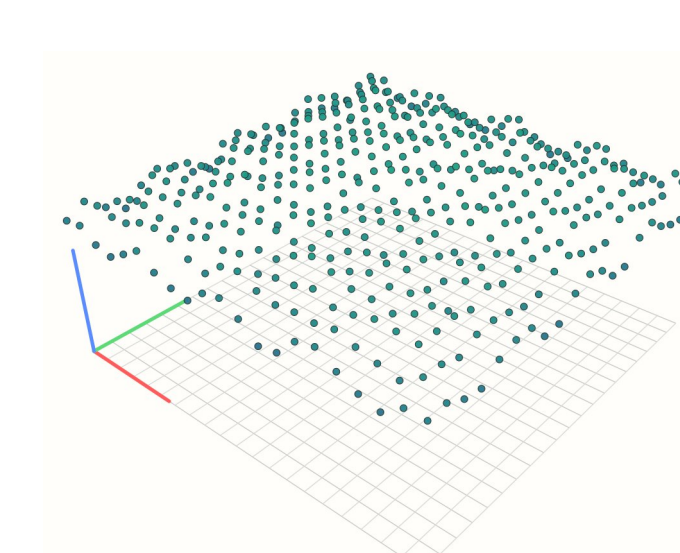
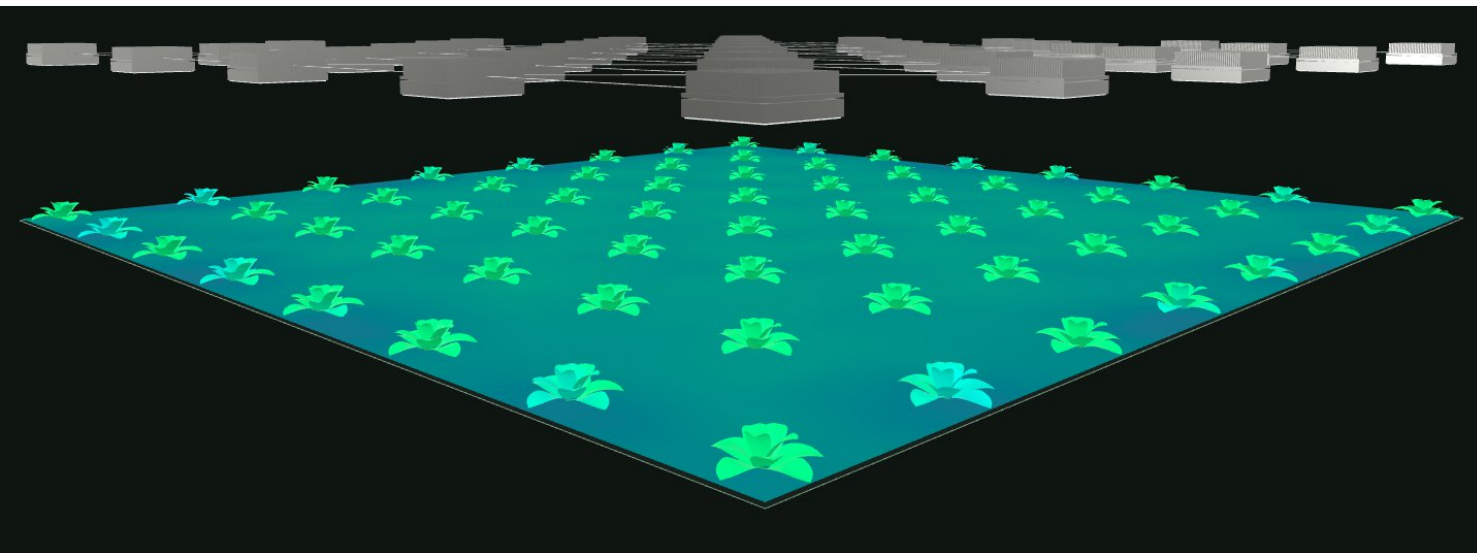
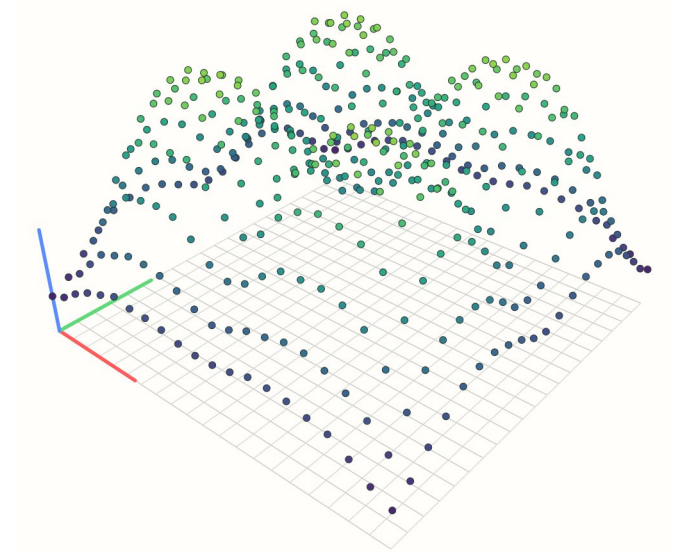
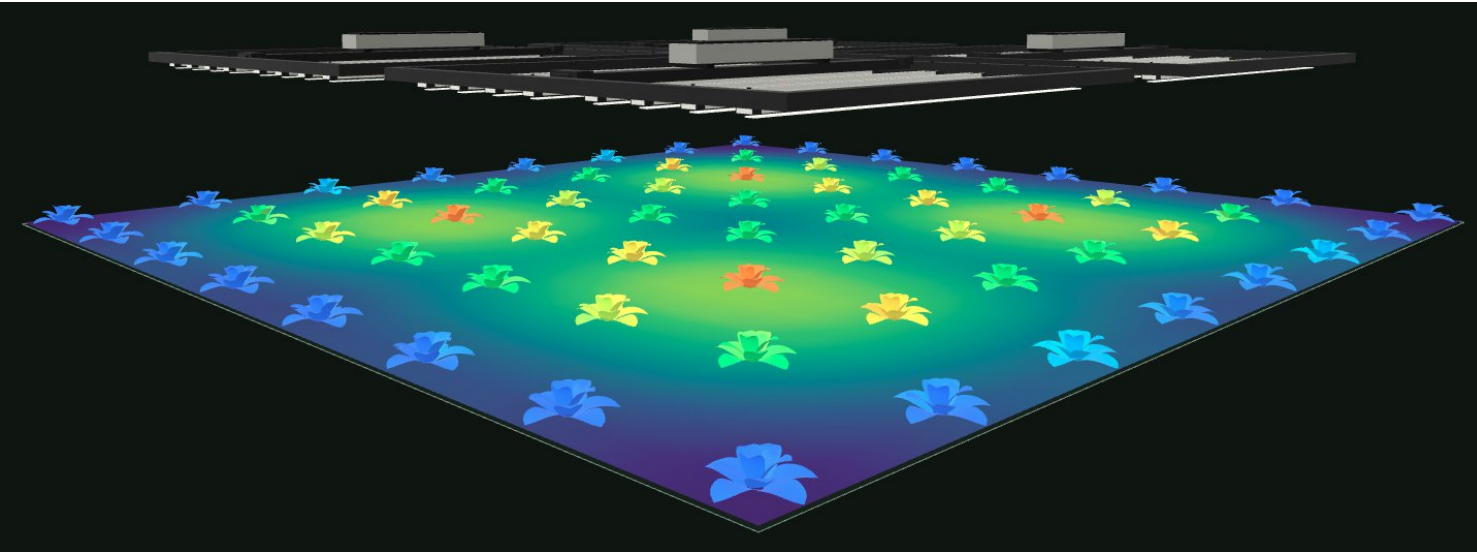


Horticulture Lighting Simulator, Powered by Radiance.



Presented by: Austin Rouse

What is the Horticulture Lighting Simulator?



A tool for inspecting lighting performance of horticultural lighting systems via useful metrics and intuitive 2D/3D visualizations.



HORTICULTURE LIGHTING SIMULATOR

Modularized LED System

Loaded

01 CONFIGURATION

Playback inputs

Lighting system

Modularized LED System

Lighting Target Policy

Mean Target

Target mean PPFD $\mu\text{mol}/\text{m}^2/\text{s}$

250

The requested authenticated-playback mean PPFD.

FSPM Reference Tolerance $\pm \mu\text{mol}/\text{m}^2/\text{s}$

25

Room Size

10' x 10'

Aisle Mode

Creates a fixed 2 ft perimeter aisle around the active grow area.

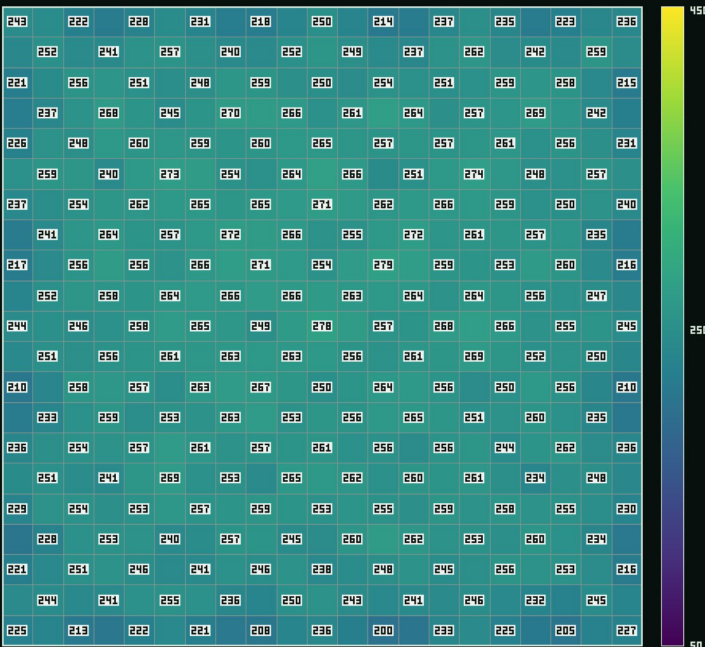
AUTHENTICATED BUNDLE SETTINGS

Available — validated compact bundle. Canonical display 10 x 10 ft · Standard quality · authenticated fixed settings.

Run Simulation

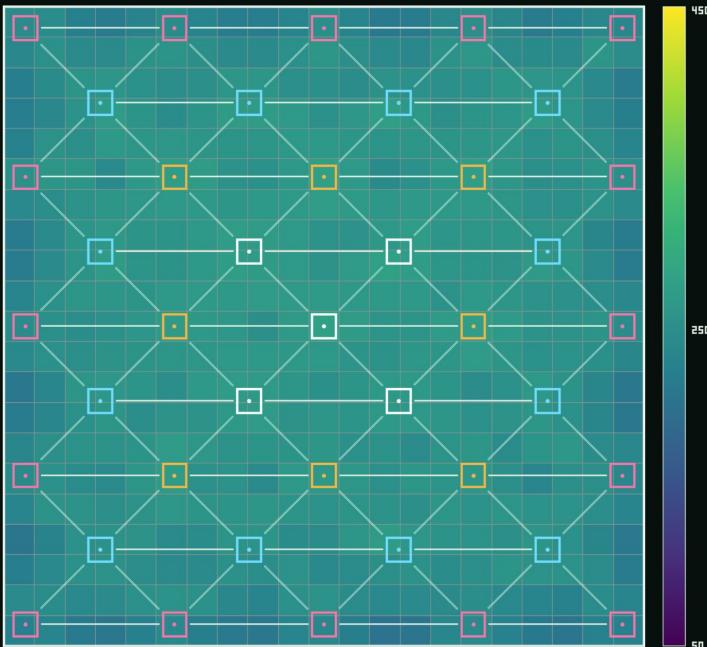
02 VISUAL OUTPUTS

Validated artifacts



PPFD Heatmap

X position (m) · Y position (m)



PPFD Heatmap with authoritative overlay

Simulation-plan geometry · scientific XY

X/Y position (m) · PPFD 50–450 $\mu\text{mol}/\text{m}^2/\text{s}$ · fspm-iridvis-8-linear-srgb-v1 · origin lower · equal aspect · 441 raw samples · Proposed modules retain authoritative control-zone colors.

csv

Final baseline PPFD

3D

Plant layout viewer

xyz

Validated PPFD scatter

What It Can Do Now and Future Possibilities

Current Capabilities

Model and compare spatial PPFD, uniformity, and target coverage

Trace multispectral photons through sources, rooms, and plant optics with Radiance

Sample both sides of deterministic leaf geometry using oriented surface receivers

Model spectral absorbed, transmitted, and reflected photon flux with diffuse-transmissive Radiance trans leaf material

Visualize lighting systems in 3D and interactively inspect PPFD intensity along the illuminated plane

Future Capabilities

Couple light transport with dynamic growth, photosynthesis, and plant-response models

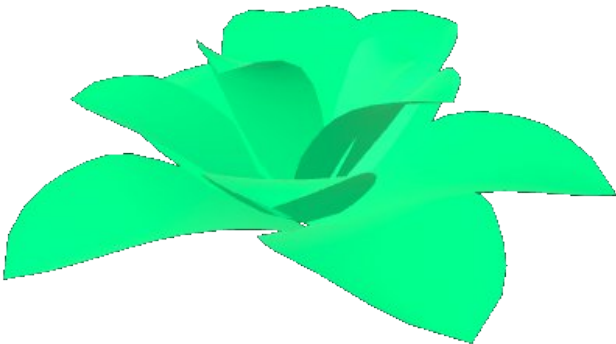
Support measured plant scans, additional crops, growth stages, and optical profiles

Combine daylight, greenhouse glazing, and supplemental lighting over time

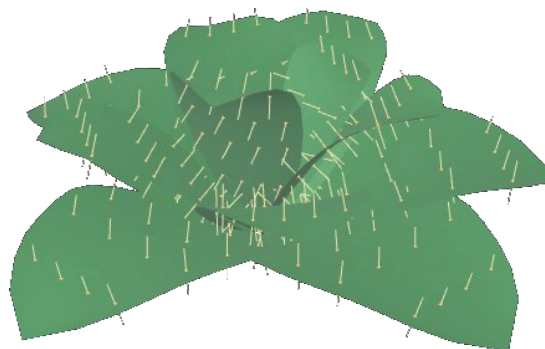
Use high-performance computing (HPC) to optimize light recipes, layouts, and production strategies

Evolve into a sensor-informed
Digital Twin Plant Production Platform

Uniform Field



Samples/Normals

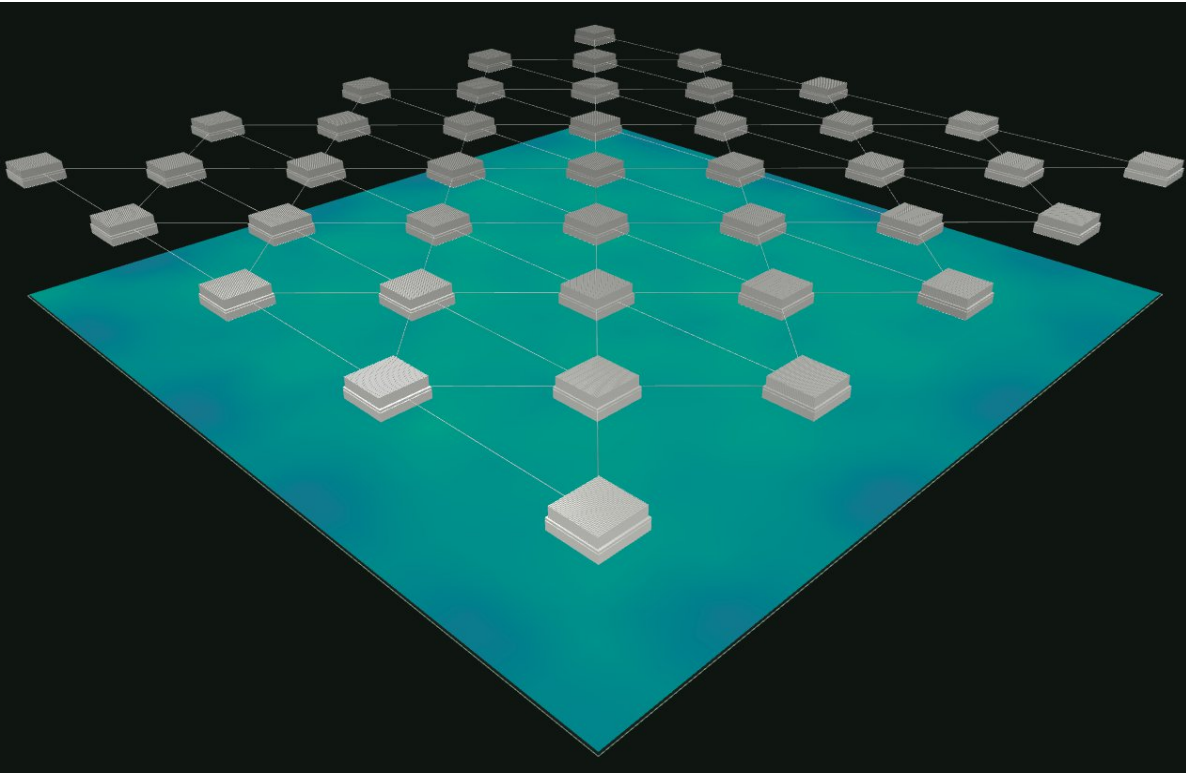


Non-Uniform Field

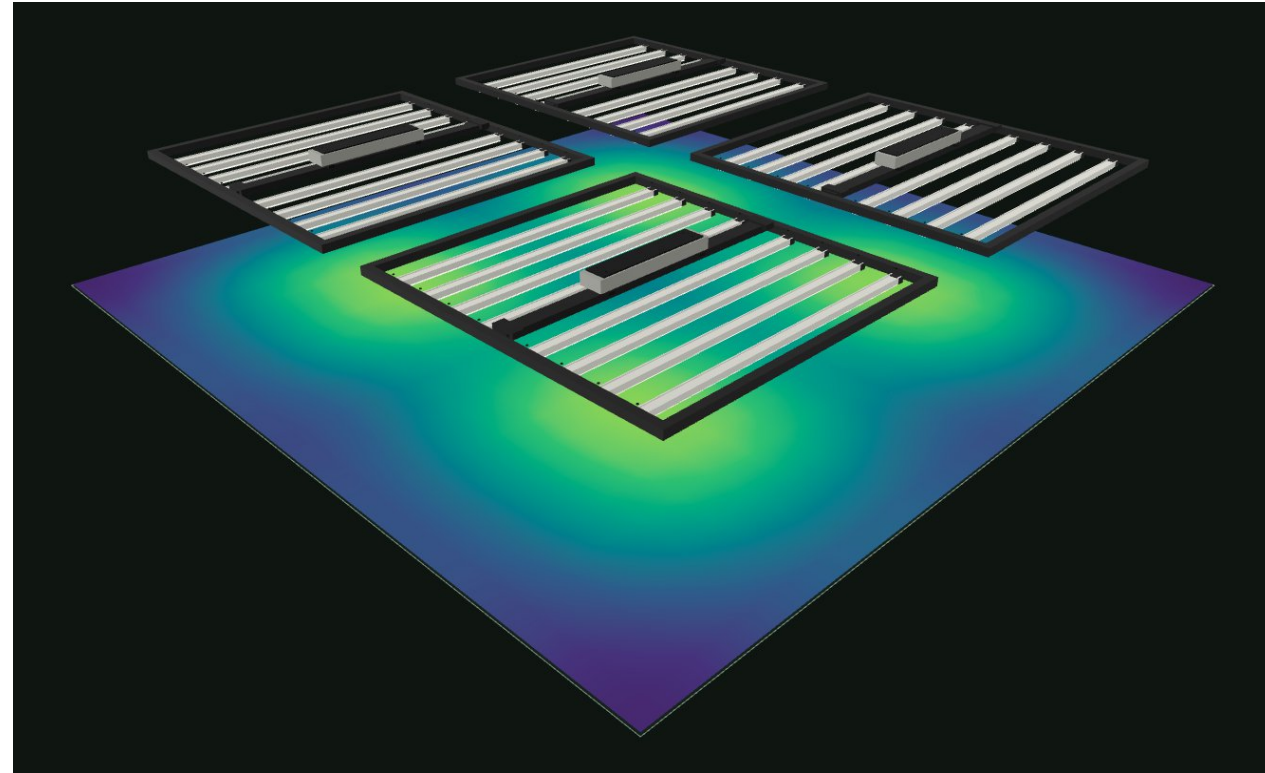


Systems We Will Use to Explore the Horticulture Lighting Simulator

1 Modularized LED Lighting System

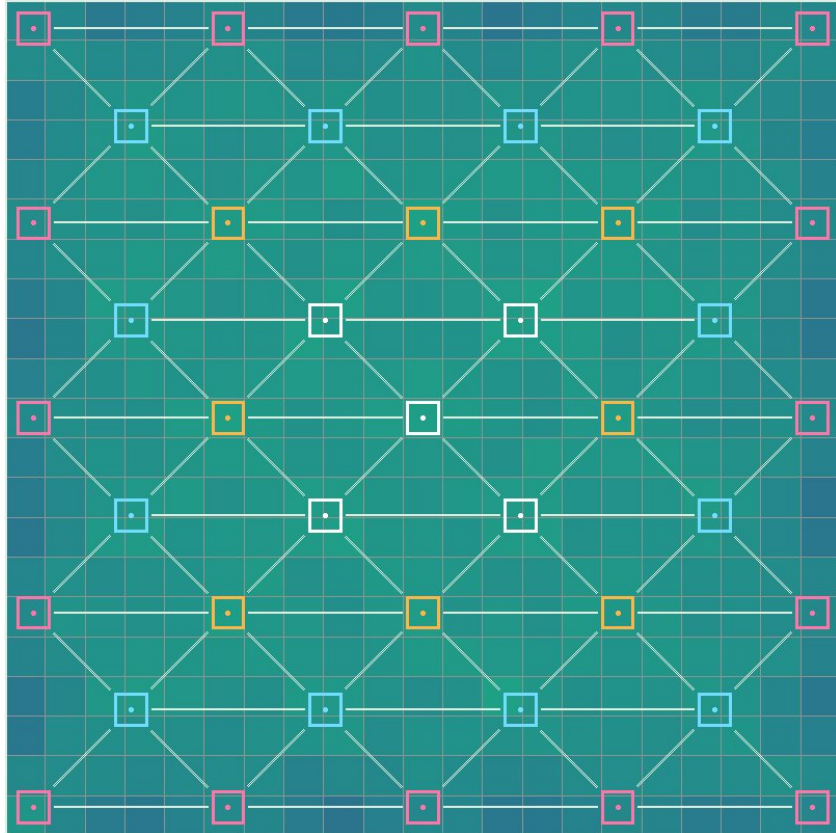


2 Conventional LED Lighting System



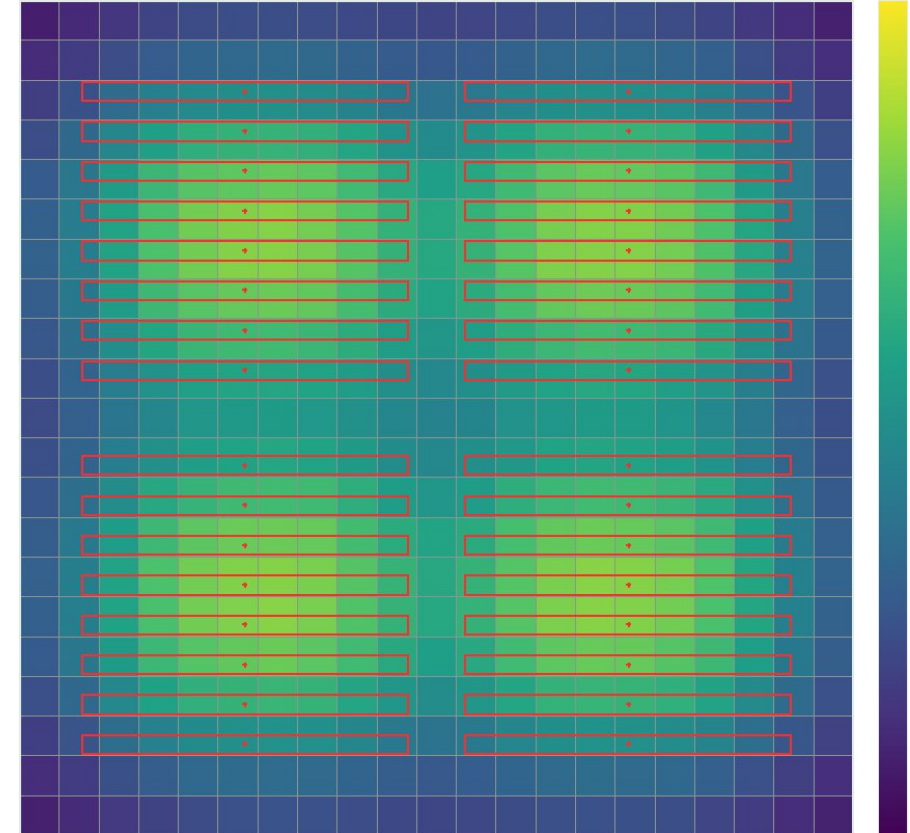
The Square Case We Will Explore (10' x 10')

Emulation of a 10'x10' grow tent with layout-optimized spacing for Conventional LED



Same Transport Contract

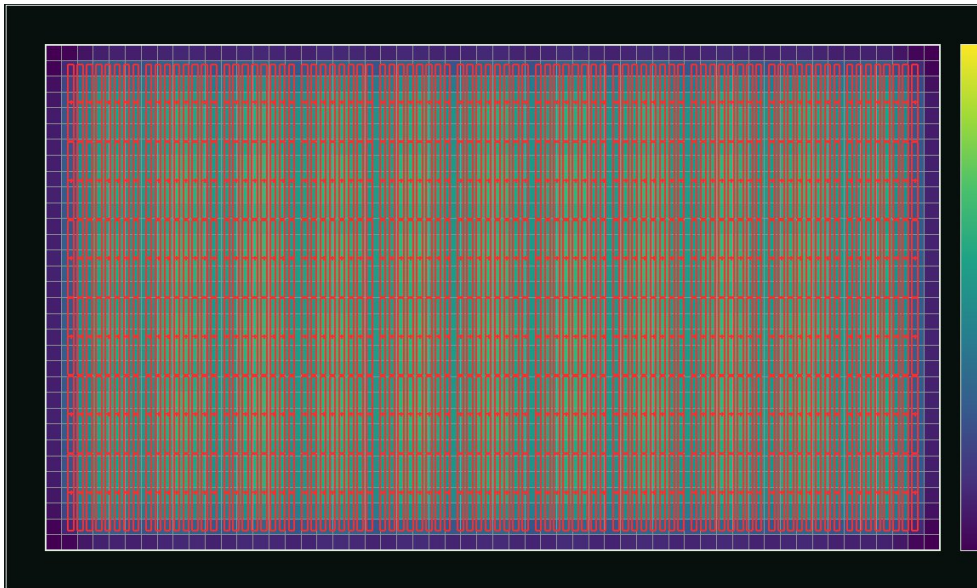
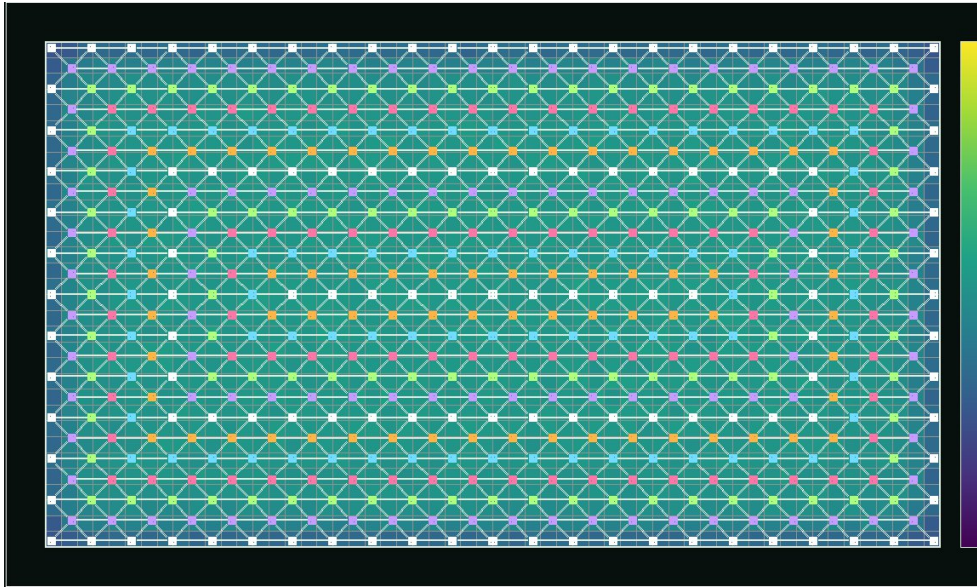
- Equal target mean PPFD
- Matched SPD
- Matched system efficacy
- Matched mounting height (18 in.)
- **Production room:**
walls/ceiling = 0.90; floor = 0.10
- Sensor plane at $z = 5$ mm
- Fixture and lattice occlusion
- Matched Radiance quality settings



Both cases we will explore use the same light transport contract

The Rectangular Case We Will Explore (30' x 50')

Emulation of a commercial indoor grow room with 2' perimeter aisles and "Rolling Bench" style spacing for Conventional LED



Modularized LED System

Centered square number-inspired arrangement of square LED modules in a modularized fixture system

Triangulated lattice cable fixture system for precision placement of LED modules

Produces a highly uniform field of lighting intensity across arbitrary square and rectangular grow spaces

Conventional LED System

Standard 8-bar configuration of linear light bars in a fixed-dimension fixture system

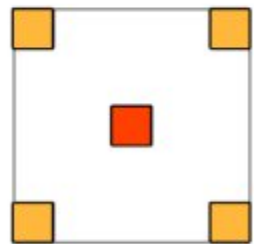
Aluminum frame fixture system that requires manual measurement for fixture placements

Produces a less uniform light field due to geometric constraints

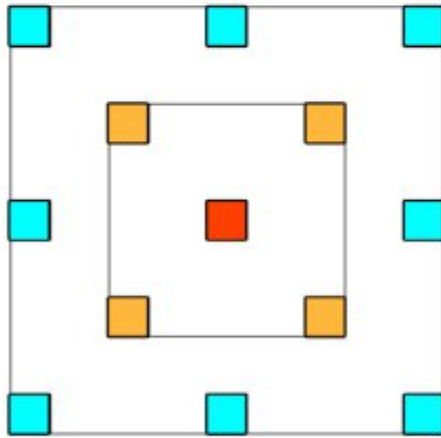
The Modularized LED Lighting System

The modularized system is based on an infinitely continuing number sequence

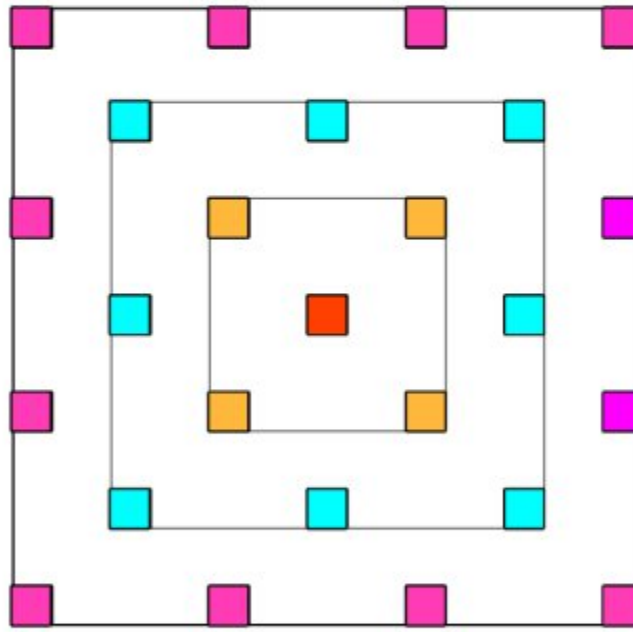
- The modularized lighting system is based on the **centered square number sequence**, from the emitter-packaging level up to the arrangements of LED modules themselves.
- Each square in the number sequence can represent either LEDs within a module or LED modules within a larger lighting array.



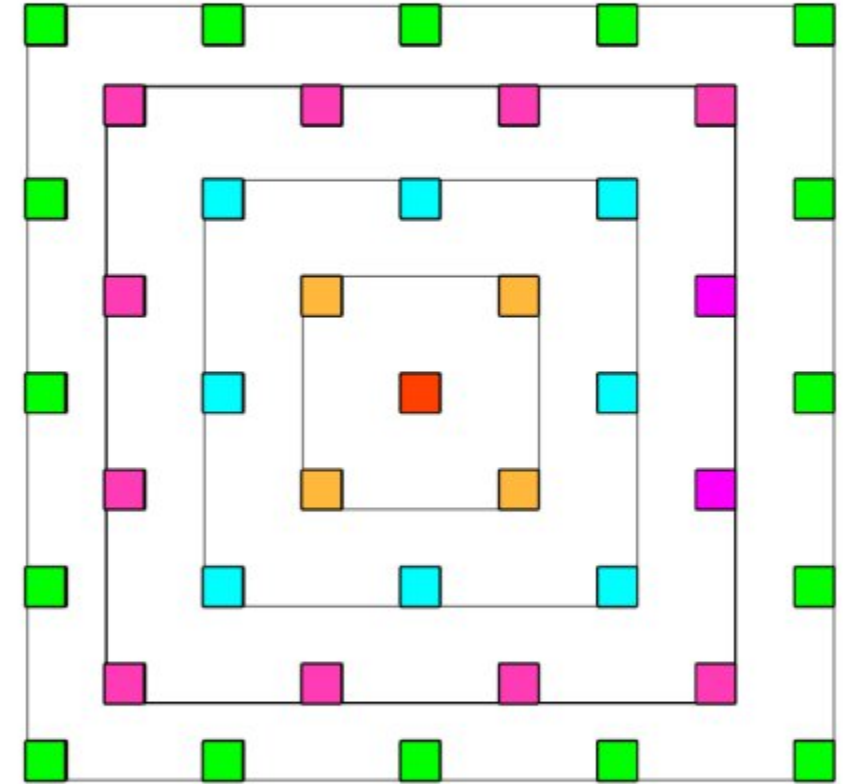
5



13



25



41

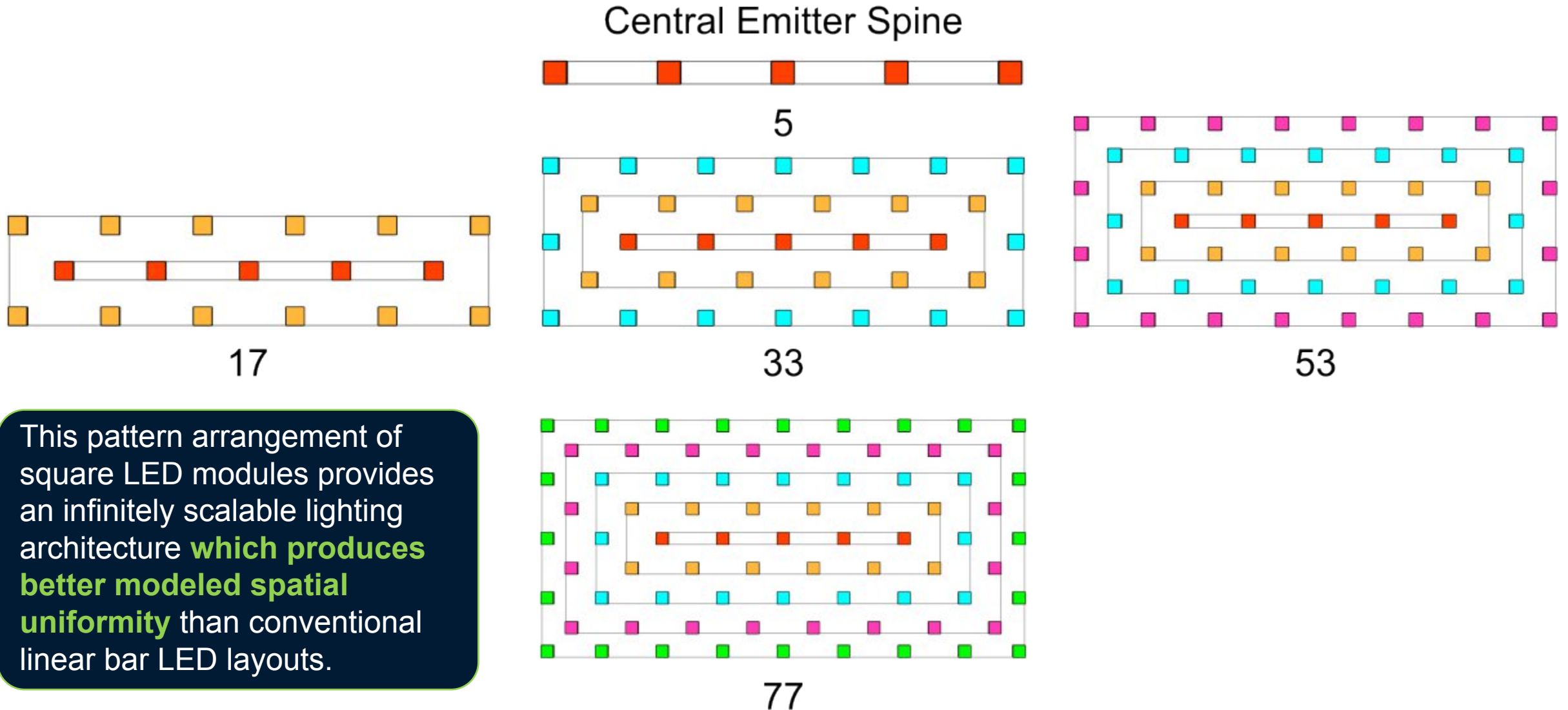
Central Emitter



1

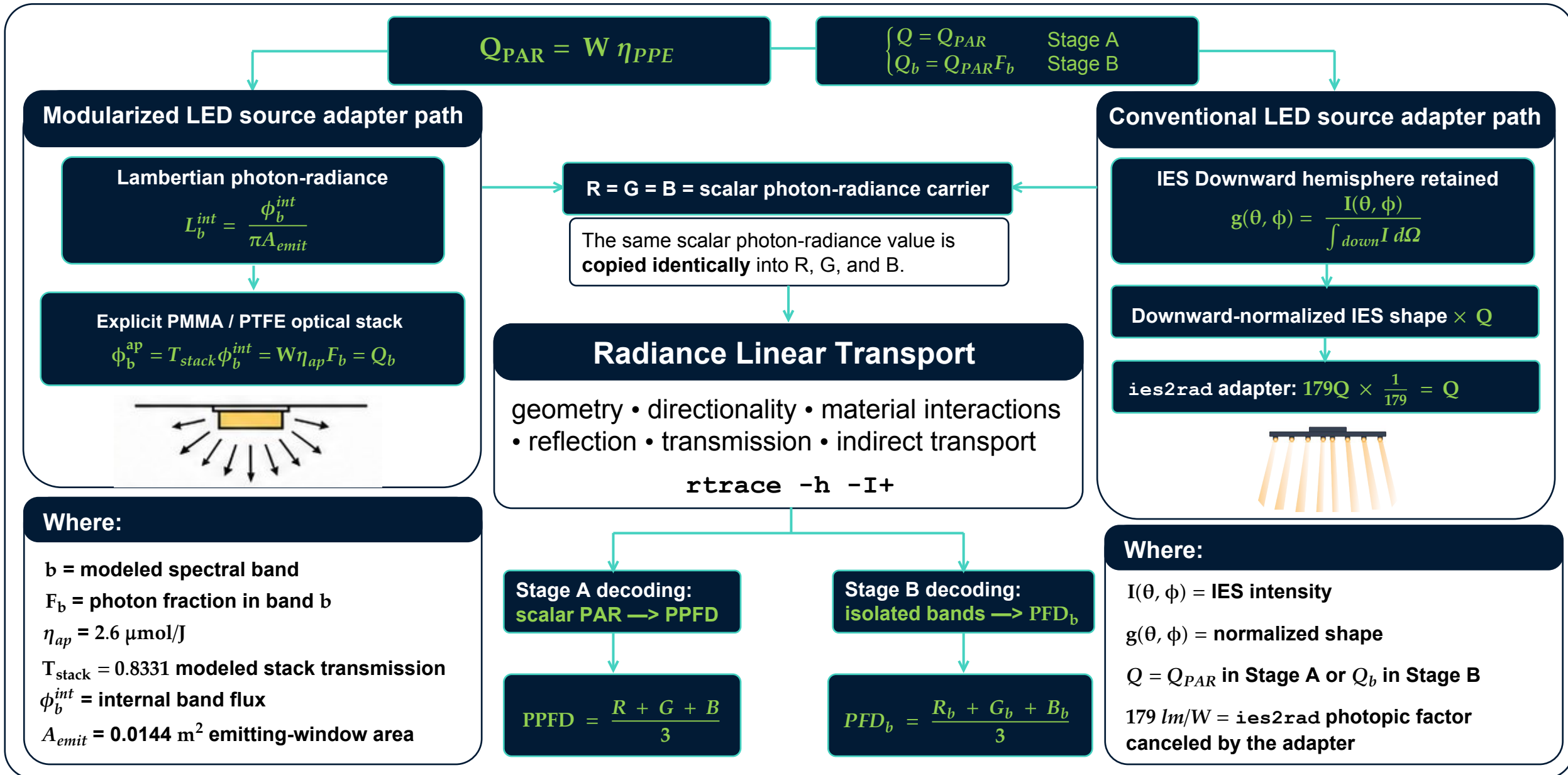
Extending the Centered Square Number Sequence to Rectangular Spaces

Replace the central point with an odd-length emitter row while preserving the concentric-shell rule.



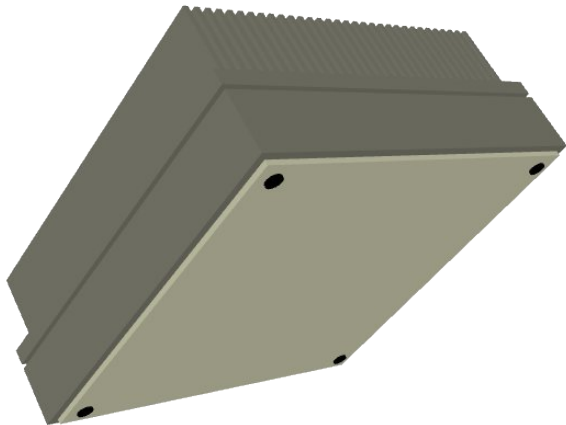
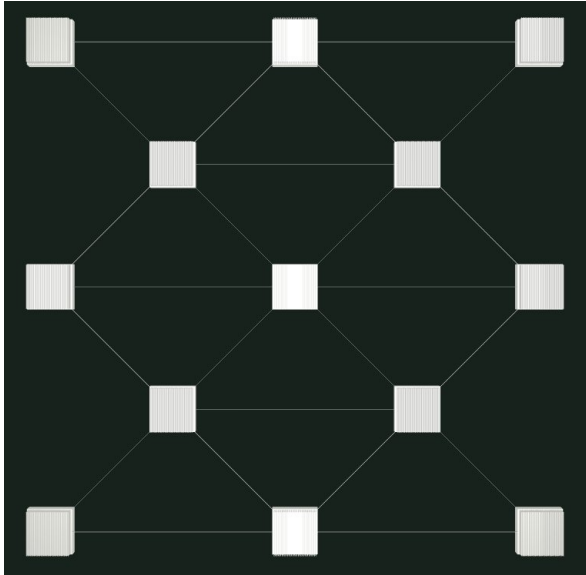
Photon-native unit contract for Radiance

The simulator assigns photon meaning and Radiance performs the light transport.



Fixture Hardware Participates in Optical Transport

The simulator compares complete lighting systems — not luminous apertures floating in empty space



Fixture Body Occlusion

Physical Geometry: Module housings, heat sinks, frames, and alignment links are included as non-emitting geometry

Optical Separation: Emitting faces are excluded from the body mesh, preventing double-counting or self-occlusion

Controlled Comparison: Both systems receive the same declared anodized-aluminum material proxy

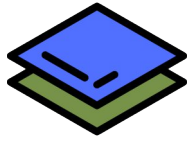
Transport Behavior: Body geometry affects direct visibility and shadowing; reflected contributions are captured

```
void metal_fixture_body_anodized_aluminum  
0  
0  
5 0.70 0.70 0.70 0.90 0.10
```

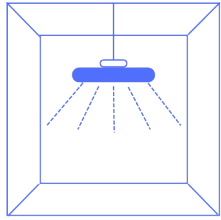
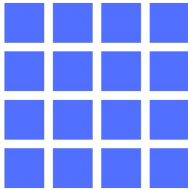
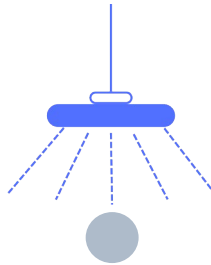
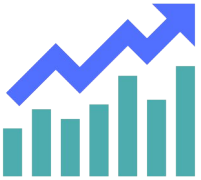
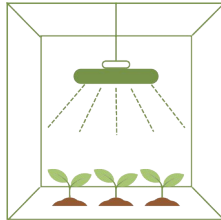


Authenticated GLB → Primitive classification → Radiance body mesh → Repeated instances

Two-layer Radiance Modeling Architecture



Two distinct stages, one seamless process

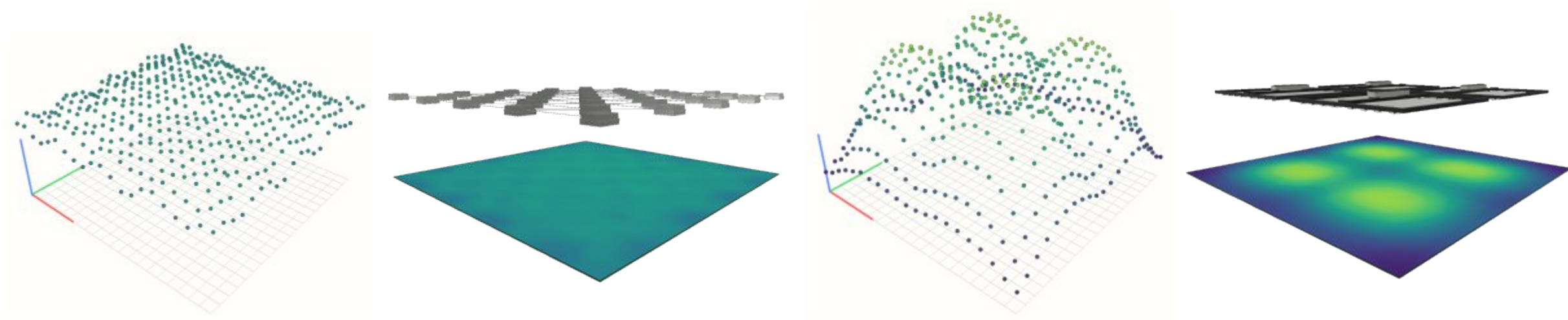
Stage	Scene	Receiver	Transport Basis	Outputs
A Baseline PPFD / uniformity	 room + fixtures	 horizontal measurement grid	 scalar PAR PPFD	 heatmaps, metrics, fixture overlays
B FSPM receiver transport	 room + fixtures + plants	 leaf-surface receiver samples	 multispectral: B / G / O / R / FR	 incident flux, modeled spectral absorption



Baseline PPFD artifacts stay plant-free; FSPM artifacts use plant geometry and leaf optical properties.

10'x10' Baseline PPF Simulation — Modularized vs Conventional LED Lighting System

The app outputs inspection artifacts from the same simulation run: metrics, 2D heatmaps, and 3D visualizations.

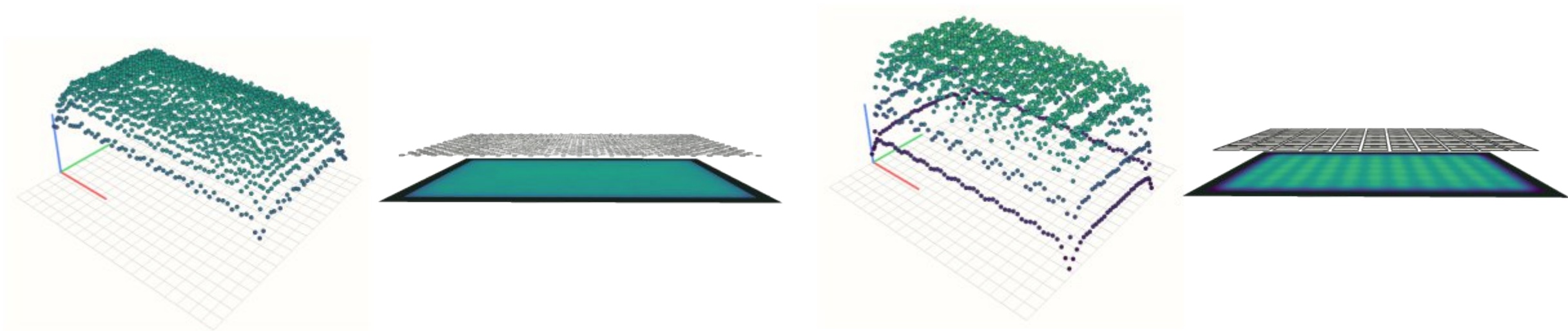


Modularized LED System	
250.00 Mean PPF ($\mu\text{mol}/\text{m}^2/\text{s}^{-1}$)	441 Sample Count
0.717 Min / Max	0.801 Min / Mean
14.864 Population Standard Deviation ($\mu\text{mol} \cdot \text{m}^2 \cdot \text{s}^{-1}$)	5.945% CV

Conventional LED System	
250.00 Mean PPF ($\mu\text{mol}/\text{m}^2/\text{s}^{-1}$)	441 Sample Count
0.213 Min / Max	0.326 Min / Mean
80.484 Population Standard Deviation ($\mu\text{mol} \cdot \text{m}^2 \cdot \text{s}^{-1}$)	32.194% CV

30'x50' Baseline PPFD Simulation — Modularized vs Conventional LED Lighting System

The app outputs inspection artifacts from the same simulation run: metrics, 2D heatmaps, and 3D visualizations.

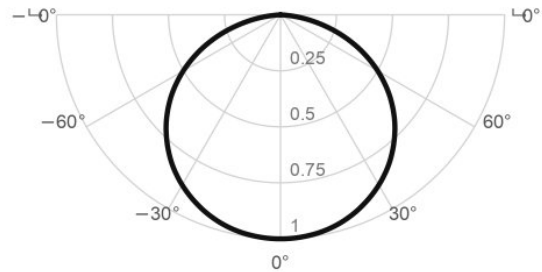


Modularized LED System	
250.00 Mean PPFD ($\mu\text{mol}/\text{m}^2/\text{s}^{-1}$)	1,792 Sample Count
0.523 Min / Max	0.596 Min / Mean
24.851 Population Standard Deviation ($\mu\text{mol} \cdot \text{m}^2 \cdot \text{s}^{-1}$)	9.941% CV

Conventional LED System	
250.00 Mean PPFD ($\mu\text{mol}/\text{m}^2/\text{s}^{-1}$)	1,792 Sample Count
0.100 Min / Max	0.127 Min / Mean
67.158 Population Standard Deviation ($\mu\text{mol} \cdot \text{m}^2 \cdot \text{s}^{-1}$)	26.863% CV

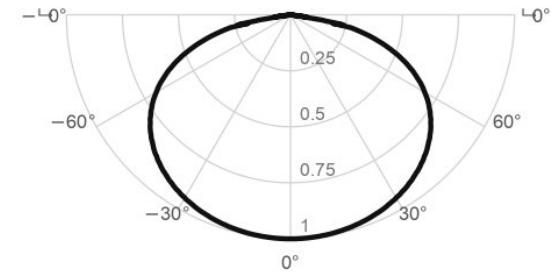
Is the uniformity advantage just a result of beam shape?

(a) Conventional LED



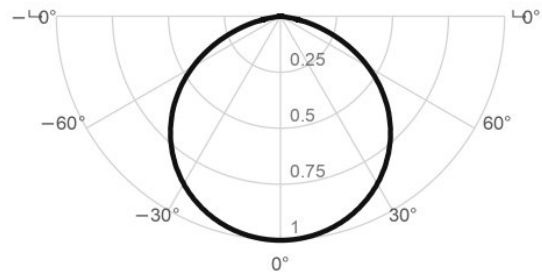
Computed FWHM: 120.129°

(c) Modularized-Altered (140° FWHM)



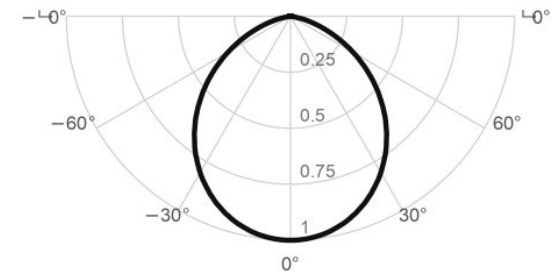
Computed FWHM: 139.712°

(b) Modularized System



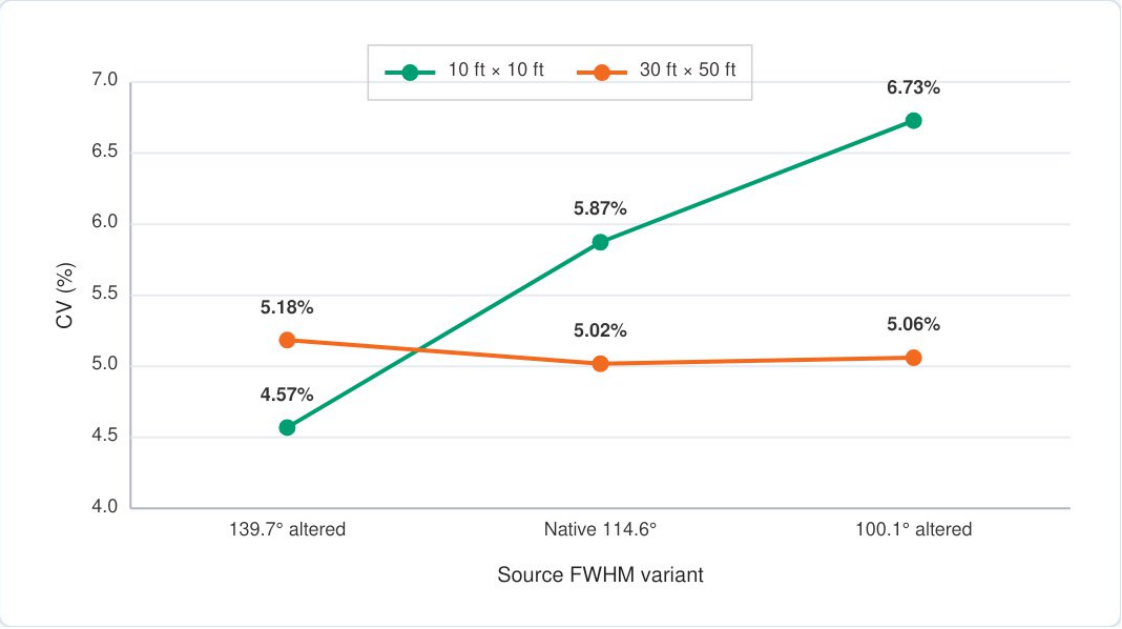
Computed FWHM: 114.647°

(d) Modularized-Altered (100° FWHM)



Computed FWHM: 100.082°

Sensitivity check: change the beam, keep the system logic fixed



Room	Variant	Mean PPFD ($\mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$)	CV (%)	Min/Mean	Min/Max
10 ft x 10 ft	Native — 114.6°	250.00	5.87	0.786	0.707
10 ft x 10 ft	140° altered — 139.7°	250.00	4.57	0.811	0.752
10 ft x 10 ft	100° altered — 100.1°	250.00	6.73	0.775	0.683
30 ft x 50 ft	Native — 114.6°	250.00	5.02	0.768	0.701
30 ft x 50 ft	140° altered — 139.7°	250.00	5.18	0.793	0.705
30 ft x 50 ft	100° altered — 100.1°	250.00	5.06	0.753	0.689



Changing beam width changes CV, but the system’s uniformity remains robust across plausible source-shape perturbations.

Functional-Structural Plant Modeling receiver model

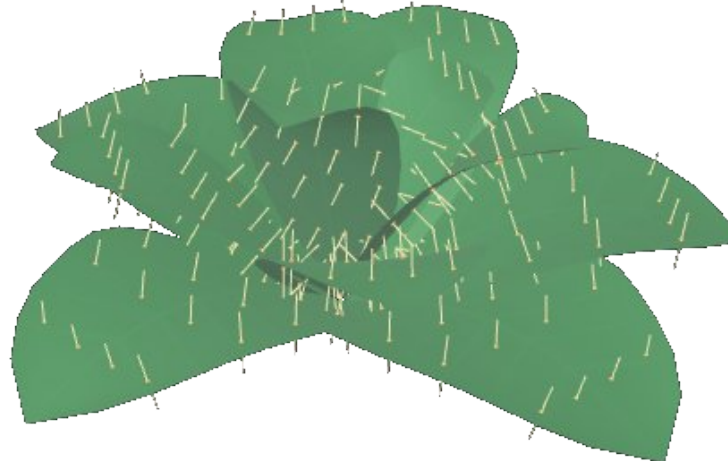
Plant geometry as receiver layer • receiver samples evaluated along leaf-surface normals with `rtrace -h -I+`

Surface samples



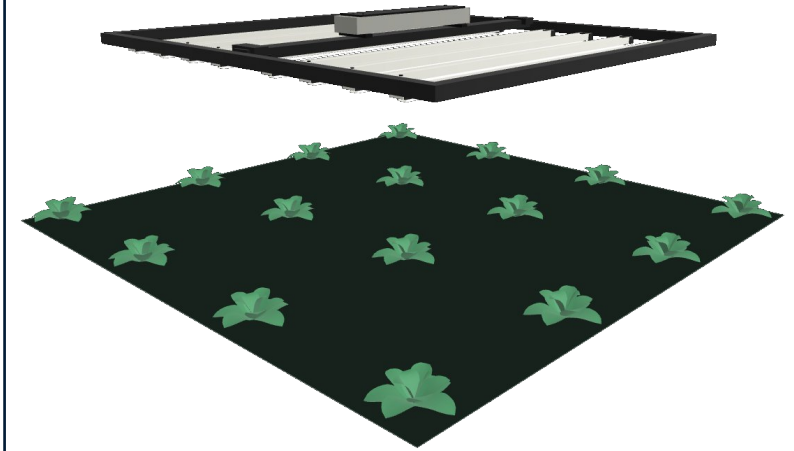
Leaves are subdivided into 16 mesh patches on each side, adaxial (top) and abaxial (bottom).

Surface normals



The surface normals define the orientation of the hemisphere over which incident radiance is integrated.

Plant-inclusive Radiance scene



Room + fixtures + plant geometry +
Rex lettuce diffuse-transmissive
leaf material

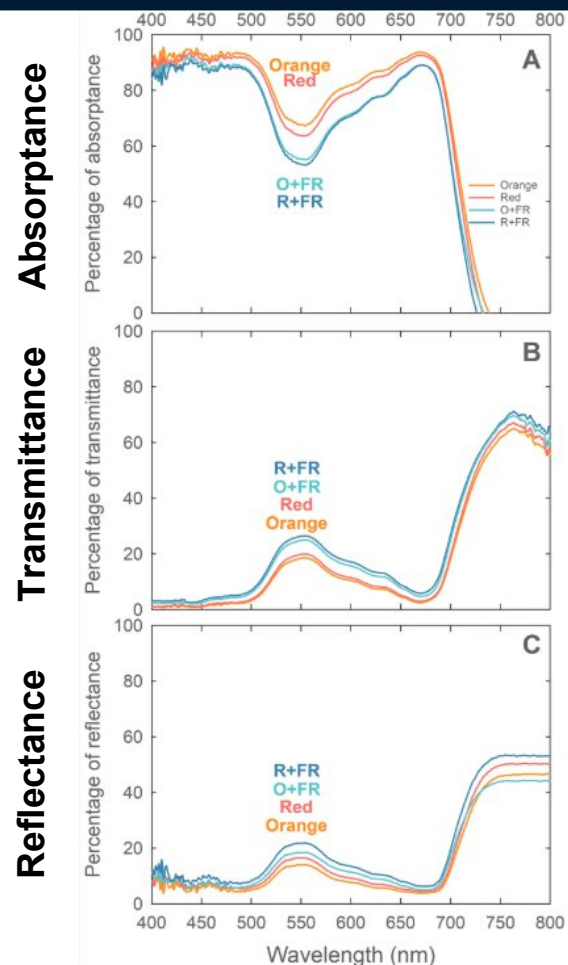
`rtrace -h -I+`



Plant geometry becomes a receiver layer for modeled spectral absorbed photon flux, while baseline PPFD artifacts remain plant-free.

Rex lettuce diffuse-transmissive Radiance trans leaf material

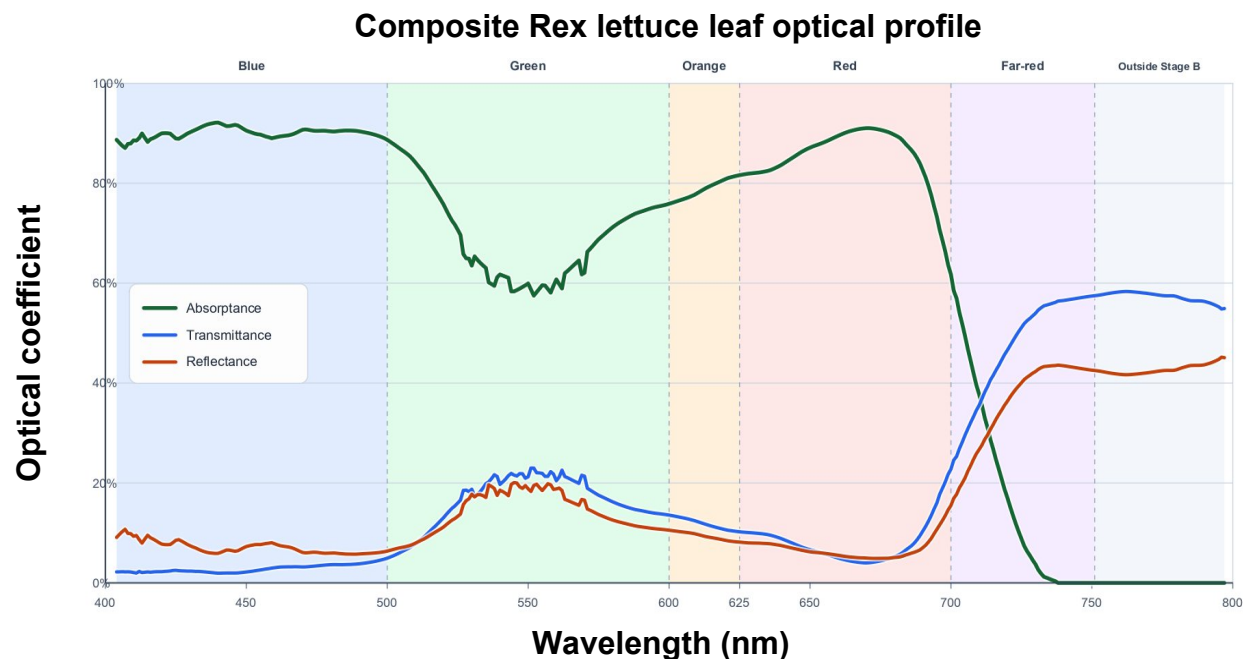
Source leaf-optics figure



The published absorbance (A), transmittance (B), and reflectance (C) curves for green lettuce 'Rex' were used as the source basis for the simulator's leaf-optics profile.

Figure sourced from Kang and Zhen (2025), CC BY.

Digitization and band integration



Rex lettuce leaf optical-profile-weighted coefficients

Band	Blue 400-499 nm	Green 500-599 nm	Orange 600-624 nm	Red 625-699 nm	Far-red 700-750 nm
Coefficient					
A (absorbance)	0.902	0.691	0.786	0.858	0.331
T (transmittance)	0.030	0.168	0.120	0.075	0.382
R (reflectance)	0.068	0.141	0.094	0.067	0.287

The model derives optical-profile-weighted coefficients for:

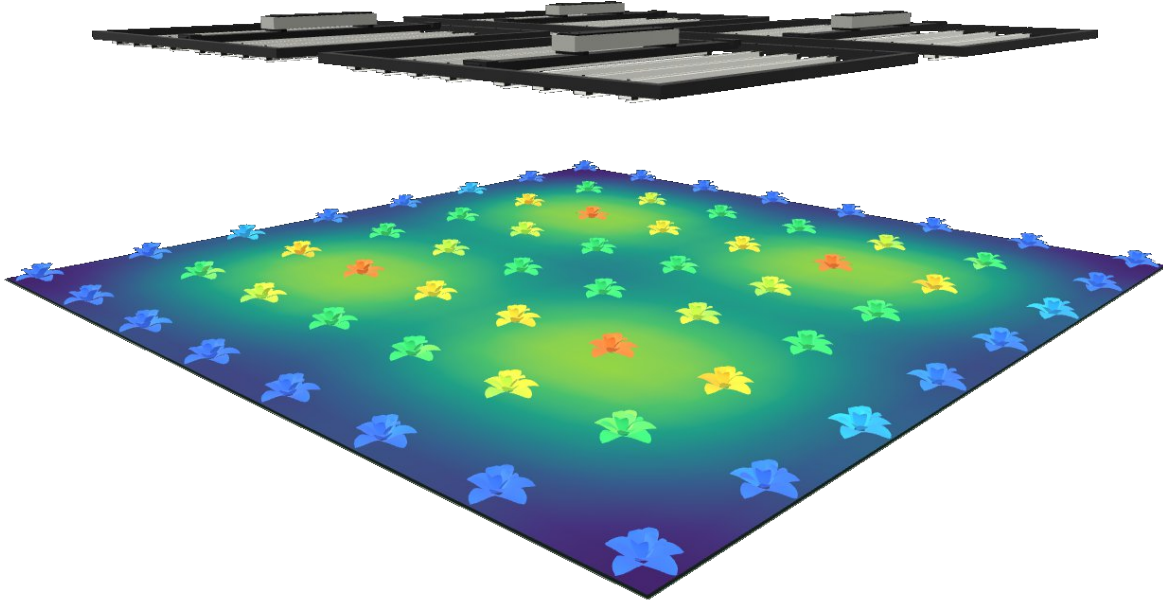
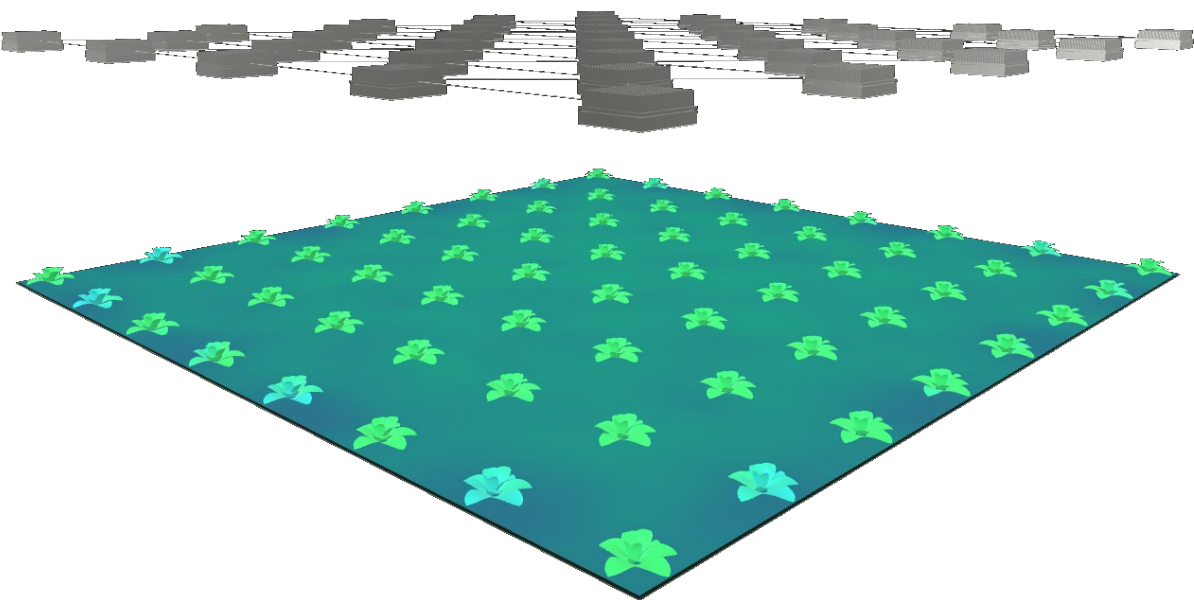
- absorbance
- transmittance
- reflectance

For each band, absorbance + transmittance + reflectance define the leaf optical profile used by the simulator.

Values shown use the shared workshop control SPD for within-band photon weighting.

10'x10' FSPM Receiver Simulation — Modularized vs Conventional LED Lighting System

Target PPFD range: 225-275 $\mu\text{mol} \cdot \text{m}^2 \cdot \text{s}^{-1}$ • 768 leaves • 24,576 receiver samples • Lettuce rosette model

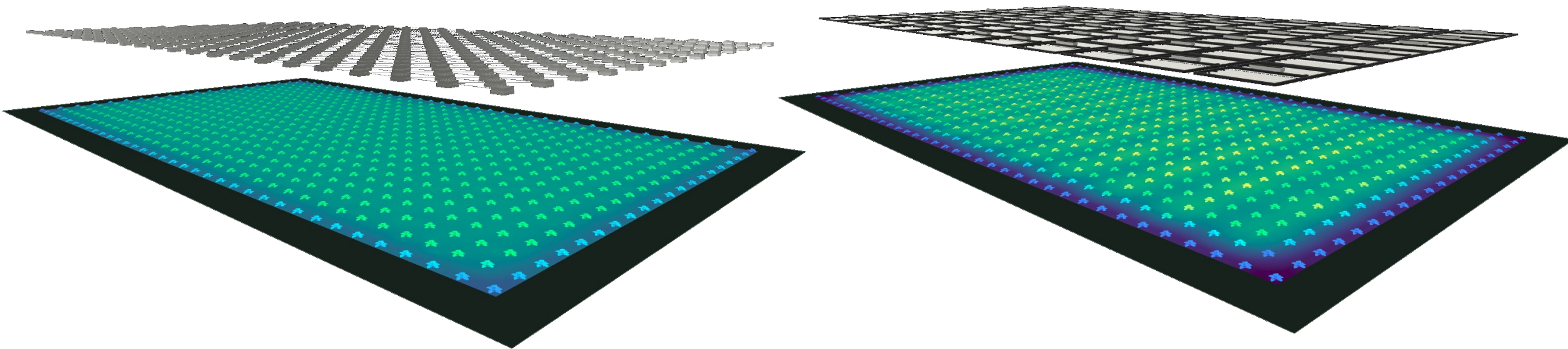


Modularized LED System	
82.2% Target-range leaves	137 / 0 Underlit / Overlit leaves
110.275 PAR combined absorbed exposure ($\mu\text{mol} \cdot \text{m}^2 \cdot \text{s}^{-1}$)	6.080% Plant-to-plant absorbed exposure CV
141.442 PAR combined incident exposure ($\mu\text{mol} \cdot \text{m}^2 \cdot \text{s}^{-1}$)	0.857 Plant minimum / mean absorbed exposure

Conventional LED System	
21.1% Target-range leaves	336 / 270 Underlit / Overlit leaves
102.598 PAR combined absorbed exposure ($\mu\text{mol} \cdot \text{m}^2 \cdot \text{s}^{-1}$)	36.298% Plant-to-plant absorbed exposure CV
131.581 PAR combined incident exposure ($\mu\text{mol} \cdot \text{m}^2 \cdot \text{s}^{-1}$)	0.369 Plant minimum / mean absorbed exposure

30'x50' FSPM Receiver Simulation — Modularized vs Conventional LED Lighting System

Target PPFD range: 225-275 $\mu\text{mol} \cdot \text{m}^2 \cdot \text{s}^{-1}$ • 8,640 leaves • 276,480 receiver samples • Lettuce rosette model

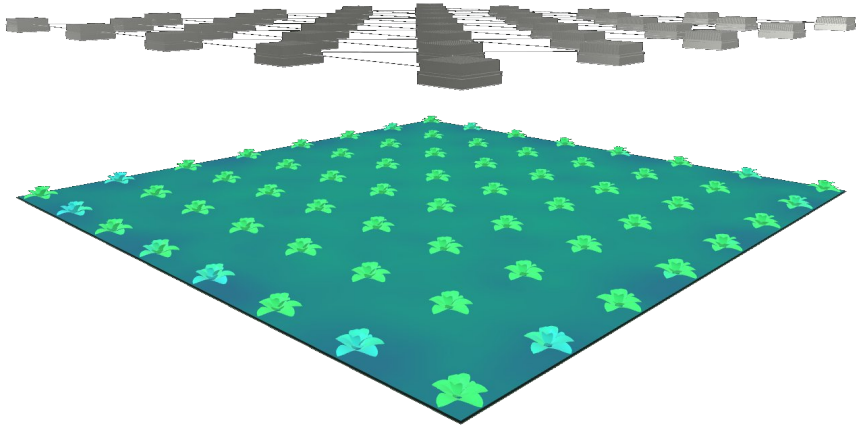


Modularized LED System	
82.1% Target-range leaves	1,350 / 195 Underlit / Overlit leaves
107.631 PAR combined absorbed exposure ($\mu\text{mol} \cdot \text{m}^2 \cdot \text{s}^{-1}$)	13.971% Plant-to-plant absorbed exposure CV
138.065 PAR combined incident exposure ($\mu\text{mol} \cdot \text{m}^2 \cdot \text{s}^{-1}$)	0.537 Plant minimum / mean absorbed exposure

Conventional LED System	
25.7% Target-range leaves	2,482 / 3,935 Underlit / Overlit leaves
105.212 PAR combined absorbed exposure ($\mu\text{mol} \cdot \text{m}^2 \cdot \text{s}^{-1}$)	32.126% Plant-to-plant absorbed exposure CV
134.917 PAR combined incident exposure ($\mu\text{mol} \cdot \text{m}^2 \cdot \text{s}^{-1}$)	0.115 Plant minimum / mean absorbed exposure

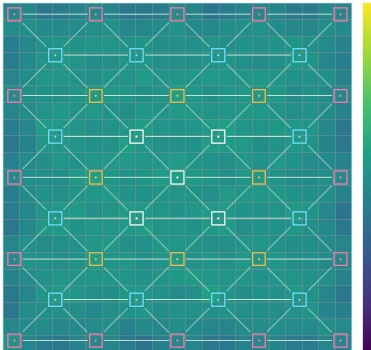
Key Takeaways and Future Vision for the Horticulture Lighting Simulator

Using Radiance as the light transport engine for a new and useful FSPM tool



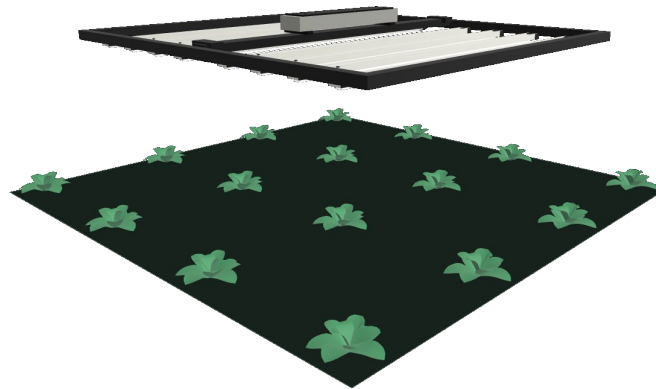
- 1 FSPMs depend on the light inputs you feed them.
- 2 Many FSPM tools use simplified or application-specific light transport modules, which makes Radiance an interesting foundation for more rigorous optical simulation.
- 3 Building an FSPM engine integrated with Radiance is worthwhile, especially for large and complex scenes.

Scalable uniformity strategy



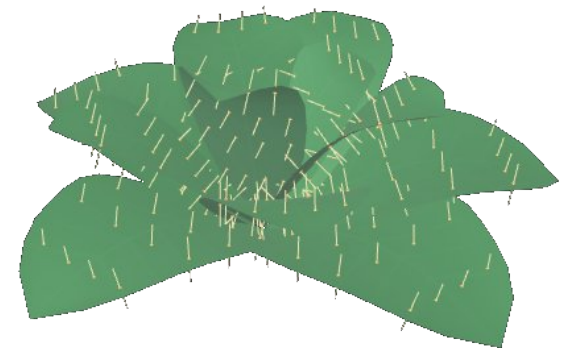
Centered square layouts flatten the PPFD field across any square or rectangular space.

3D visualization engine



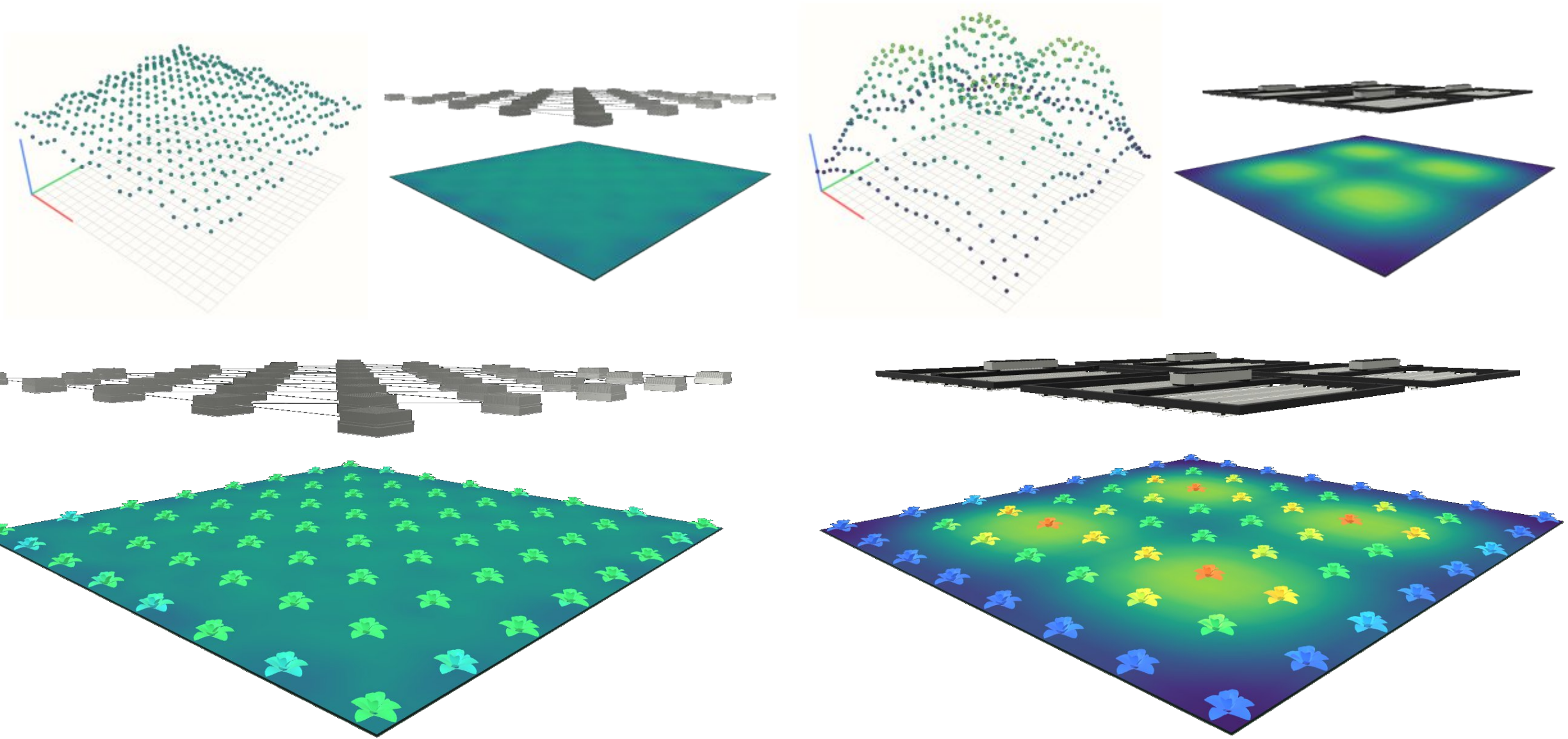
Intuitive 3D visuals make inspecting different layouts and understanding metrics easier.

FSPM receiver transport



Plant geometry becomes a receiver layer using Rex lettuce optical-profile-weighted leaf materials and five-band multispectral transport.

Thank you for listening!



The floor is now open for questions.