Quantifying Materials in Lighting Simulations

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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
"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


**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

Legend
Plot 1
Elevation
- 23.48 - 31.35
- 31.35 - 37.00
- 37.00 - 45.36
- 45.37 - 56.07
- 56.07 - 65.25

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

Clear sky with sun
Overestimation/Underestimation of gap fraction

Avoid Shadows

Overcast sky
Normal estimation of gap fraction

Avoid Variable Clouds
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 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.
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

\[ n \text{ polygons} = \sim 30,000 / \text{tree in this example} \]
A (rough) line of different, typical trees

\[ n \text{ polygons} = \sim 30,000 / \text{tree in this example} \]

Note: Jittering the polygon vertices increases rendering time significantly.
Future work: Application to different species of trees
30,000 -- too many polygons?

• 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!

Visualization of polygon counts in an architectural model with furniture included
Reflectance properties -- just measure it?

- 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

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 am 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

- 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.

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.
Materials we need to know more about: Potential for glare

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

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

Circadian function / Melanopsin

Photosynthetically active radiation (PAR)

Visual sensitivity

Relative Photopic Response

Wavelength (nm)

380 430 480 530 580 630 680 730 780

555nm peak

blue green red

blue
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

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The lighting-materials.com homepage displaying materials by total reflectance and specularity.
Display of spectral data

- 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

Spectral measurement of green-painted concrete walls
Display of RGB-only or reflectance-only data

Measurement of concrete floors in Gund Hall, Harvard GSD

R, G, B channels and resulting color are displayed.
Standard environment for (simple) material visualizations

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

<table>
<thead>
<tr>
<th>Filter Materials</th>
<th></th>
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<tbody>
<tr>
<td><strong>Name</strong></td>
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<td>Name</td>
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<td><strong>Reflectance</strong></td>
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<td>Object Type</td>
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<td><strong>Roughness</strong></td>
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<td>Object Transparency</td>
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<td><strong>Total Transmittance</strong></td>
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<tr>
<td>Measurement Type</td>
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</tbody>
</table>

**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

- 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).
Colors spaces: 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.
Colors spaces: 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

• 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.

Location search parameters
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.
- Details on the ‘Submit Materials’ page.
Thank you!

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