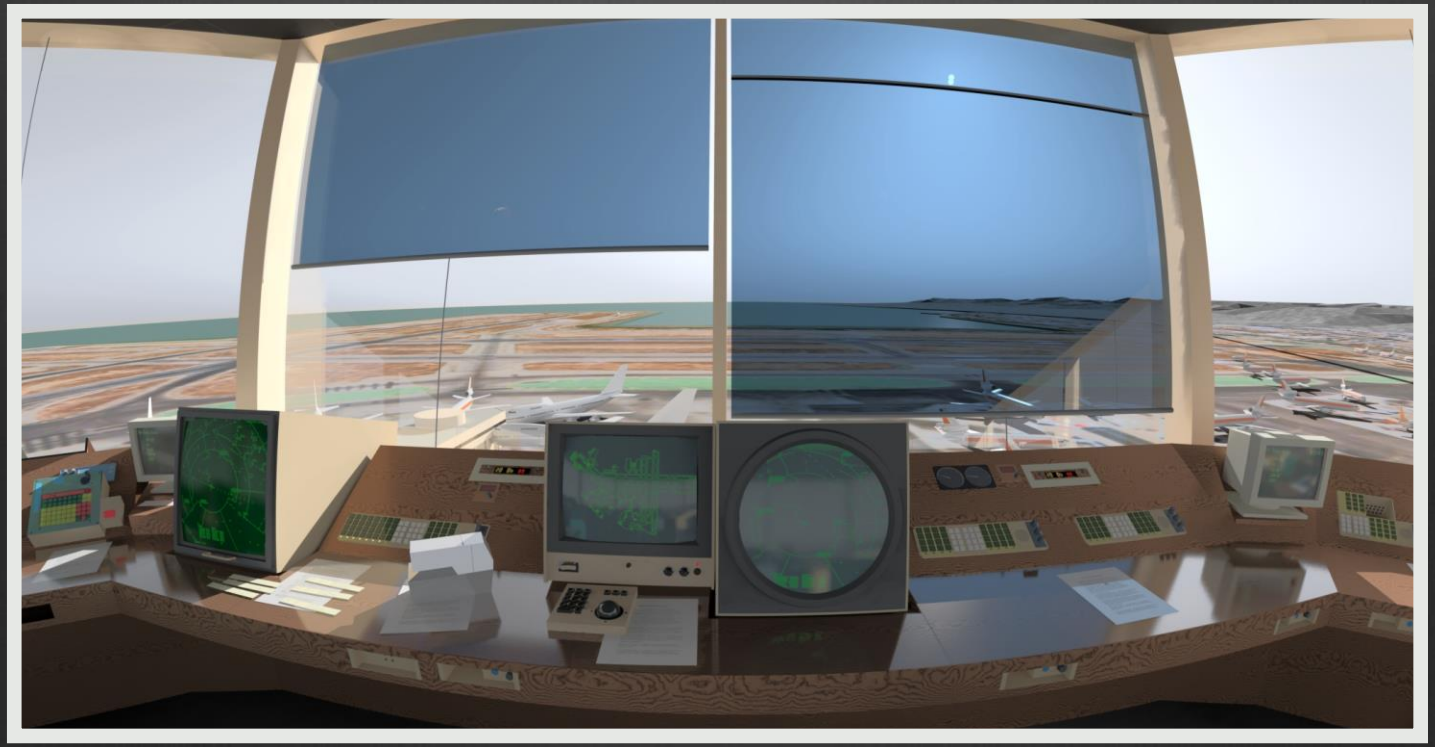
Radiance - the Interaction of Light & Matter in Building Simulations

Greg Ward
Anyhere Software

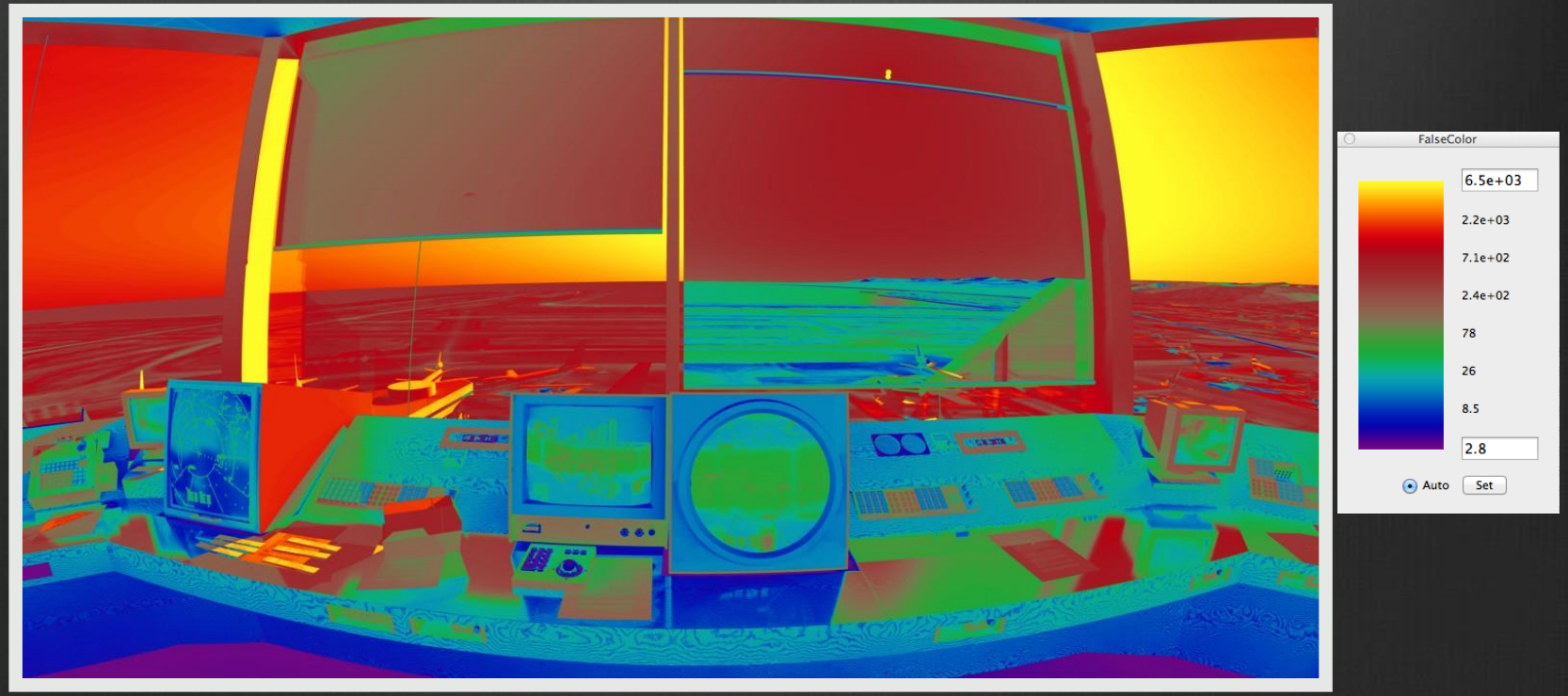
What Is Daylight Simulation?

- Predicting performance of a candidate building design under a given set of daylight conditions
- Input is a building model with materials in suitable detail
- Output is a set of images and/or performance metrics
- Simulation software implements a set of useful approximations to mimic aspects of problem we care about

SFO Air Traffic Control Tower



SFO Air Traffic Control Tower



Requirements

- Geometry (typically converted from CAD software)
- Materials, textures, patterns (scanned/measured/estimated)
- Daylight condition(s) and electric lighting layout & control
- Analysis points and metrics, views, animation paths, etc.
- Calculation parameters controlling time vs. accuracy

What Is *Radiance*?

- *Radiance* is a collection of over 150 command-line tools that perform specific functions
- For example, one tool might import the CAD model, then another will compile it together with a set of luminaires that were converted by a third and placed by a fourth tool. A fifth tool will render an HDR picture that a sixth tool will convert to a false color image, and a seventh tool will put it up on the display.
  - That's a lucky number of tools
- Standard file formats are an important part of the design

Example File Header

Most of the 16+ *Radiance* file types include a preamble of metadata (info header), which can be read using **getinfo**, e.g.:

```
#?RADIANCE
oconv basic.mat diorama_walls.rad rect_opening.rad front_cap.rad gymbal.rad sunset_sky.rad
oconv -f -i trans2.oct ilXNF2S9
rpict -vf inside.vf -x 2048 -y 2048 -dp 256 -ar 24 -ms 0.27 -ds .2 -dj .9 -dt .1 -dc .5 -dr 1 -ss 1 -st .1 -ab 1 -af
trans2.amb -aa .1 -ad 1536 -as 392 -av 0.062 0.062 0.062 -lr 8 -lw 1e-4 -u+ -st .02 -ss 32 -ps 4 -pt .08
SOFTWARE= RADIANCE 5.3a lastmod Thu Feb 28 18:03:46 PST 2019 by gward on Behemouth
VIEW= -vtv -vp -0.2 3.0728 2.77765 -vd -2.7336 -0.482008 -1.02483 -vu 0 0 1 -vh 45 -vv 45 -vo 0 -va 0 -vs 0 -vl 0
CAPDATE= 2019:03:22 10:05:11
GMT= 2019:03:22 17:05:11
FORMAT=32-bit_rle_rgbe
pfilt -1 -e +3 -r .6 -x /2 -y /2
EXPOSURE=8.000000e+00
```

Radiance Tool Categories

- Geometry generators (10)
- Geometry importers (12)
- Rendering tools (8)
- HDR picture filters (14)
- Image converters (13)
- Visualization tools (12)
- Glare analysis tools (5)
- Matrix/data processing (18)
- BSDF utilities (13)
- Plotting tools (14)
- Animation tools (4)
- Specialty tools (19)

Why Not Combine the Tools?

- Flexibility, mainly - think of a DSLR camera vs. a phone
- However, there are a few "executive" tools in *Radiance* that call other tools for common tasks, the **rad** program being a good example
  - **trad** even adds a simple GUI as a memory aid
- However, you can only do so much with a combined interface, and programmability is critical to solving general problems

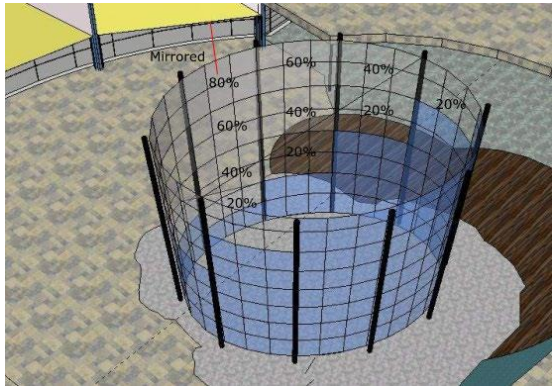
Who Uses *Radiance*, and What Is It Good for?

- *Radiance* is used by Architecture & Engineering firms to predict performance of novel designs and daylighting systems
- Users of *Radiance* "in the raw" tend to be fairly advanced
  - Others use it through third-party interfaces, often without knowing
- *Radiance* excels at solving the really difficult problems…

Experiences with Radiance in Daylighting Design, Part VIII

Zack Rogers
Daylighting Innovations, LLC

Cascading frit for stage visibility/backdrop and reflection



2019 International Radiance Workshop, New York, NY

Modeling of Prismatic Film Glazing with Climate-Based Weather Data and Field Measurement

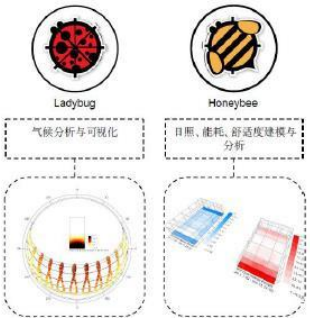
Zhen Tian
School of Architecture, Soochow University

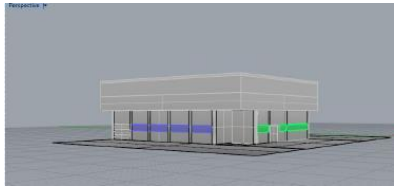
Yaping Lei
Suzhou Institute of Building Science Group

Jacob Jonsson
Lawrence Berkeley National Laboratory

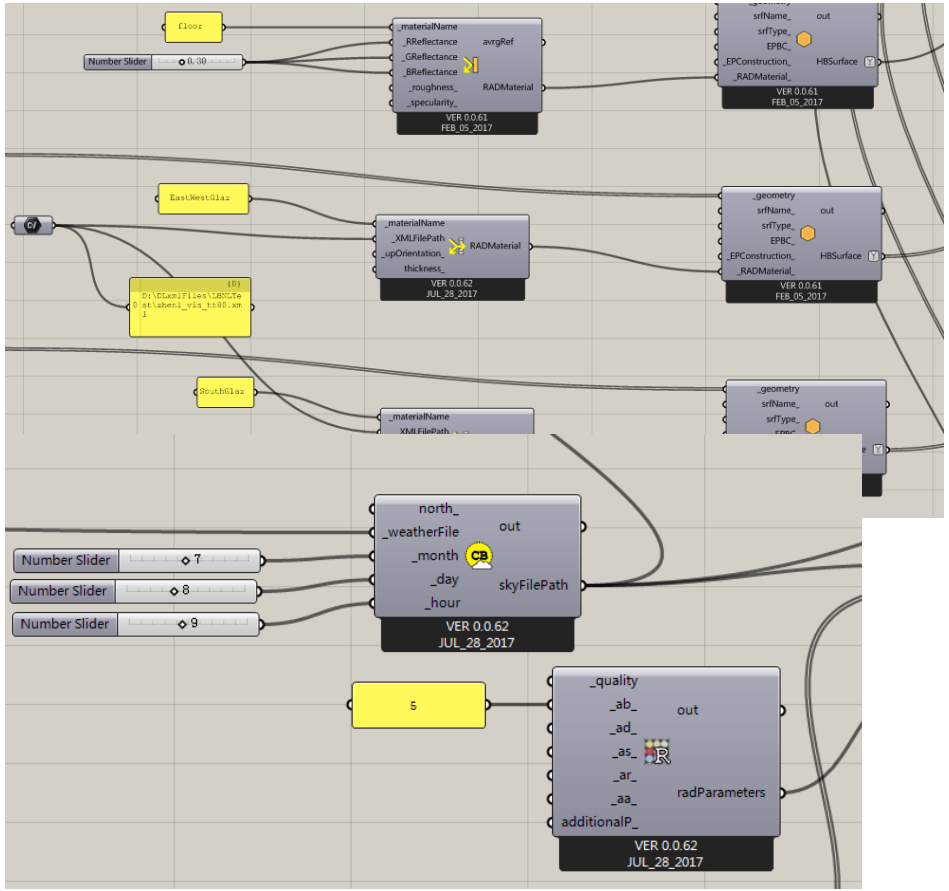
2018 International Radiance Workshop, Loughborough, UK

Climate-Based Daylight Modelling



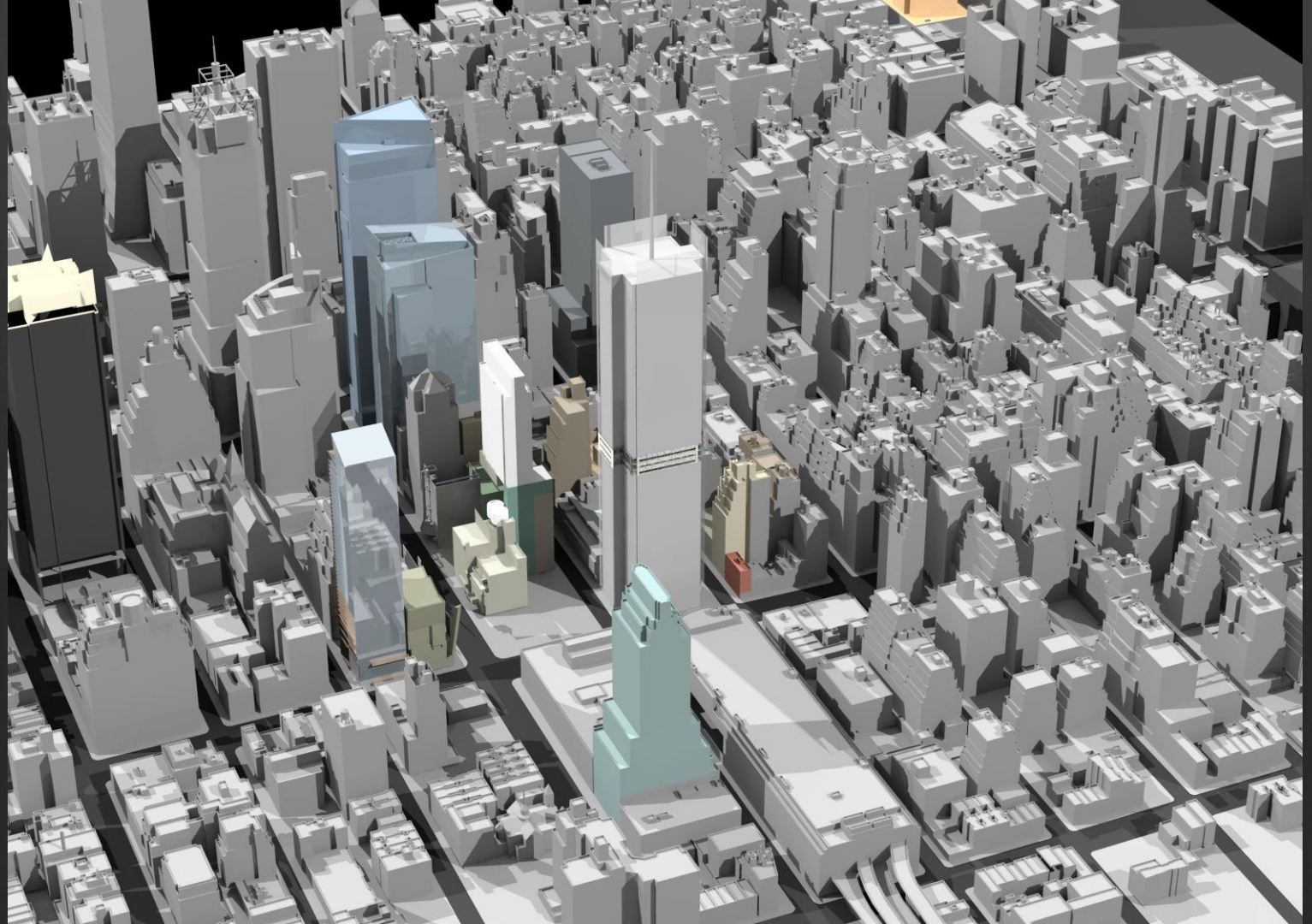


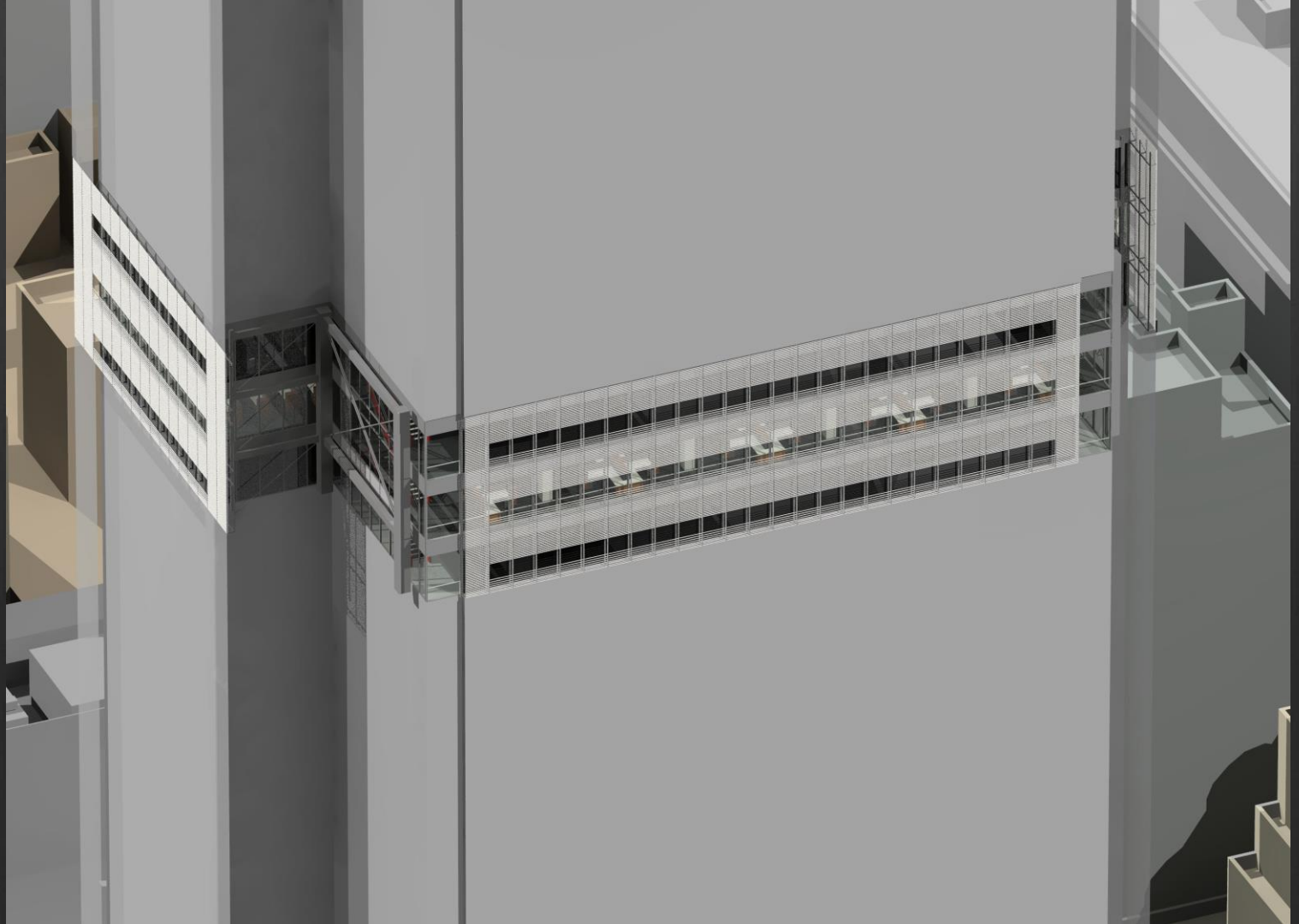
Case Study Simulation Setup

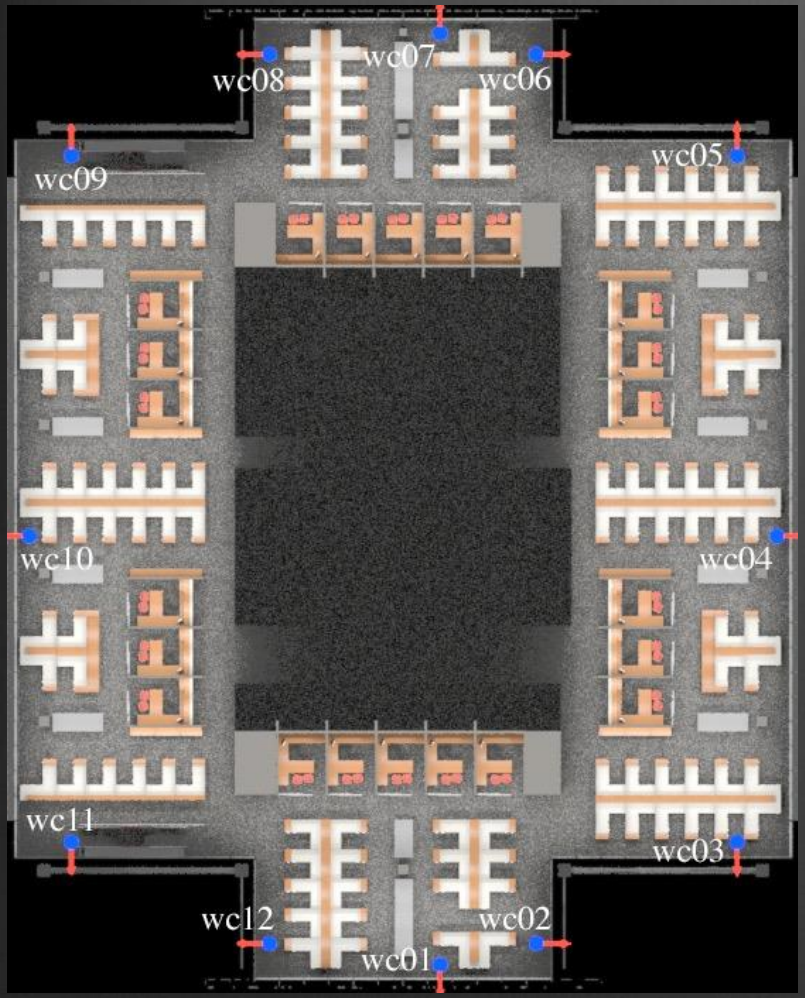


New York Times Building

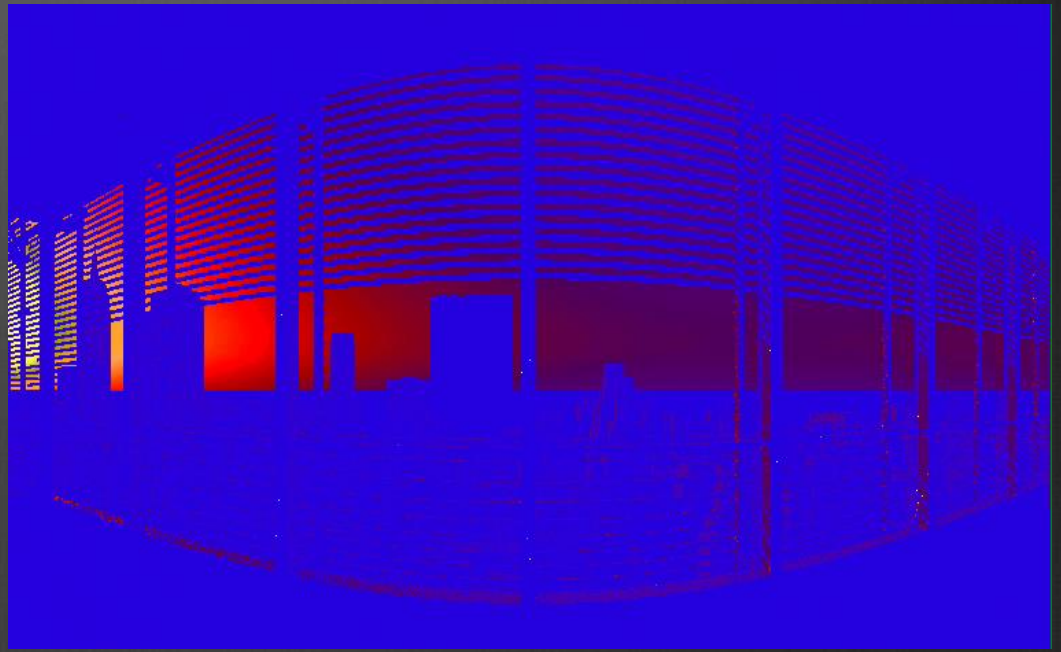
- Renzo Piano Architects
- Analysis and shade deployment recommendations by Eleanor Lee & John Mardaljevic







Q: Where & when to deploy shades?

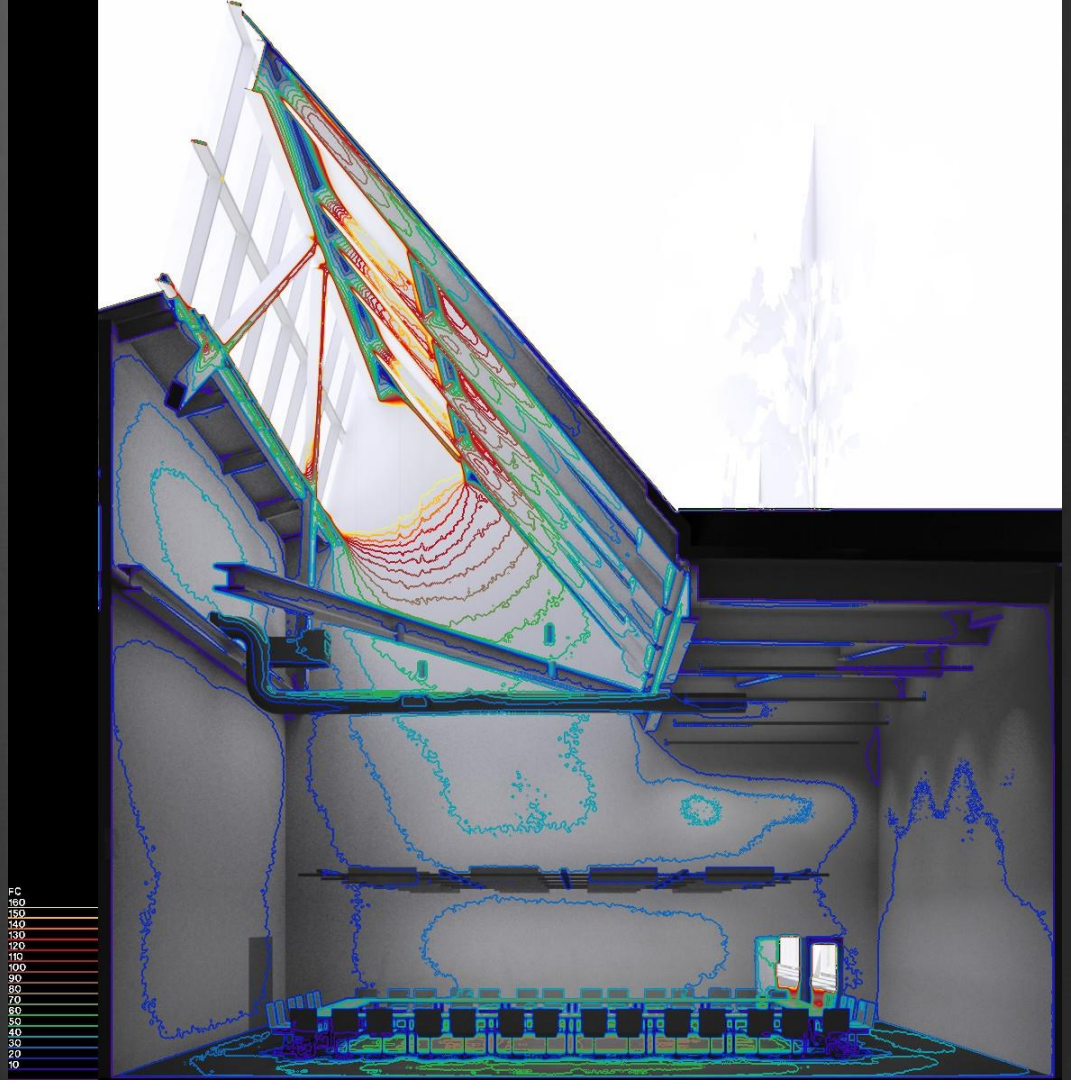


~140 Gb of simulated data to post-process / analyze

Examples from Loisos-Ubbelohde

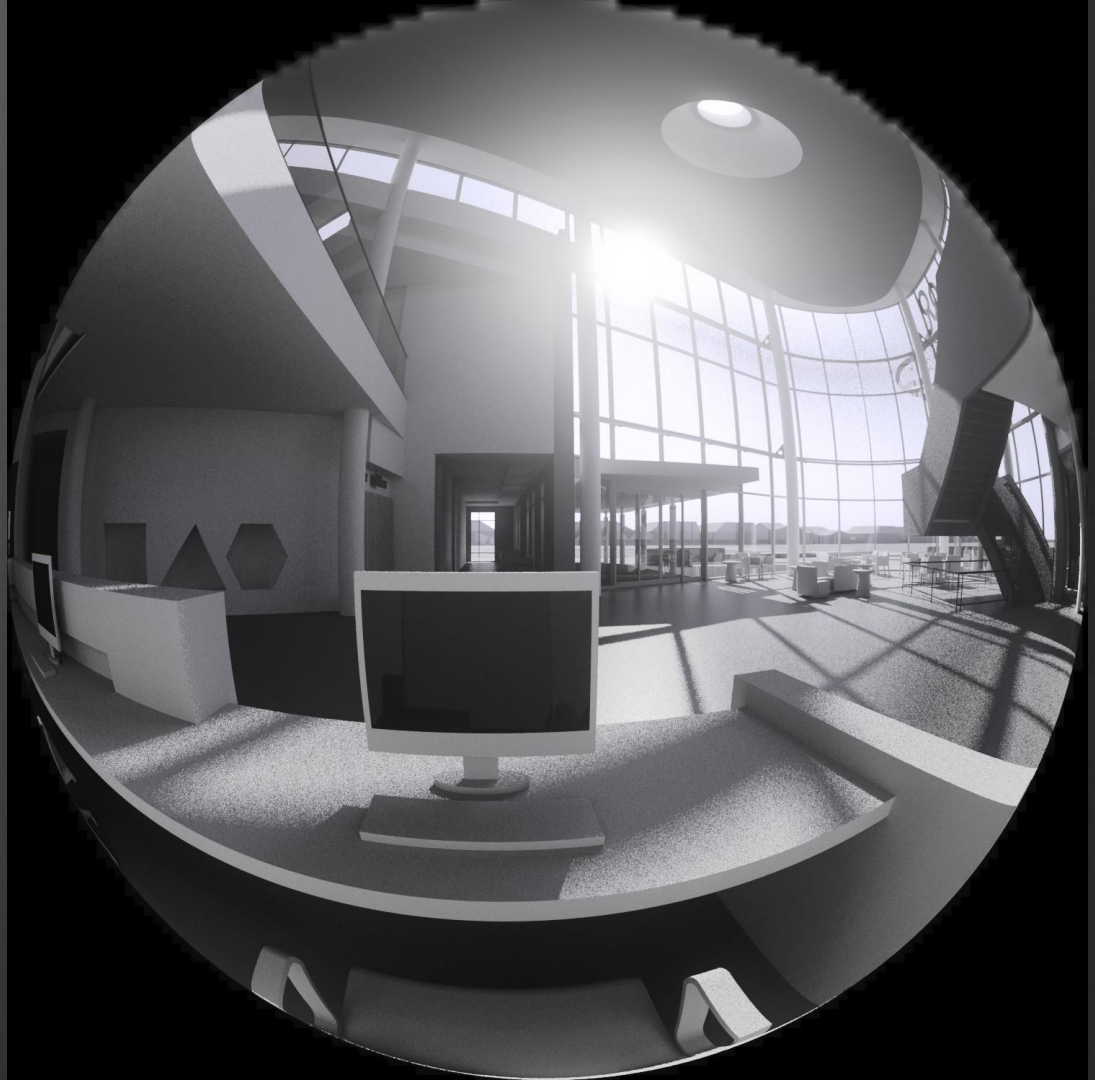
Kol Emeth Synagogue in Palo Alto, CA

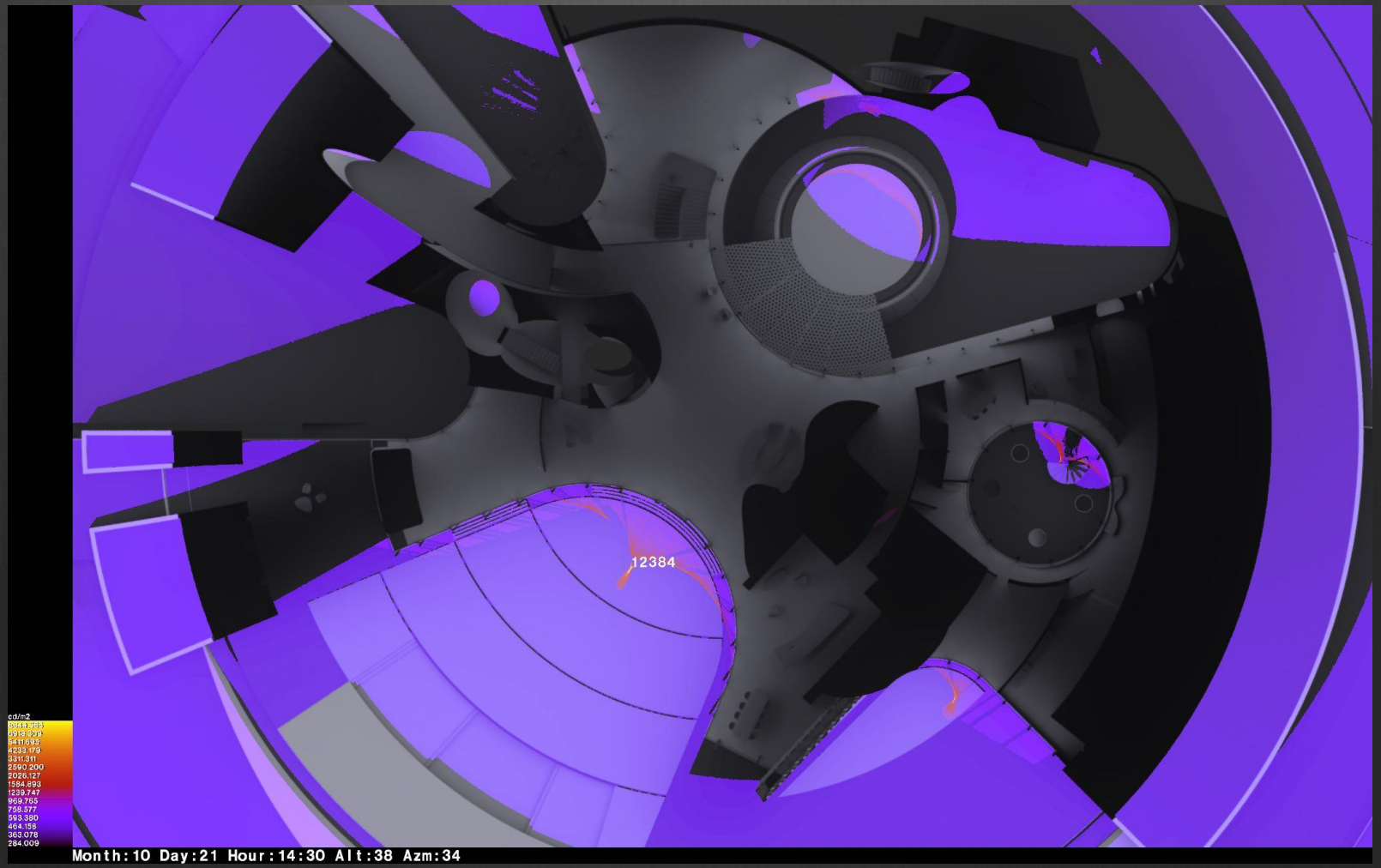
Warehouse renovation with sawtooth profile skylights



Valley Children's Hospital,
Outpatient Center,
CA Central Valley
(Bakersfield and Modesto)

Valley Children's Hospital,
Outpatient Center,
CA Central Valley
(Bakersfield and Modesto)




12384
cd/m2
8844.385
6918.309
5411.695
4233.179
3311.311
2590.200
2026.127
1584.893
1239.747
969.765
758.577
593.380
464.158
363.078
284.009
Month:10 Day:21 Hour:14:30 Alt:38 Azm:34

How *Radiance* Became the Premier Daylight Simulation

- Development began in 1985, evolutionary growth since
- Heavily validated against real-world measurements
- Open source invites contributions from daylighting research
- Designed primarily as a calculation engine others could use
- Little incentive to compete when you can adopt & improve

Problems *Radiance* Solves

- Determining how much light arrives at a point and from which direction (radiance is the actual radiometric unit)
  - Historically known as “the global illumination problem”
- How light interacts with surfaces, a.k.a. material properties
  - The BSDF is an important part of this
- Surrounding input and output problems
  - Importing, conversion, data manipulation, scripting, image filters, human perception, annual analysis, visualization, etc.

Problems *Radiance* Does Not Solve

- Creating the geometric model of a building
  - Although we import standard formats such as Wavefront OBJ
- Measuring the material properties
  - Although we provide tools to interpolate measured BSDF data
- Connecting to glazing and luminaire databases
- Automating standard analyses such as sDA
- Linking to whole-building simulations

Integrated Tools Using *Radiance*

- DAYSIM
- DIVA for Rhino
- IESVE
- OpenStudio
- LightStanza
- Groundhog
- Ladybug & Honeybee
- Maybe half a dozen others…

Ongoing Research & Development

- Further refinements to data-driven BSDF accuracy
- Glare analysis for scenes where solar orb is visible
- Error analysis for annual simulation matrix methods
- Executive program for running matrix annual simulations
- Integrating *Radiance* daylight simulations into *Spawn*

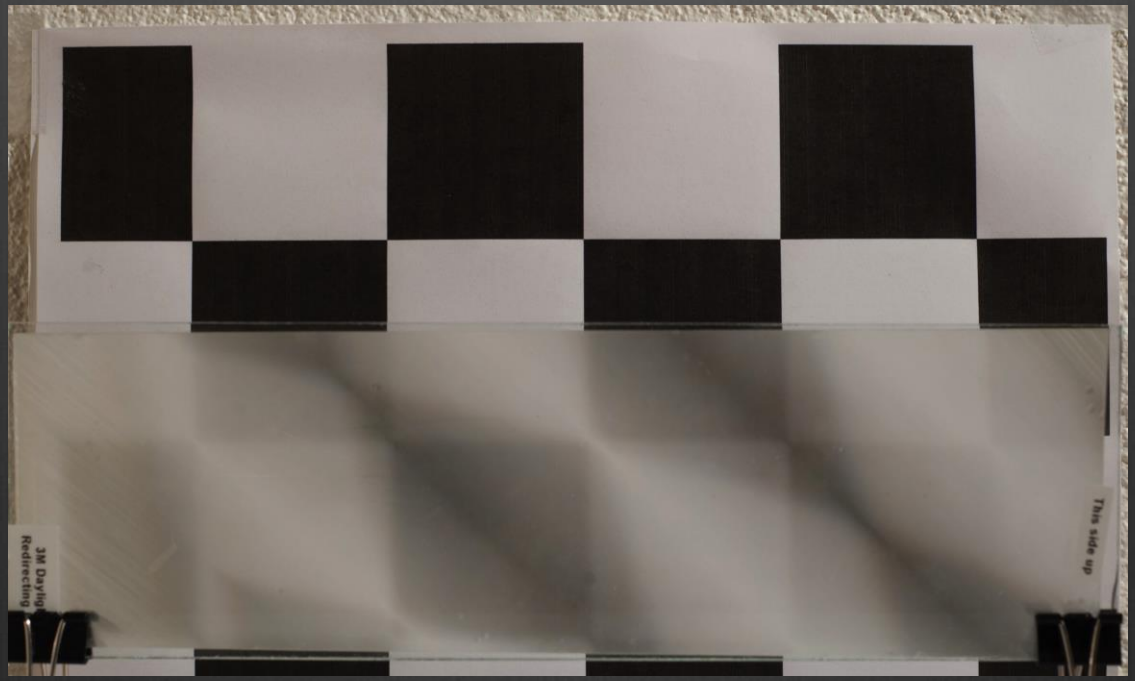
BSDF Models

- Most simulations rely on mathematical BSDF models as the best representation of material reflection and transmission
- For example, here is the widely regarded Ashikhmin-Shirley BRDF model, which describes outgoing radiation as a function of incident radiation and a few parameters:

$$\rho_s(\mathbf{k}_1, \mathbf{k}_2) = \frac{\sqrt{(n_u+1)(n_v+1)}}{8\pi} \frac{(\mathbf{n}\cdot\mathbf{h})^{n_u \cos^2\phi + n_v \sin^2\phi}}{(\mathbf{h}\cdot\mathbf{k})\max((\mathbf{n}\cdot\mathbf{k}_1),(\mathbf{n}\cdot\mathbf{k}_2))} F((\mathbf{k}\cdot\mathbf{h}))$$

3D Plot Comparison for Brushed Aluminum

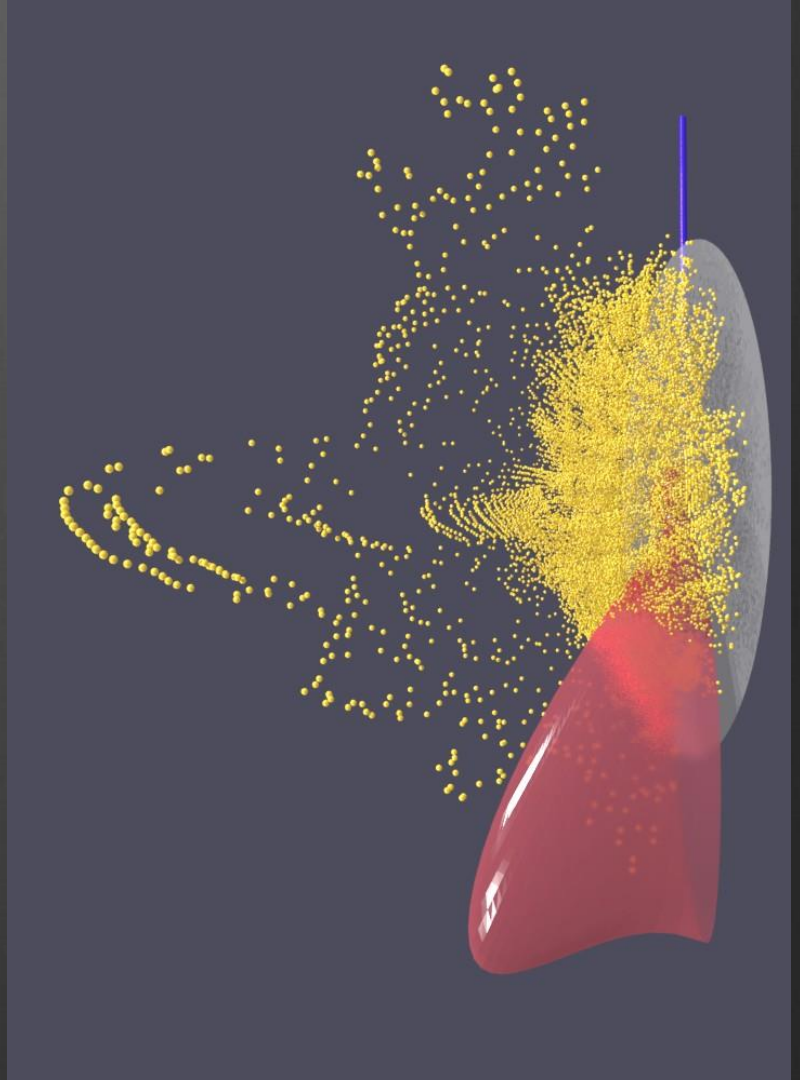
Daylight Redirecting Film



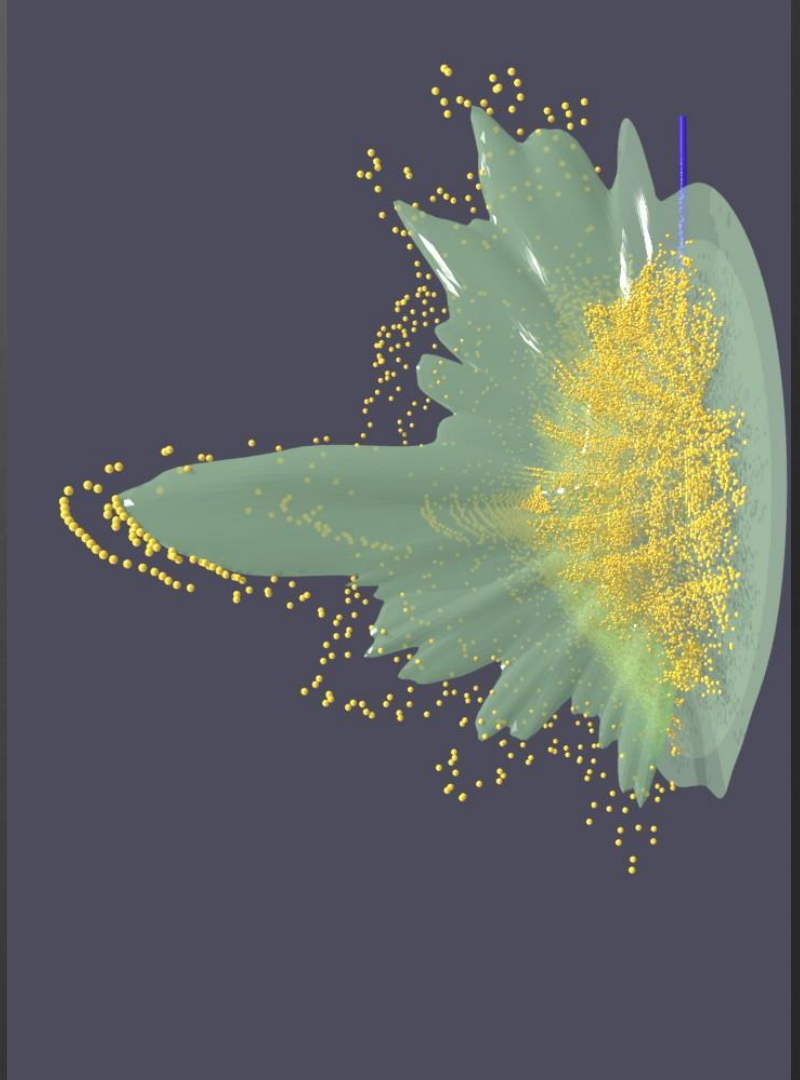
Walter et al. (2007) Model

Our Data-driven BSDF

BTDF measurement points
compared to Walter et al. model fit



Our data-driven BTDF



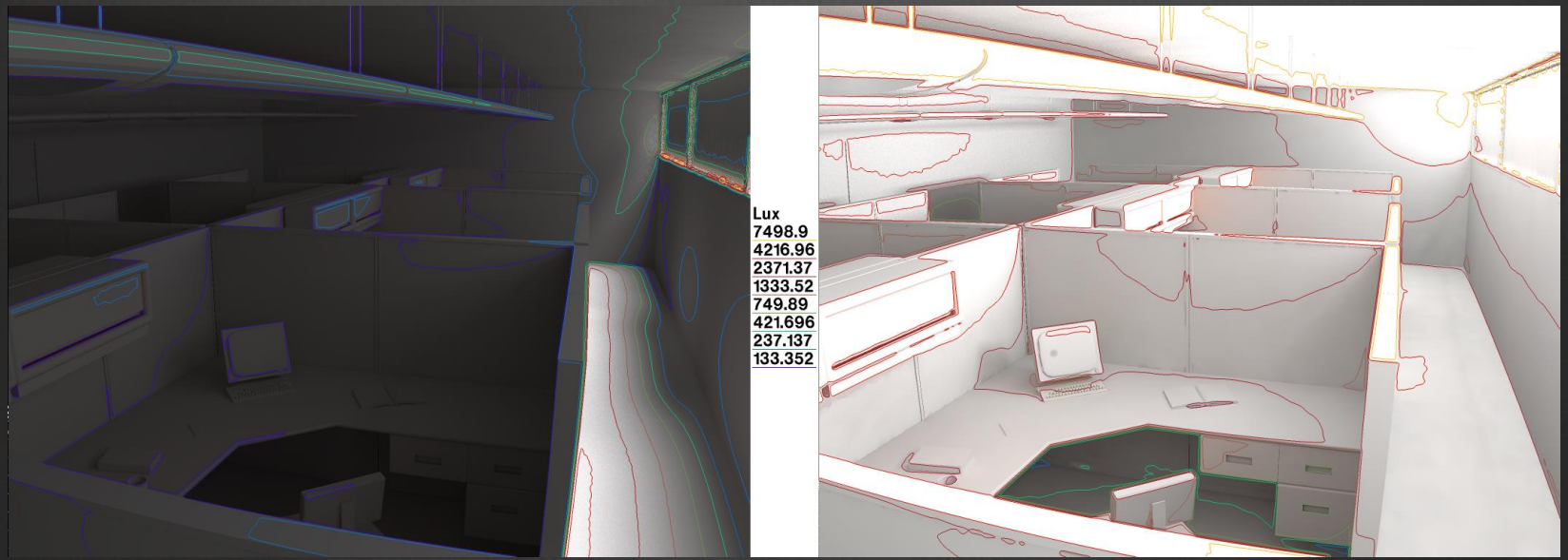
Effect on Rendering

Walter et al. model

Effect on Rendering

Data-driven BTDF

Light Levels



Walter et al.

Data-driven

What Is the Future of *Radiance*?

- New regression tests ensure changes do not break anything
  - These should be more comprehensive than they are now…
- LBNL continues to have a stake, as do EPFL and others
  - DOE funding has been steady for the past few years
- Developers of tools such as Accelerad, Honeybee, or DIVA could eventually take over code maintenance

Collaboration & Community

- *Radiance* owes its success to the individuals who have taken it on over the three decades it has been a shared tool
- Most of the ideas that went into its development did not come from me alone
- A spirit of collaboration is essential to any collection of tools that hundreds of experts use but none completely masters

Thank You