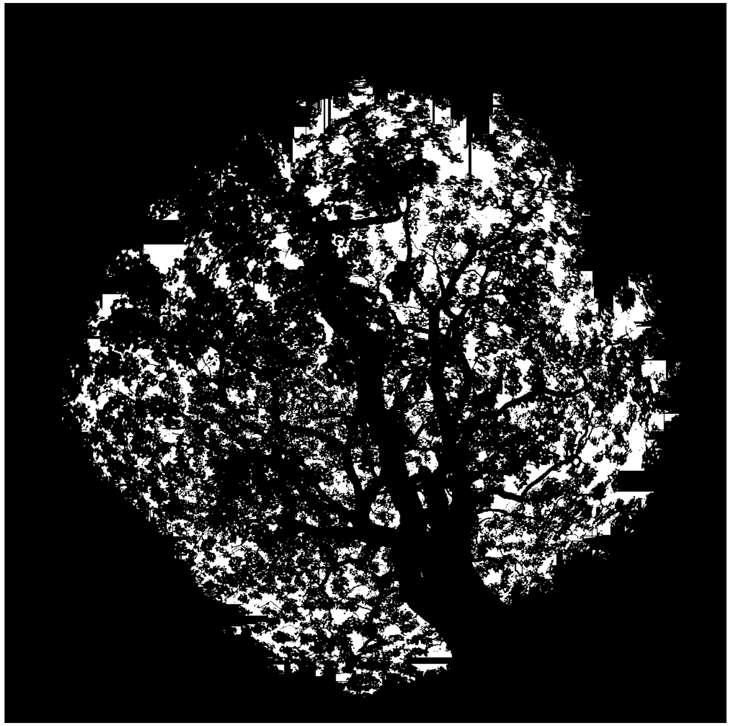
E: Direct Radiation

F: Diffused Radiation

Light transmission through trees: Leaf area Index and gap fraction



Leaf Area Index :
Leaf Area (foliage area) / Ground area it covers



Gap Fraction:
Fraction of view in some direction from beneath a canopy that the foliage does not obstruct

Methods to measure gap fraction

Methods to measure gap fraction

Based on transmission of light through canopies.

MEASURING LIGHT/ RADIATION

PAR sensors

IMAGE PROCESSING

Hemispherical Photography

REMOTE SENSING

LiDAR

HEMISPHERICAL HDR PHOTOGRAPHY

PAR Sensors: Under canopy and over canopy measurements

LI COR – Plant Canopy Analyzer LAI - 2200

SunScan– Canopy Analysis System SS1

Sensitive to PAR (Photosynthetically Active Radiation) – about 400 – 700nm

Hemispherical photography: Undercanopy measurements

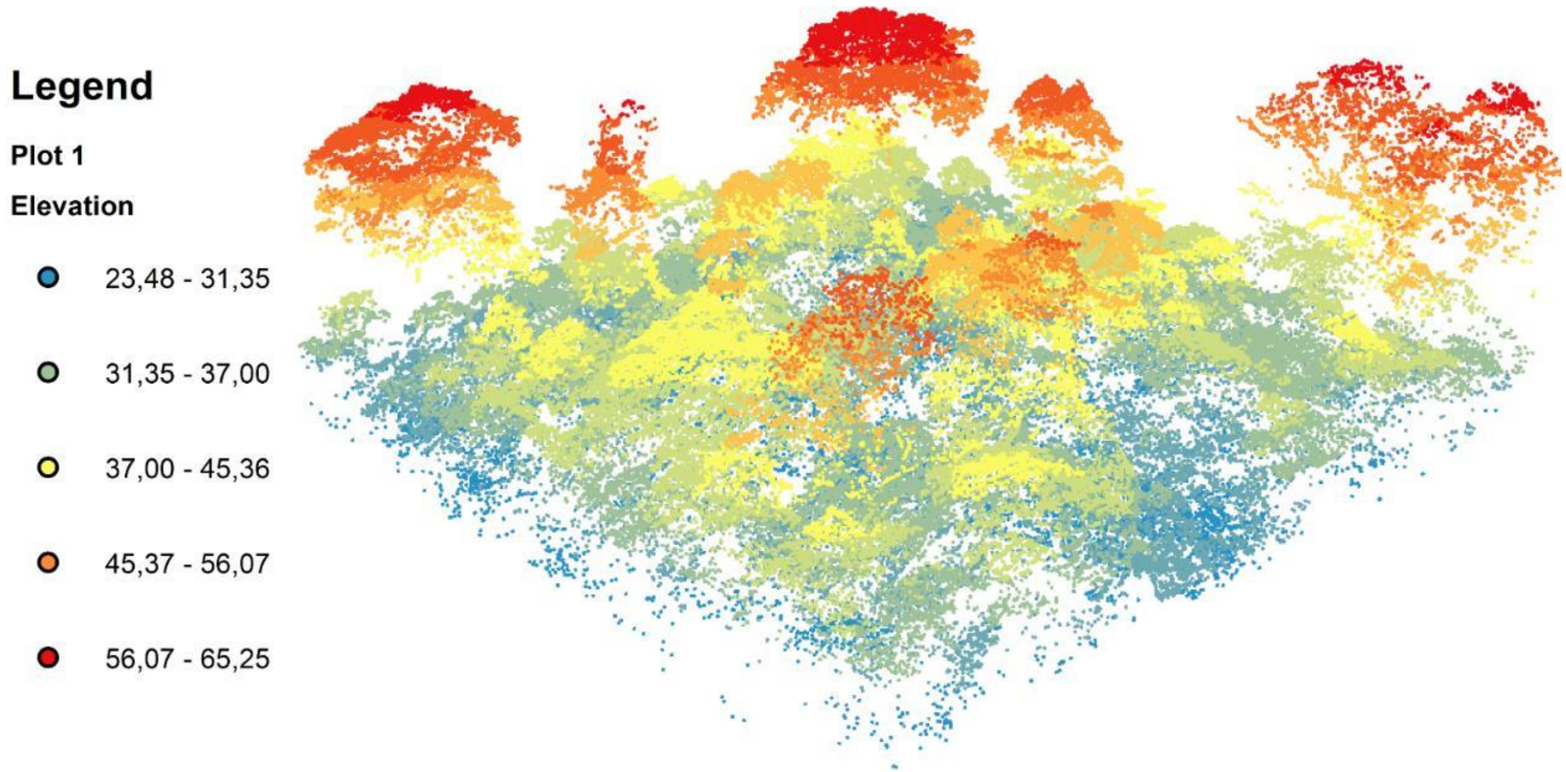
CI-110– Plant Canopy Imager

WinSCANOPY– Digital Camera and fish eye lens

A hemispheric photo of a boreal forest. These photos are used to calculate estimates of LAI.

Source: http://goo.gl/2iw8BT

LiDAR



SOURCE: https://jappliedecologyblog.files.wordpress.com/2015/07/lidar.jpg. ***LiDAR-generated 3D model of forest canopy structures***

Hemispherical HDR photography

Vertical canopy fieldwork

Hemispherical HDR photography

INSTRUMENTS USED :

1. DSLR Camera
2. Equisolid fish eye lens
3. Full frame sensor
4. Tripod

NATURE OF PHOTOGRAPHY:

Vertical Canopy

METHOD USED:

Gap Fraction and Luminance based

Taking hemispherical HDR photos

Avoid **Solar Disk** | **Avoid** **Shadows** | **Avoid** **Variable Clouds**

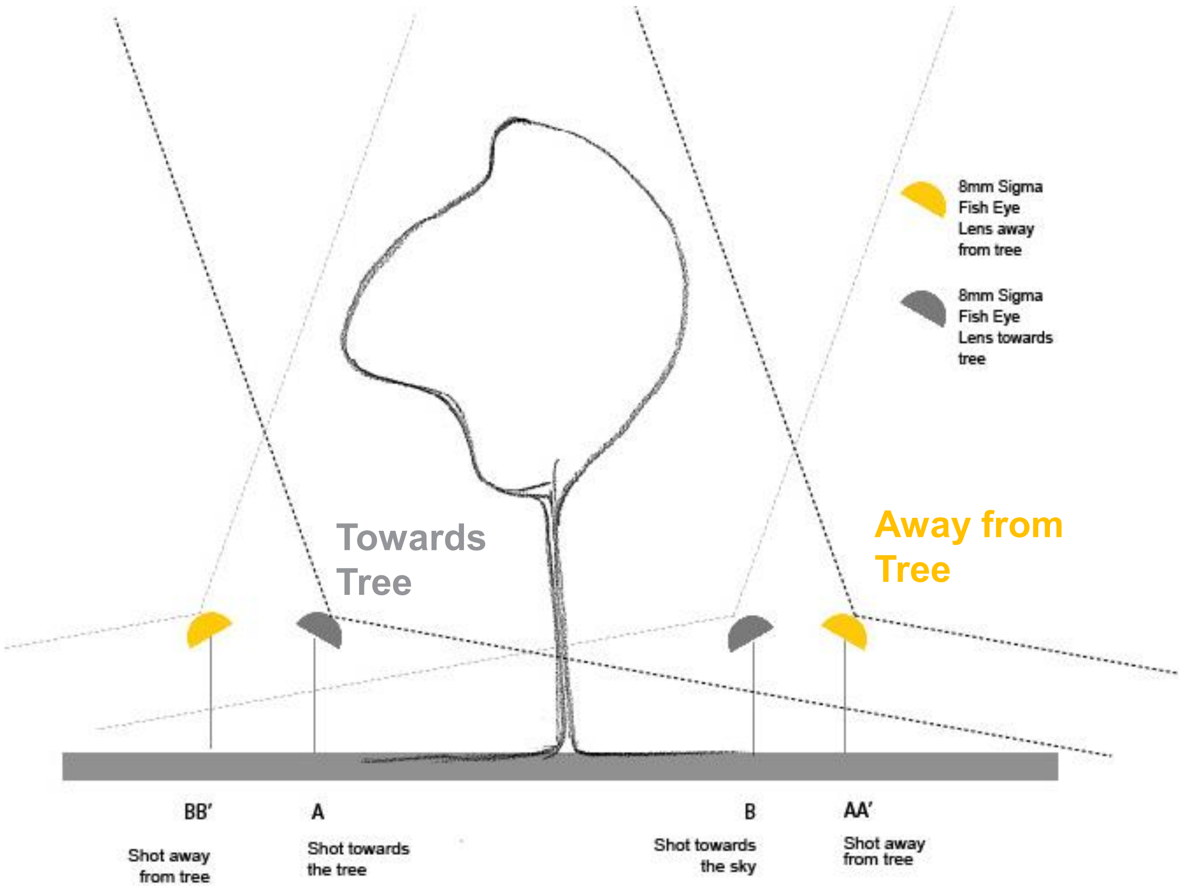
Clear sky with sun

Overestimation/ Underestimation of gap fraction

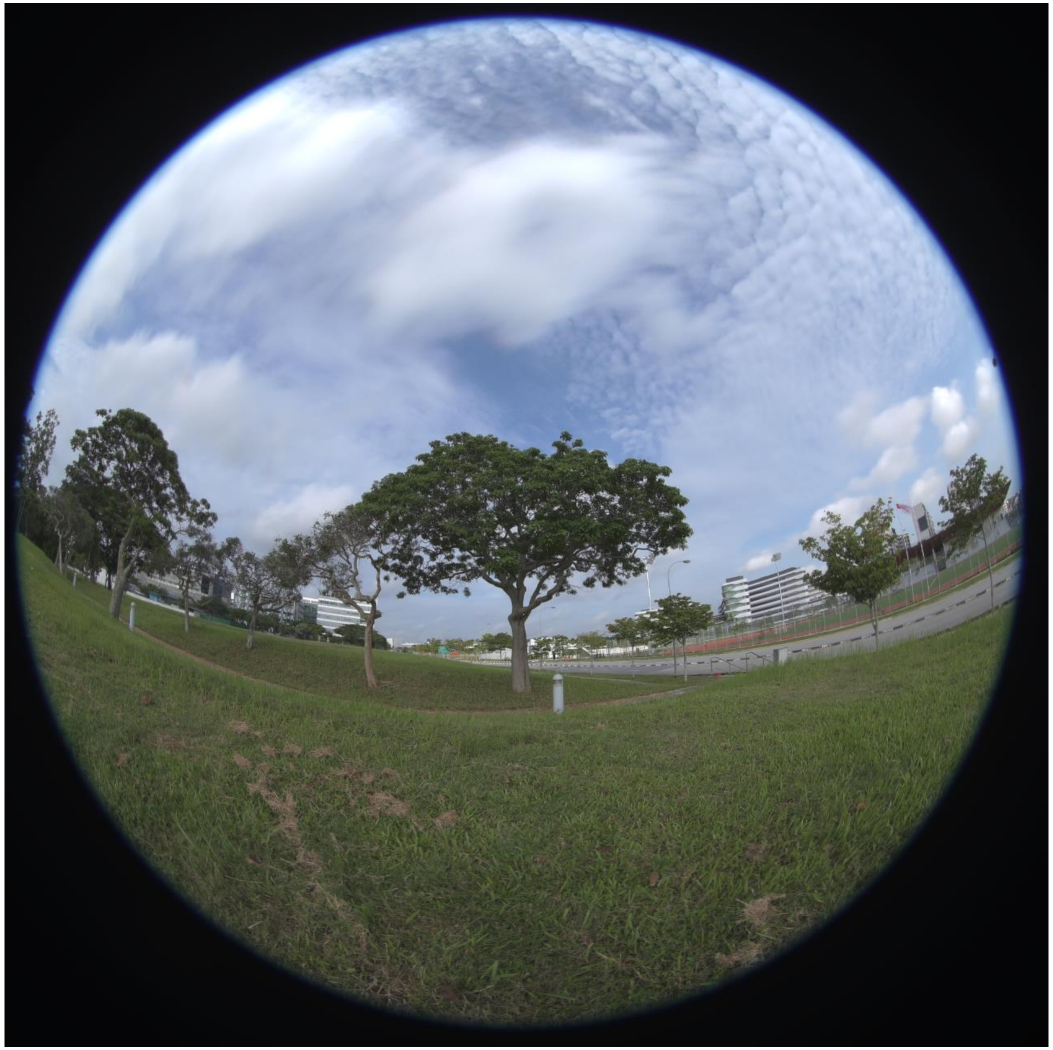
Overcast sky

Normal estimation of gap fraction

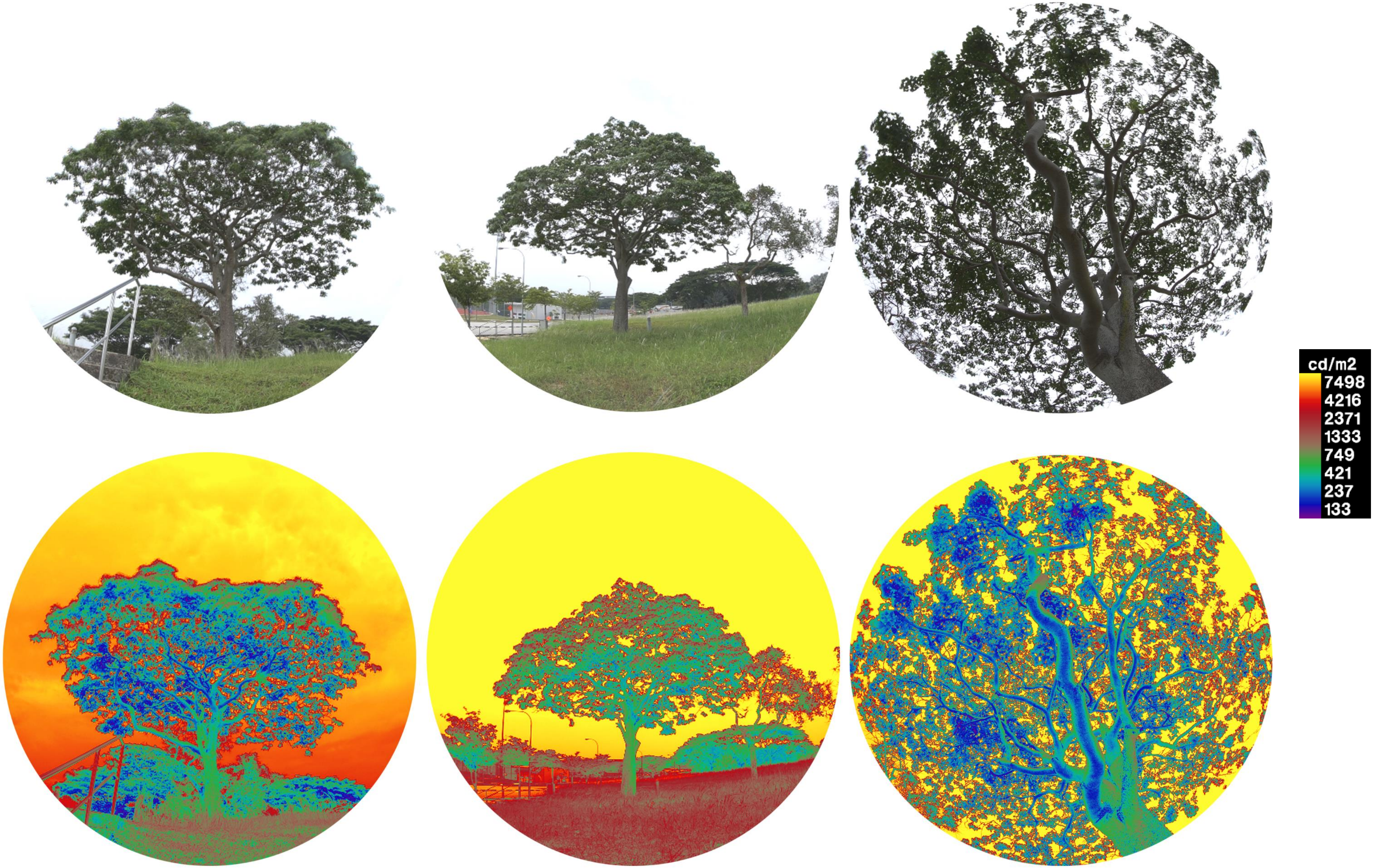
Taking hemispherical HDR photos



Taking hemispherical HDR photos



Hemispherical HDR photography



Post-processing of HDR photos

Post-processing HDR photos

THRESHOLDING

Is converting a colour image into a binary image of black and white pixels.

The aim of thresholding is to separate the tree in question from the background, in most cases this is the sky.

Hence here the black pixels are foliage and white pixel is the sky.

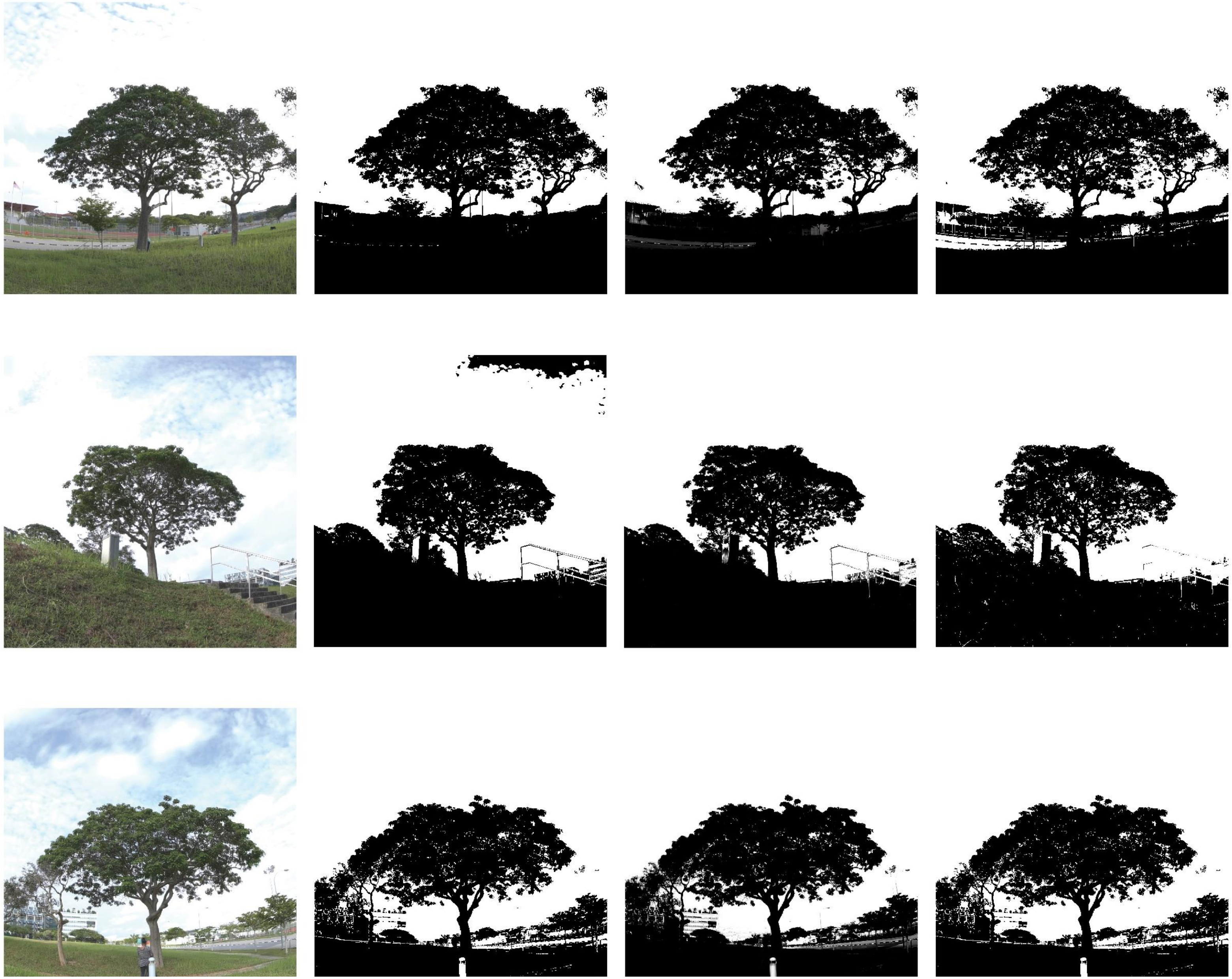
MASKING

Is to determine the shape and area of the canopy.

Masking is subjective based on the amount of foliage and outline we want to consider in and of a vertical canopy.

Thresholding

Threshold Automated **Threshold Manual** **Threshold Average**



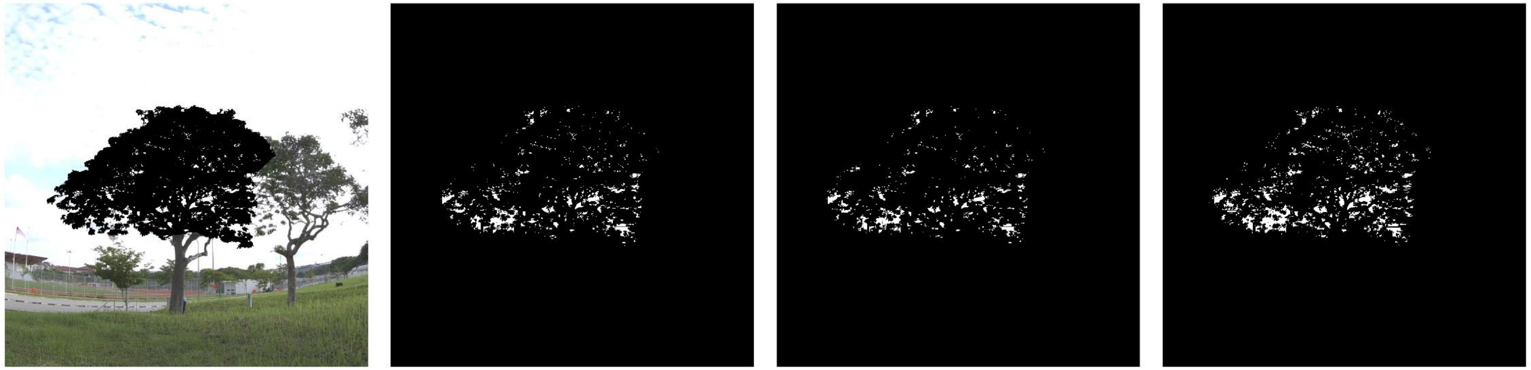
Threshold Automated:
The threshold value is obtained by an automated method proposed by *Michael Nobis and Urs Hunziker. (MATLAB)*

Threshold Manual:
Maximum threshold value is applied after manually removing background sky pixels of the image. (PHOTOSHOP)

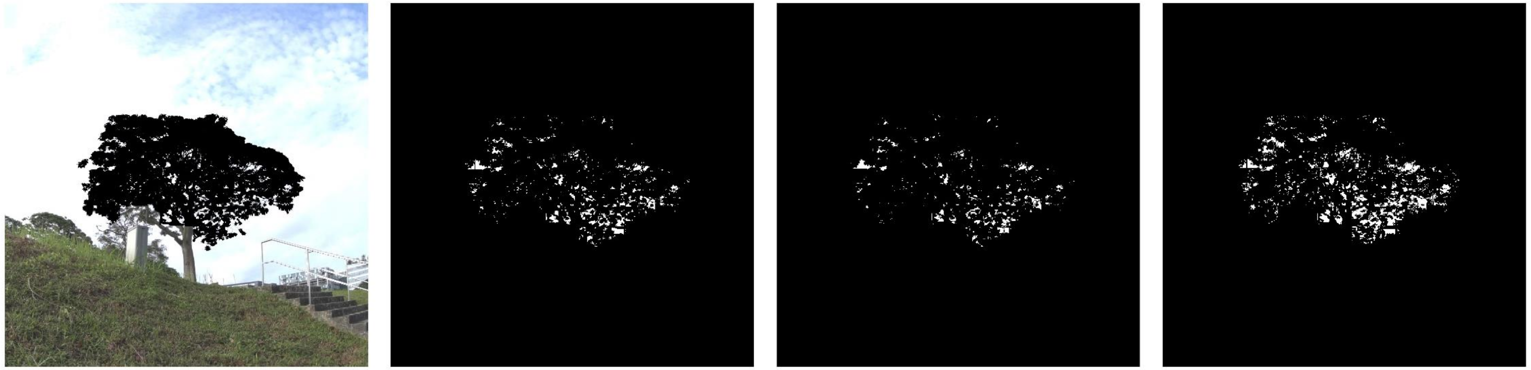
Threshold Average:
Threshold value is determined based on average brightness of the image. *(MATLAB)*

Thresholding

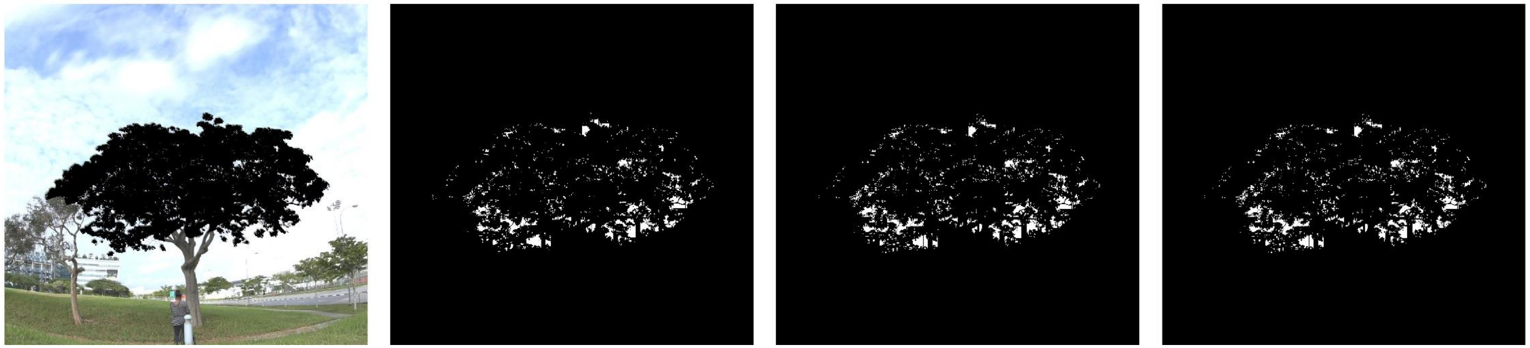
Threshold Automated | **Threshold Manual** | **Threshold Average**



Gap Fraction : 8.1 | Gap Fraction : 6.9 | Gap Fraction : 12.1



Gap Fraction : 7.55 | Gap Fraction : 5.6 | Gap Fraction : 14.197



Threshold Automated and Manual: have similar values in most cases but manual is labor intensive and can lead to variation in results.

Threshold Average : over estimation of gap fraction.

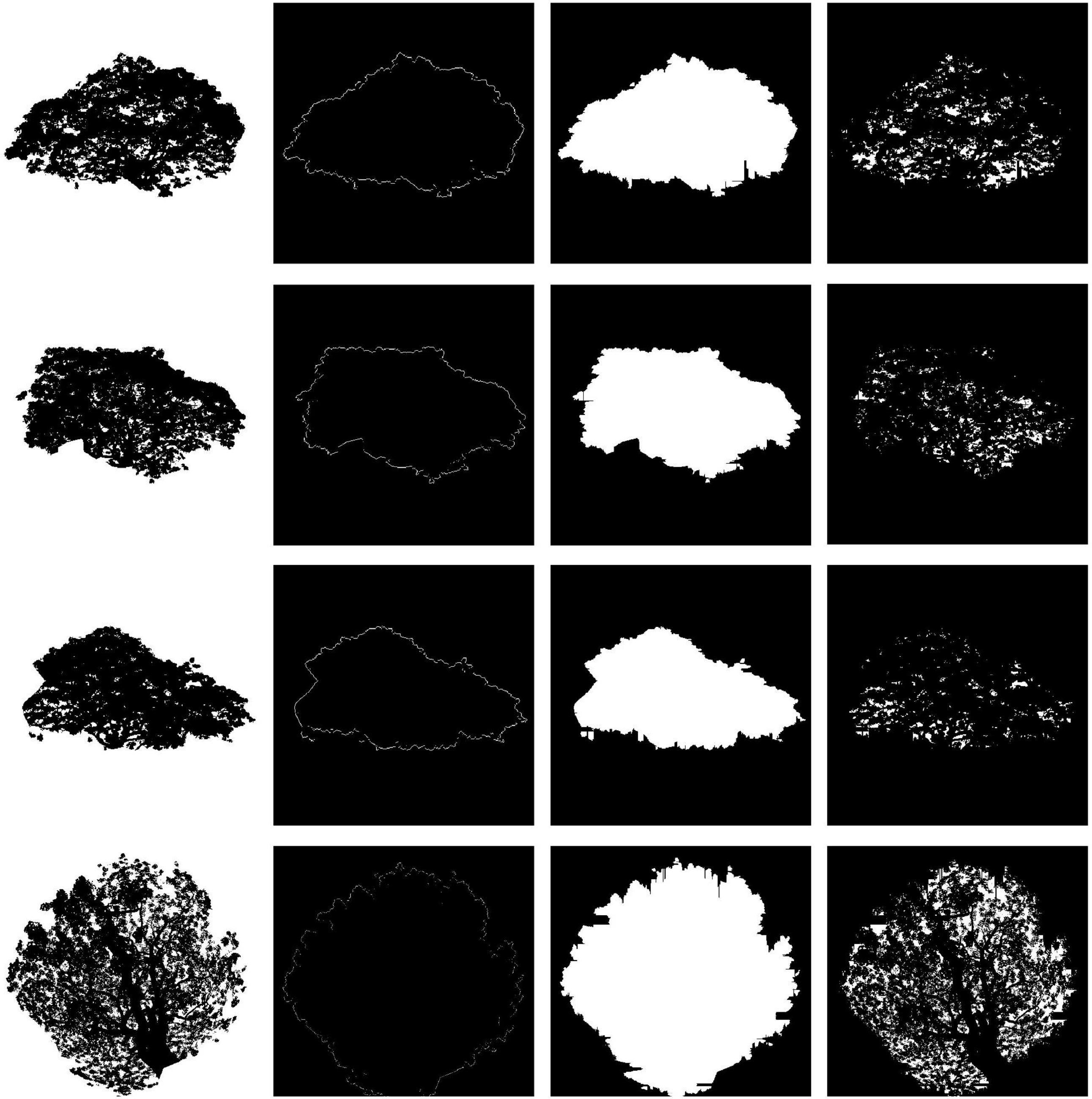
Threshold Automated: is a more standard and uniform method of thresholding.

Masking

Cropping tight to get the vertical canopy boundary

Cropping the immediate background

Gap fraction method



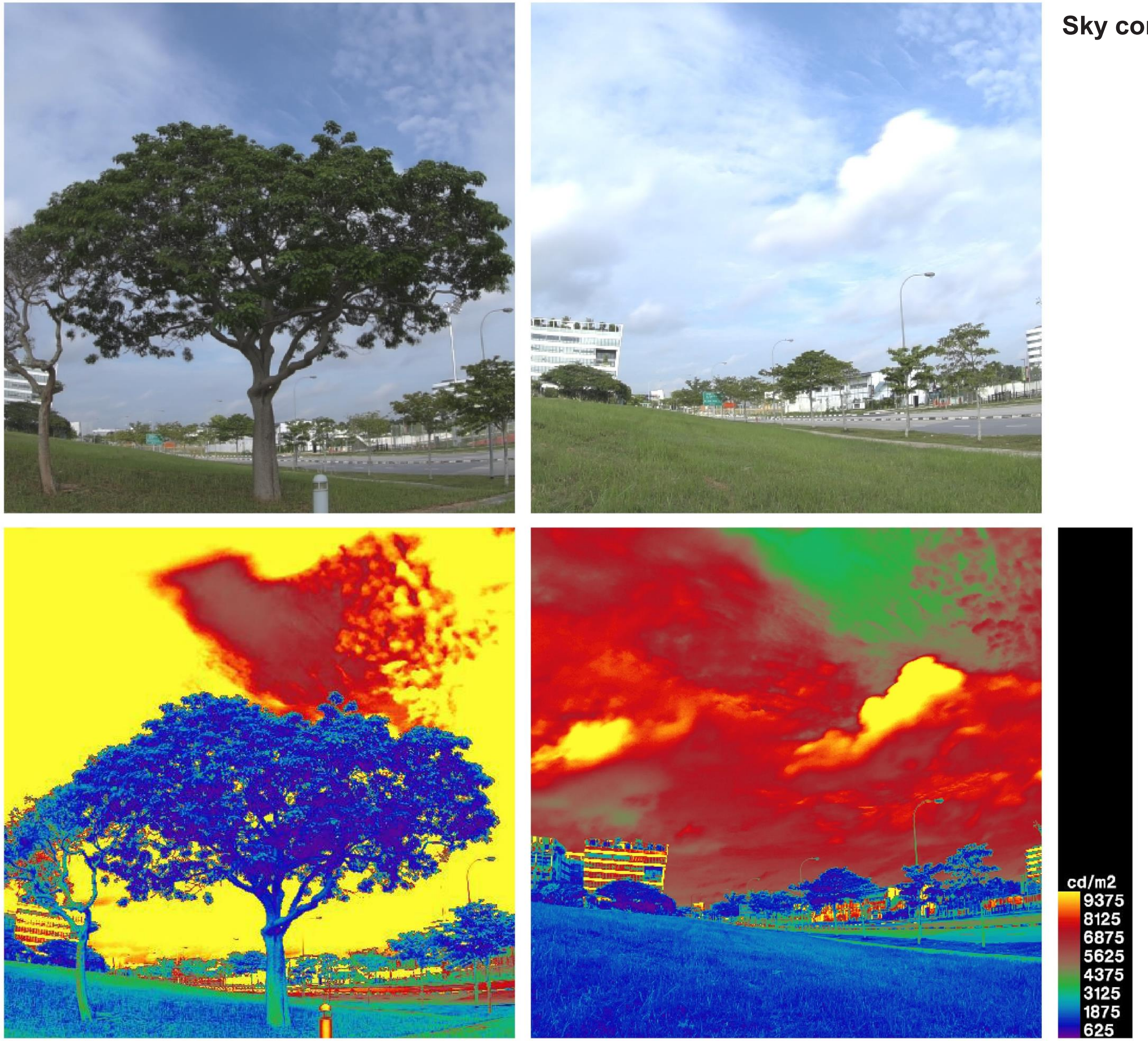
Gap size percentage : 13.6%
Vertical canopy

Gap size percentage : 9.4%
Vertical canopy

Gap size percentage : 7.4%
Vertical canopy

Gap size percentage : 26.6%
Under canopy

Luminance-based method

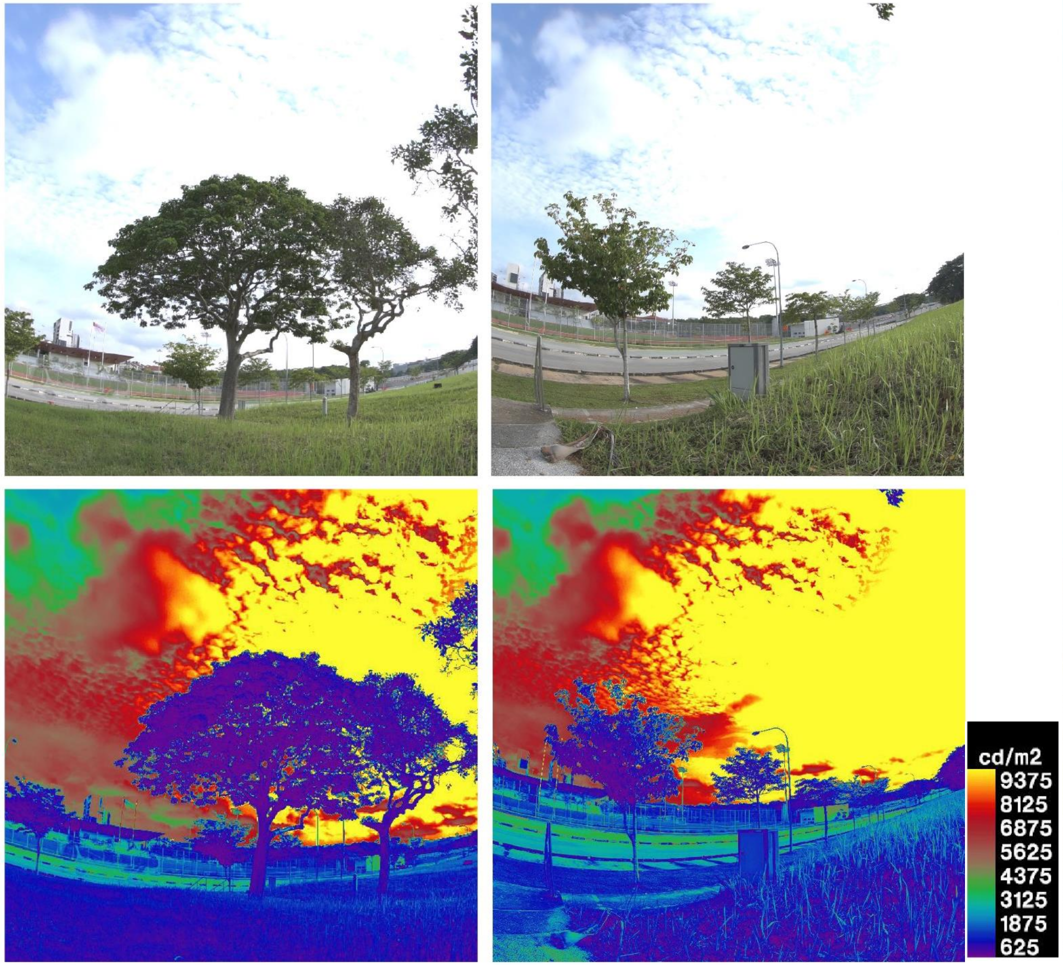


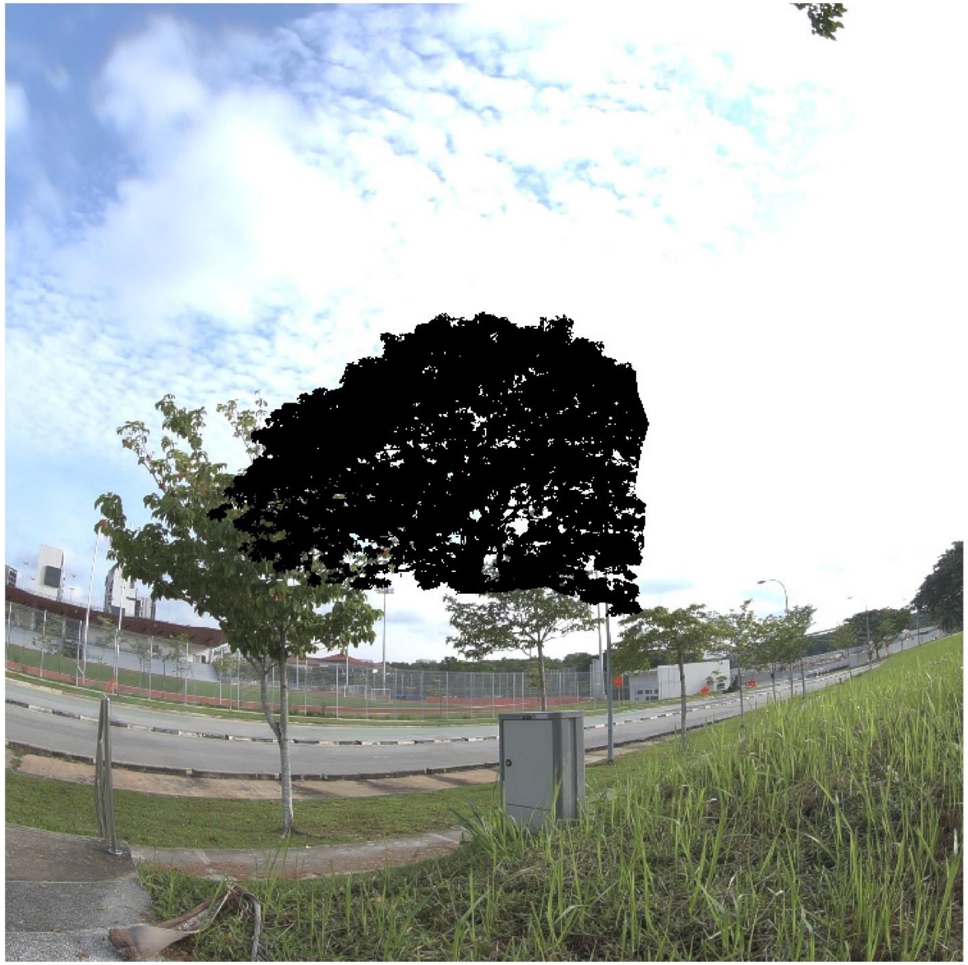
Sky conditions changing

Transmittance : **0.09**

Luminance-based method

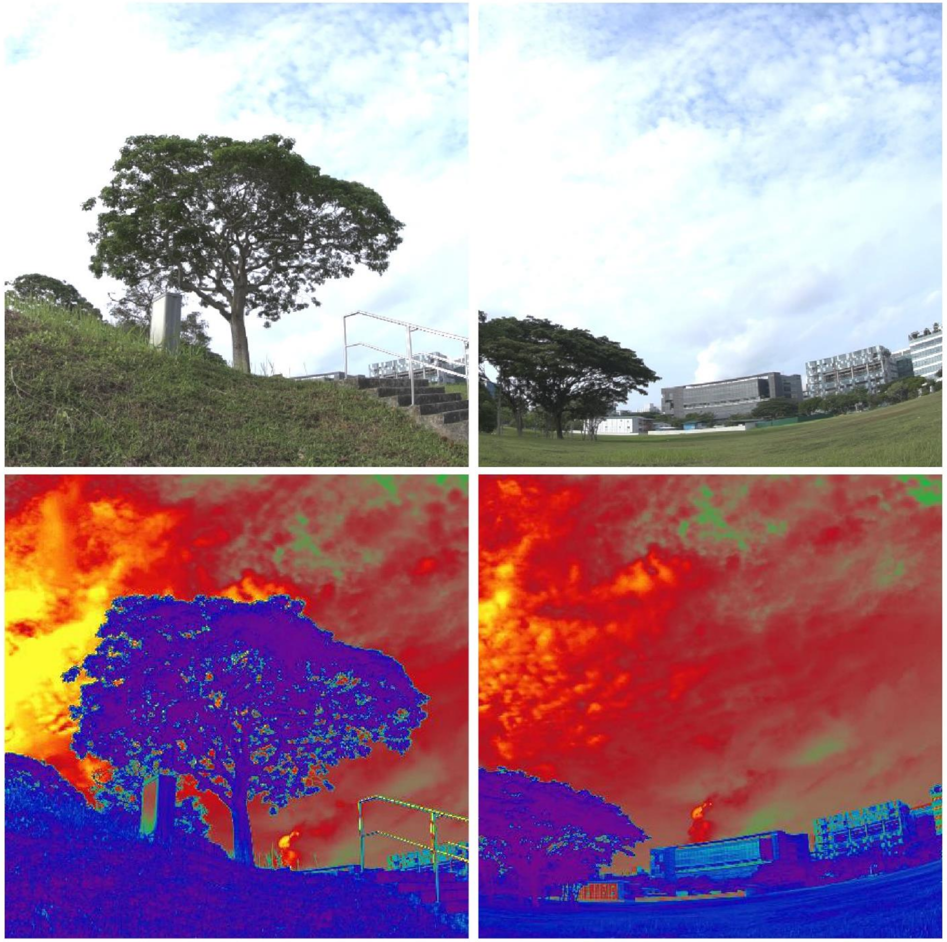
Camera angles varying towards and away from the tree



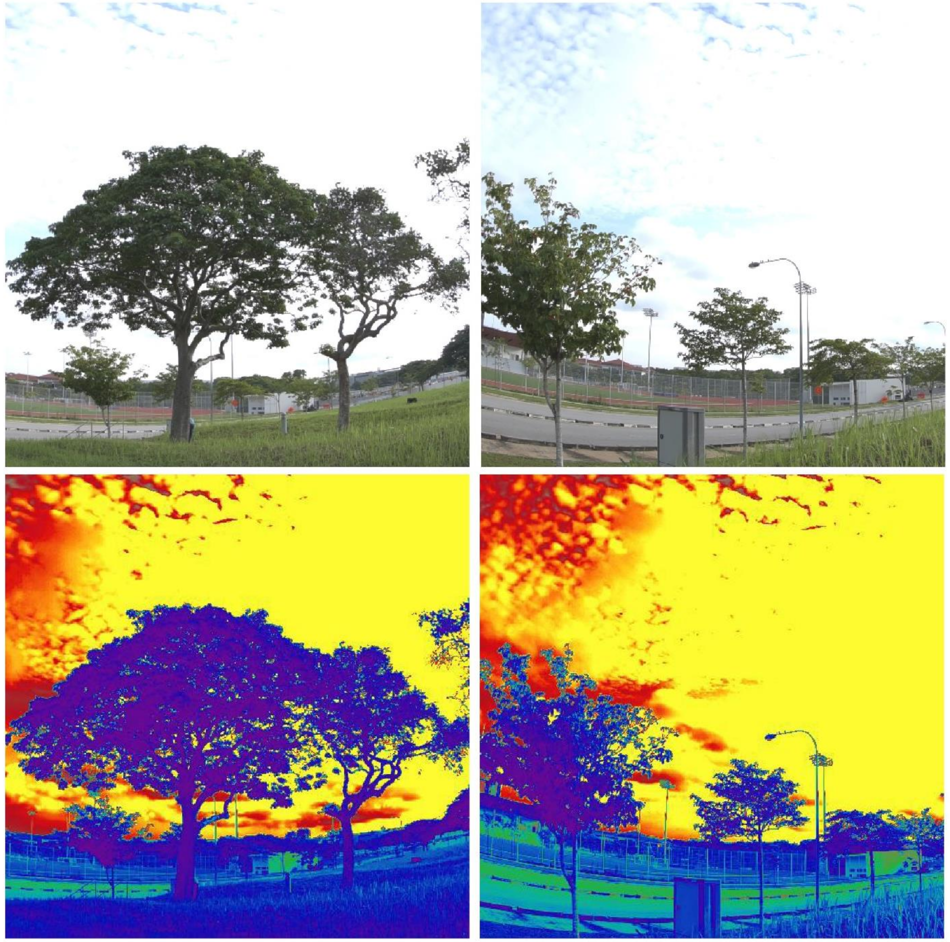


Transmittance : **0.04**

Luminance-based method

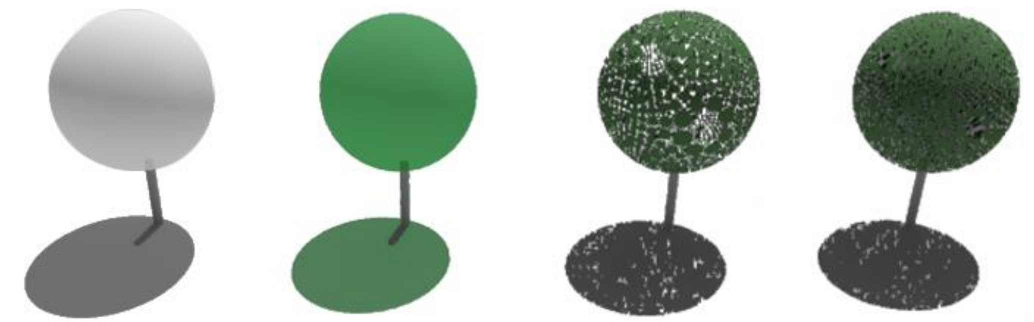


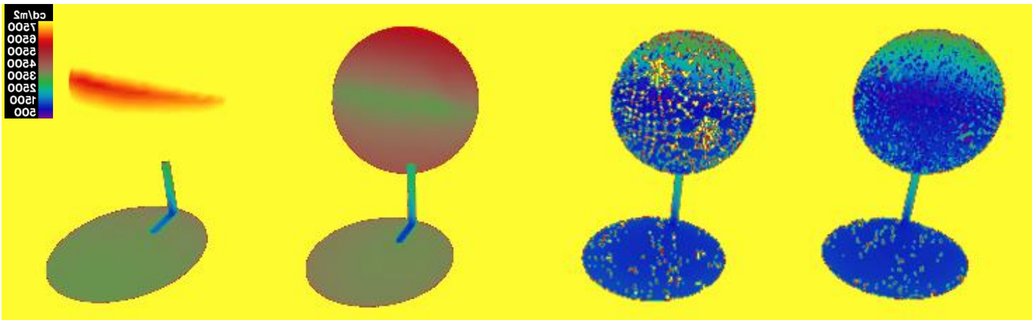
Transmittance : **0.03**

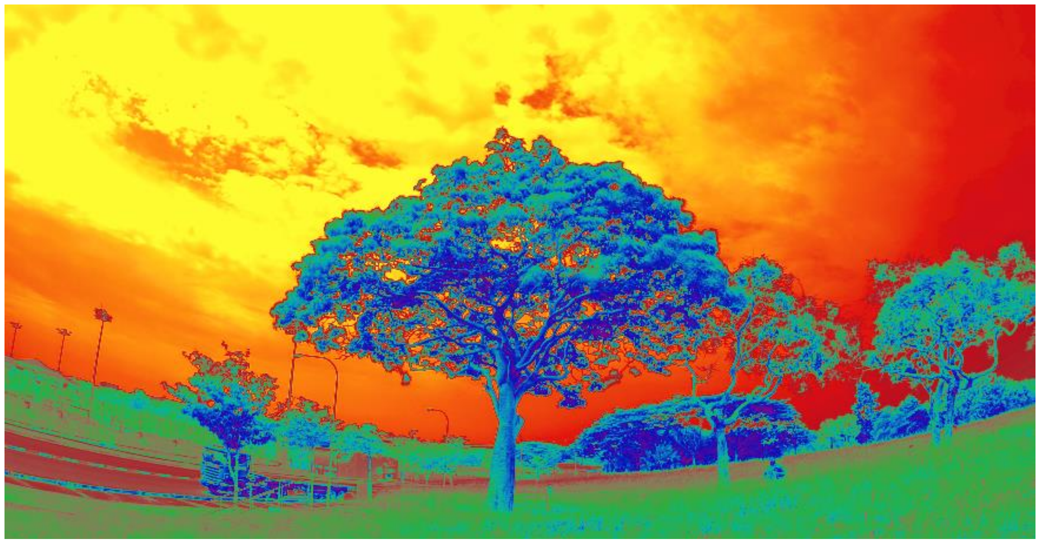


Transmittance : **0.05**

Measurement conclusions

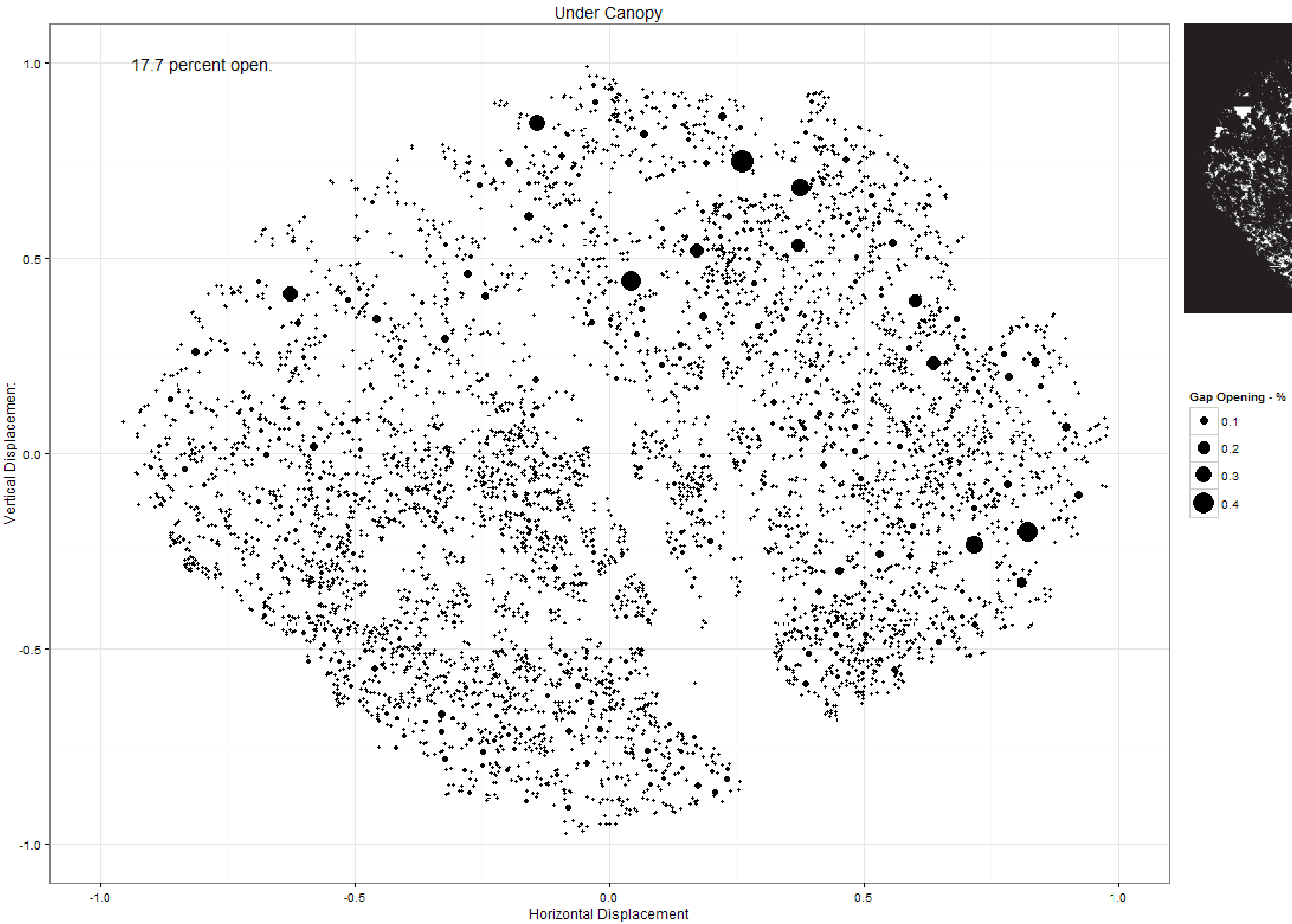


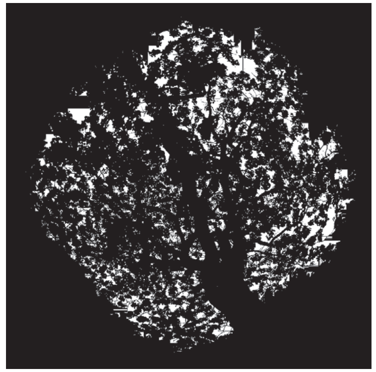




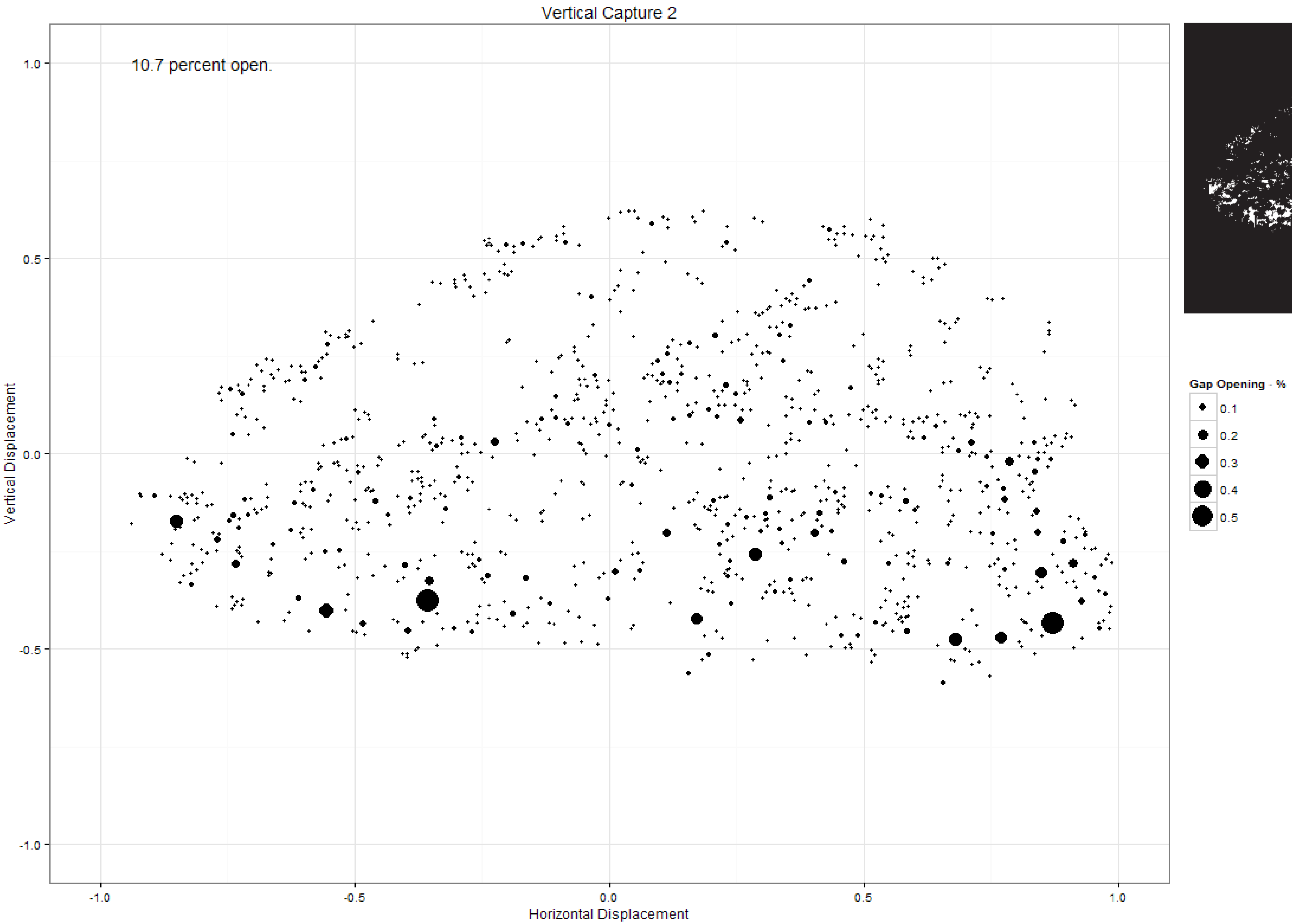
- Gap fraction method gives us a way to model the trees geometrically / as radiance material definitions ('to get an appropriate void percentage')
- Luminance method gives us a way to determine the transmittance coefficients of the trees.
- The reflectance percentage of the trees is a major component when quantifying the light through trees. This is something we need to research further.

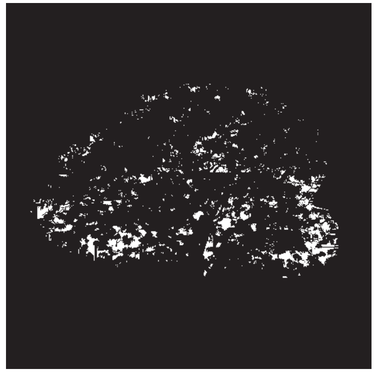
Distribution of openings: Under canopy



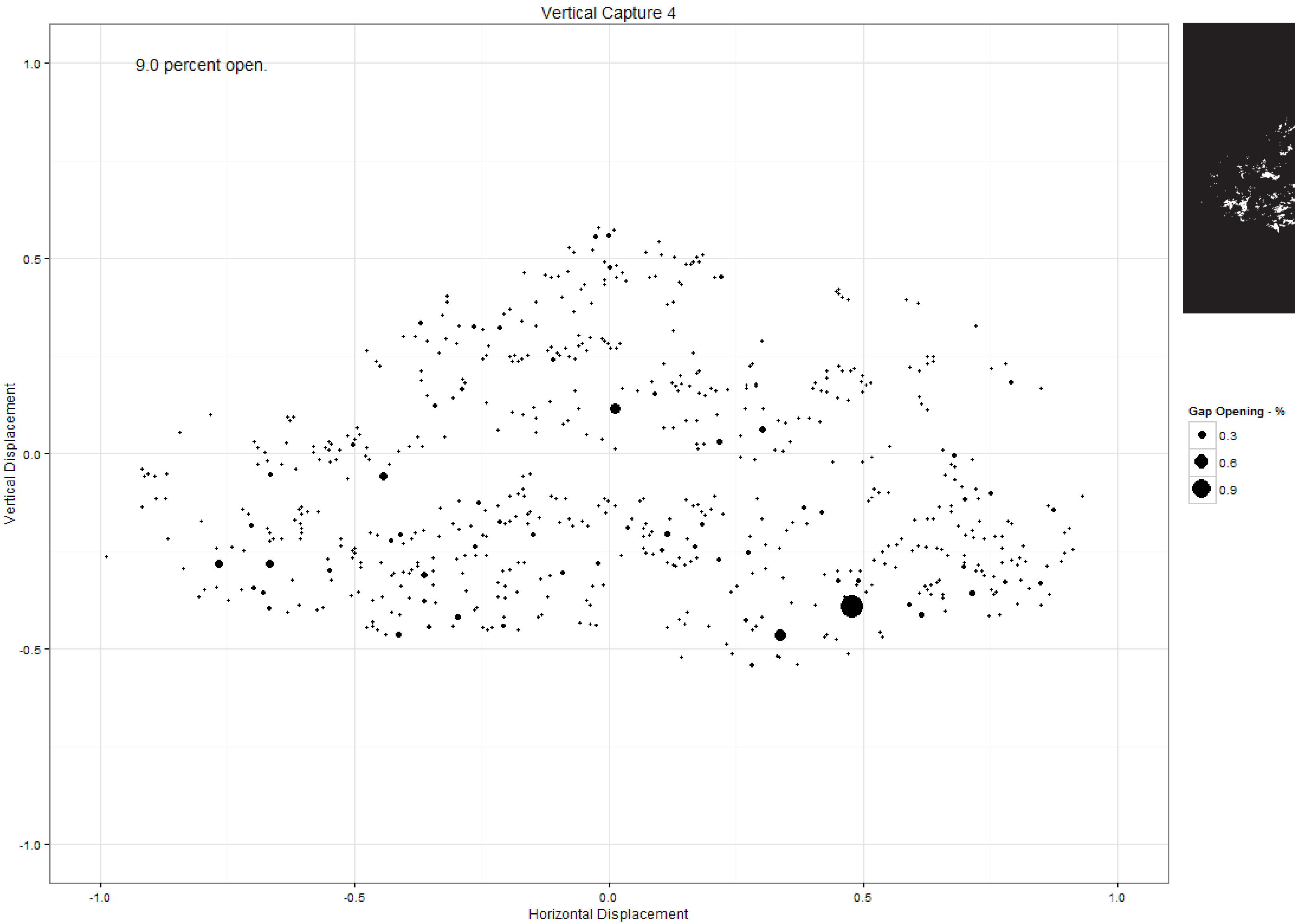


Distribution of openings: Side capture

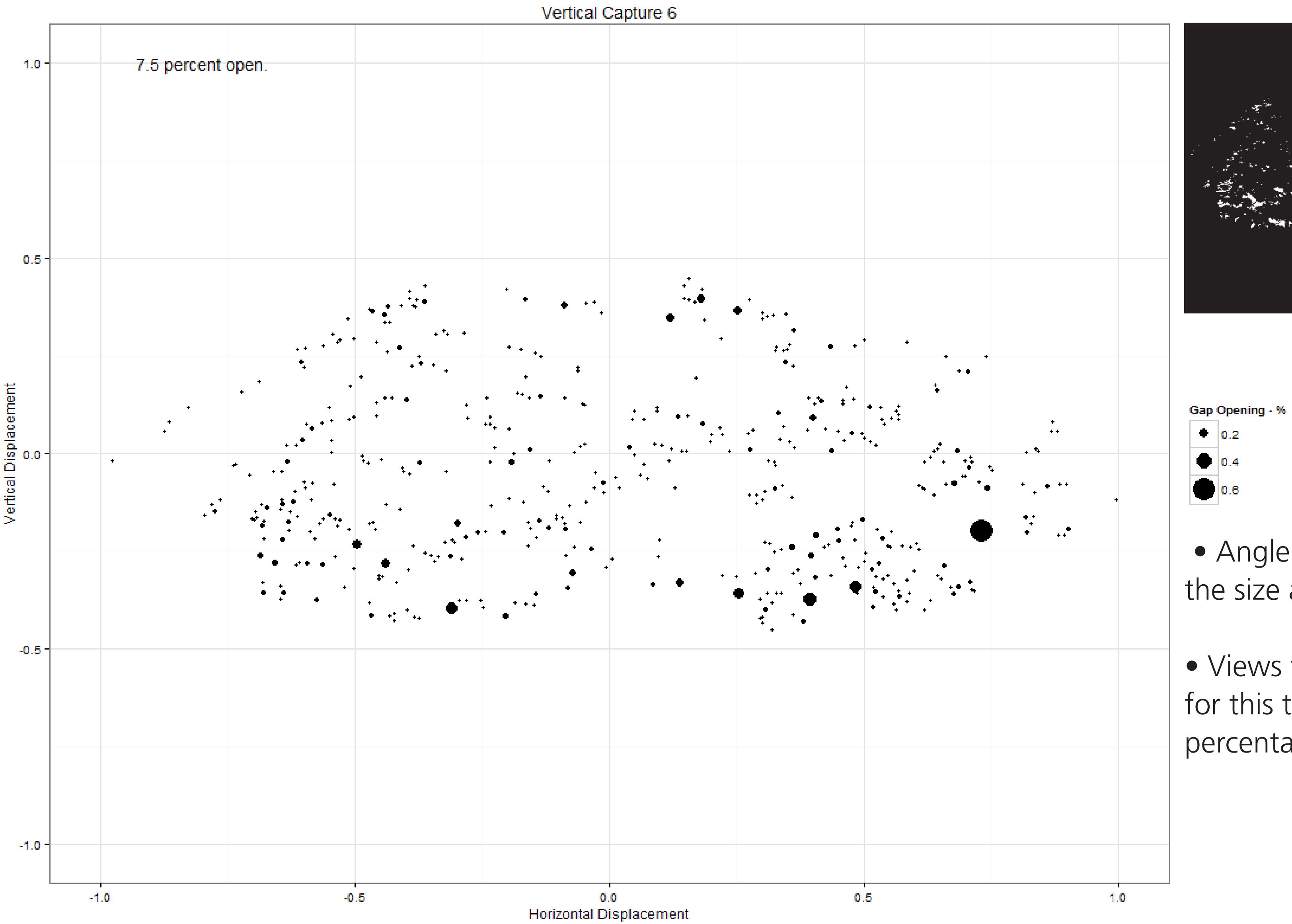




Distribution of openings: Side capture



Distribution of openings: Side capture

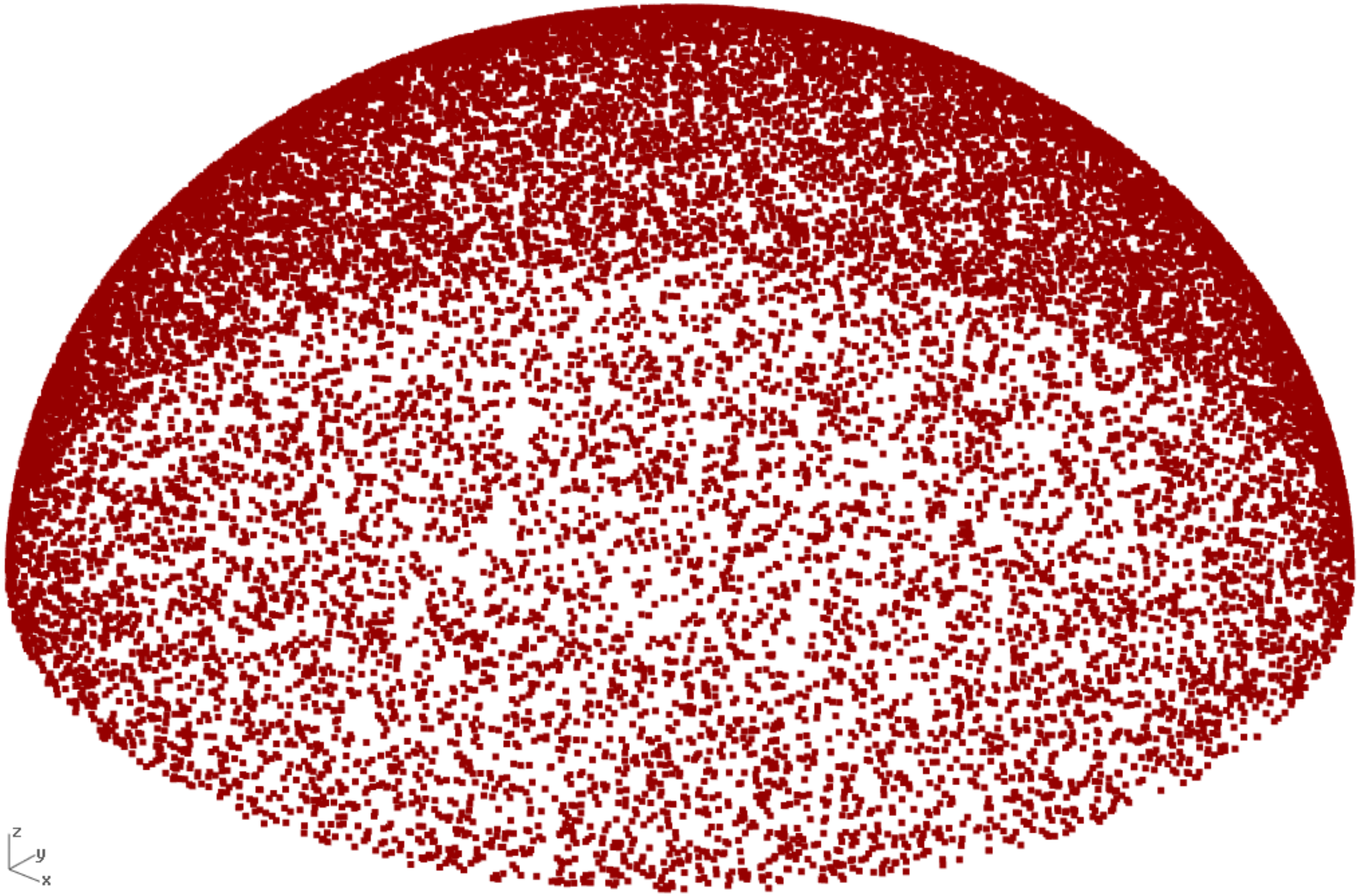


- Angle of view significantly impacts the size and total percentage of gaps.
- Views from under the canopy, for this type of tree, have a higher percentage of gaps.

Begin with random points on a (squished) hemisphere

• Tree generator program: Work in progress!!

• We use a slight variation of George Marsaglia's method for achieving a random distribution.



Randomly generated points mapped across a squished hemisphere

Procedurally fill areas

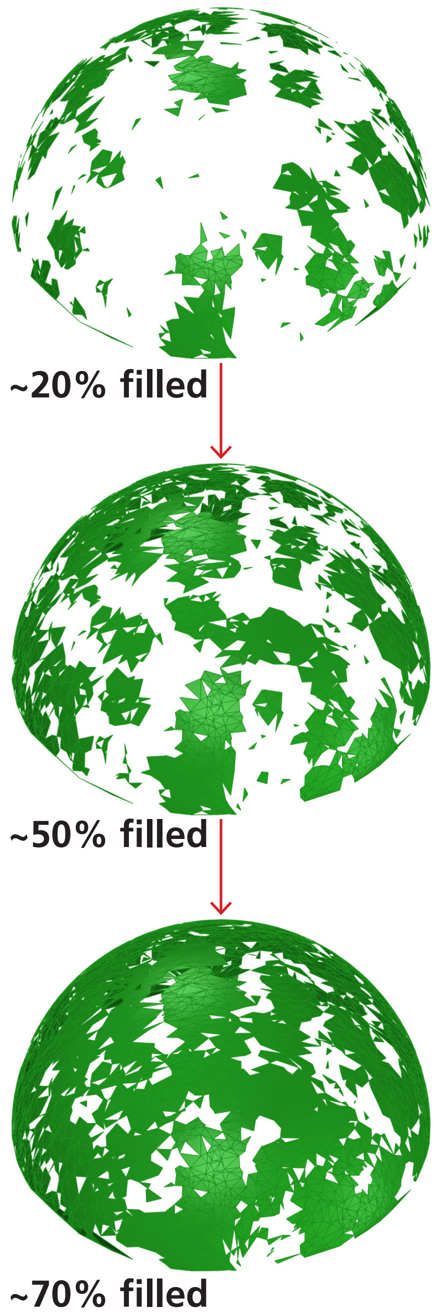
• Begin with a set of rules that are triggered based on observations of the frequency of small and large gaps.

(1) Fill a single triangle based on point neighbors.

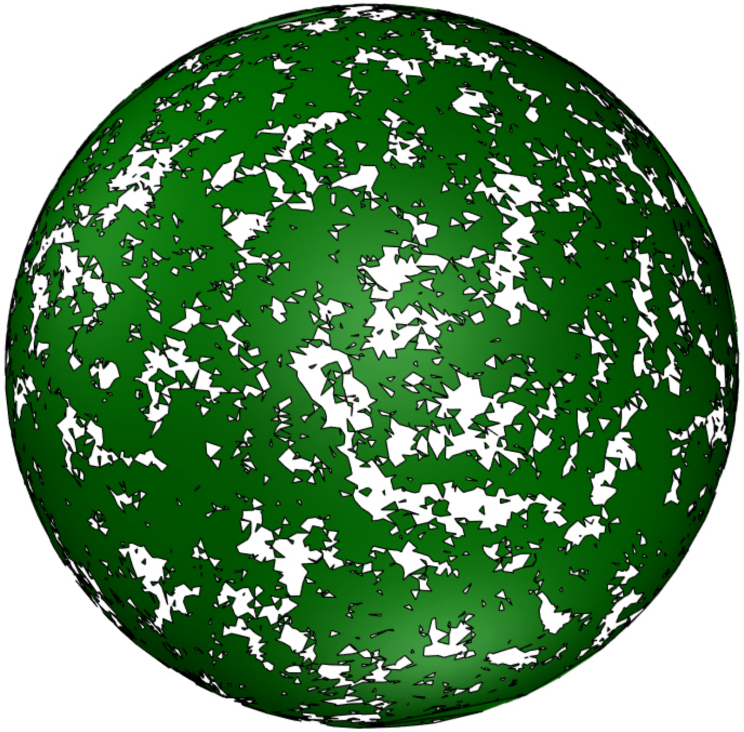
(2) Fill a larger area (concentration / bunch of leaves) while leaving some small gaps.

• Iterate until the percentage of filled areas are equal to 1-gap percentage. Some translation needs to happen between the area of the sphere and the view of the camera here.

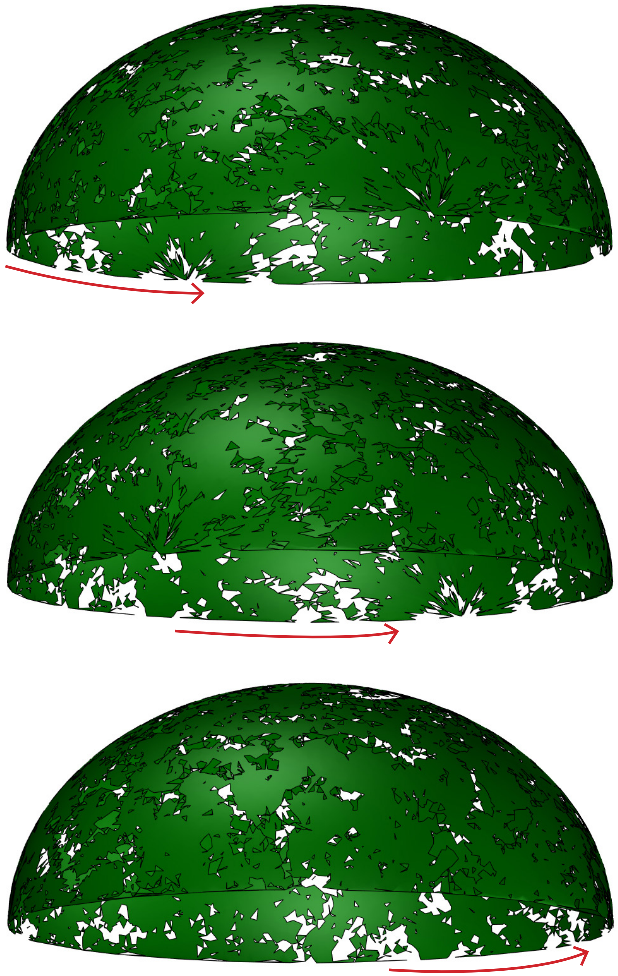
- If the gap percentage is taken from below the canopy, projection of the polygons to a plane works OK.



Resulting tree canopy

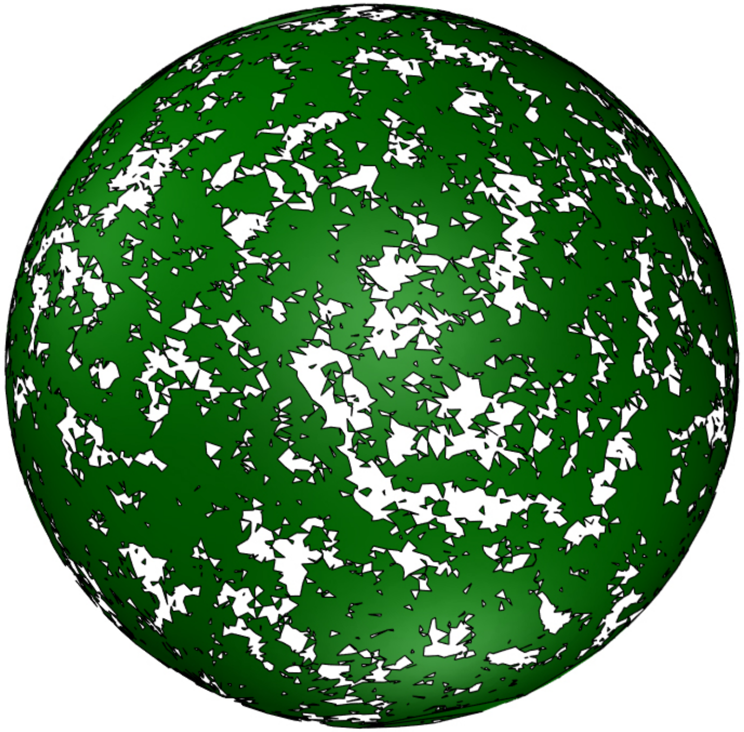


Under-canopy view of resulting tree. Gap percentage is larger than in accompanying vertical views.

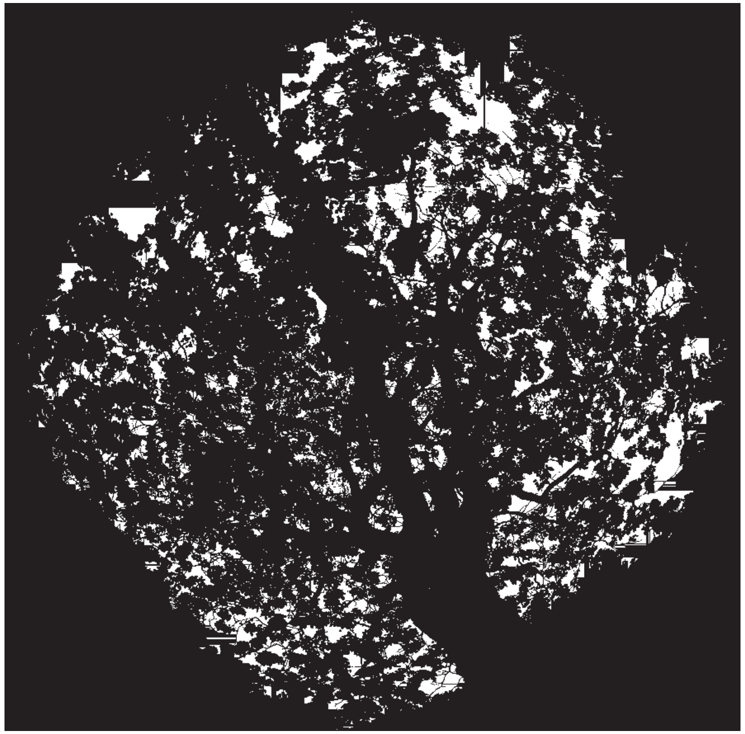


Vertical views of resulting tree. Distribution and total gap percentage vary with viewing angle.

Resulting tree canopy

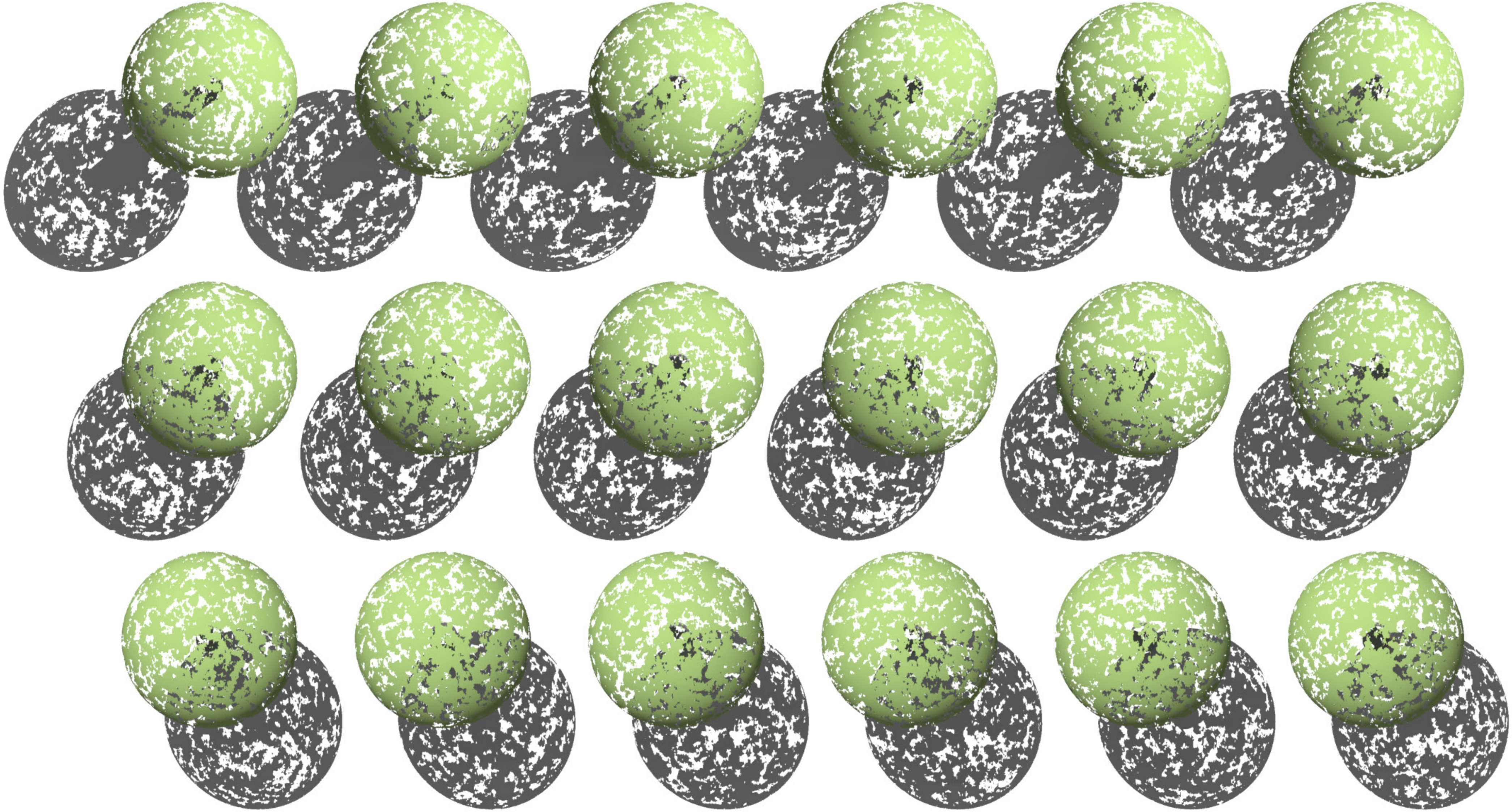


Under-canopy view of resulting tree.
Gap percentage is larger than in accompanying vertical views.



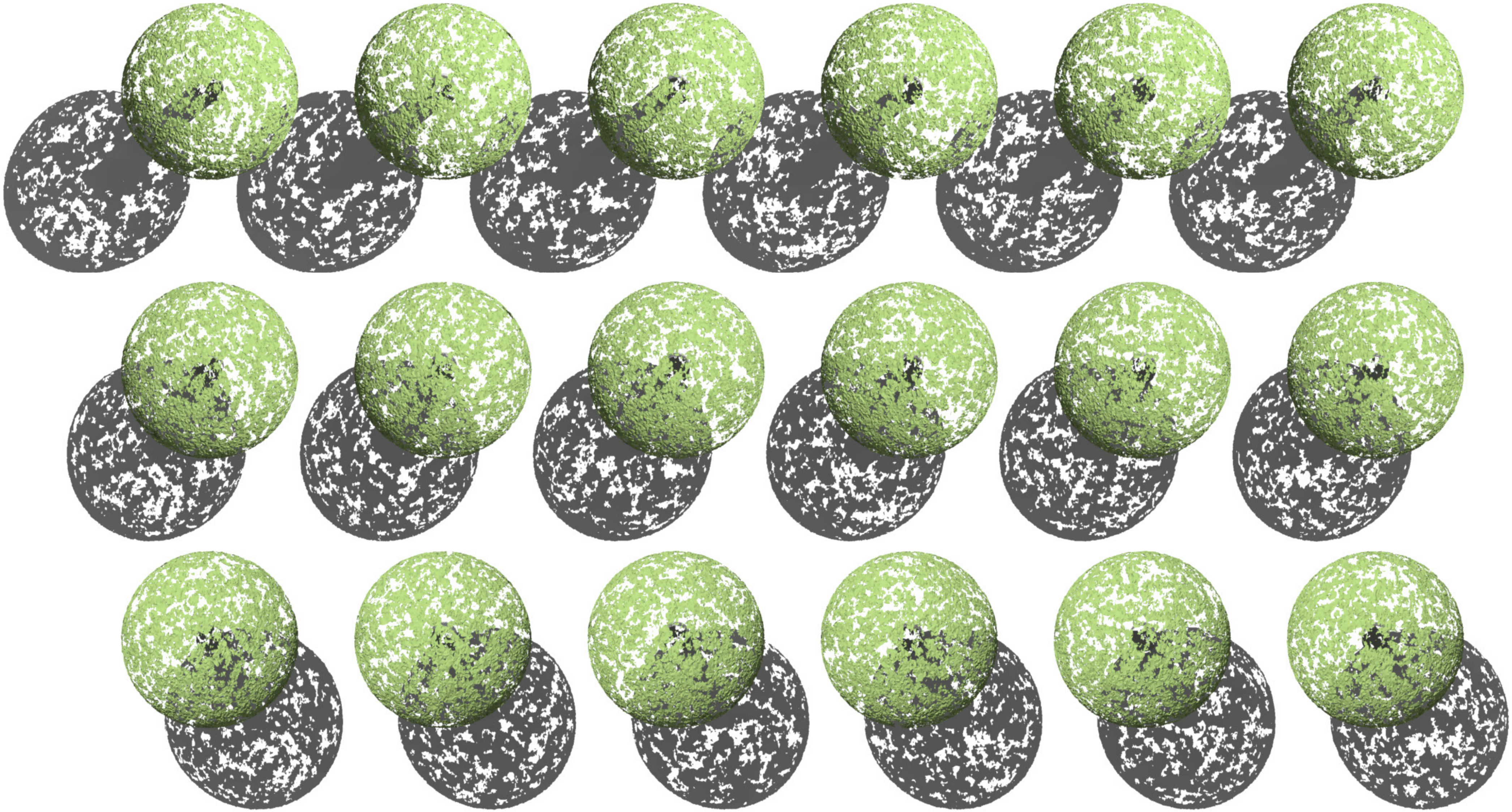
Comparison to measurement.

A (smooth) line of different, typical trees



n polygons = ~30,000 / tree in this example

A (rough) line of different, typical trees

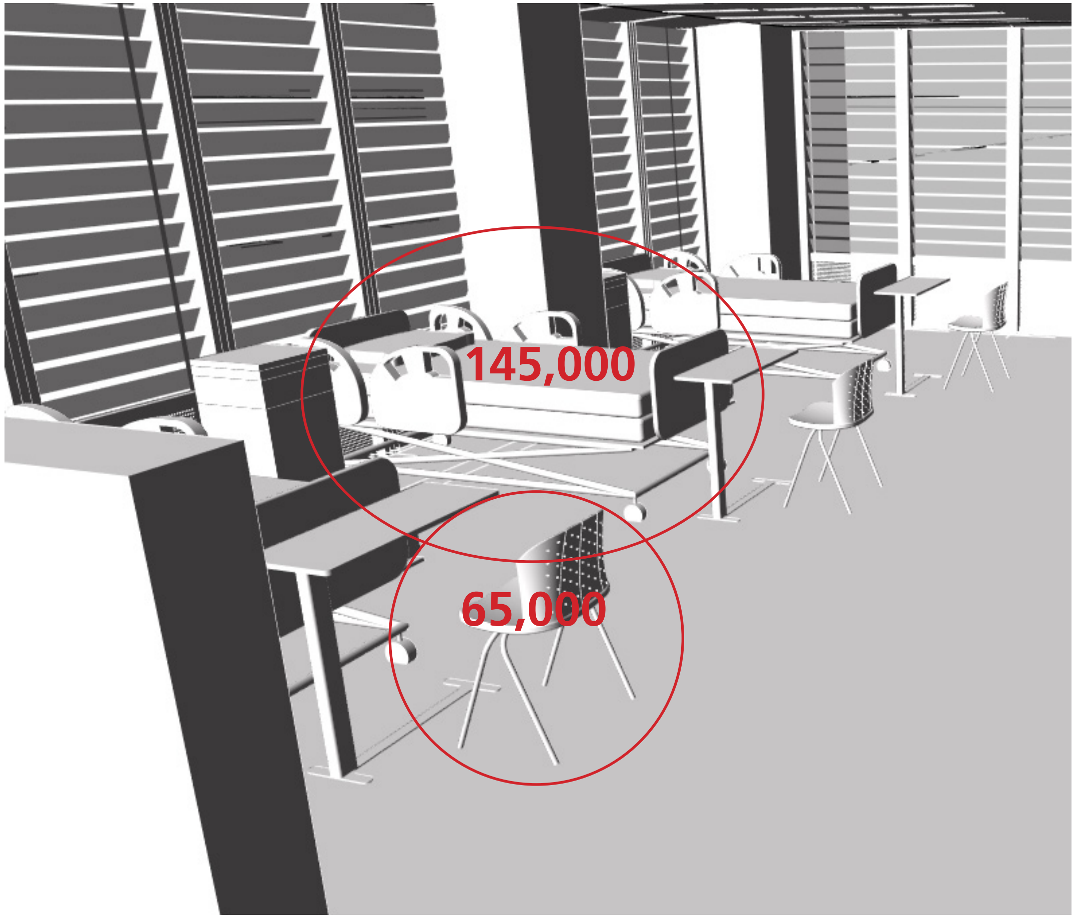


n polygons = ~30,000 / tree in this example

Note: Jittering the polygon vertices increases rendering time significantly.

Future work: Application to different species of trees

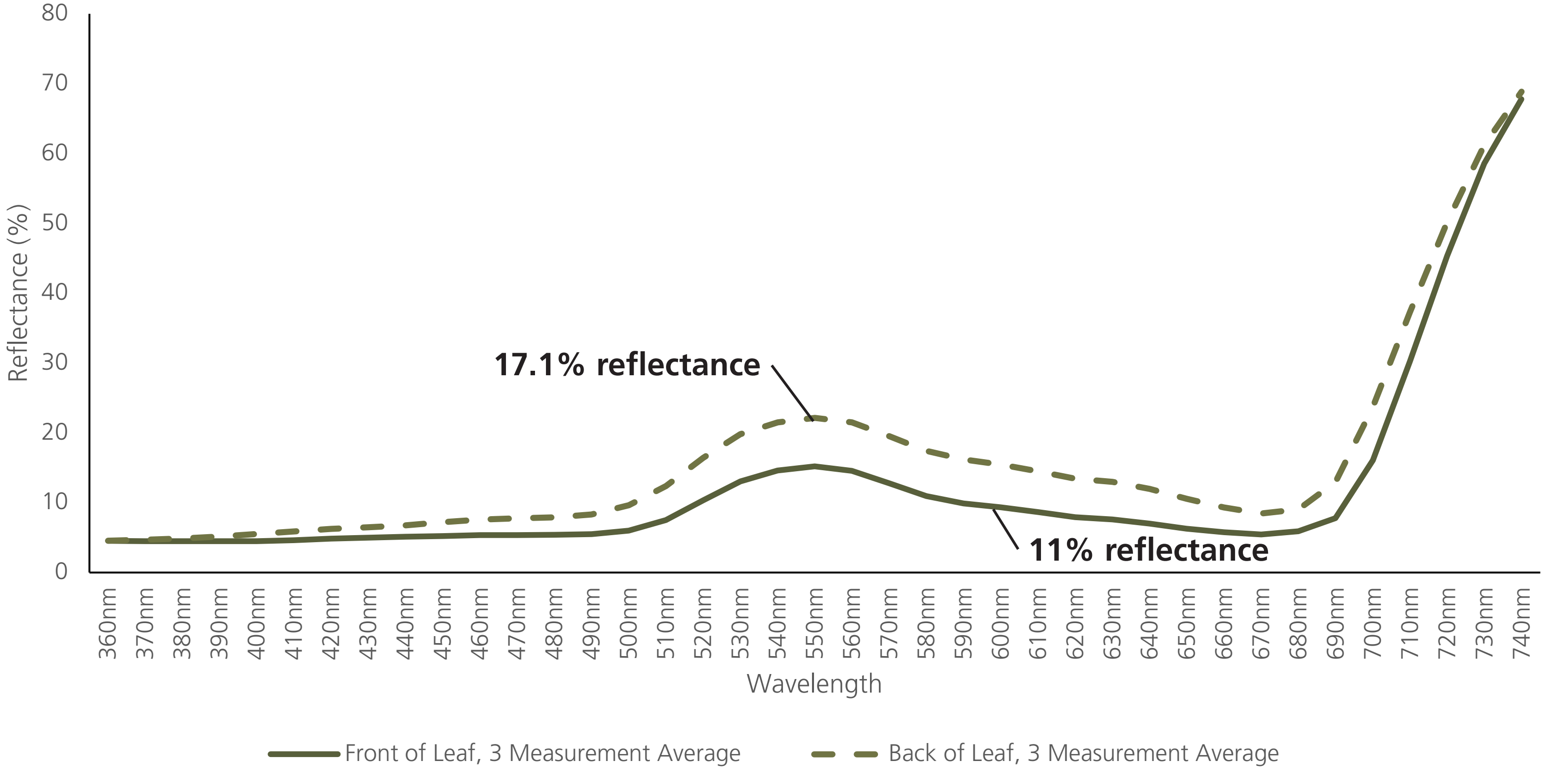
30,000 -- too many polygons?



Visualization of polygon counts in an architectural model with furniture included

- Simple solution to large poly counts: generate less points in the initial step.
- We found ~30,000 to give good visual results.
- Oconv plays very nicely with the trees, because the points are, on average, equally spaced.
- Detailed furniture models can have between 65-145,000 polygons!

Reflectance properties -- just measure it?



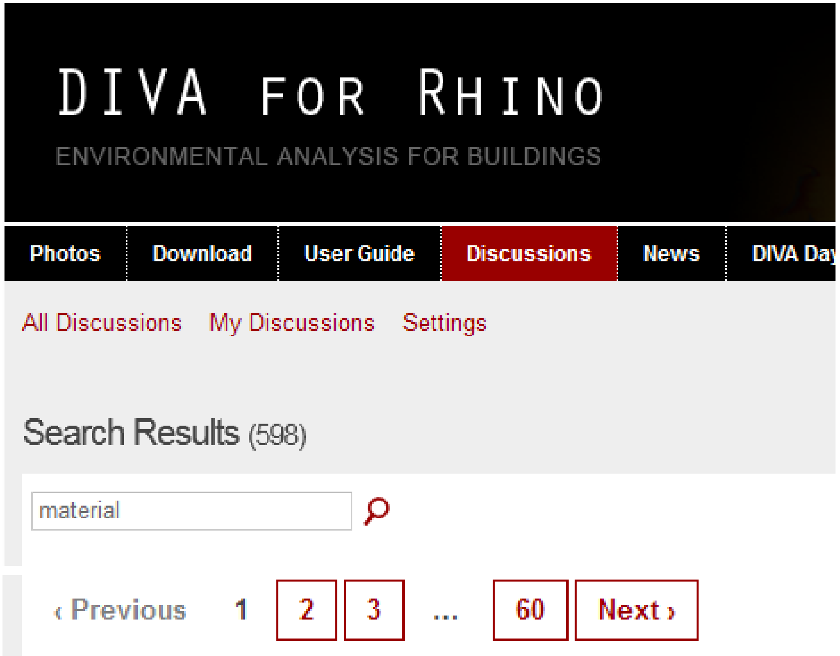

```
void plastic front_of_leaf
0
0
5     0.0838     0.1262     0.0418     0     0

void plastic back_of_leaf
0
0
5     0.1450     0.1922     0.0548     0     0
```

- RGB values from spectral data derived using the method in Rendering with Radiance -- it is still useful!

- For now, we use the front-of-leaf reflectance rather than get into two-sided materials in Radiance.

Questions about materiality in Radiance



Search results for 'material' on DIVA's discussion forum: Nearly 600 posts and 60 pages of inquiries result. Some of these are for thermal materials and software-based questions, but many are about defining highly specific material types or looking for measured data.

I'm wondering if it is possible to map bitmap textures onto [Radiance] materials. [...]

> Colorpict examples could be helpful -- actually, it is not easy to use (see Mostapha Roudsari's useful work).

I have added a customized material, but the simulation stopped working.

> Radiance materials documentation could use some examples, especially the 'mod' portion is confusing.

I have a polycarbonate opal and I just have this data: Light transmission 35%; Solar Transmission 38%; Solar Refraction 40%; SHG 0,42%. I need the definition for the material in Radiance please.

> Specific material measurements are nice to have, especially in cases like this where diffuse / specular transmittance information is lacking.

I an trying to simulate [...] a real room at our university. I have RGB colour coordinates and reflectances (in cd/m2) of all the objects and constructions in those room. [...] How to translate normal RGB (0 to 255) coordinates into those used in Radiance materials (0 to 1).

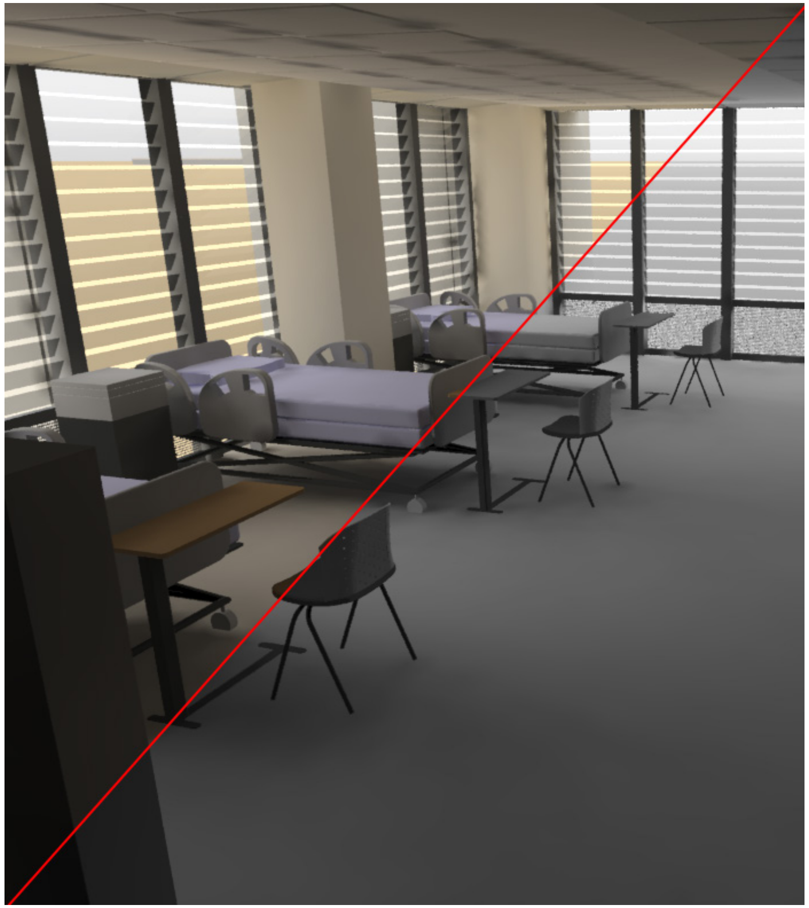
The project I am working on has a relatively heavy forested area just west of a large area of glazing. A large portion of the solar shading strategy is dependent on these deciduous trees. My thought was to build a 'wall' and apply a material with a certain opacity, say 30% for example.

I can´t find a Radiance material for solar cells and I don´t know if it´s even possible to simulate a facade like this.

> There are even many applications where simulators wish to represent accurate material properties.

Selected Radiance material questions from the first 4 pages of results

Questions about materiality in Radiance



Colored / greyscale lighting model - Patient ward room at Khoo Teck Puat Hospital. Model and measurements by Timothy Lum Jing Liang and Lee Hui Ling Alexandra.

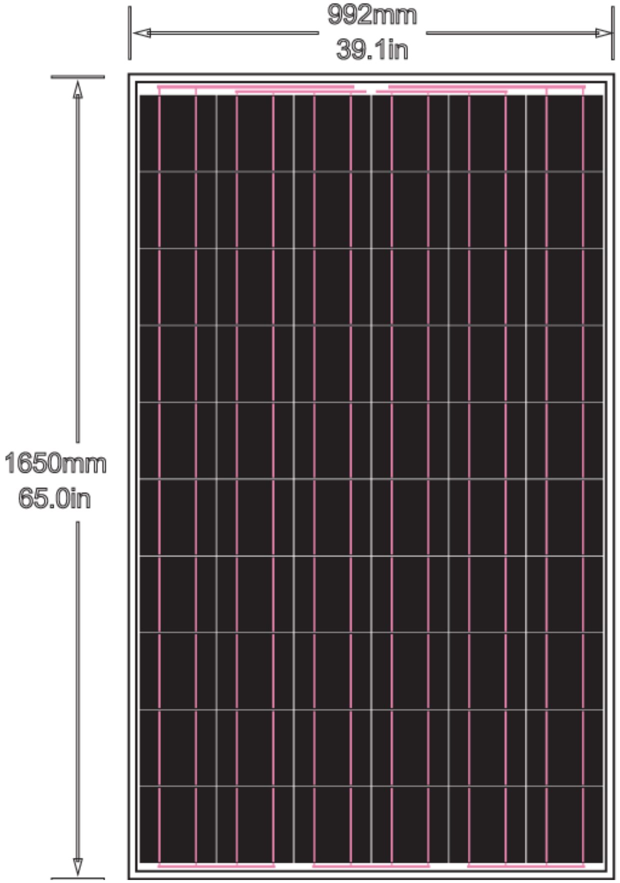
- What is a reasonable material definition for common or even unusual items?
  - Brushed aluminum
  - Specular whiteboard (potential for glare)
  - PV panels
  - Walls
  - Exterior facades
  - Tree leaves / foliage
  - etc...

- Is there a basis for the opaque reflectance standards we use from day-to-day?

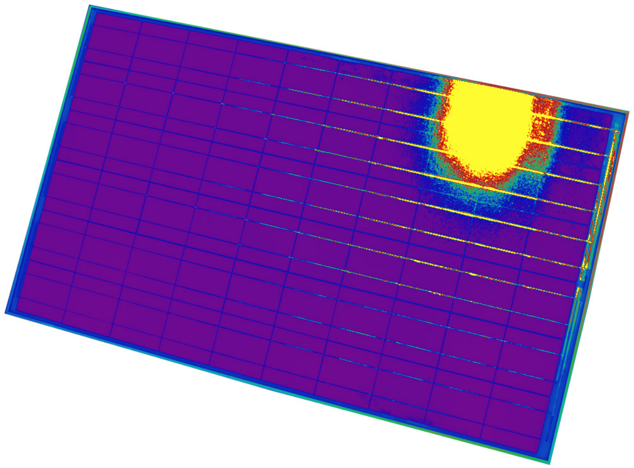
- What are appropriate reflectance values for colored materials? Specularity parameters?
  - Too many >1.0 R, G or B primaries in Radiance have been seen to produce, for example, an 80% reflective blue wall.

- Spectral-data for opaque surfaces?
  - Circadian sensitivity does not really map well to typical calculations.

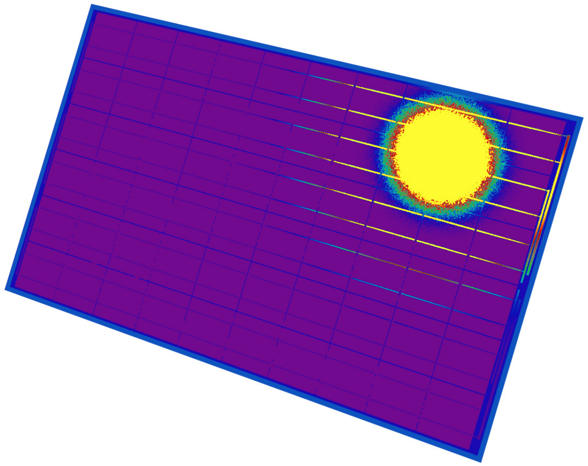
Materials we need to know more about: Potential for glare



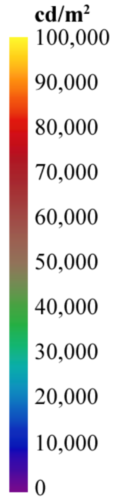
```
void ashik2 Motech_Area_Averaged
4 1 1 1 .
0
8     0.066383837 0.071325444 0.089379555
      0.048882908 0.048729741 0.048597544
      100 100
```



HDR photograph
taken on August 31st, 2012

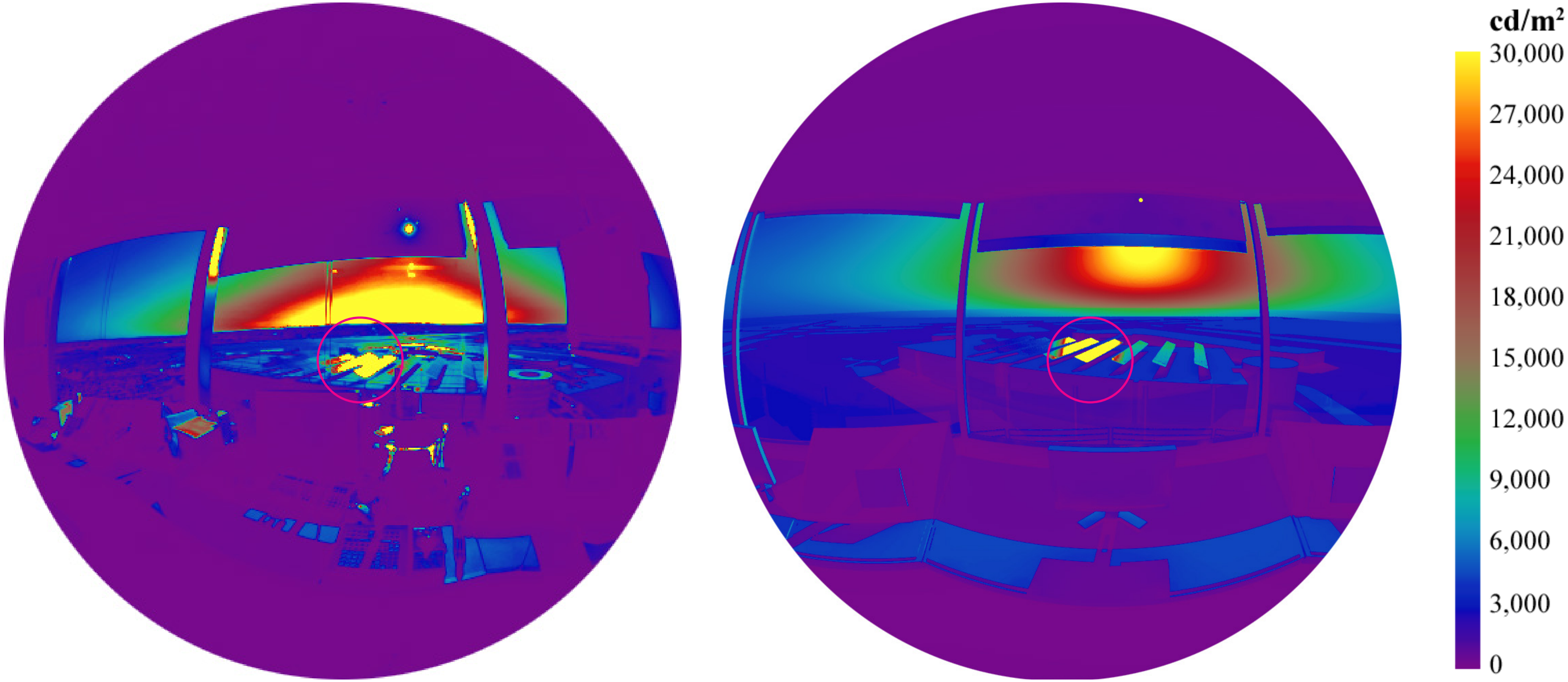


Clear-sky rendering
at same time



Highly-specular PV panels: Reflections are not purely specular; there is a scattering component as well. Note: The above material definition does not perfectly resolve observed spread differences based on incident angle or direct sunlight.

Materials we need to know more about: Potential for glare



HDR photograph
taken on 8-30-2012 at 7:22 solar time

Physically-based rendering
simulated for 8-30-2012 at 7:22 solar time

Extreme disability glare problems were encountered due to not considering this specular spread. Consulting engineers treated the panels as a mirror in initial studies.

Materials we need to know more about: Potential for glare

The (temporary) solution: To cover the glaring panels with tarps, preventing glare and energy generation.

Calibrated simulation models

Simulation models of a classroom at SUTD - Standard material reflectance values are applied. 80% ceilings, 50% walls and furniture, 35% exterior vertical surfaces, 20% floors and outside ground surfaces. Electric lighting is turned off in the model.

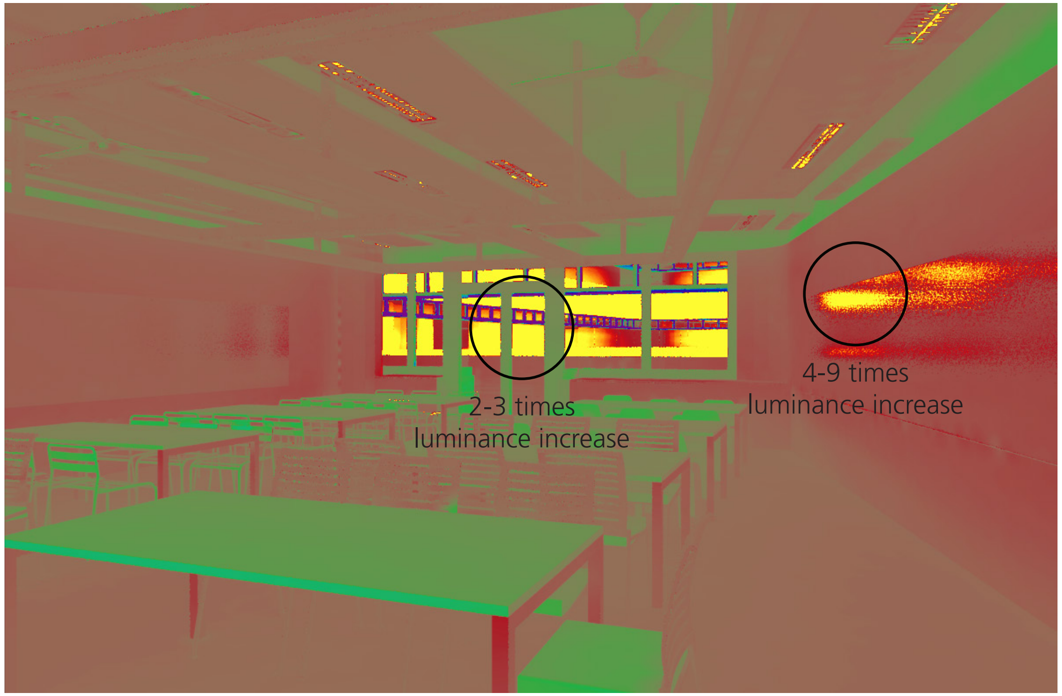
3D model provided by Ong Li Yen and Timothy Lum Jing Liang.

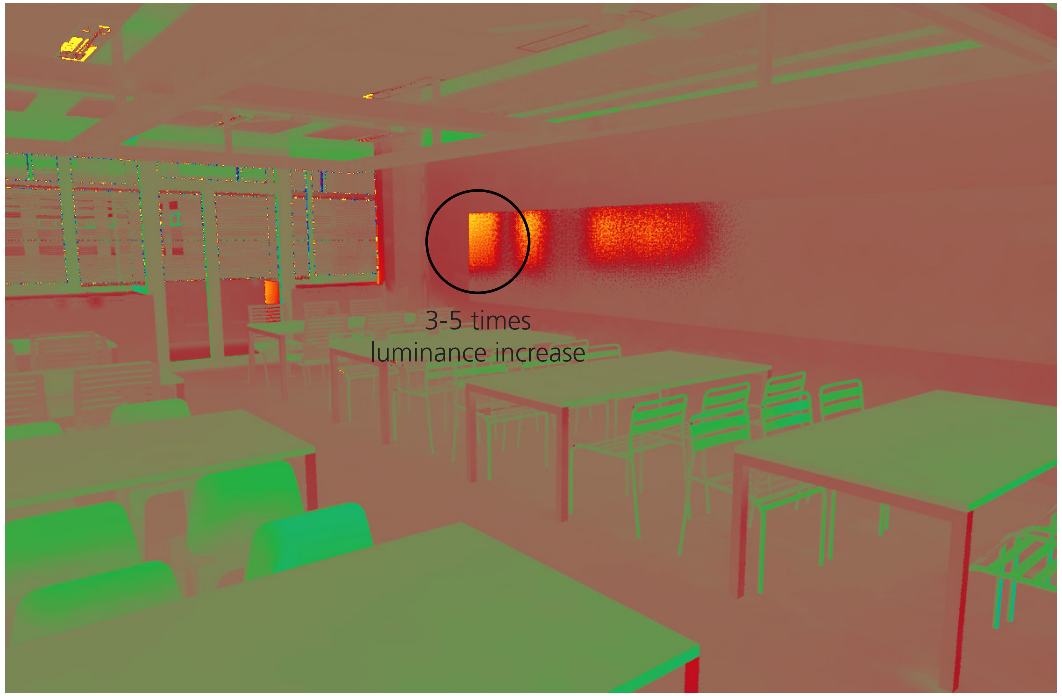
Calibrated simulation models

Simulation models of a classroom at SUTD - Measured material reflectance values and specularities are used. Roughness values are estimated. Electric lighting is turned off in the model.

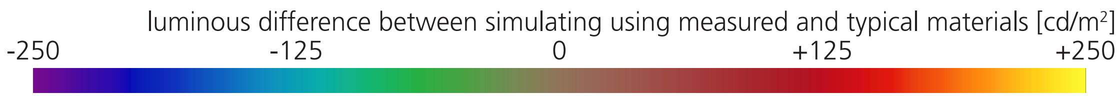
3D model provided by Ong Li Yen and Timothy Lum Jing Liang.

Luminous differences

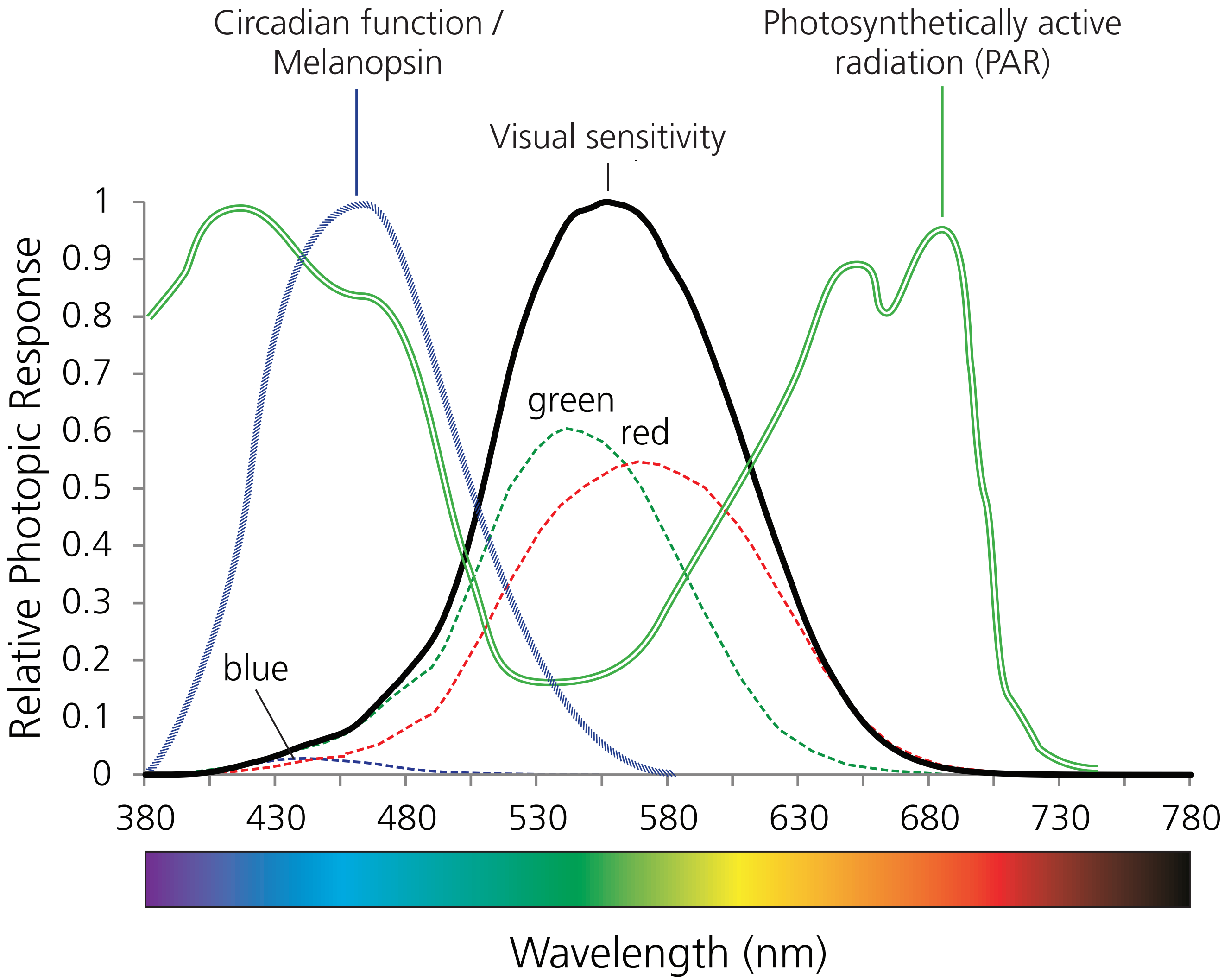




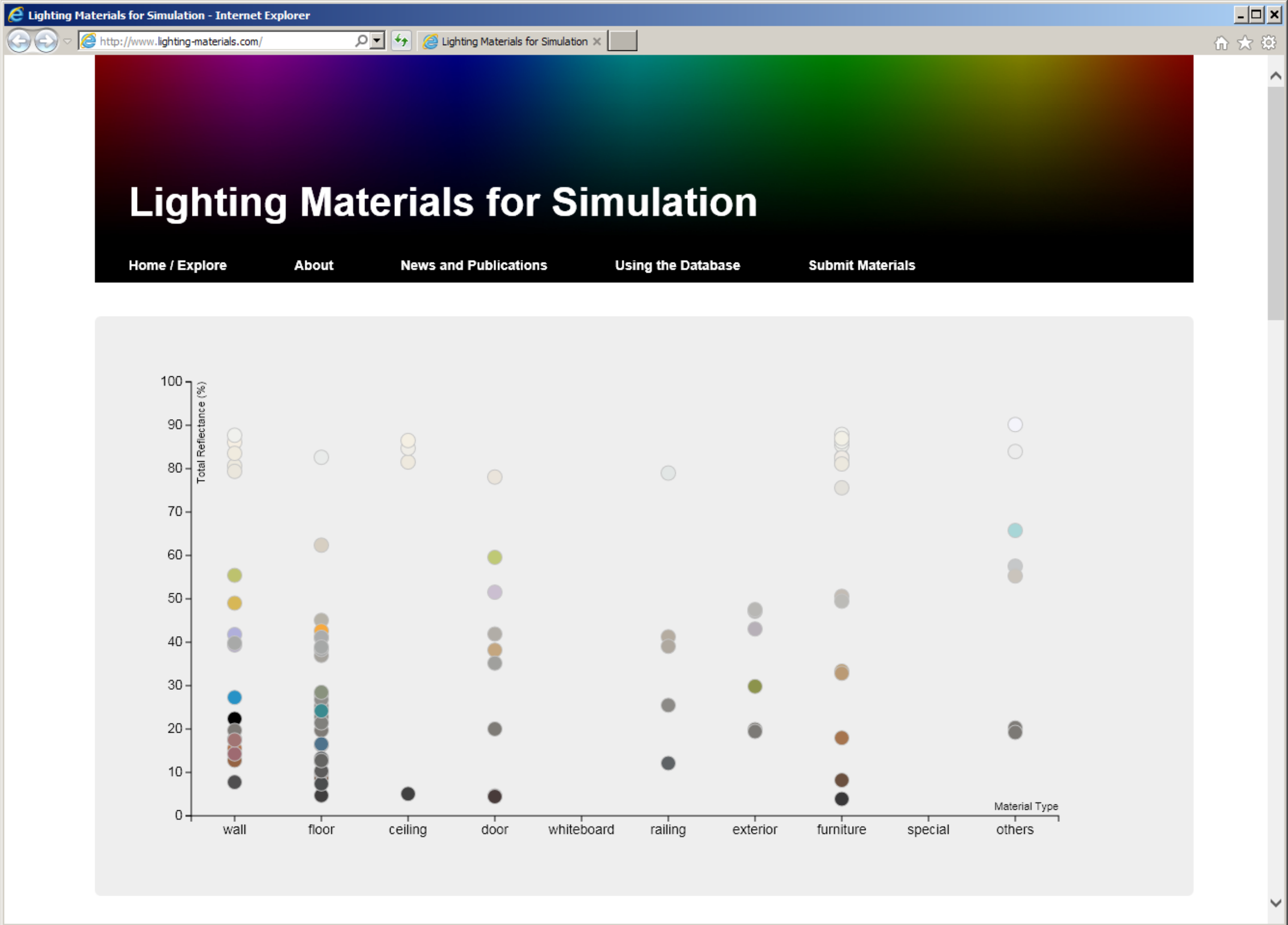
Luminance differences between measured and typical material model



Full-spectrum lighting calculations



Lighting materials database for simulation



The lighting-materials.com homepage displaying materials sorted by building surface type (under revision) and total reflectance.

www.lighting-materials.com

Goals:

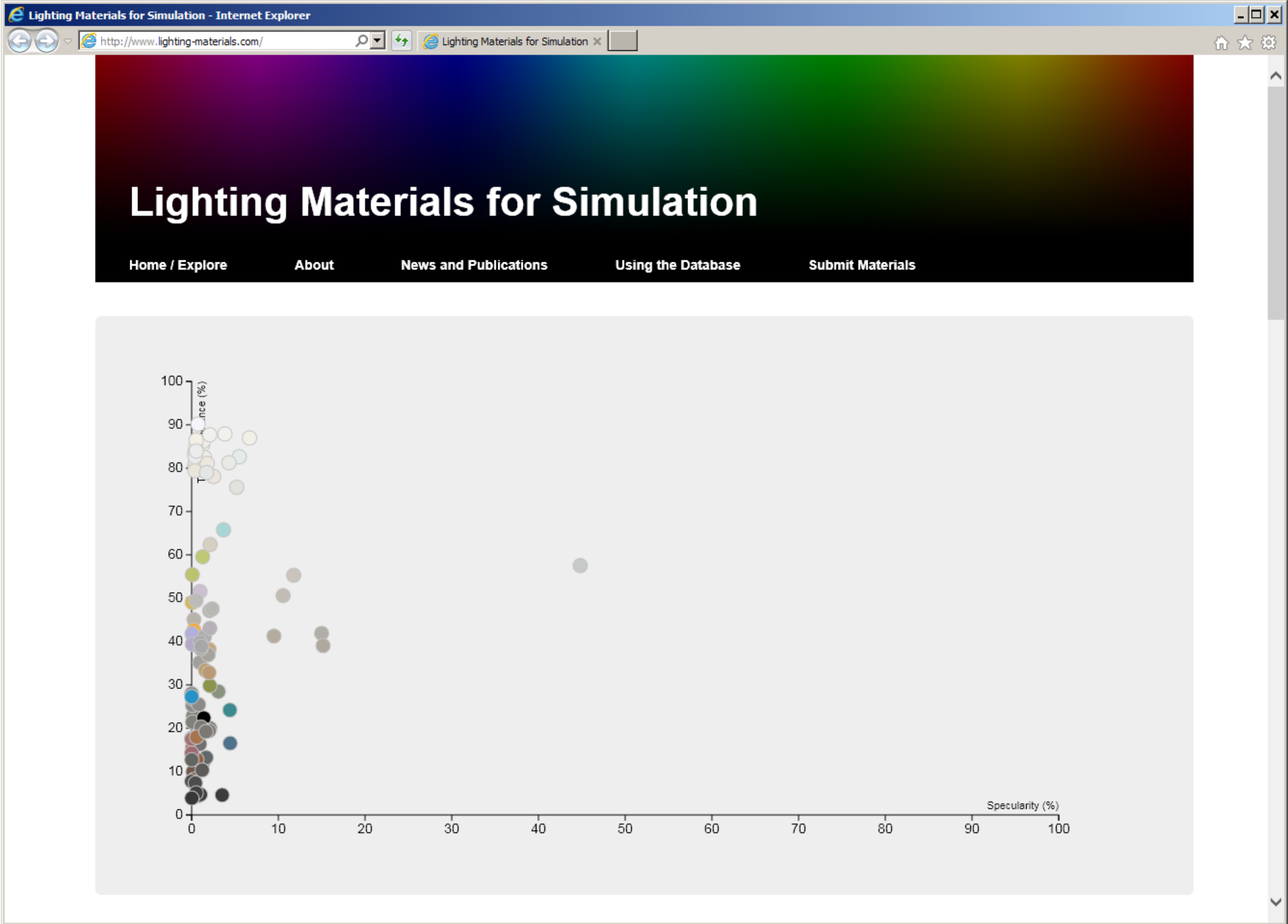
- to build up a critical mass of typical measurements in order to get a realistic idea of the reflectances for such materials,

- to document measurements of unusual materials that are necessary for appropriate visual comfort calculations such as photovoltaic panels, polished metals, and other specular materials,

- to provide examples of material definitions in the Radiance material format,

- and to provide a venue for researchers, practitioners and manufacturers to share materials relevant to the larger lighting community.

Lighting materials database for simulation



The lighting-materials.com homepage displaying materials by total reflectance and specularity.

www.lighting-materials.com

Goals:

- to build up a critical mass of typical measurements in order to get a realistic idea of the reflectances for such materials,

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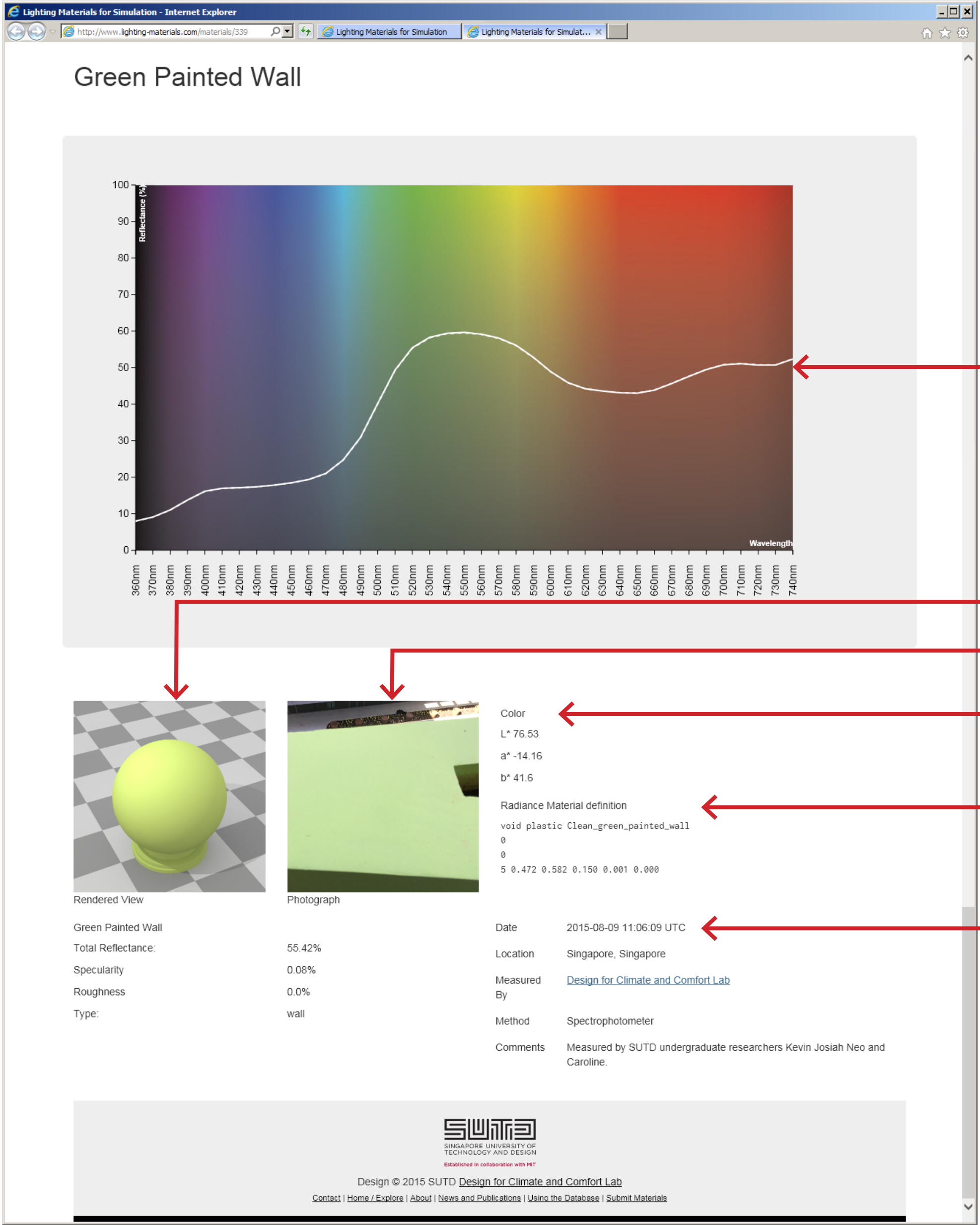
Display of spectral data



Spectral measurement of green-painted concrete walls

Ability to download full spectral data: coming soon.

Spectral chart with specular component included (SCI) and excluded (SCE).

Rendering of material in a standard environment

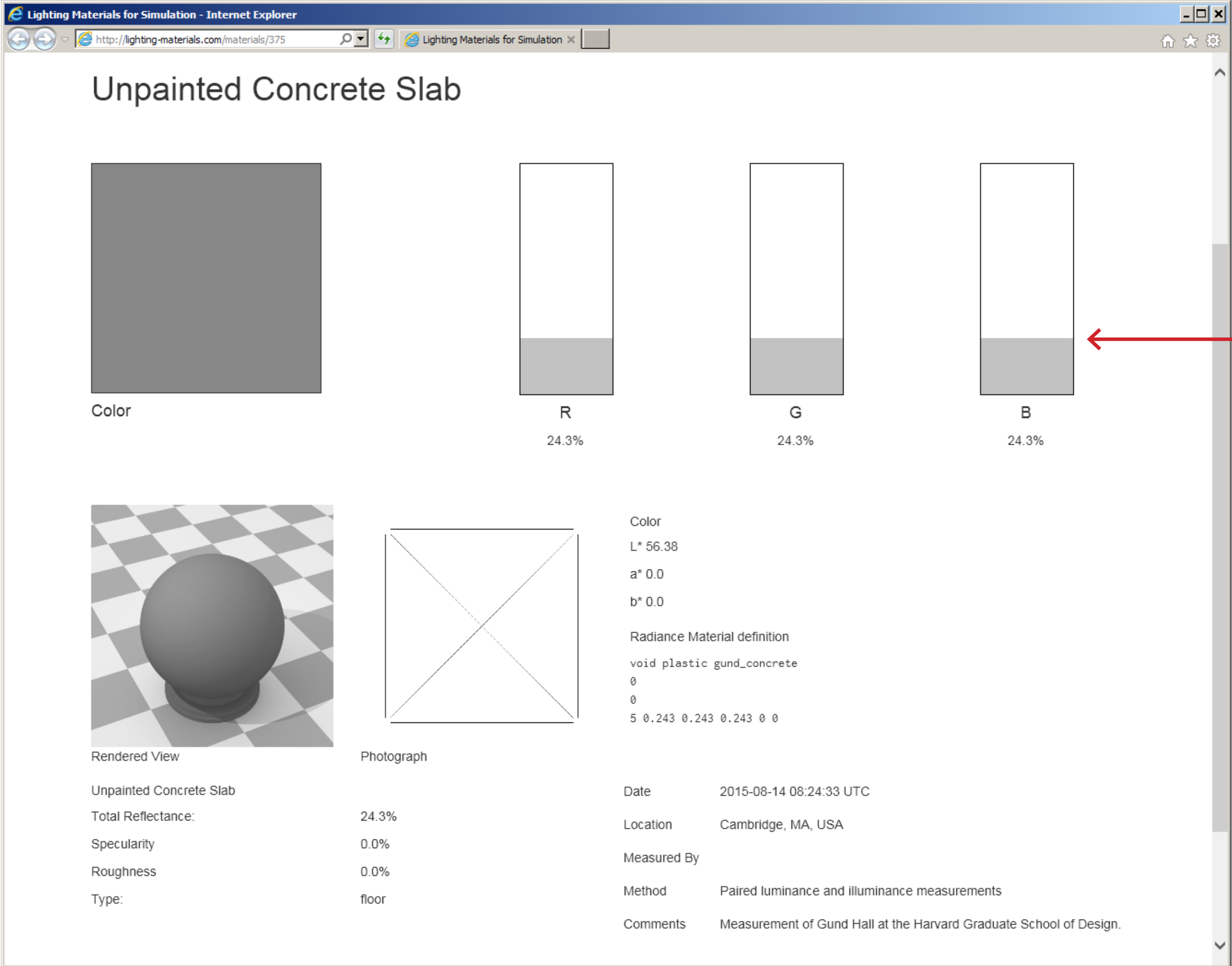
Photograph of material if available

Color information (L*a*b*)

Radiance material definition

Metadata
- Date / location
- Attribution and link to measurer's homepage
- Methodological information
- Open comment section provided by measurer

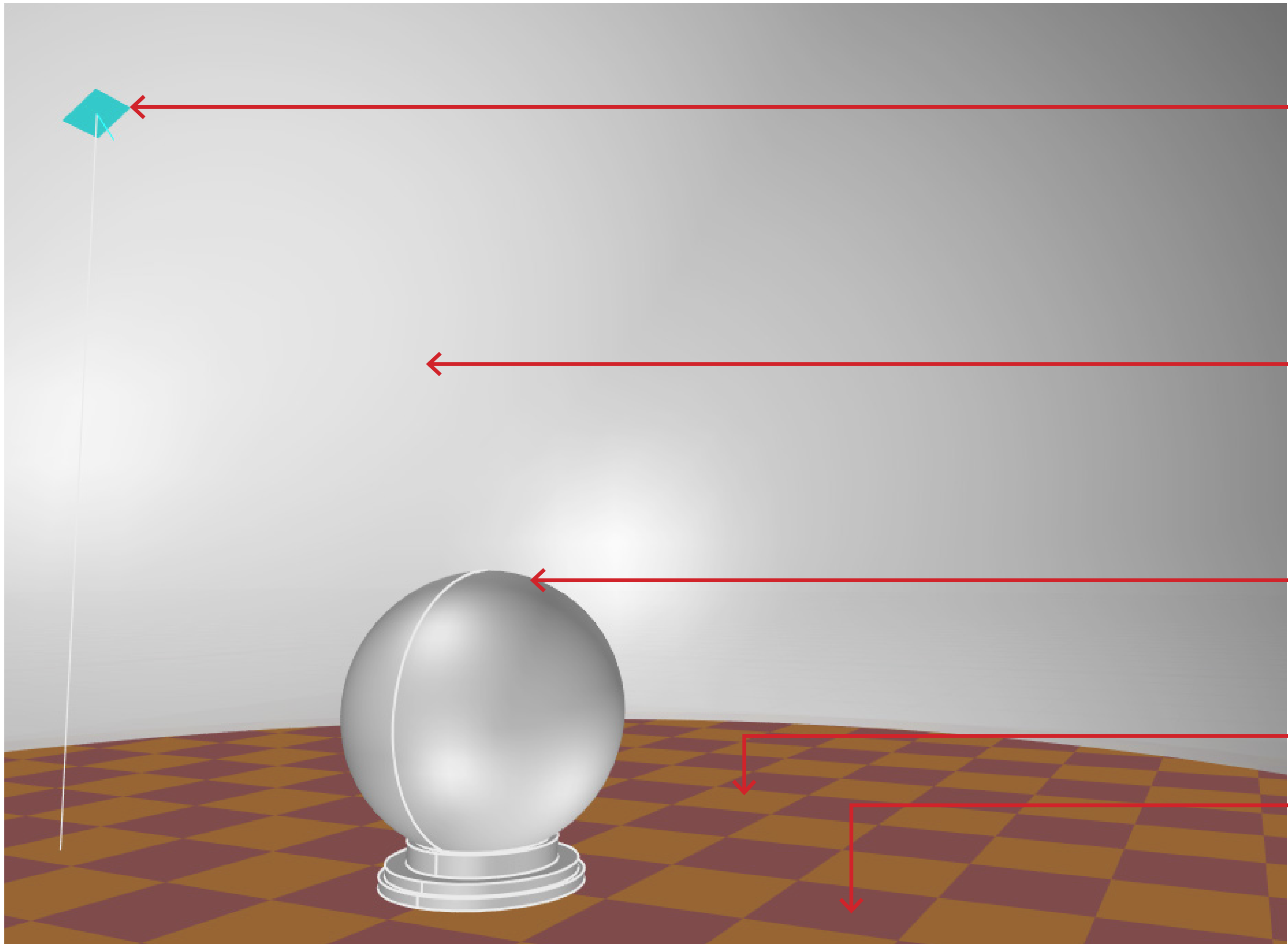
Display of RGB-only or reflectance-only data



R, G, B channels and resulting color are displayed.

Measurement of concrete floors in Gund Hall, Harvard GSD

Standard environment for (simple) material visualizations



36°, 1200 lm IES definition

100% diffusing, hemispherical trans surface to avoid seeing any sort of horizon line from the ground hemisphere

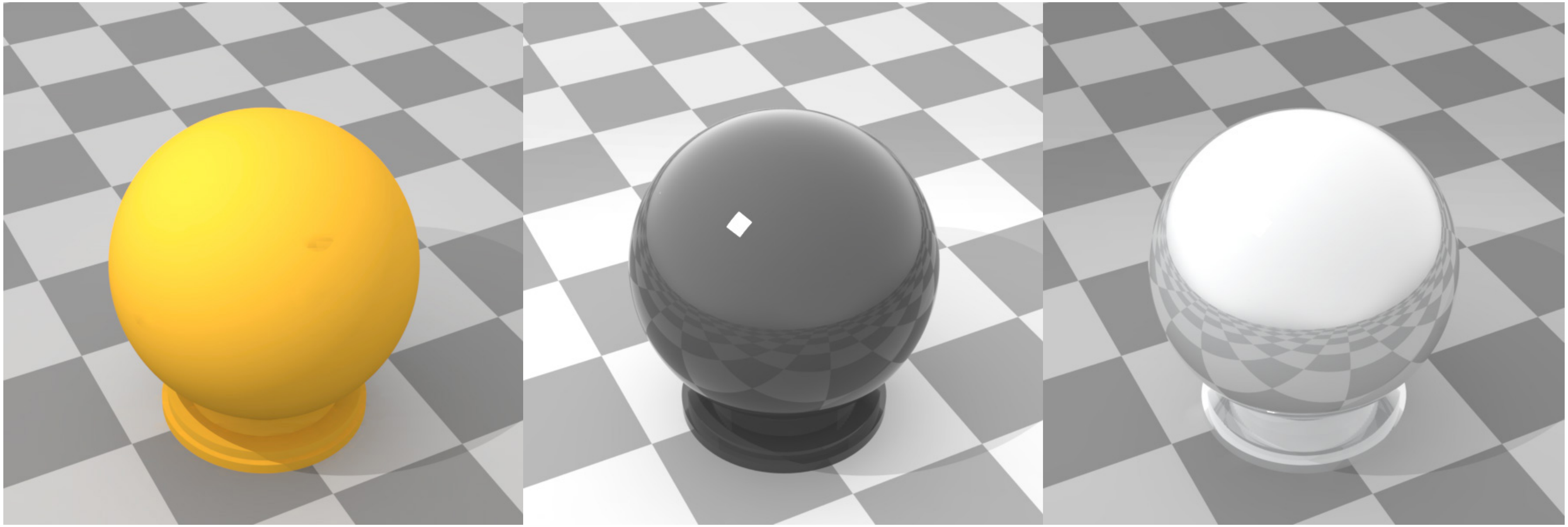
Sphere (Radiance primitive) and pedestal (polygon mesh) modified by material being visualized

50% lambertian plastic polygons

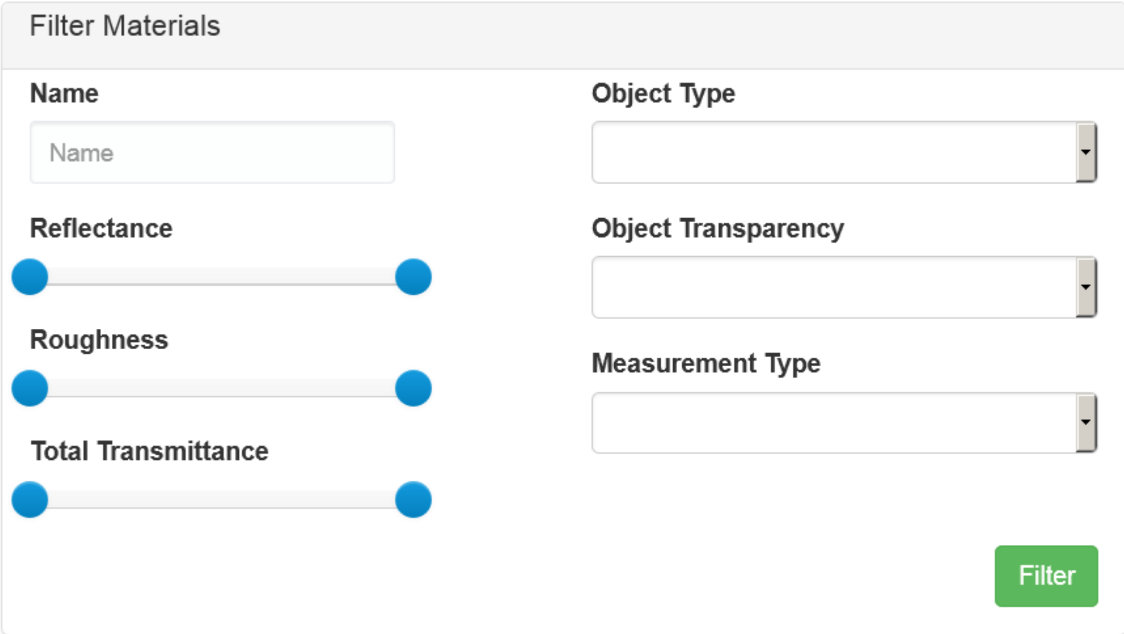
25% lambertian plastic polygons

Radiance model created for the display of opaque materials.
The model allows for specular reflections (IES file) and diffuse components (sky and trans dome).

Standard environment for (simple) material visualizations



Searching for materials



Material search parameters

- **Name**: string-based descriptive search.
  Examples: 'Aluminum', 'wood' or 'screen'

- **Reflectance**: physical range of percent light reflected between 0 and 1.

- **Roughness**: the Radiance roughness parameter associated with a material.

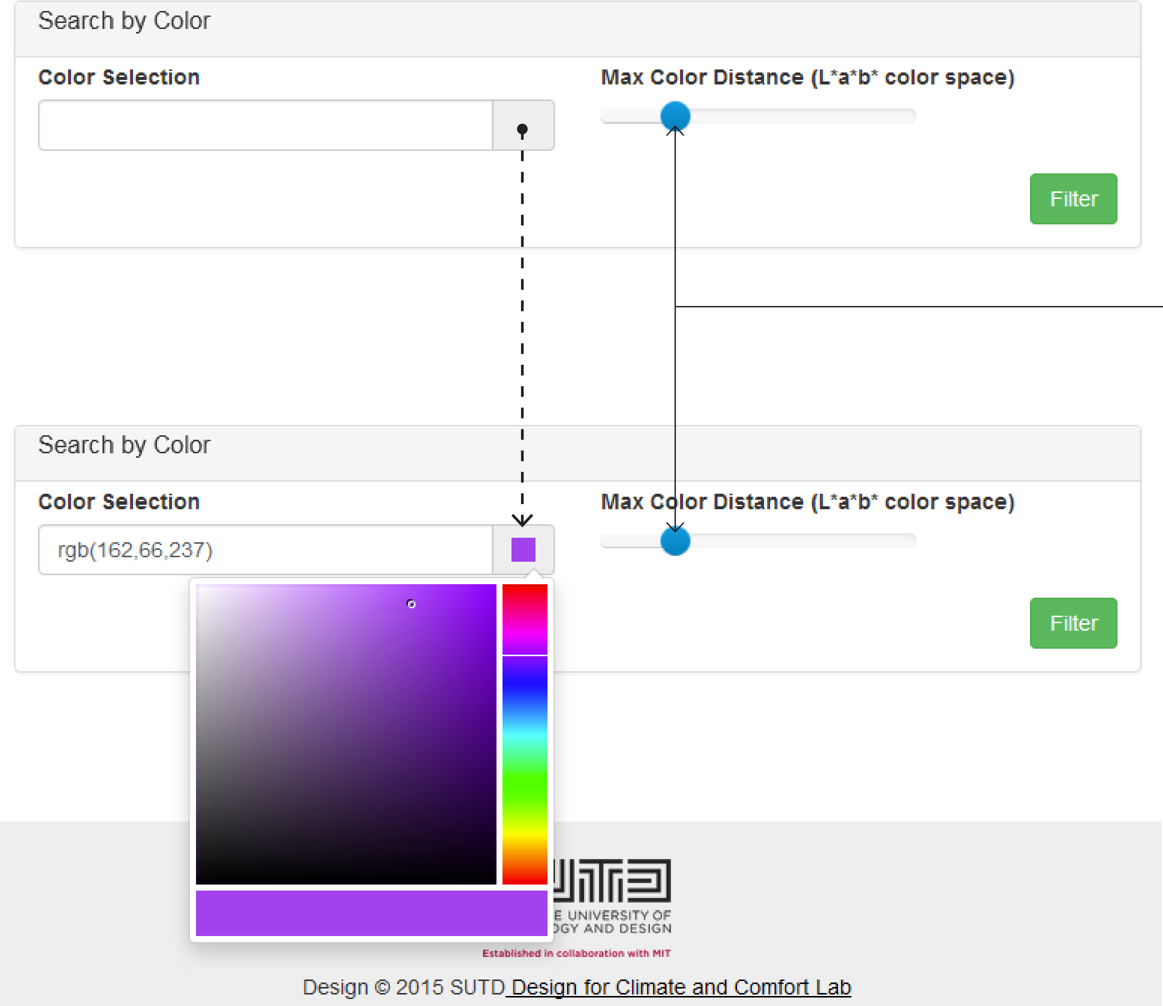
- **Total Transmittance**: for translucent materials, the percent of light transmitted.

- **Object Type**: type of object in building.
  Examples: floor, ceiling, wall, furniture, exterior surface

- **Object Transparency**: opaque or translucent

- **Measurement Type** [in development]: describes the device or method used to take the measurement. For example, 'spectrophotometer' measurements include full spectral data and 'theoretical' materials are interesting but not based on a physically-accurate measurement.

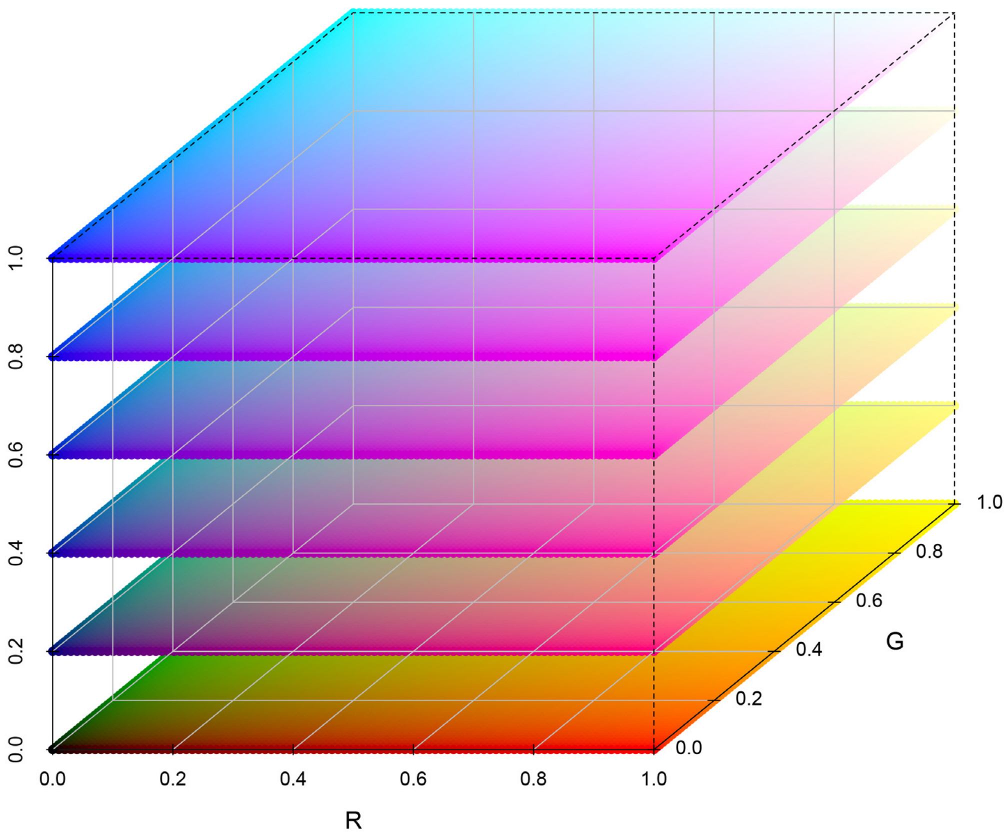
Searching by color



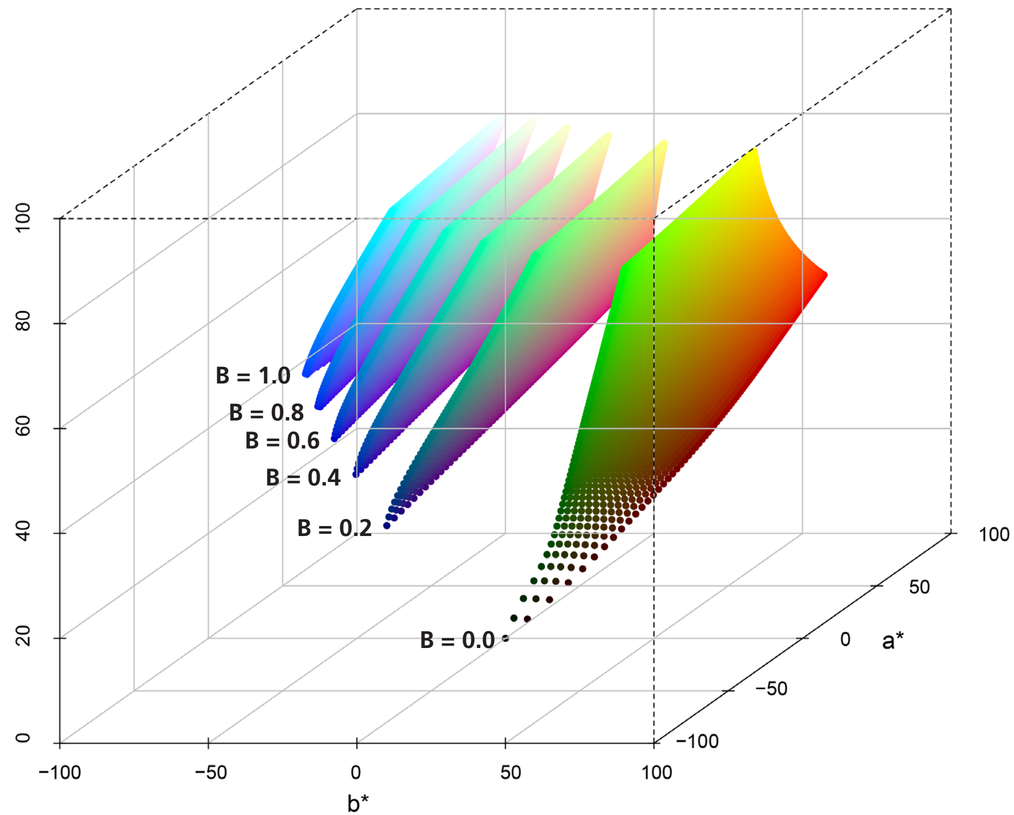
Color search parameters

- RGB colorspace picker or text-based entry of RGB color primaries is supported.
- Conversion happens on the fly to the L*a*b* colorspace in the background.
- Euclidean distance is calculated between the selected color and all colors in the database in the L*a*b* colorspace. Results are sorted by distance.
  - Color similarity requirement is adjustable by this distance.
  - A distance ~2.3 corresponds to just noticeable (supposedly).

Colorspaces: RGB vs L*a*b*

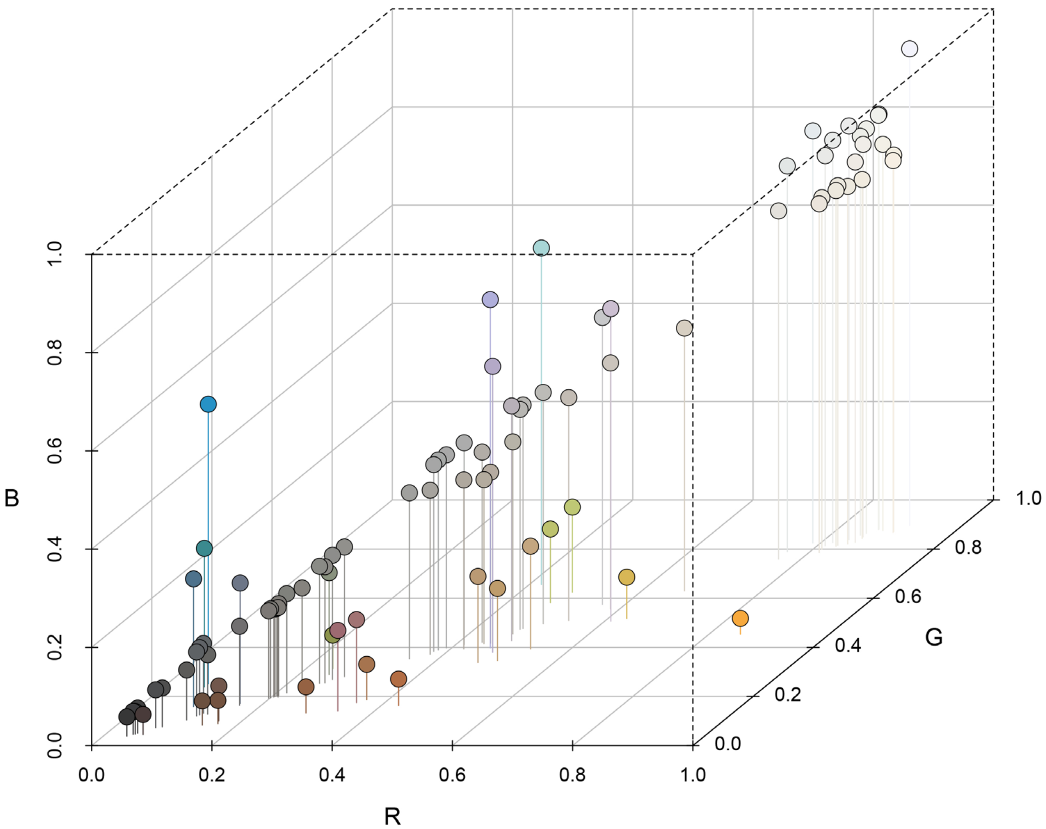


Planes cut through the RGB colorspace: Planes cut at intervals of 0.2 along the B color channel. 10,000 equally spaced color samples taken at each plane.

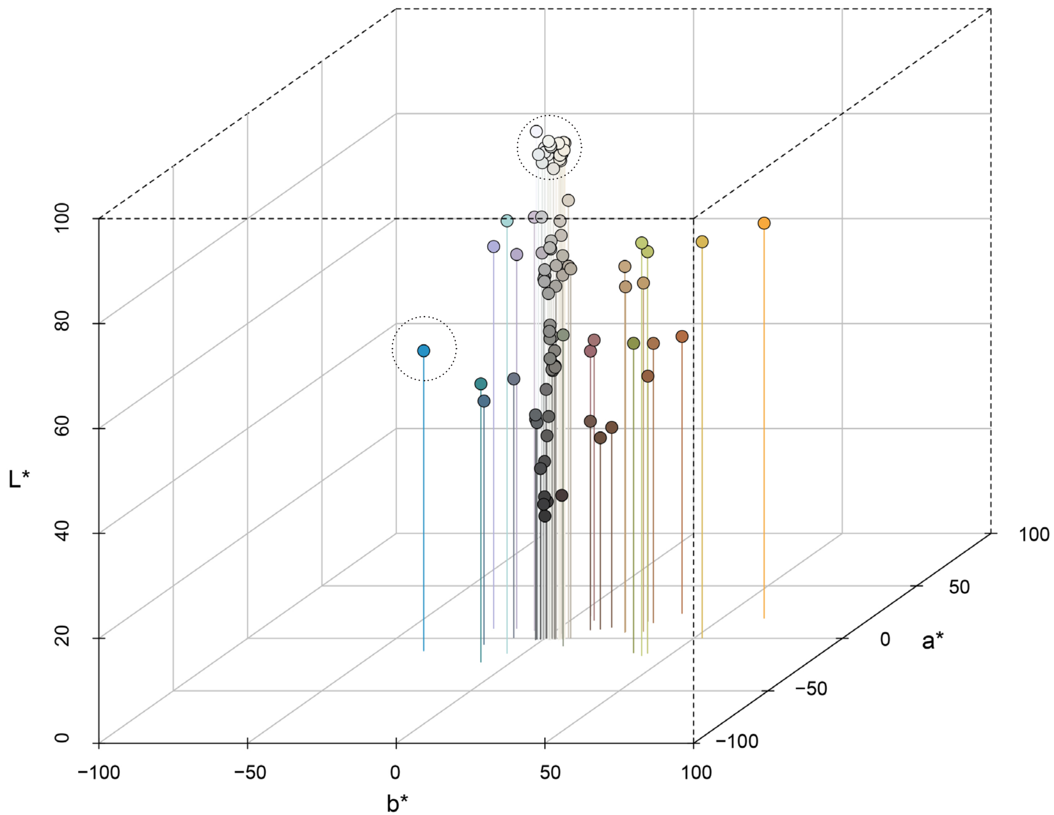


Same planes displayed in the L*a*b* colorspace: Note the differences when colors are displayed at a ‘perceptually uniform’ distance.

Colorspaces: RGB vs L*a*b*

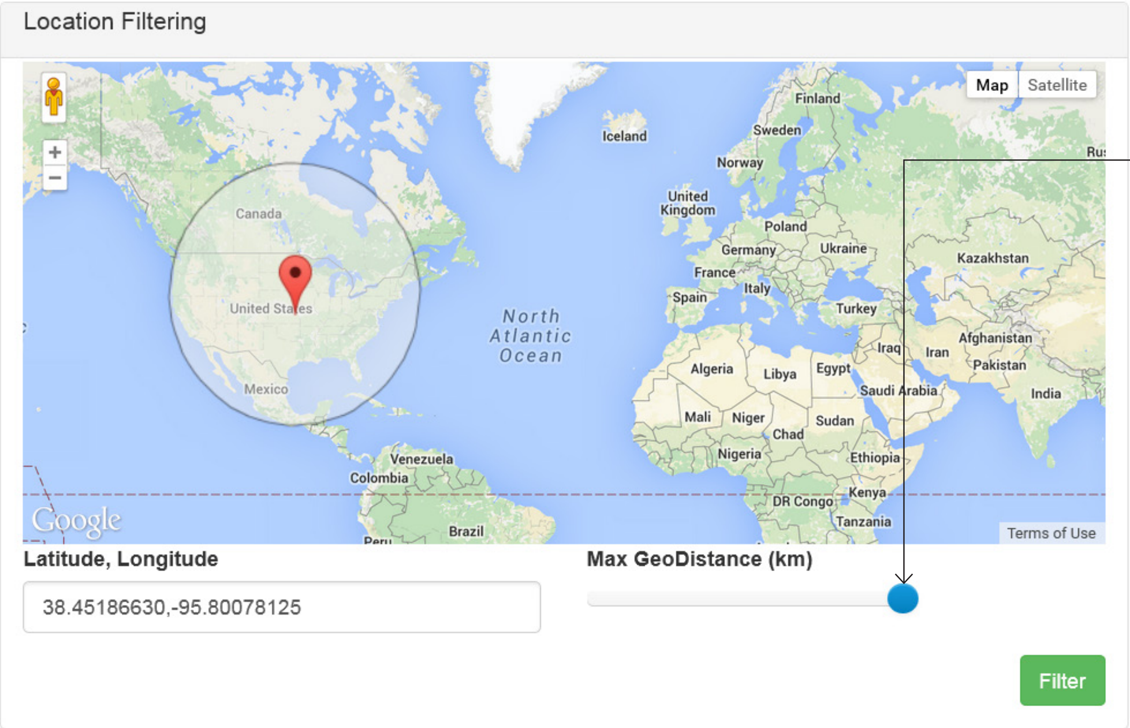


94 material measurements displayed in RGB colorspace



94 material measurements displayed in L*a*b* colorspace

Searching by location of measurement



Location search parameters

- Latitude, longitude input or click-based graphical input via Google Maps API.
- Maximum distance slider from 0 to 2500 km.
- Search results will have been measured at a geographic location within the circle.

Attribution

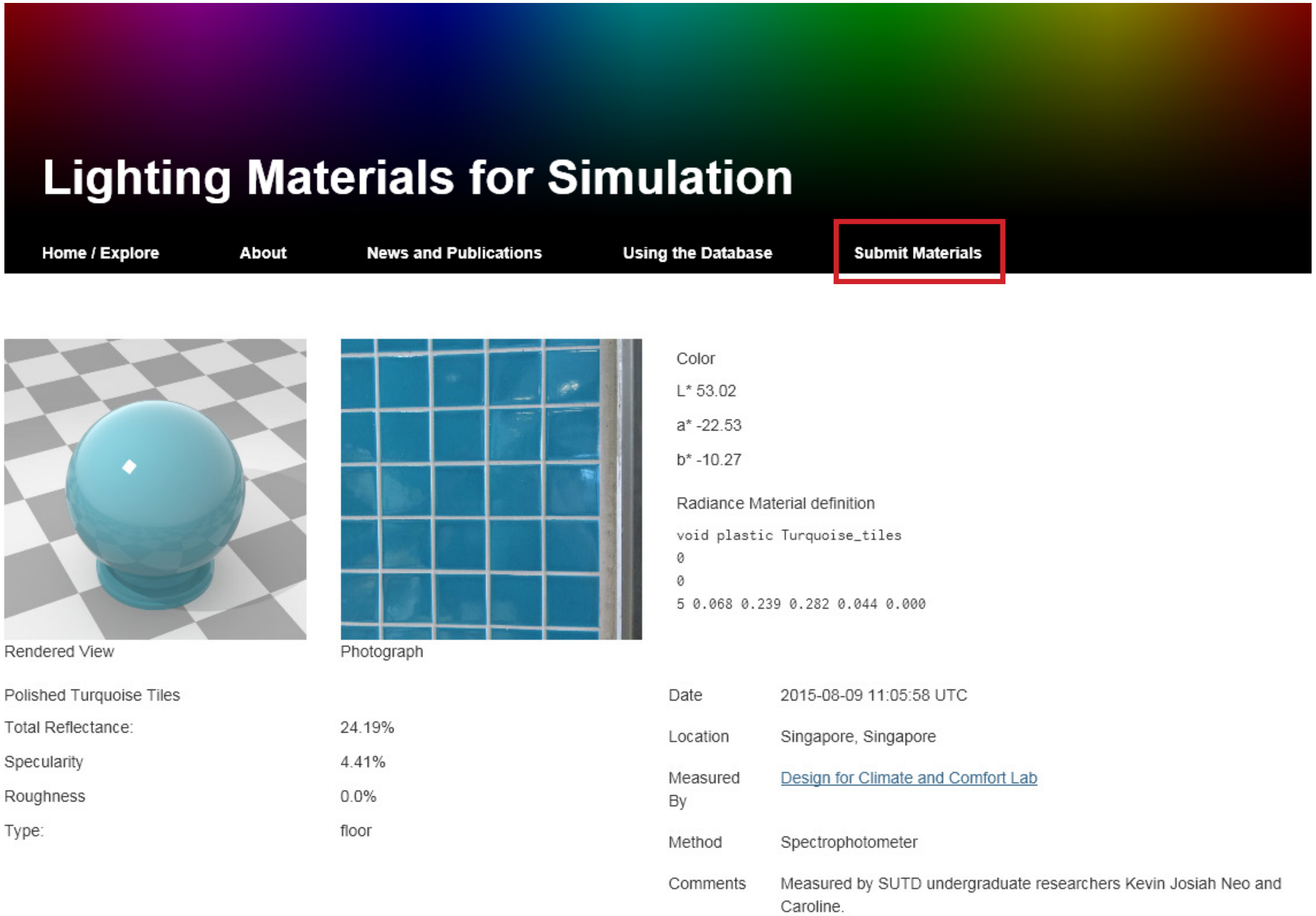
Materials Project
• Initial material measurements and mockup database interfaces were greatly aided by SUTD undergraduate research opportunities program (UROP) students Kevin Josiah Neo and Caroline.

• Further material measurements were taken by Timothy Lum Jing Liang and Lee Hui Ling Alexandra as part of their capstone thesis project.

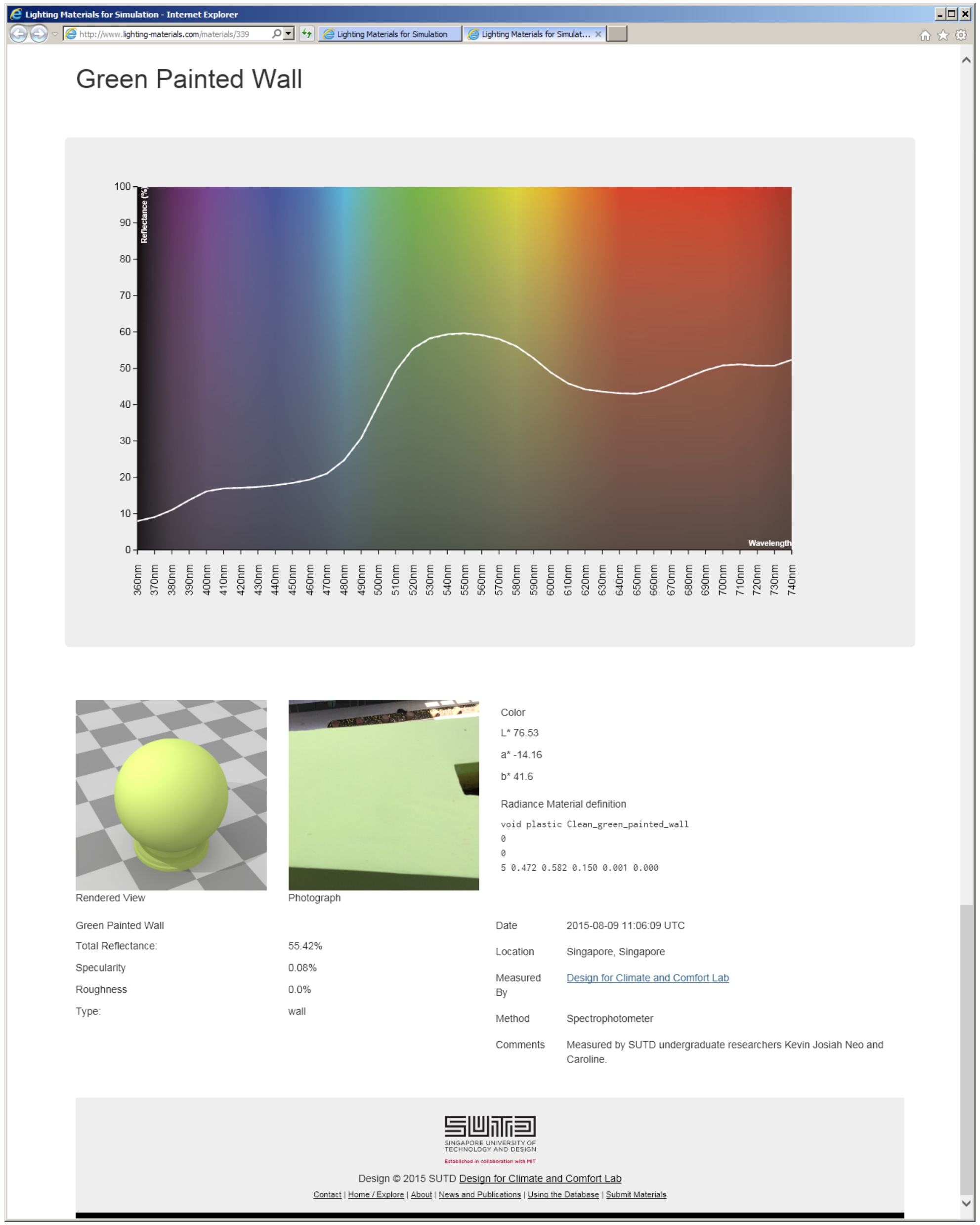
Tree Measurement and Simulation Project
• Thanks are due to Thommen George Karimpanal for help with the image-processing code in Matlab.

Both Projects
• We thank the SUTD-MIT International Design Centre for generous funds provided through an infrastructure grant.

Request for submissions



- Easily share material definitions with your lighting-simulation colleagues.
- Full attribution, links to your website and room for comments.
- Visit at **www.lighting-materials.com**.
- Details on the 'Submit Materials' page.



Thank you!

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