Building and Validating a BSDF of a Looped Metal Mesh

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Loisos + Ubbelohde, Alameda CA

L+U Contributors

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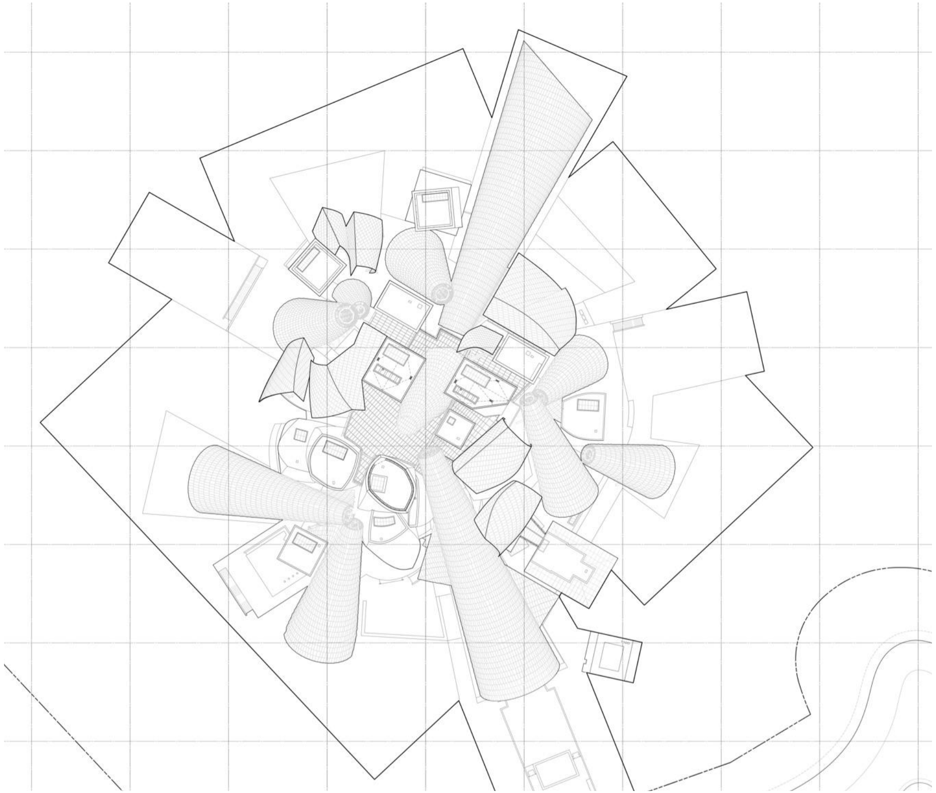
The Project



Art museum in the UAE

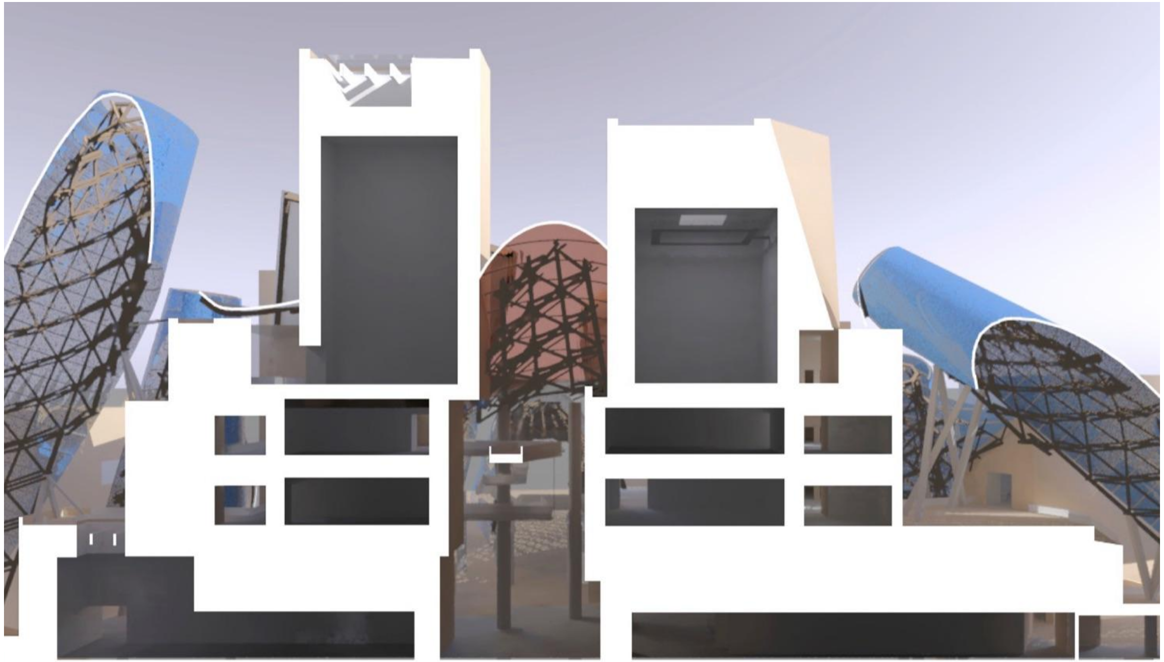
L+U had worked on the project 2010-2014, work resumed 2019-2021

The project features toplit and sidelit galleries, a 4-storey glazed atrium, and extensive exterior program including:

- entry causeway
- sculpture terraces
- circulation
- cafes
- performance spaces

significant portions of which are located under large conical shading structures ("cones")

The Project: Previous work



Section through atrium, cones, and galleries from daylight studies done in 2010. At that time the cones were glass with blue ceramic frit.

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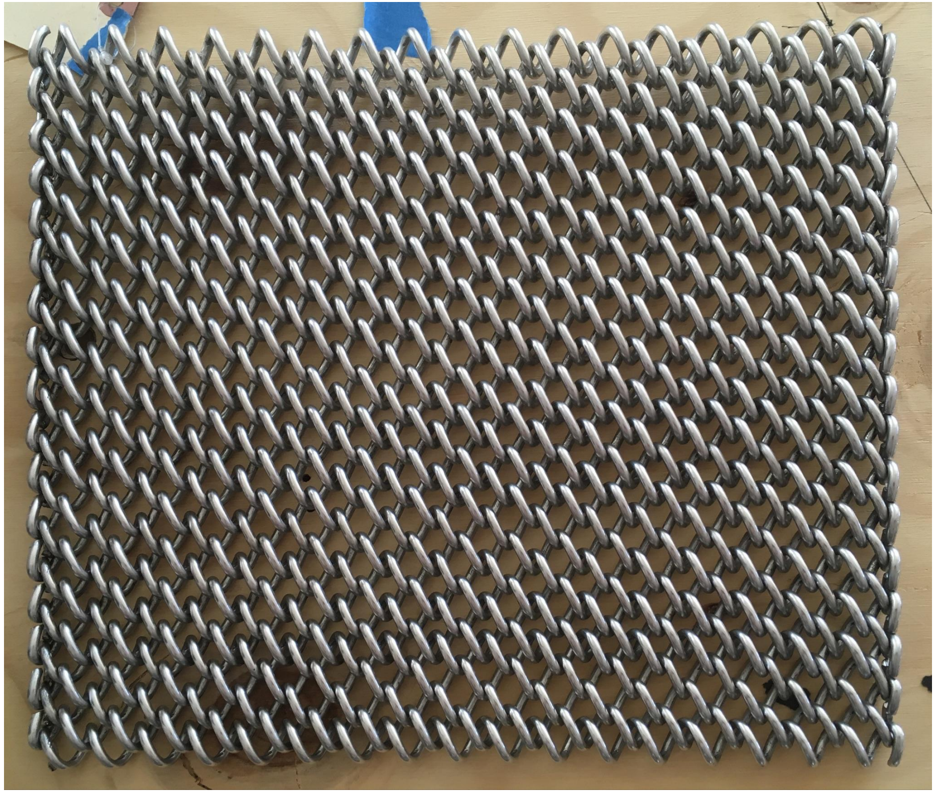
The Problem : A material change to the cones

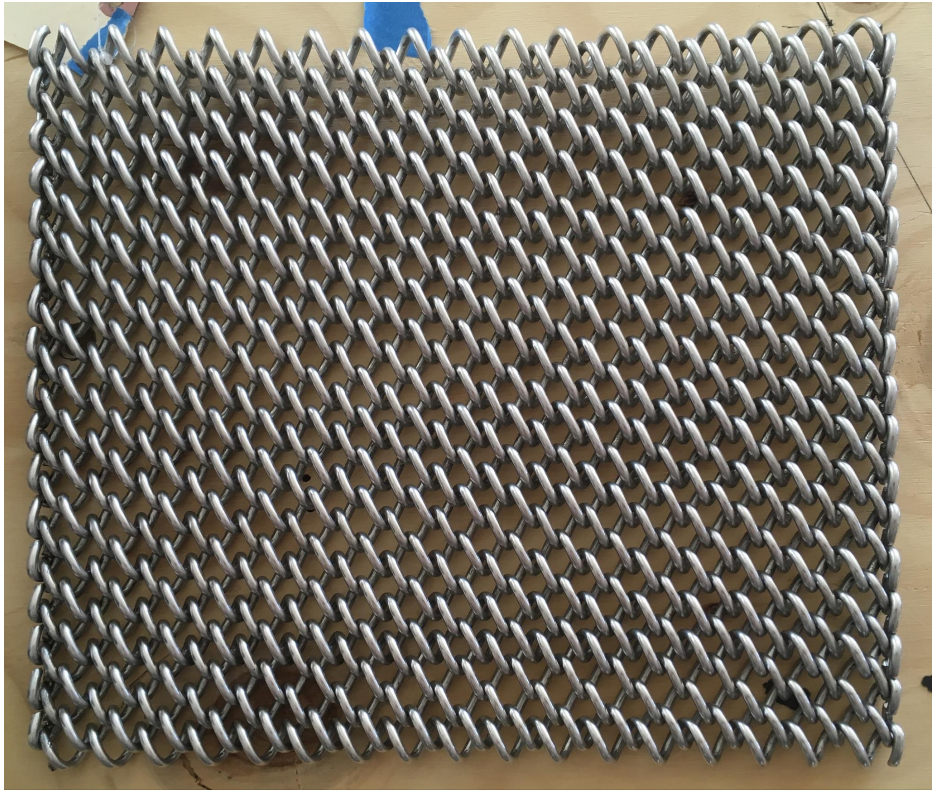


9 gauge specular aluminum looped metal mesh

Also called mini-mesh chain link

Typically used for fencing

The Problem : Daylighting considerations



The mesh will cover an enormous area (tens of thousands of square feet)

The mesh is reflective and transmissive.

Mesh reflection and transmission varies with orientation in 3-dimensions (anisotropic)

The mesh is specularly reflective and may pose a hazard for visual comfort and for light levels within daylit museum galleries.

The Problem : Old tricks no longer apply

www.358meshfence.com

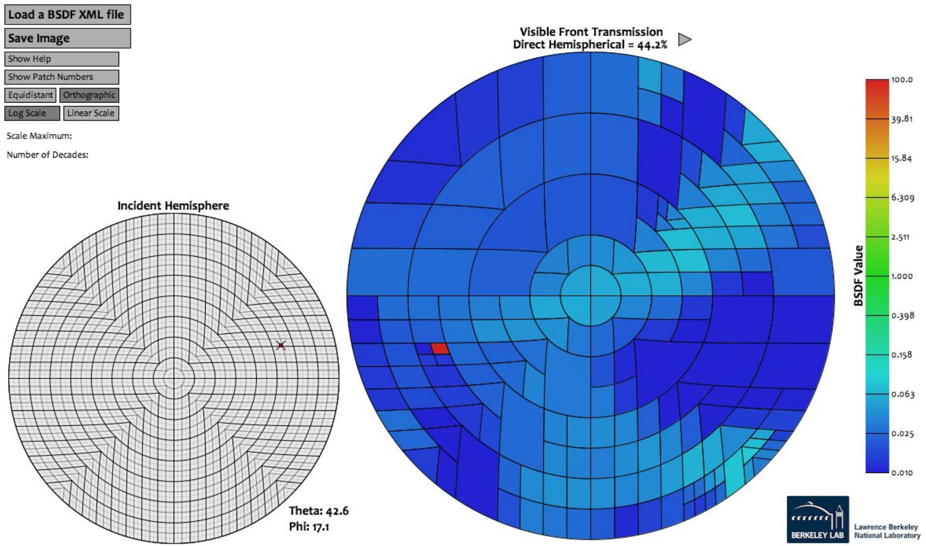
We have used chain link before.

Functionally defined materials (via .cal files), very open, and with little impact to scene.

When in doubt, instantiate the actual geometry.

This is different.

The Simulation Solution : Use a variable resolution BSDF



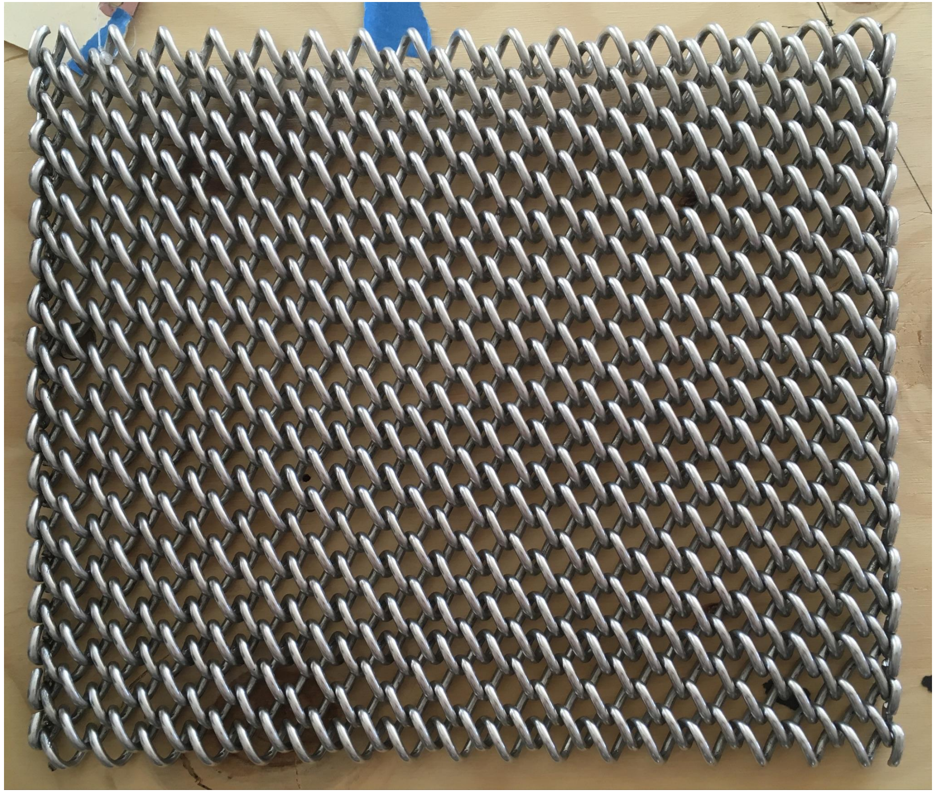
The grain of this material is so fine that it will almost always be perceived as a continuous surface

BSDFs represent both angular transmission and angular reflection

Tensor Tree BSDFs efficiently represent complex angular data including peaky transmission and reflection

TT-4 BSDFs are anisotropic, like our material

More Problems : Where do we get a BSDF?



The mesh is not designed as a daylighting product. It is made by fencing manufacturers.

The manufacturers would never make a BSDF of this product. (It won't show up in any glazing databases)

This product is not suitable for measurement on a goniophotometer.

Which means we've got to do it ourselves

The Rest of This Presentation

What are we trying to achieve?

Building and Validating the Mesh Material and Geometry

Physical Testing of the Mesh

Generation and Validation of the BSDF

Use of the BSDF in Daylight Simulations

Use of the BSDF in Electric Lighting Simulations

Use of the BSDF in Reflections Studies

Good Analytical Practice : What are we trying to achieve?

We need to understand the mesh as a daylighting product outside of simulation

We need to produce a robust, validated simulation material for the mesh to use in our radiance simulations

We need to understand the limitations of the simulation material

We need to communicate to the client how long this process could take and why it's crucial

We then can use the BSDF to answer specific questions in illumination, visual comfort, electrical lighting, and reflections studies

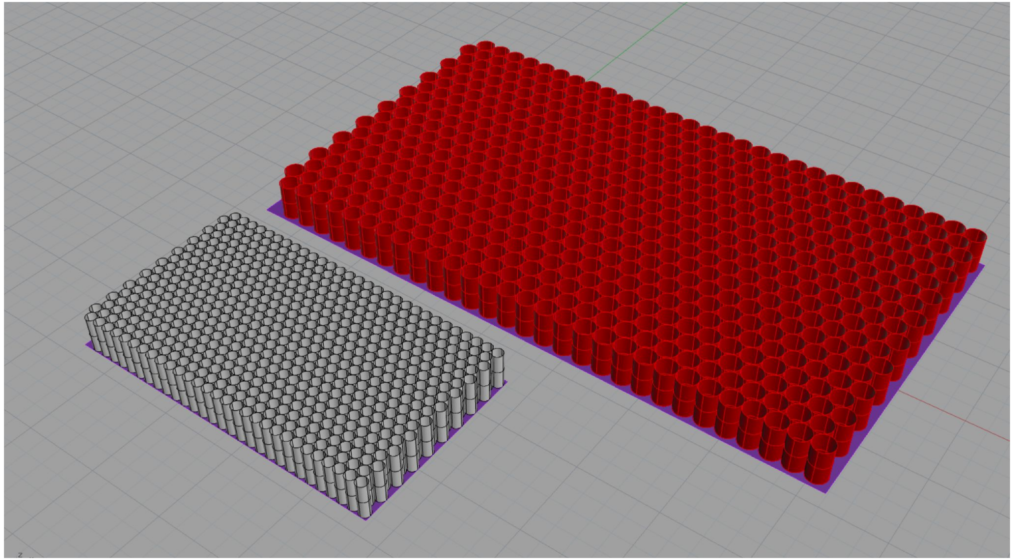
Good Practice Practice : Working Together

How do we eat this elephant?

We divided work for a couple reasons:

- Neither of us could work on this full time
- We could work on the material and building model simultaneously
- Radiance Checks and Balances
- Forces us to document processes for posterity (or the next project)
- Internal deadlines

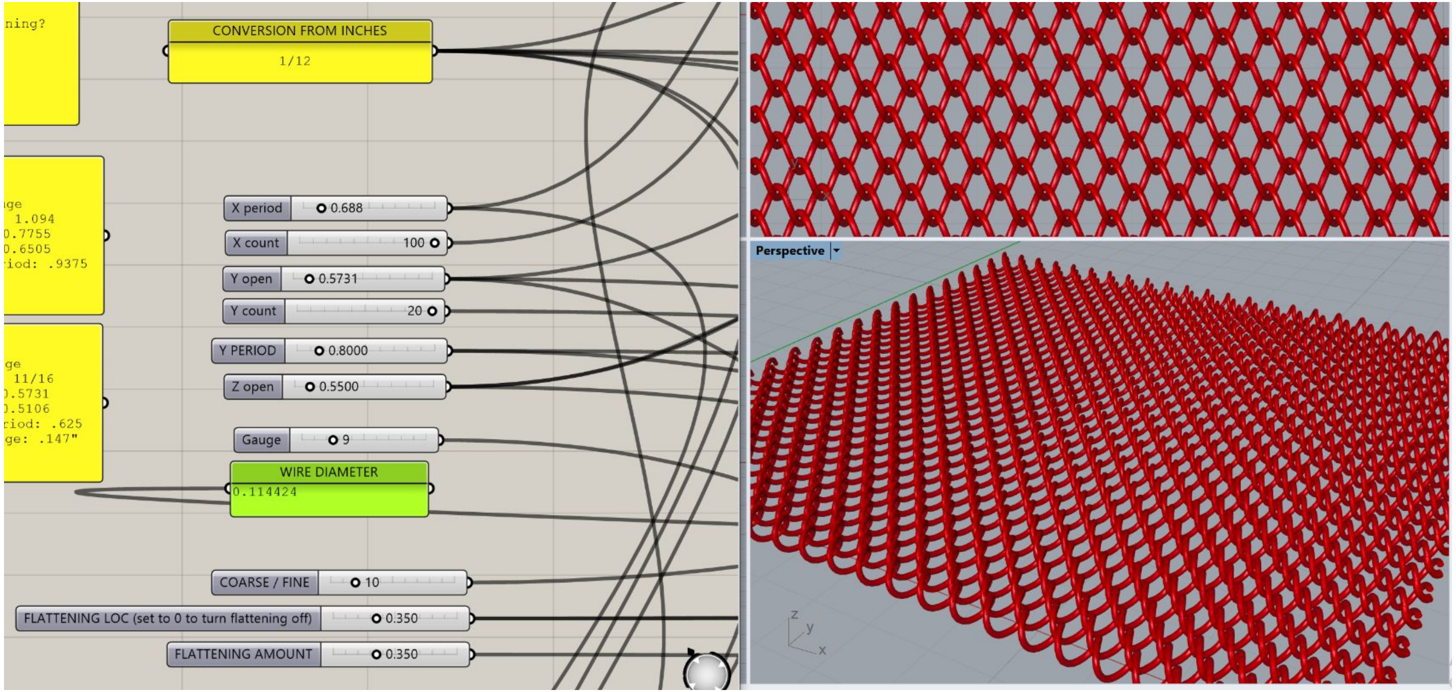
Standard path to generating a BSDF



Ordinarily, we make a one-off Rhino model of the geometry we will feed into genBSDF. (Shown here are two types of Panelite)

Can we get a high resolution scan? No.

Building the Geometry of the Mesh



This time, we knew we would need to validate and tweak the geometry so we wrote a grasshopper script to parametrically generate the mesh.

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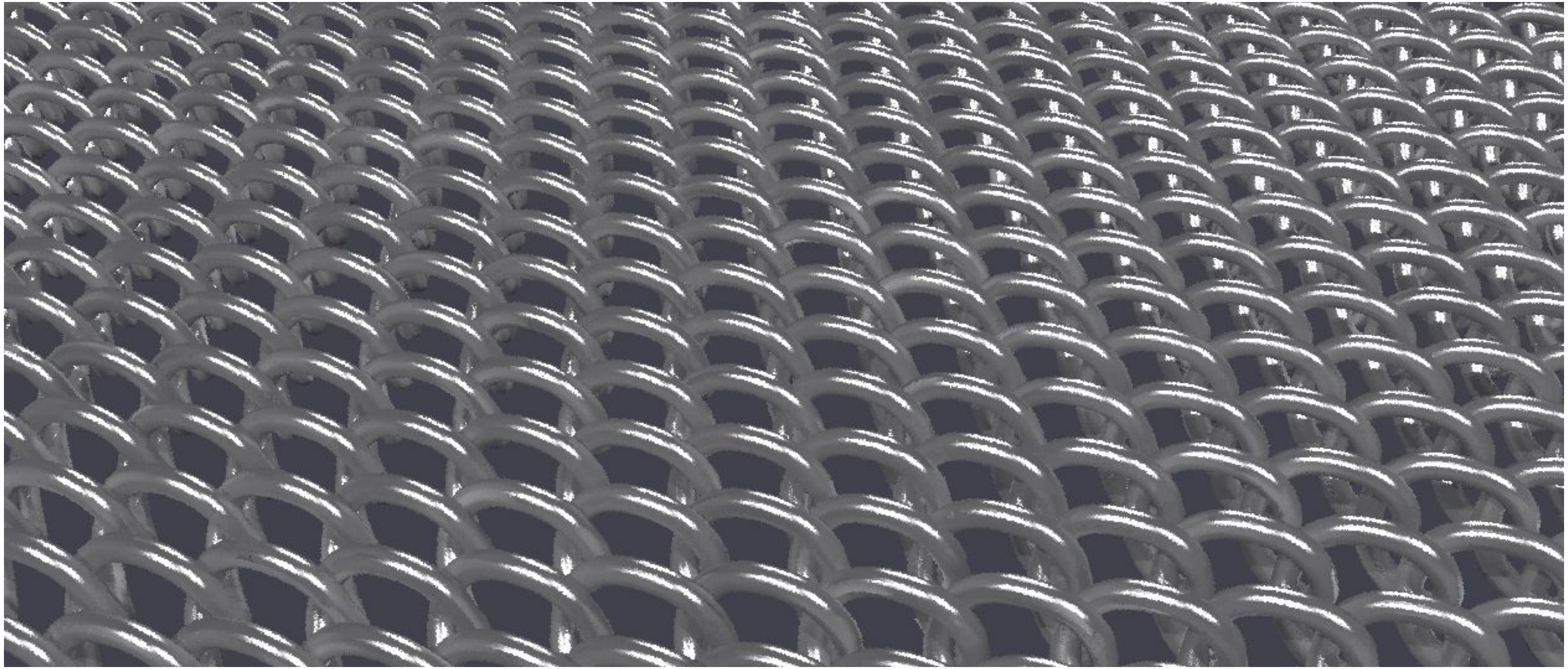
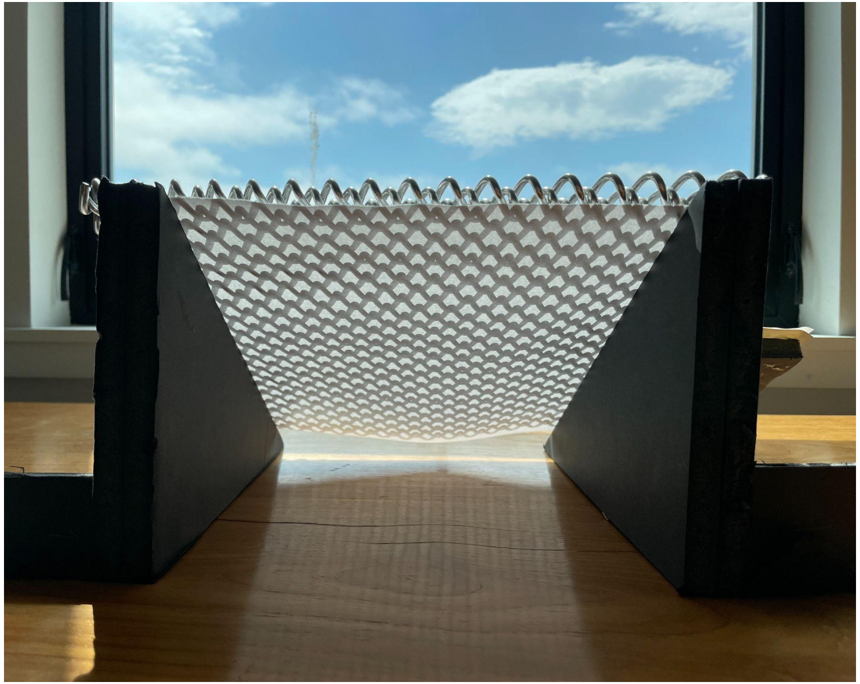
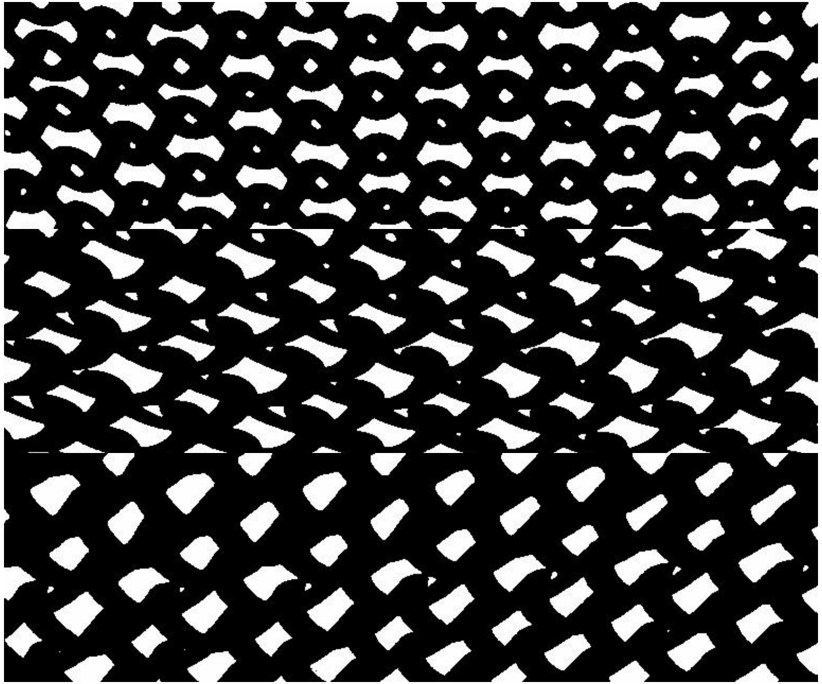
Building the Geometry of the Mesh



Simulation mesh previewed in objview

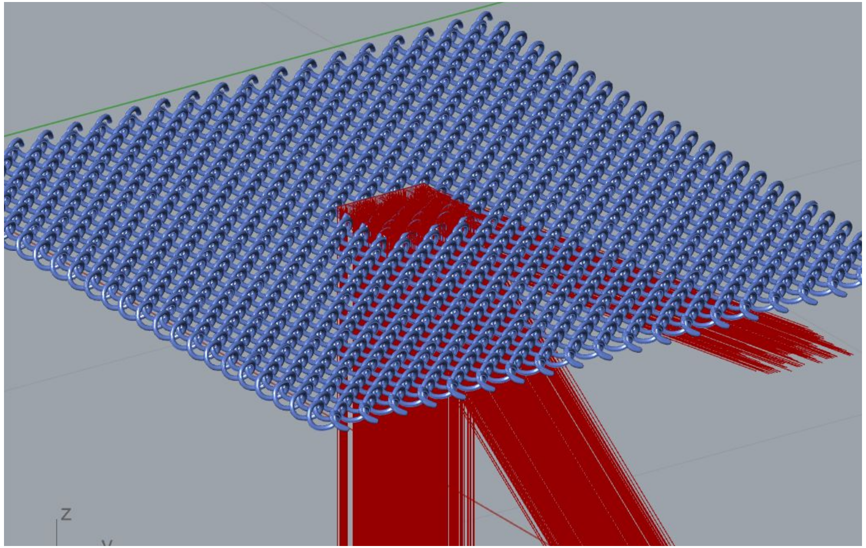
Validating the Geometry of the Mesh : Transmission

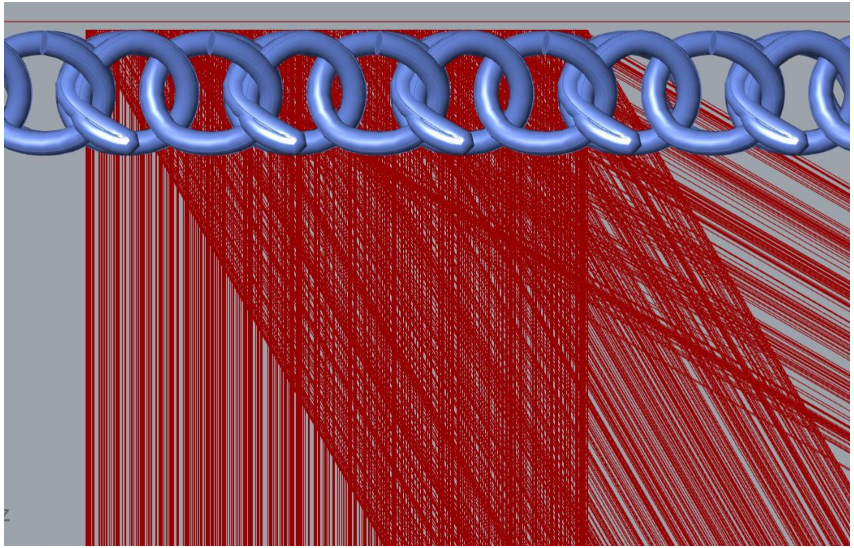




shadow projections used to calculate angular VLT of physical sample

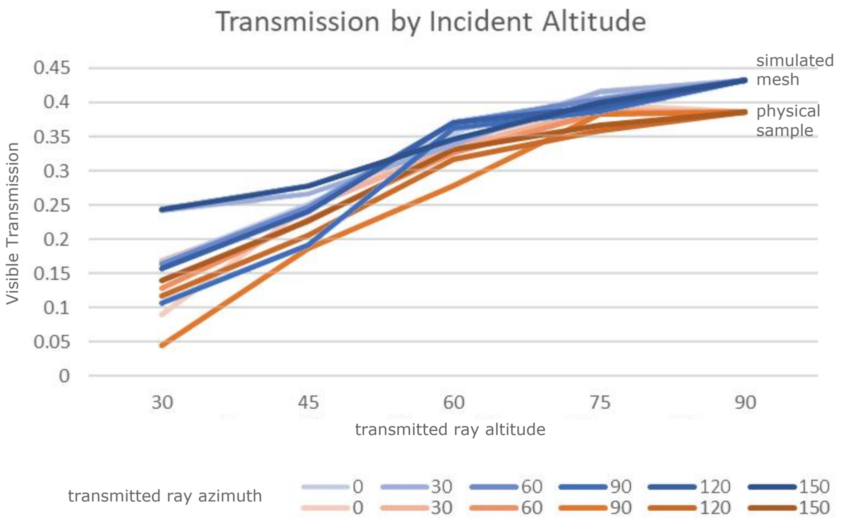
Validating the Geometry of the Mesh : Transmission

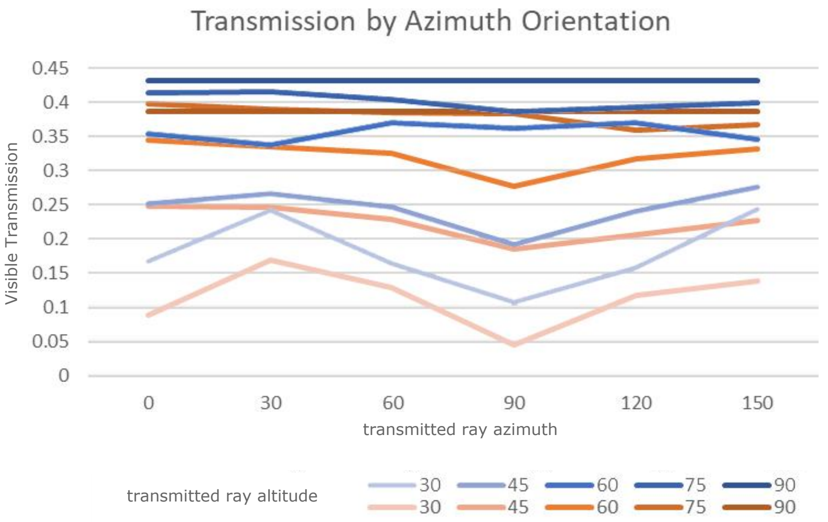




ray-intersect angular VLT in the grasshopper mesh tool

Validating the Geometry of the Mesh : Transmission





Comparisons between the angular VLT of the measured physical sample (in orange) and the simulated metal mesh (in blue) at 30 different altitude / azimuth angles.

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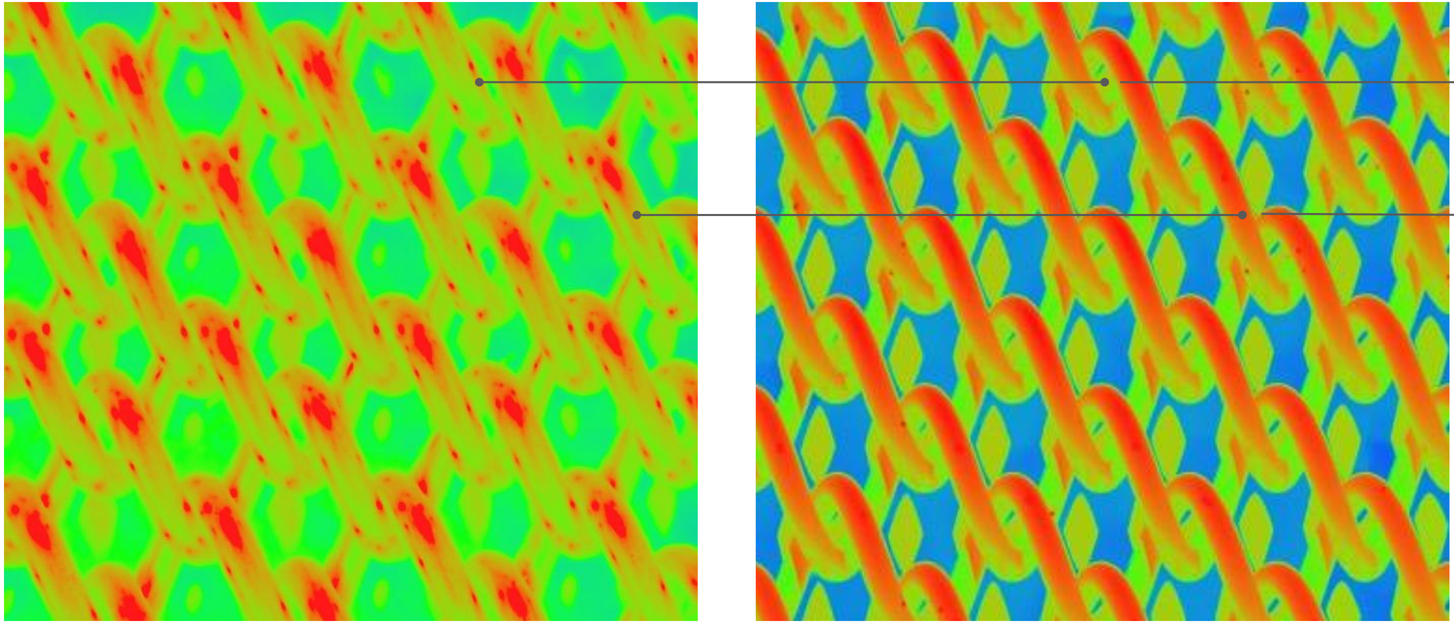
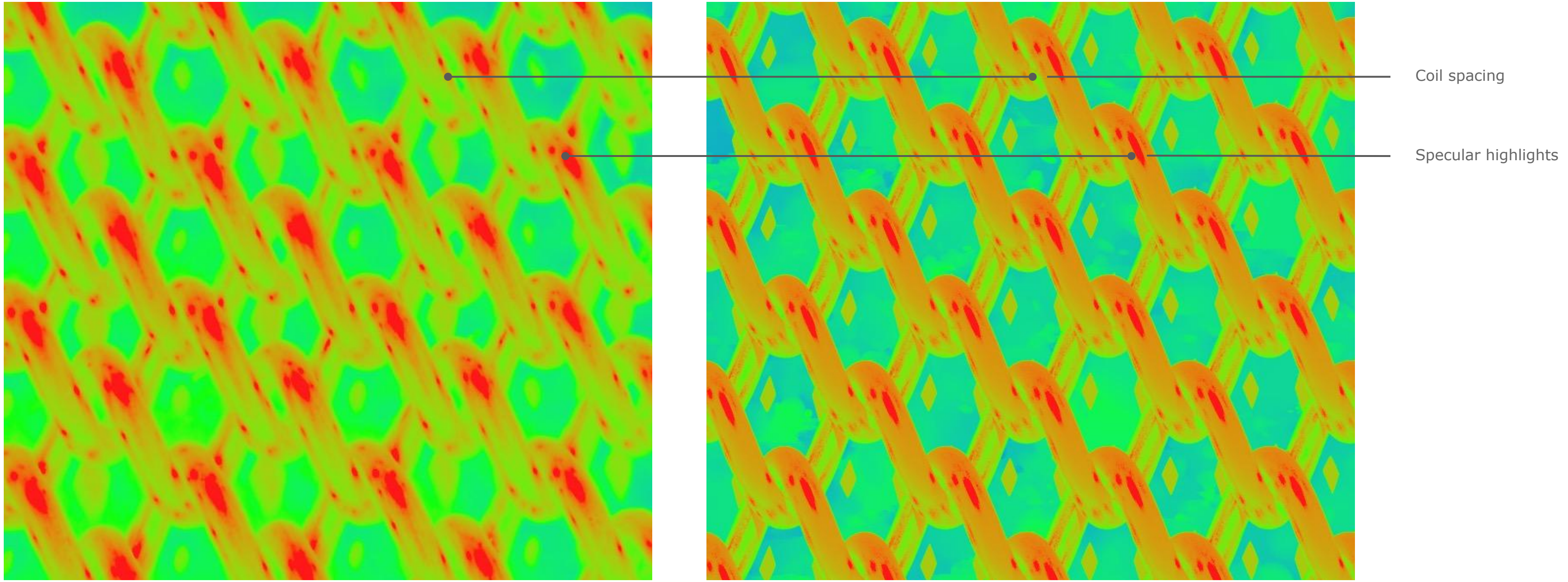
Validating the Geometry of the Mesh : Reflection



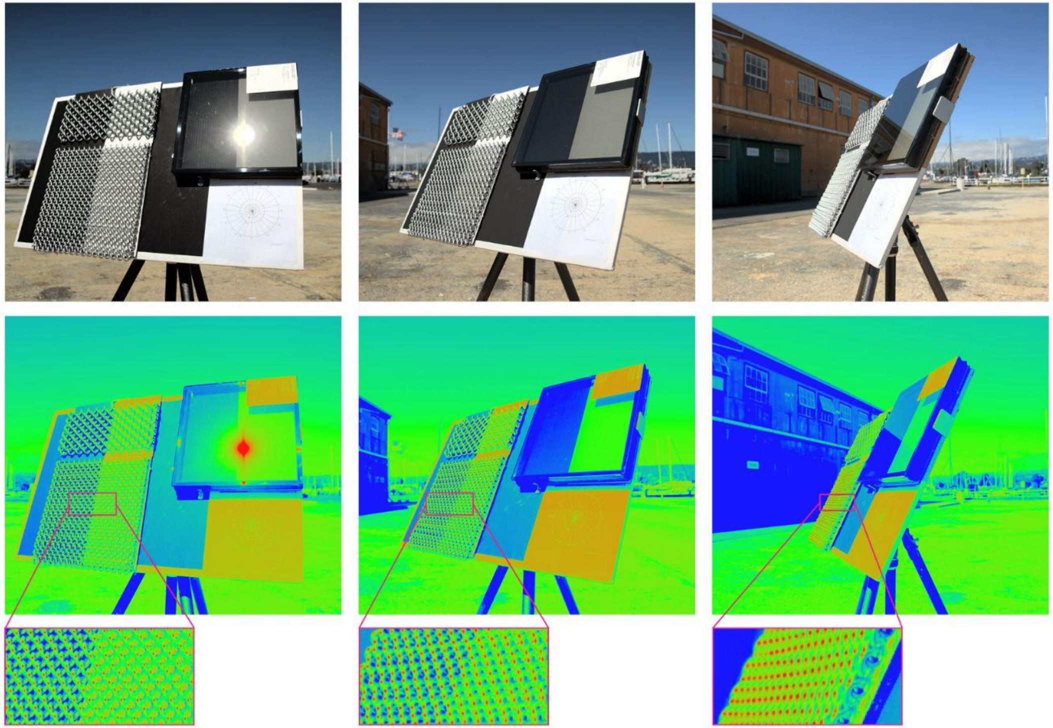
Comparisons between HDR photograph of the physical sample (left) and Radiance simulated mesh (right) under similar conditions

Validating the Geometry of the Mesh : Reflection



Comparisons between the physical sample (left) and simulated mesh (right) after adjustment to material and with flattening added to mesh geometry

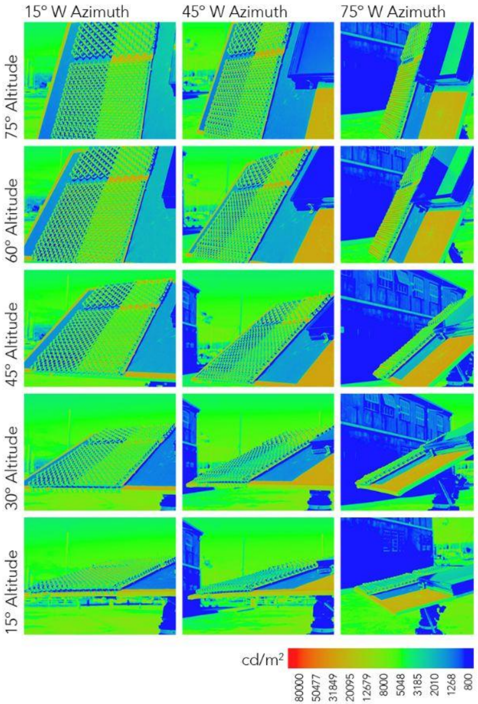
Physical Testing of Metal Mesh Samples



Specular reflections off of glass panels are intense, but angularly dependent and of limited duration. At the same sun and view angles, reflections from metal mesh are less extreme, but will remain for longer

Reflections from the metal mesh remain of similar intensity through most view angles.

At acute angles of view, reflections from the mesh compound. The brightest reflections from the mesh will be experienced at these angles and can occur both opposite the sun and with the sun behind the viewer (retroreflection)



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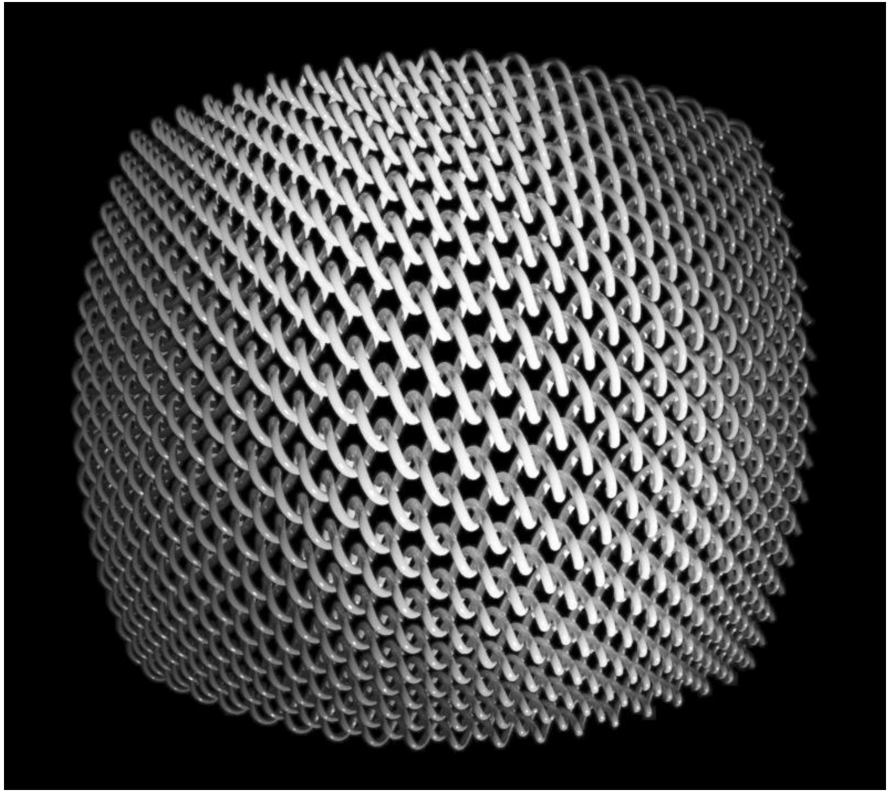
Brute Force Simulation Tactics



Initial Tensor Tree rank 4 BSDFs were generated at a resolution of 3 or 4.

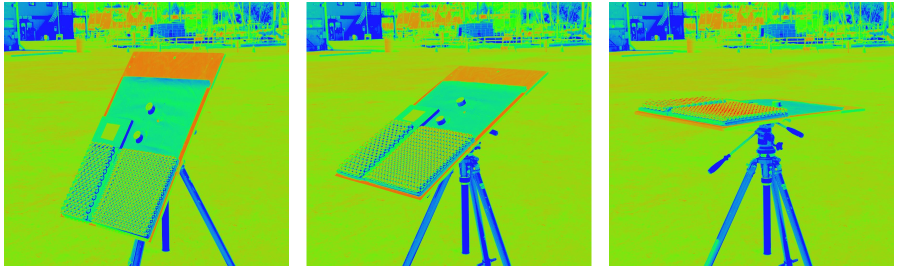
The final BSDF was generated at a resolution of 5 and took about 3 days to run (using genBSDF) on an i9 iMac.

The .rad file of the simulation geometry was meshed at such a high resolution that a 15x15" sample resulted in a 3GB file.

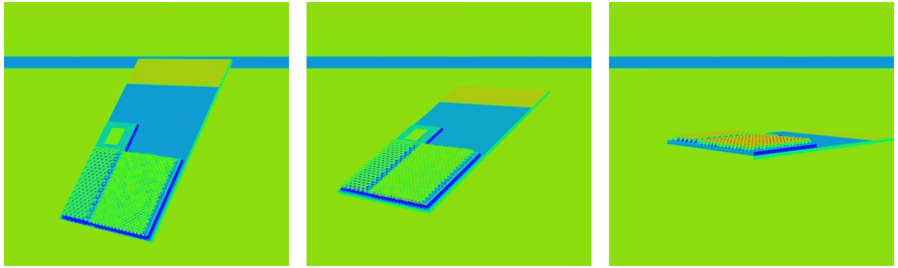
This was the only way to get adequate smoothness and resolution for peaks and reflections.

Further Validation of Simulated Mesh

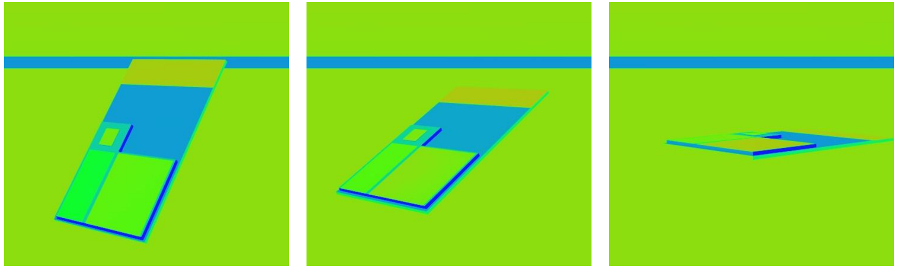
HDR of Physical Sample



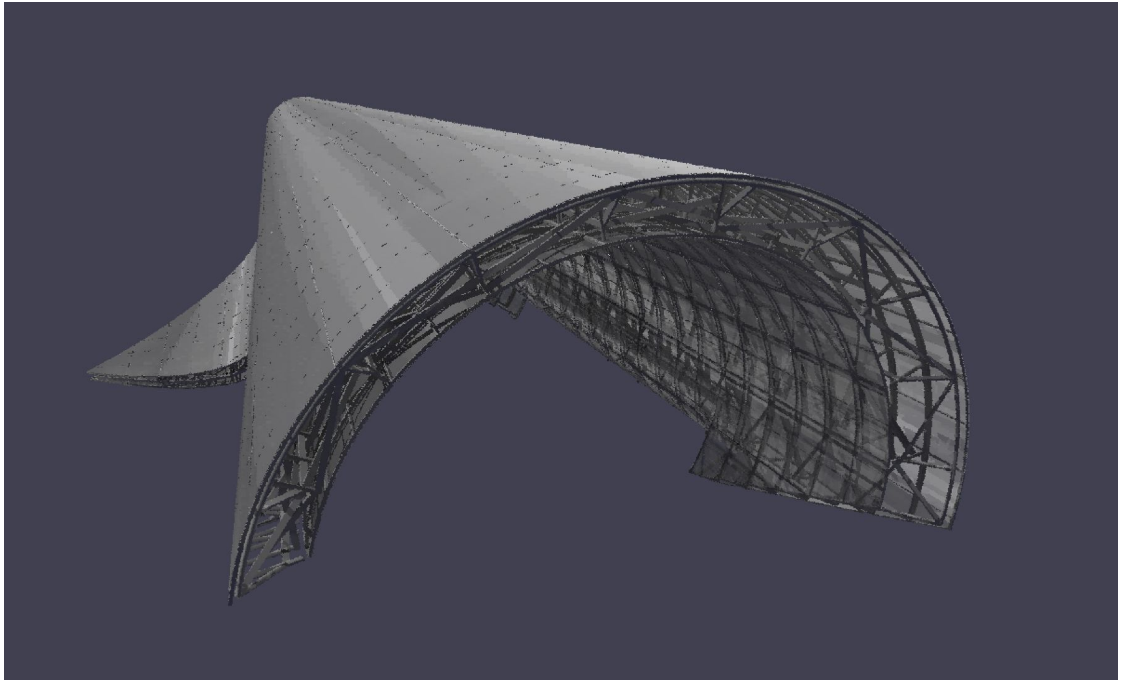
Simulated Ground Truth Geometry



Simulated BSDF



Applying the BSDF to Simulation Geometry



A cone with BSDF applied previewed in objview

The Cones are made of two layers of mesh with an extensive steel structure, including catwalks, in between.

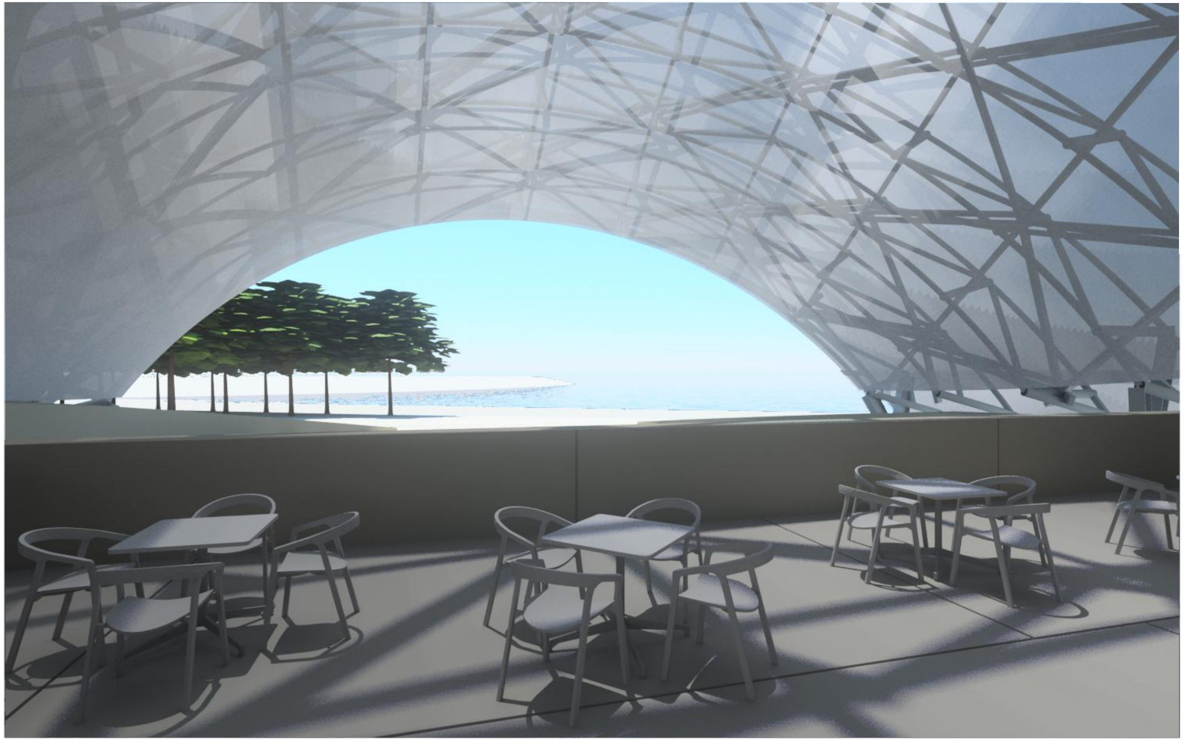
The gap between the two layers is about 3m.

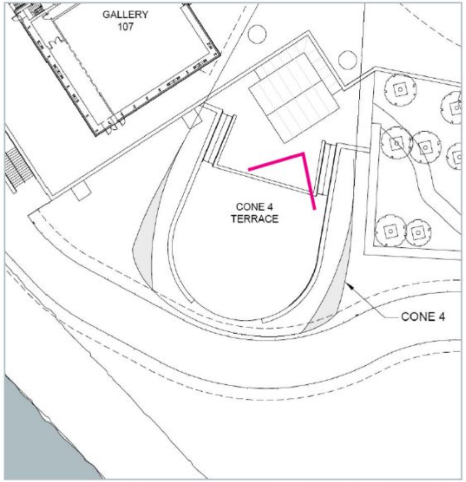
Next step: put the BSDF into a simulation to understand its limitations and capabilities

Start on the inside

Use of aBSDF in First Visual Comfort Simulations

Human Adaptation





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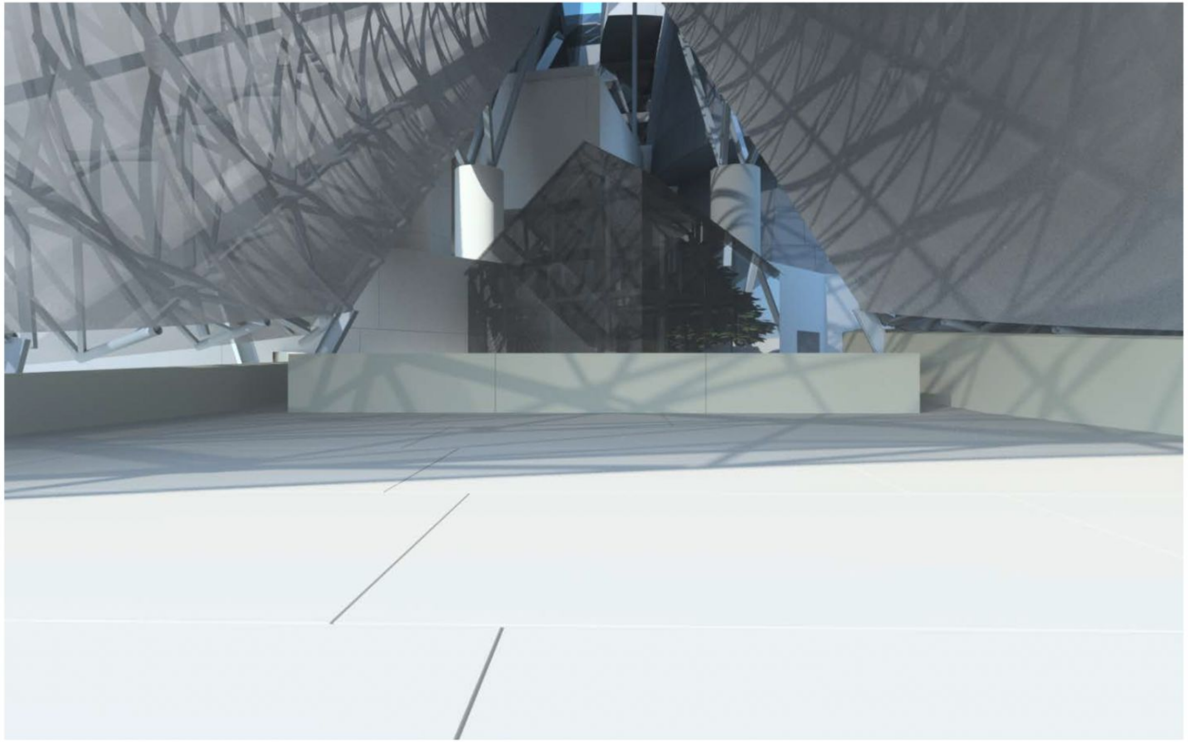
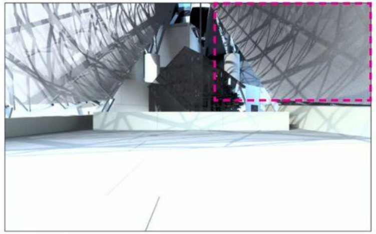
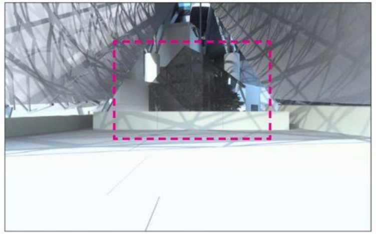
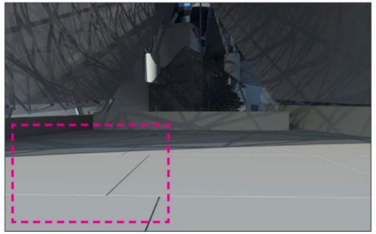
Use of BSDF in First Visual Comfort Simulations

Human Adaptation



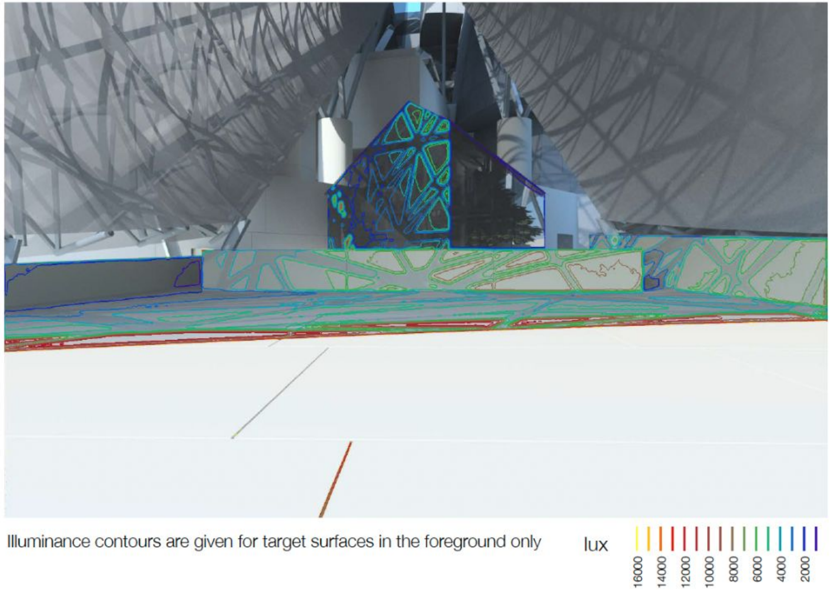






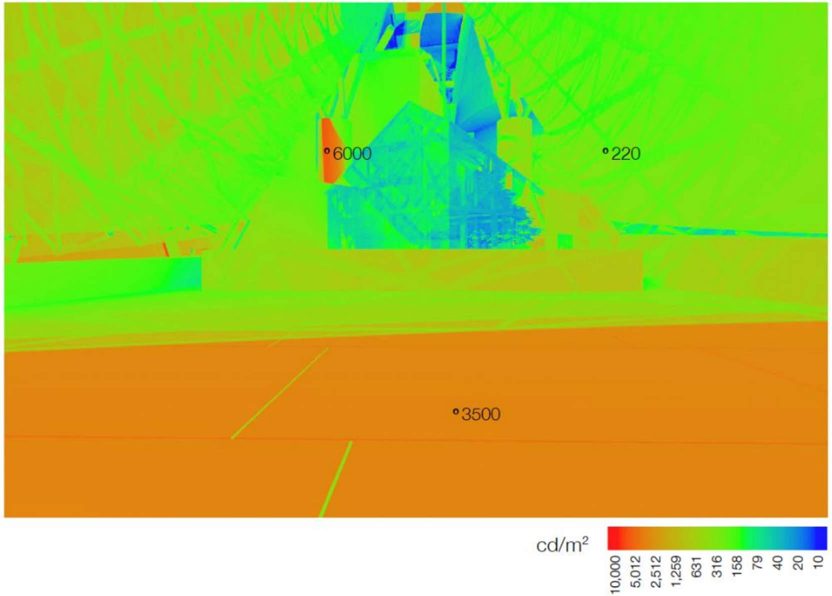
Use of BSDF in First Visual Comfort Simulations

Illuminance Contours



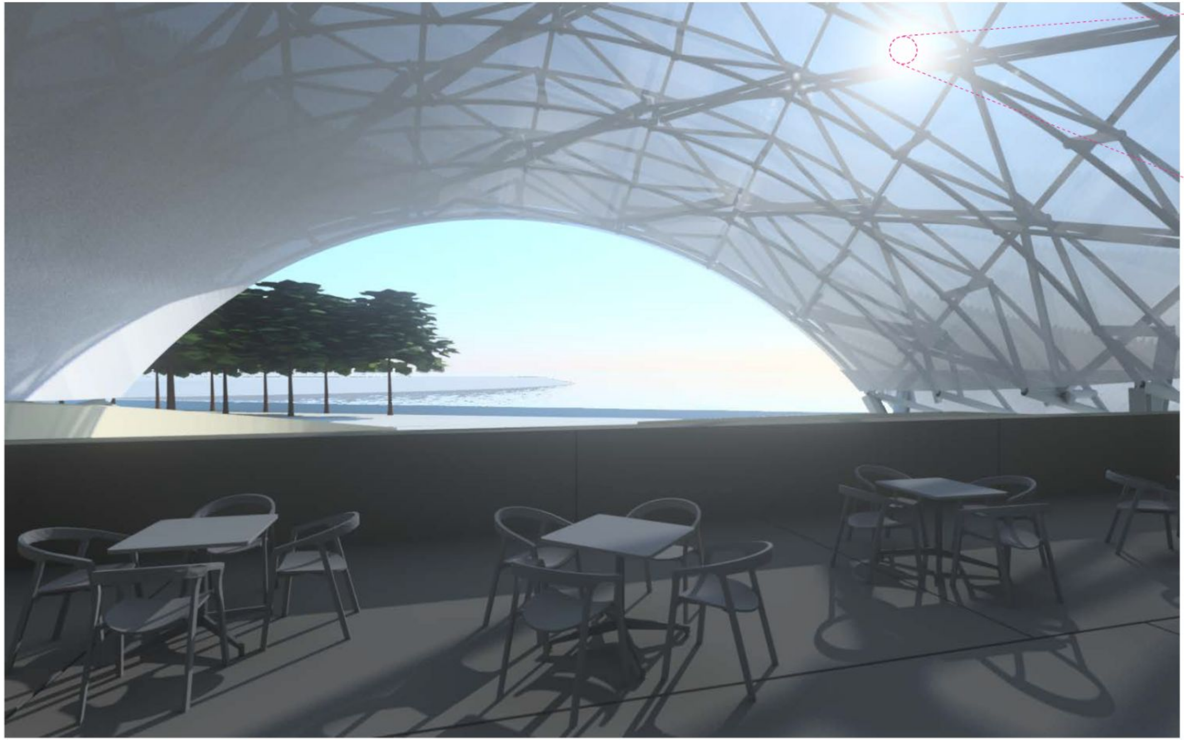
Illuminance contours are given for target surfaces in the foreground only

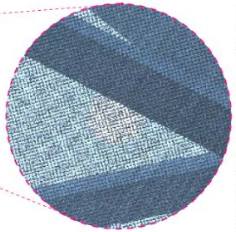
Falsecolor Luminance Map



Use of BSDF + Ground Truth Geometry

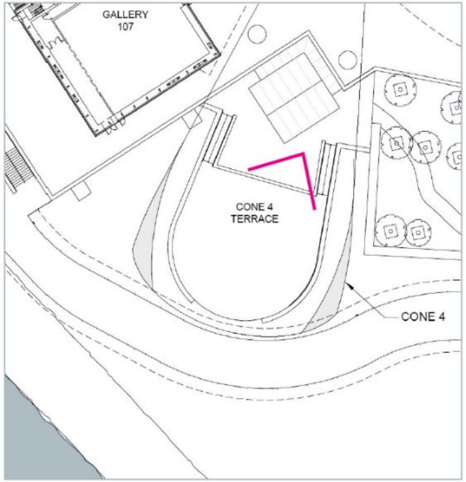
Human Adaptation



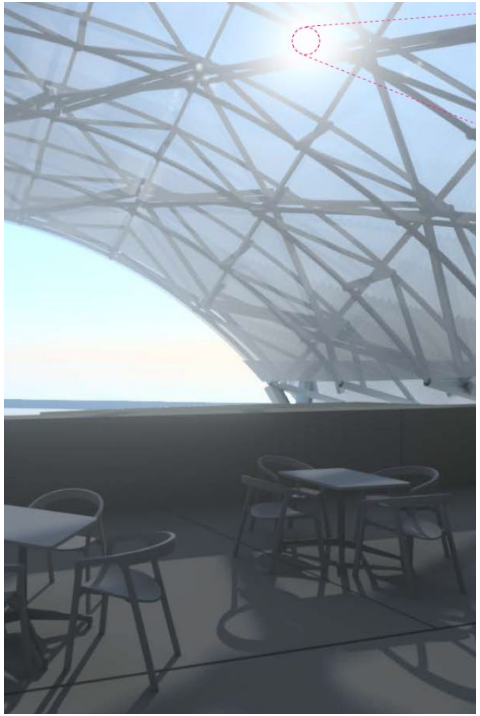


View through double layered Mesh, filtered without Human Adaptation processing so that the solar disc is visible.

A micro Moire pattern is present when zoomed in. Macro Moire patterns will only be able to be represented in physical mock-ups.



Simulation Details



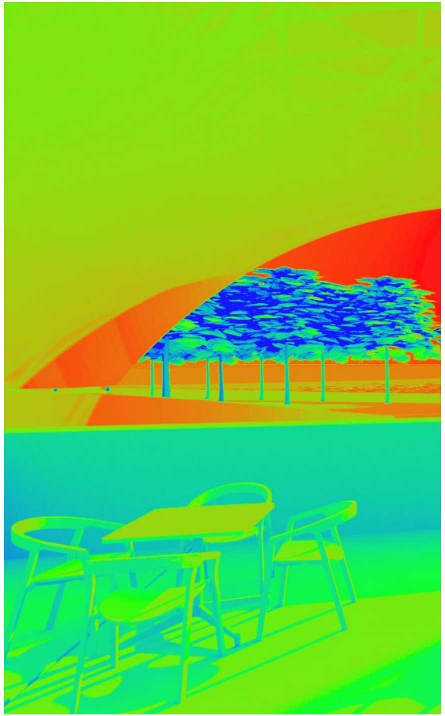
The BSDF is applied in Radiance as an aBSDF (aperture BSDF)

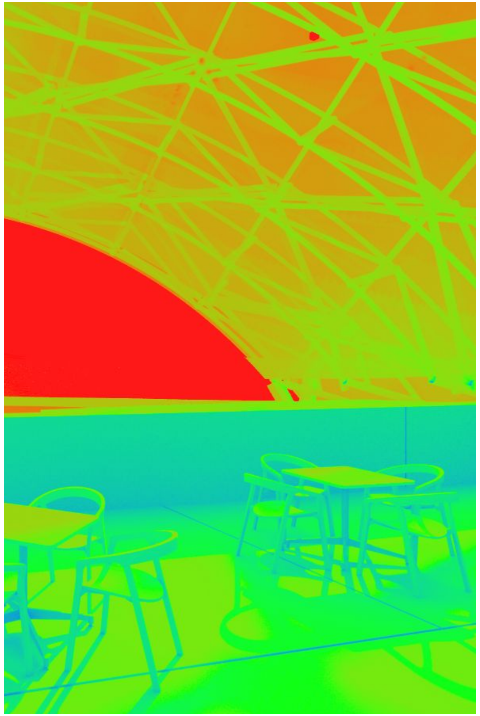
Both layers of mesh are modeled in this simulation

Simulations are done without an ambient cache due to complexity of simulation and size of bounding box

Care must be taken with BSDF alignment relative to mesh grain and cone orientation

Lessons Learned





Proxy geometry not needed due to scale of cone and distance from viewers.

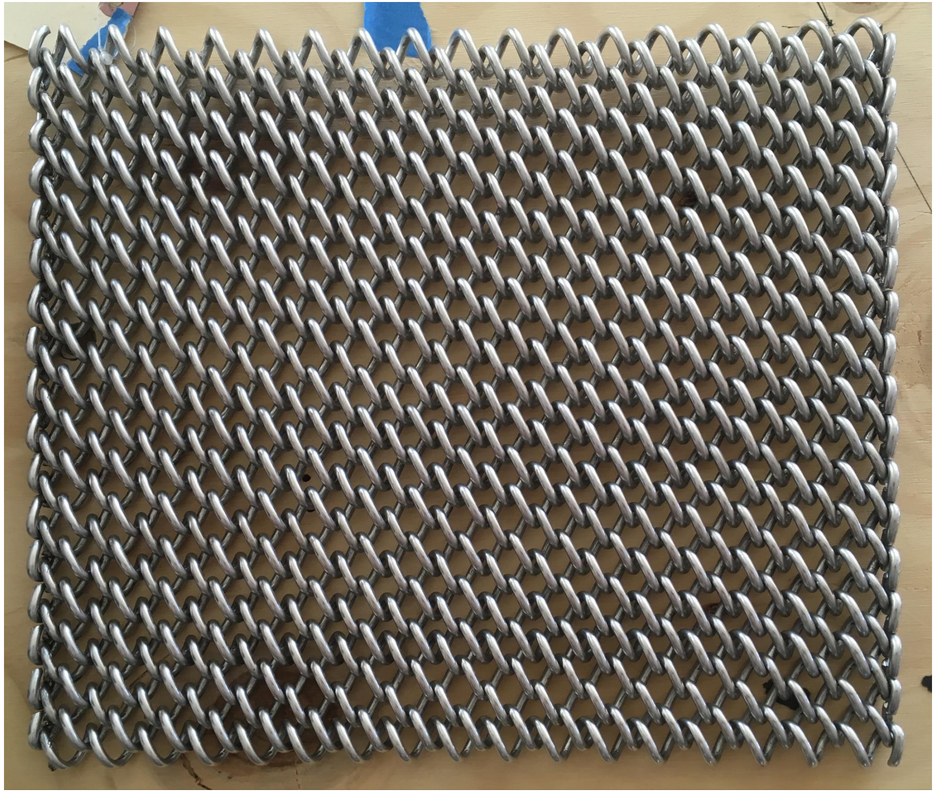
BSDF resolution + model meshing = gum wrapper effect

A controlled meshing of the NURBS geometry is needed

aBSDF noise was addressed with pixel oversampling

Direct transmission, shadow + penumbra look good but no way to validate, yet

Continued Development of BSDF

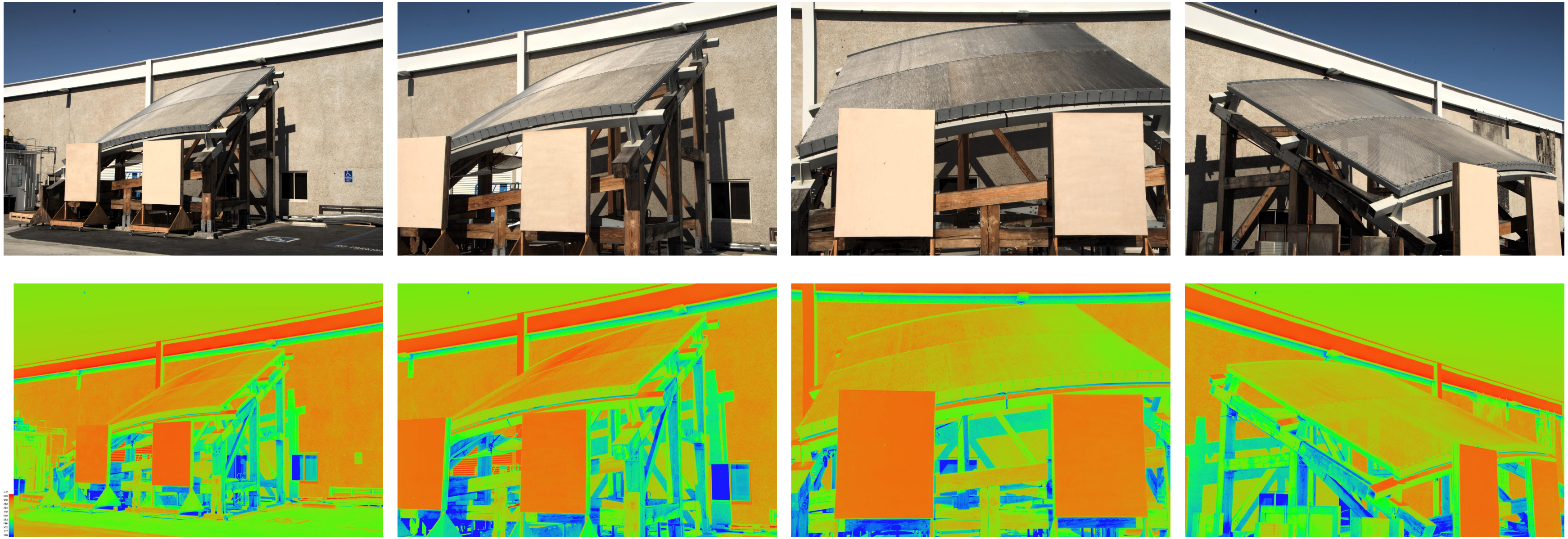


L+U had samples of a 9 gauge specular aluminum mesh and a 6 gauge galvanized steel mesh.

Architects ultimately ended up specifying a 9 gauge stainless steel mesh

L+U did not receive this mesh, but we were able to visit a mock-up with the mesh

Calibration of BSDF Using a Mock-Up



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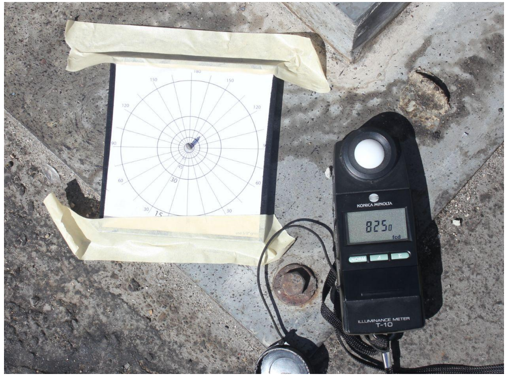
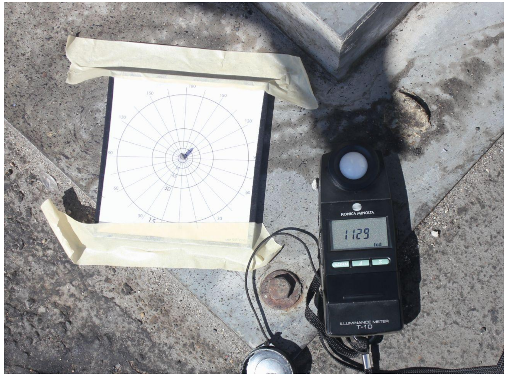
Measuring the Mock-Up





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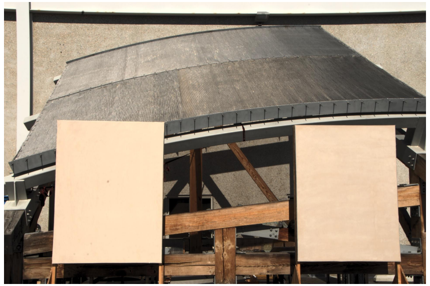
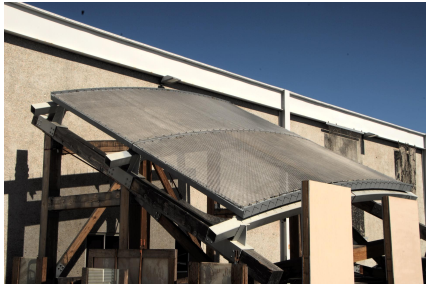
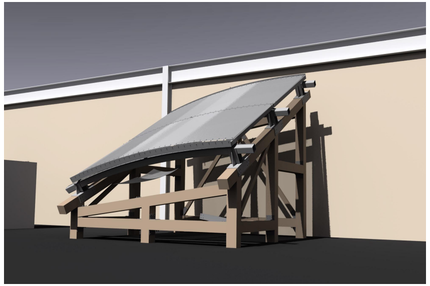
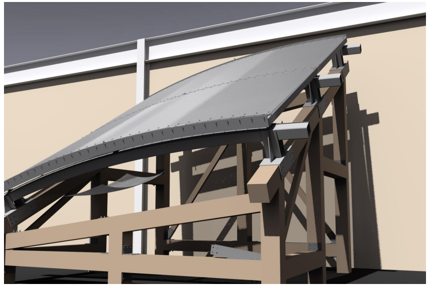
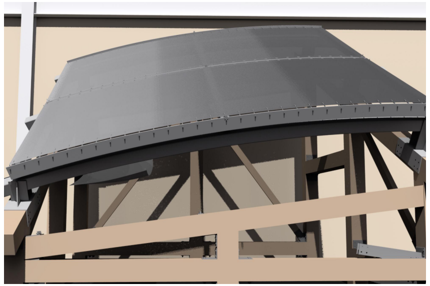
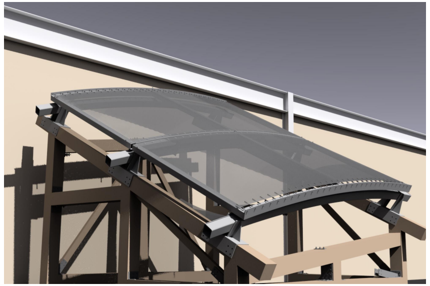
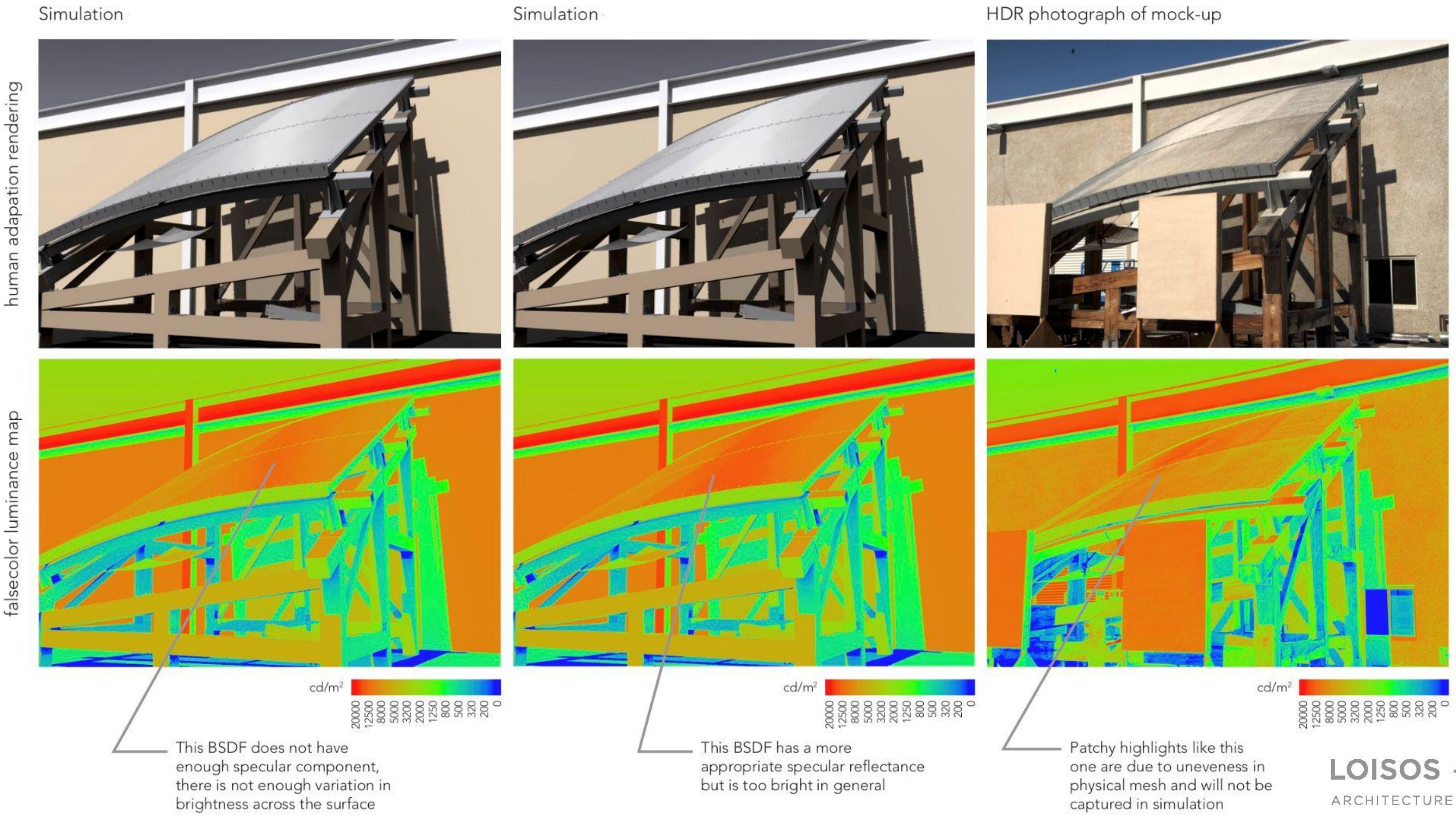
Modeling the Mock-Up



Validating the BSDF Relative to the Mock-Up



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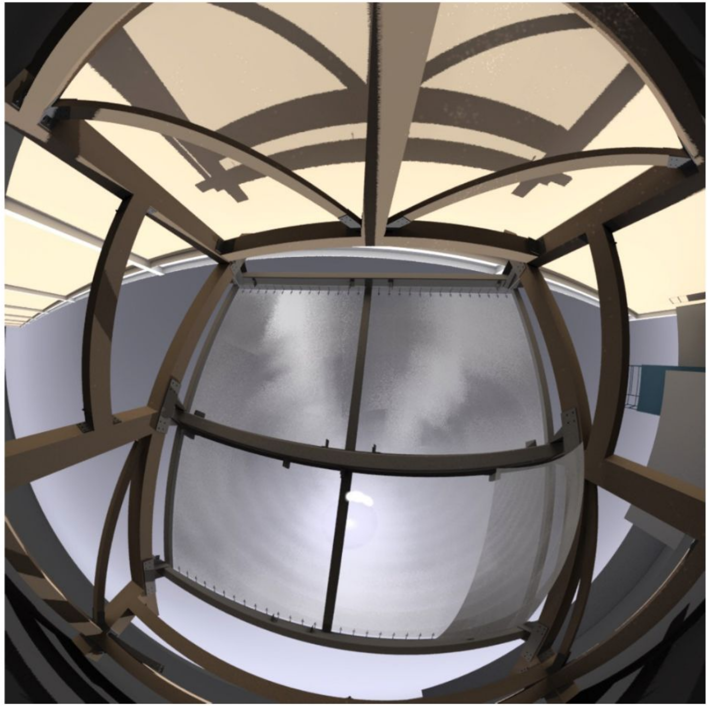
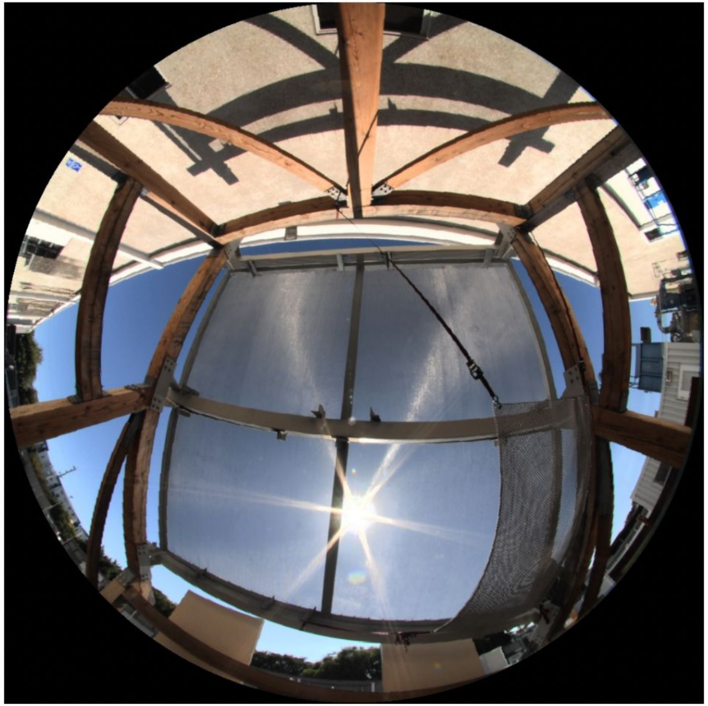
Validating the BSDF Relative to the Mock-Up

Simulation

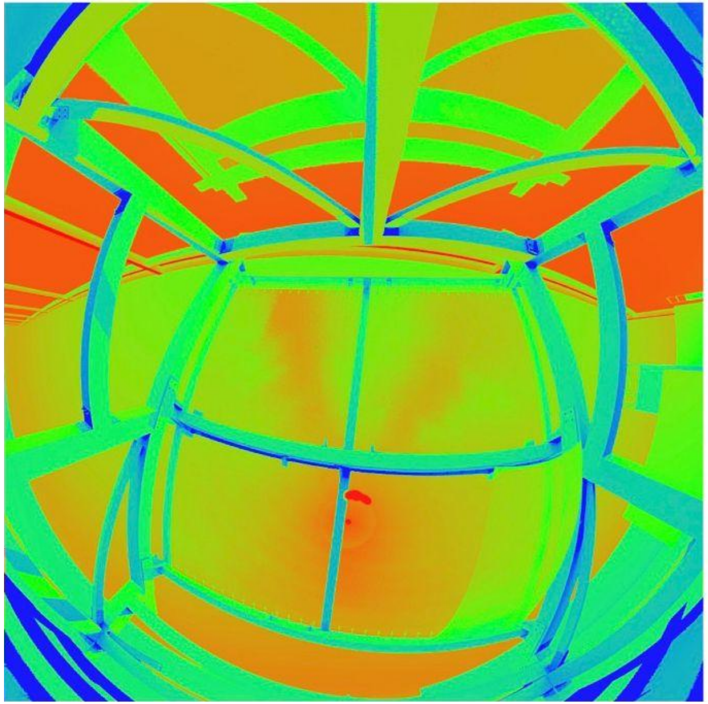


HDR photograph of mock-up

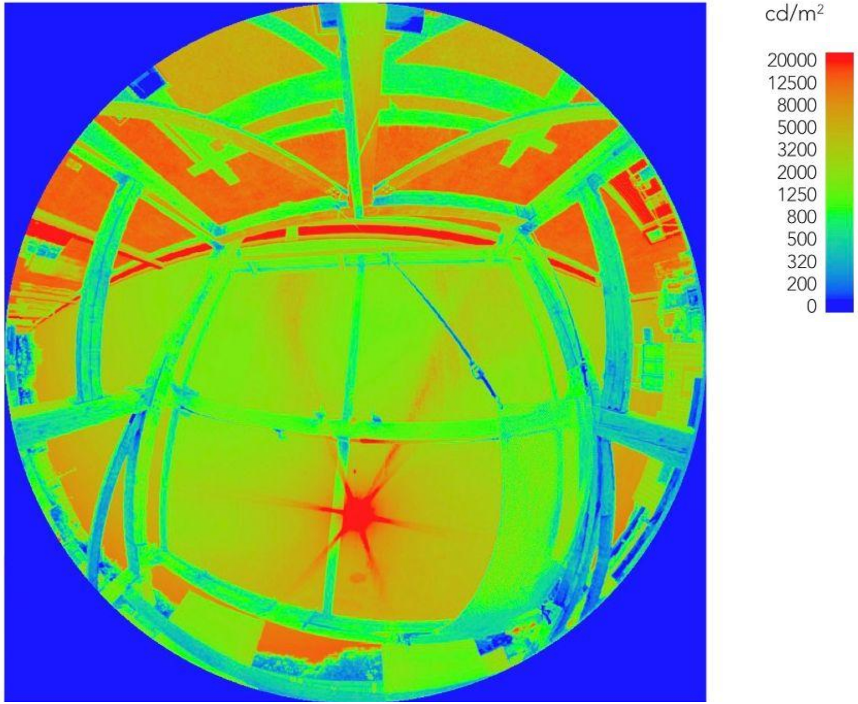


Validating the BSDF Relative to the Mock-Up

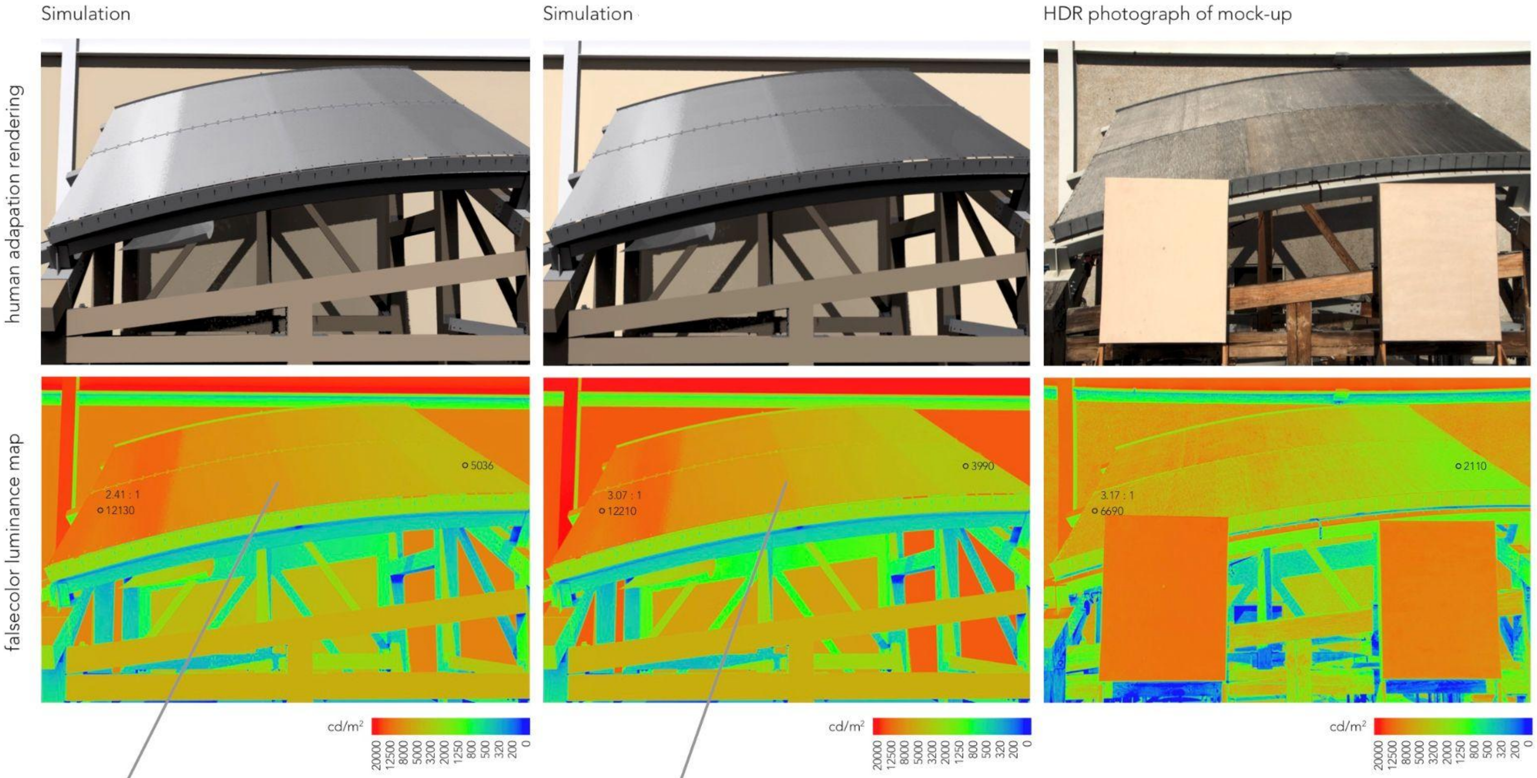
Simulation



HDR photograph of mock-up



Adjusting the BSDF Based on Mock-Up Measurements



This BSDF does not have a high enough specular reflection. The ratio of left side to right side is 75% of what it should be

The ratio of left to right in this BSDF is very close to what was seen on site in the mock-up. Absolute luminance values are higher and represent a clean mesh.

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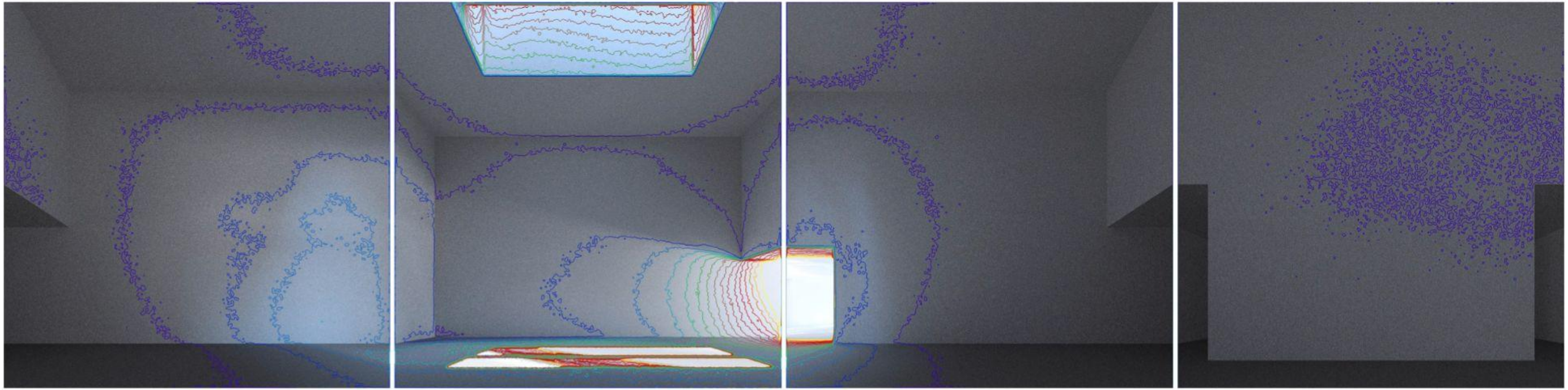
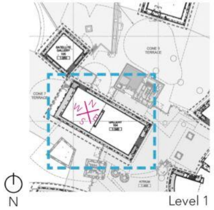
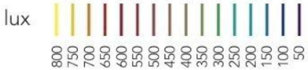
Using the final BSDF in Daylight Illuminance Studies

June 20, 12:00 - clear sky (113,500 lux global horizontal)



South | West | North (to glazed enclosure under cone 8) | East (to remainder of gallery 104)

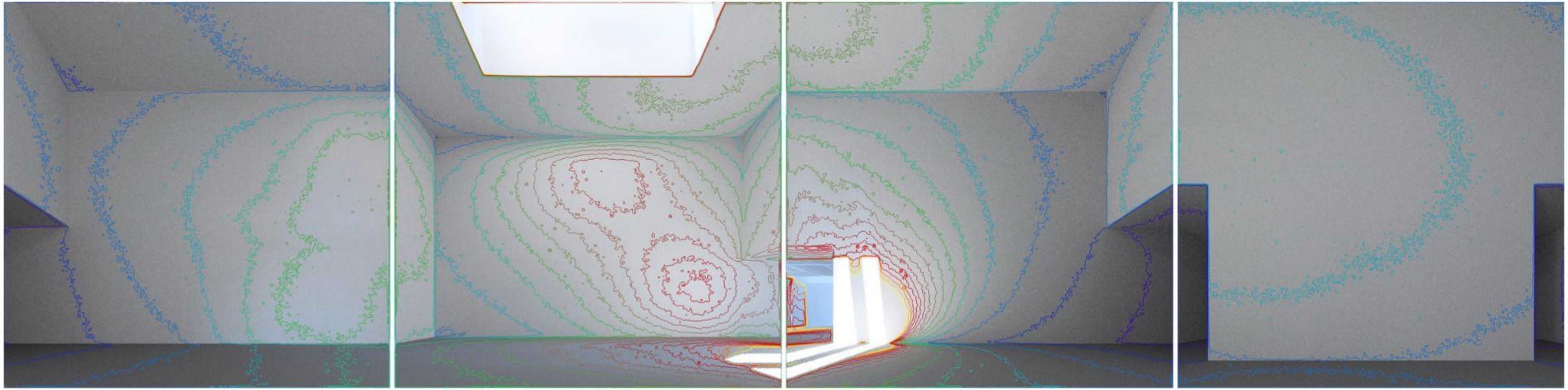




LOISOS + UBBELOHDE
ARCHITECTURE . ENERGY . LIGHT

Using the final BSDF in Daylight Illuminance Studies

September 21, 13:30 - clear sky (96,600 lux global horizontal)

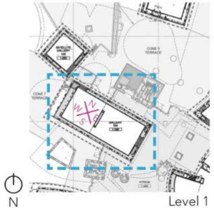


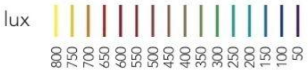
South

West

North
(to glazed enclosure under cone 8)

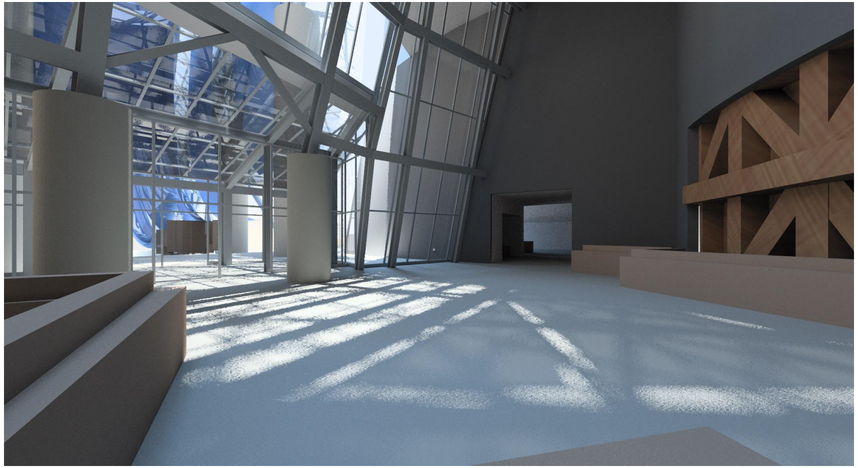
East
(to remainder of gallery 104)

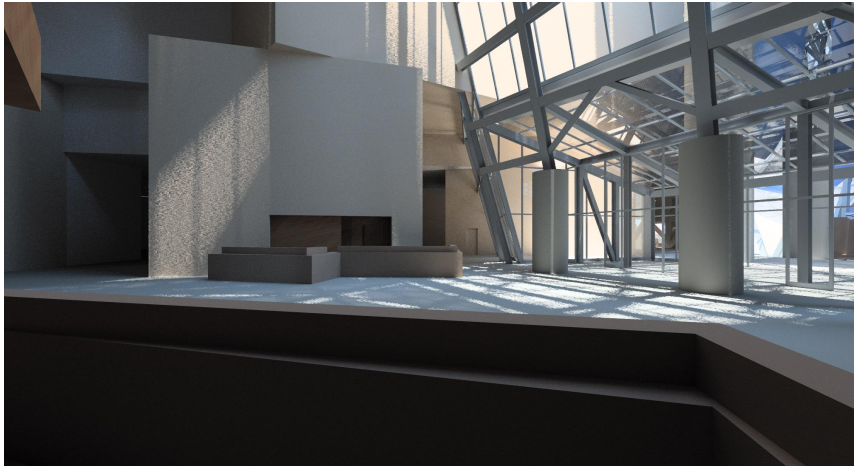




LOISOS + UBBELOHDE
ARCHITECTURE . ENERGY . LIGHT

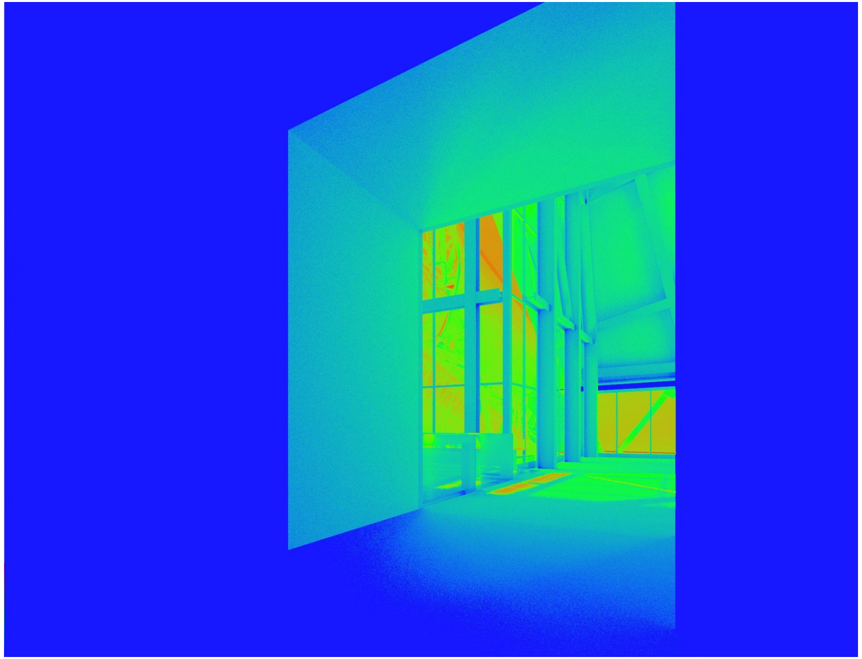
Using the final BSDF in Visual Comfort Simulations





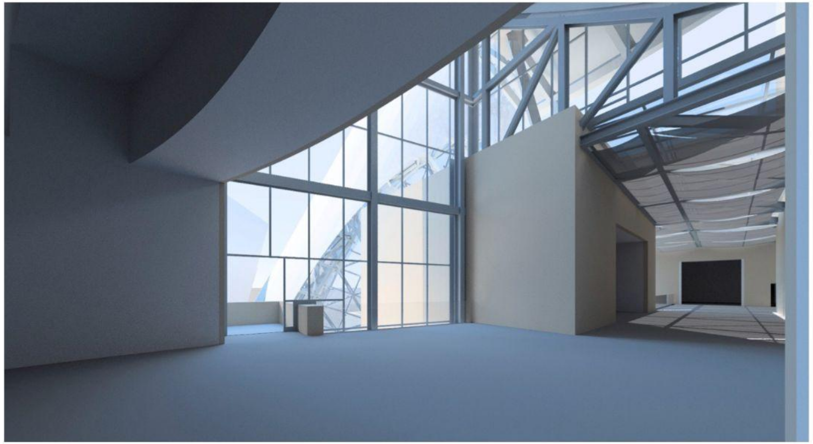
The mesh BSDF is just one of several angularly-selective transmissive materials in these views, which also include functionally-defined shadecloths and metal grating

Using the final BSDF in Visual Comfort Simulations

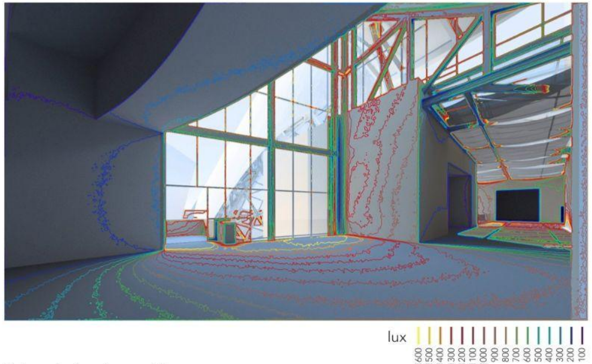


Using the final BSDF in Visual Comfort Simulations

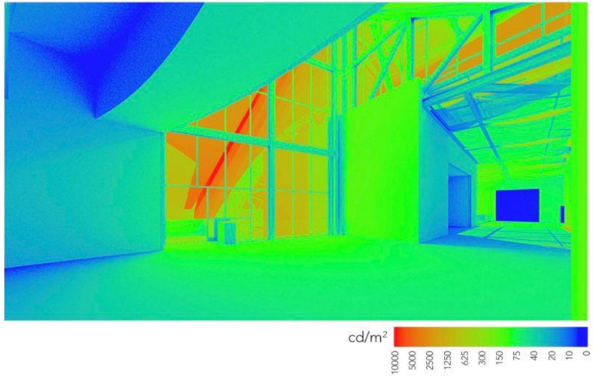
Human Adaptation Rendering

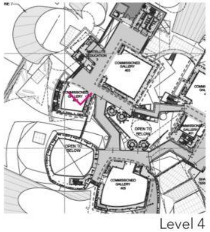


Illuminance Contours



Falsecolor Luminance Map



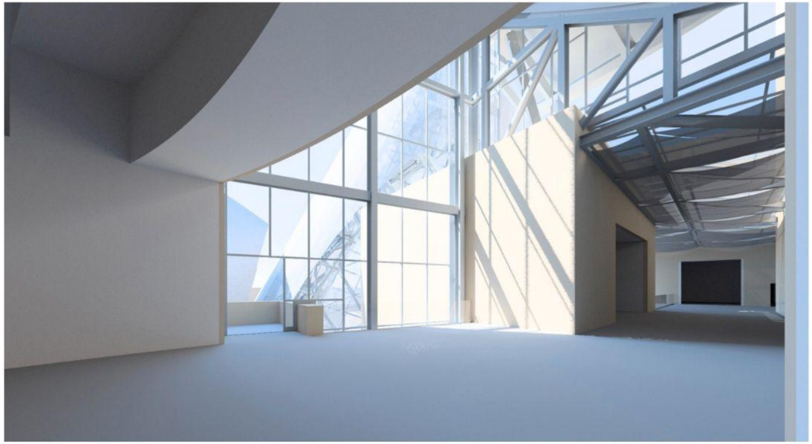


LOISOS + UBBELOHDE

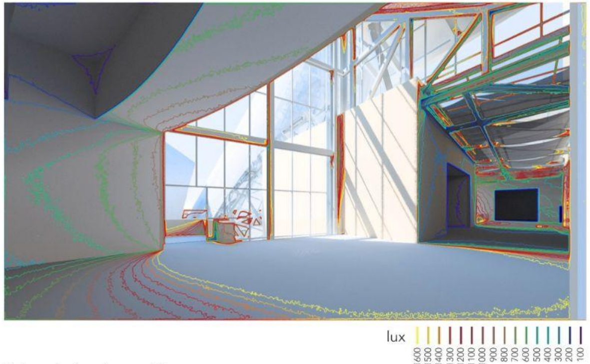
ARCHITECTURE . ENERGY . LIGHT

Using the final BSDF in Visual Comfort Simulations

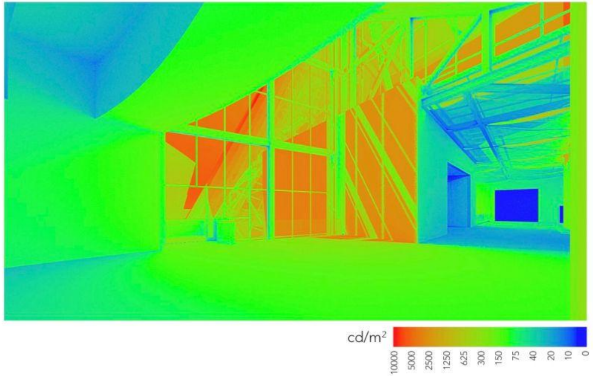
Human Adaptation Rendering

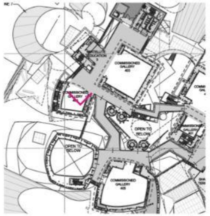


Illuminance Contours



Falsecolor Luminance Map



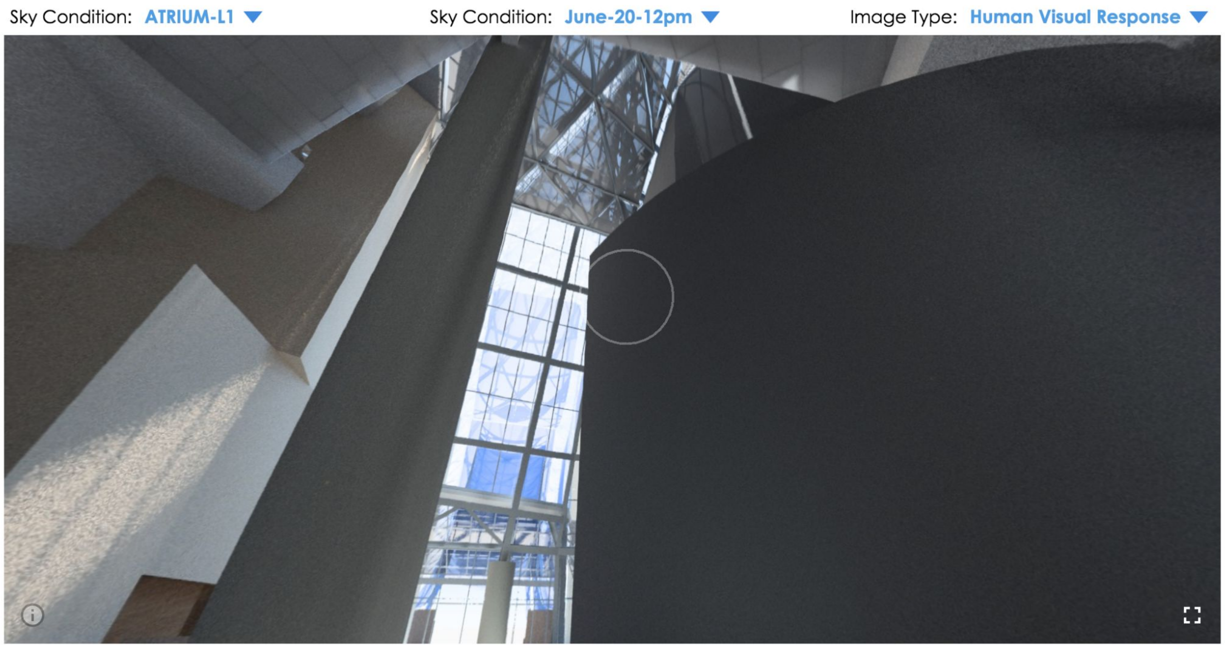


Level 4

LOISOS + UBBELOHDE

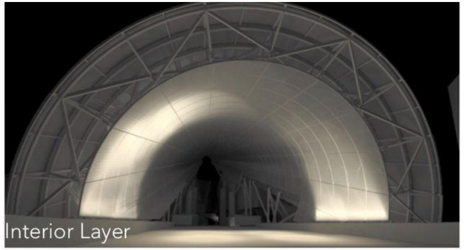
ARCHITECTURE . ENERGY . LIGHT

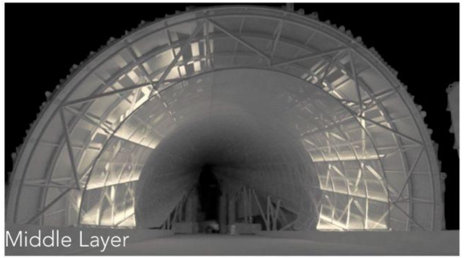
Using the final BSDF in Visual Comfort Simulations

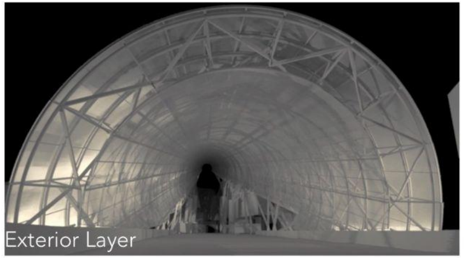


Using the final BSDF in Electric Lighting Simulations

No dimming, 0.7 LLF assumed for all fixtures

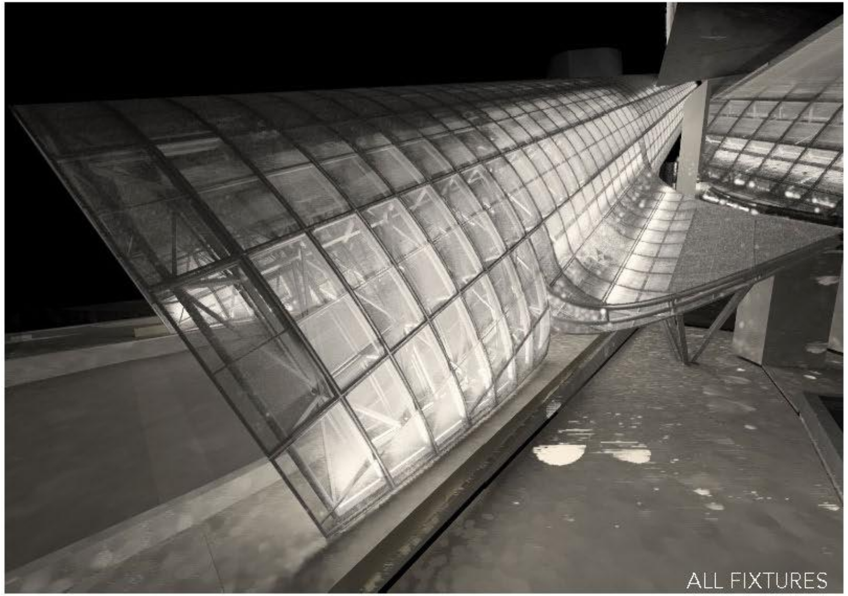




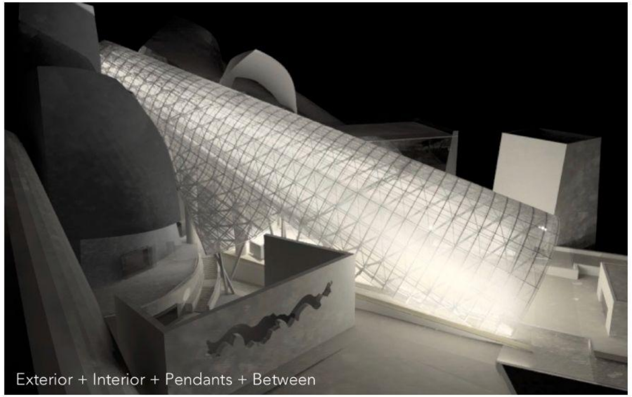


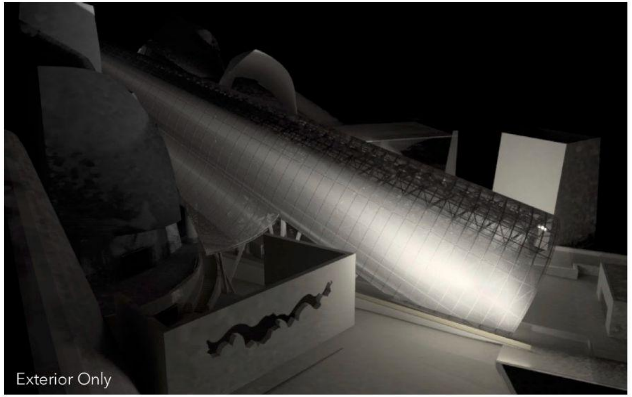
LOISOS + UBBELOHDE
ARCHITECTURE . ENERGY . LIGHT

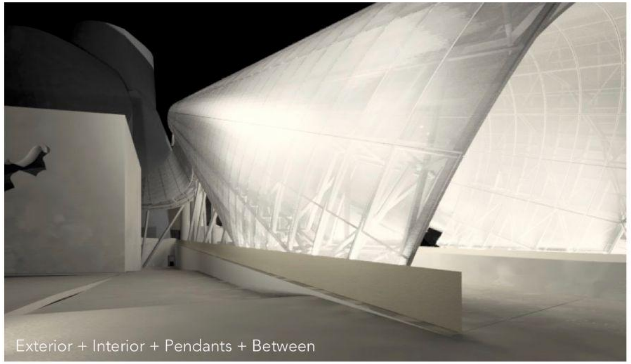
Using the final BSDF in Electric Lighting Simulations

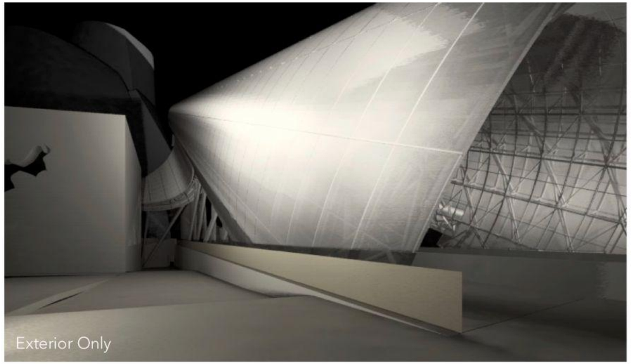


Using the final BSDF in Electric Lighting Simulations

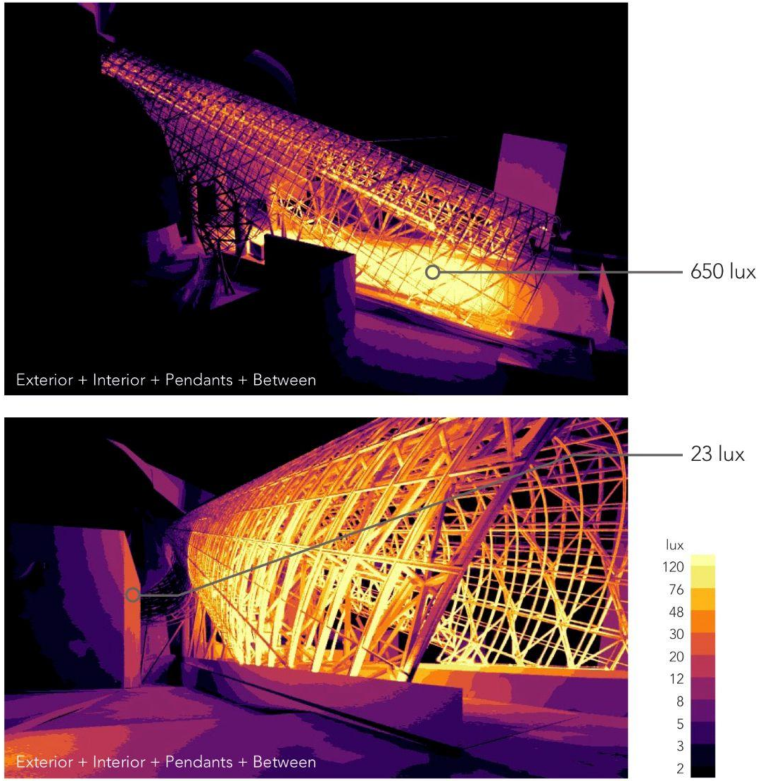

Exterior + Interior + Pendants + Between


Exterior Only


Exterior + Interior + Pendants + Between


Exterior Only

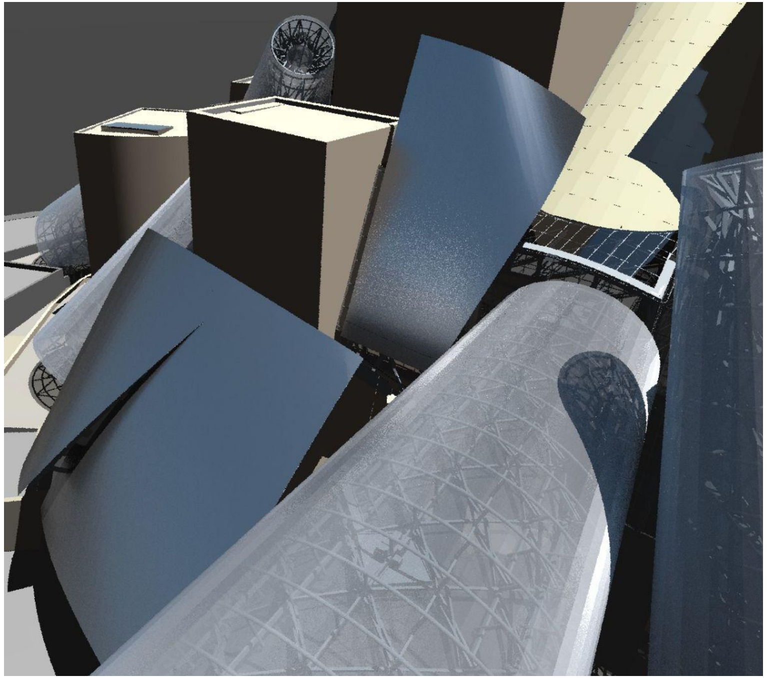
Using the final BSDF in Electric Lighting Simulations

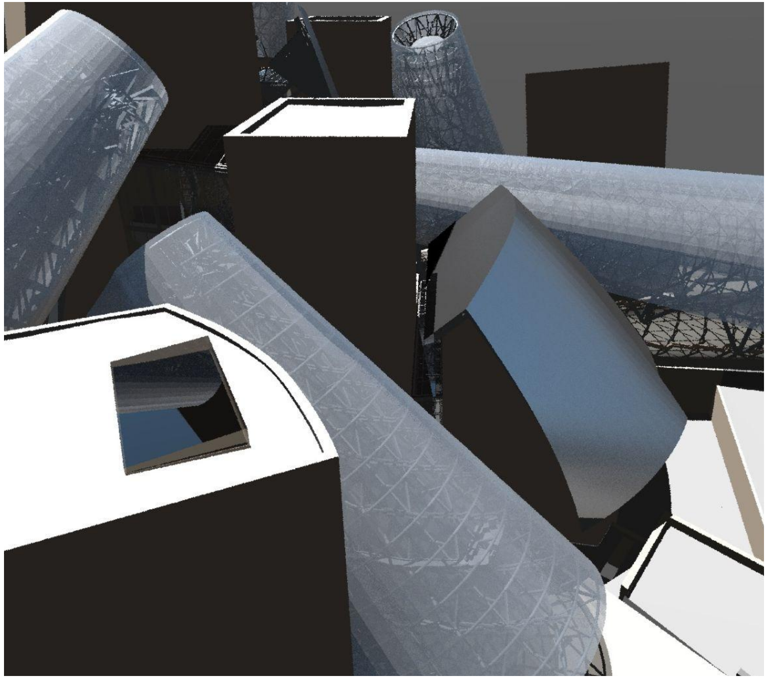


LOISOS + UBBELOHDE

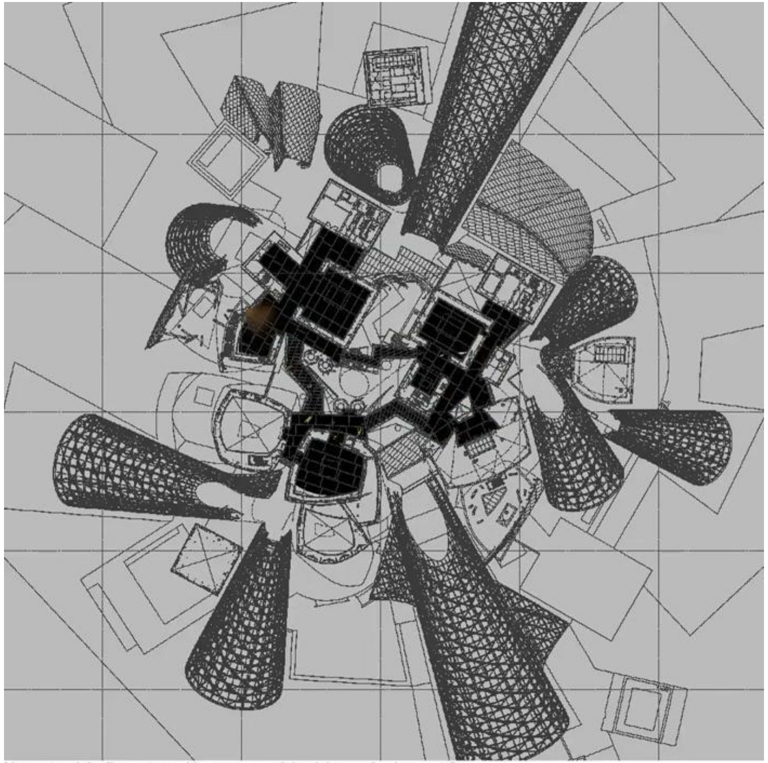
ARCHITECTURE . ENERGY . LIGHT

Using the final BSDF in Reflection Studies





Using the final* BSDF in Reflection Studies



direct sun

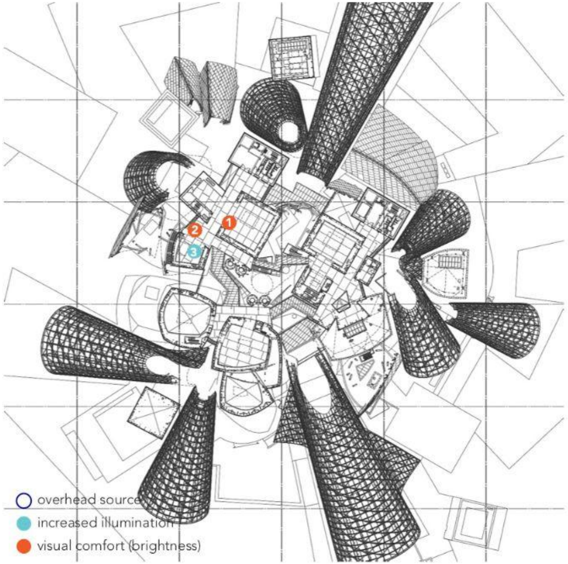
cone reflections

shard reflections

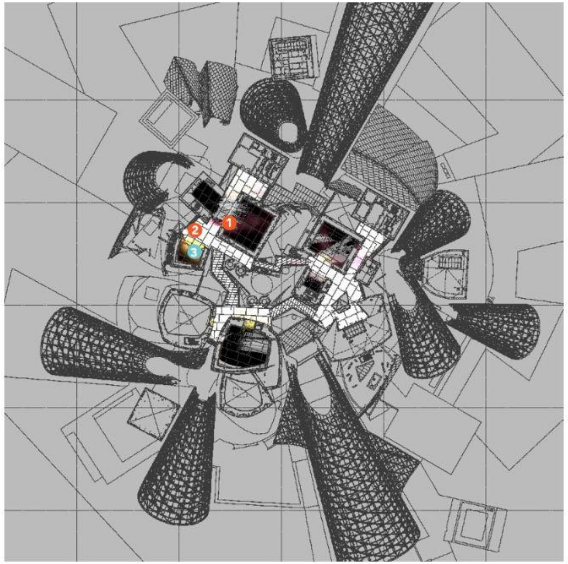
* a colorized and multiplied klems version of the variable resolution BSDF was used for the animations

LOISOS + UBBELOHDE
ARCHITECTURE . ENERGY . LIGHT

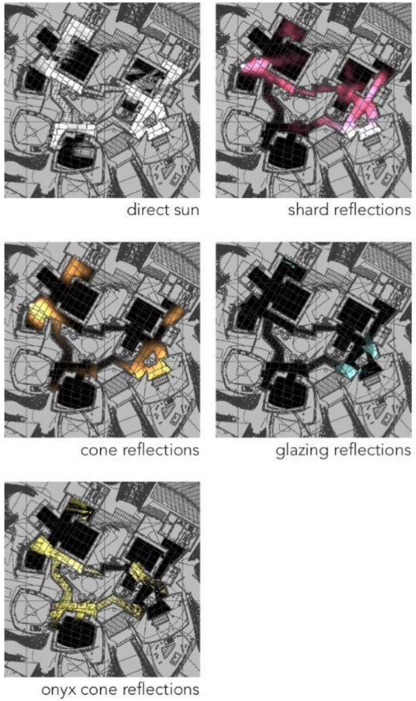
Using the final* BSDF in Reflection Studies



Annual Illumination from All Sources

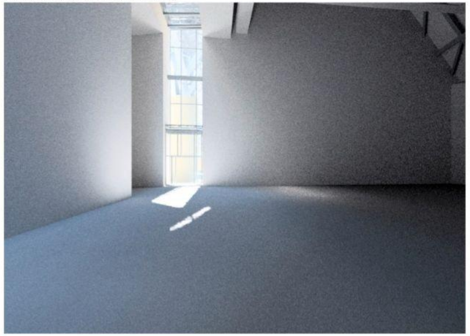


Annual Illumination by Source

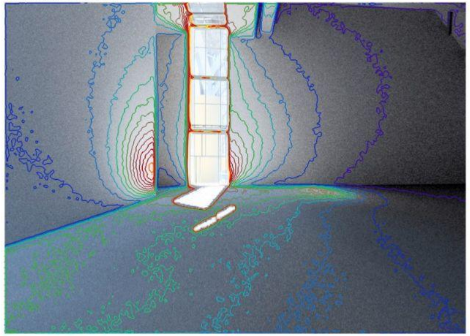


Using the final BSDF in Reflection Studies

Human adaptation rendering



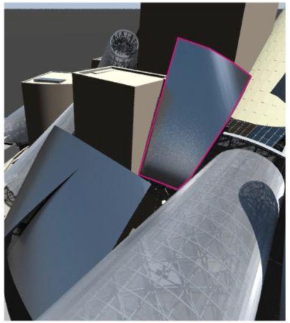
Illuminance contours



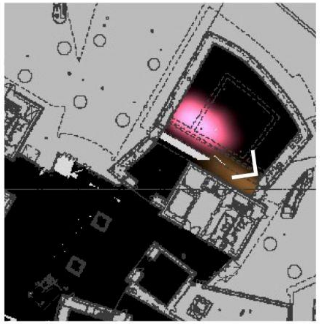
Total Illuminance, lux
800 750 700 650 600 550 500 450 400 350 300 250 200 150 100 50

Banded illuminance from reflected sources

Illuminance from reflections, lux
cone
shard
250 200 150 100 50

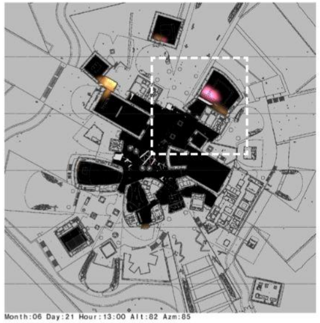


Exterior view of primary reflector (outlined in magenta)



Detail (indicated by dashed lines, right)

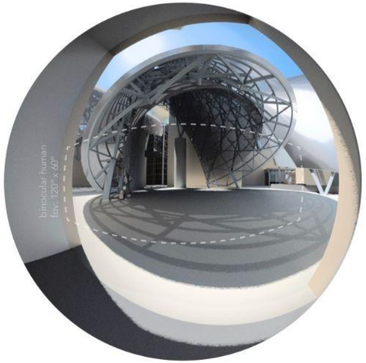
Shard Reflections
Cone Reflections



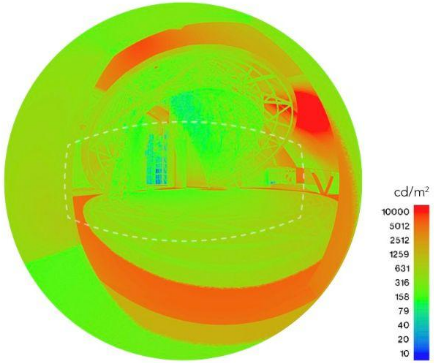
Level 1

Using the final BSDF in Reflection Studies

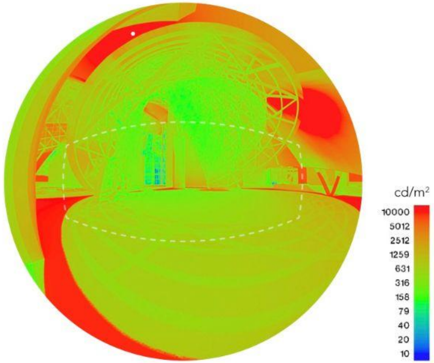
Human adaptation rendering

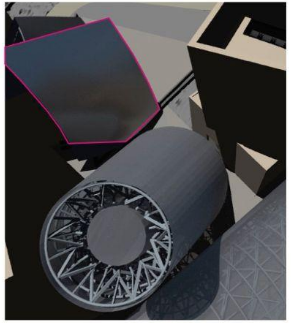


False-color luminance map

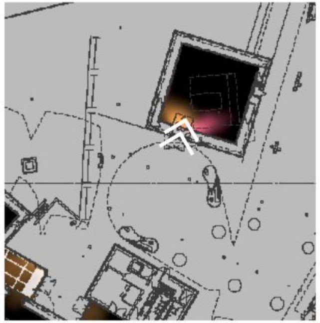


False-color luminance map



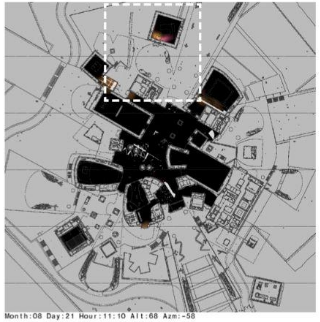


Exterior view of primary reflector
(outlined in magenta)



Detail (indicated by dashed lines, right)

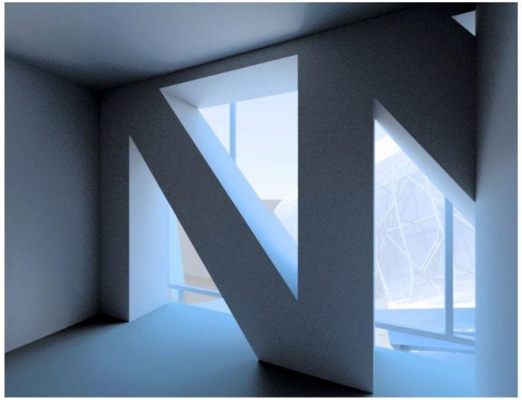
Shard Reflections Cone Reflections

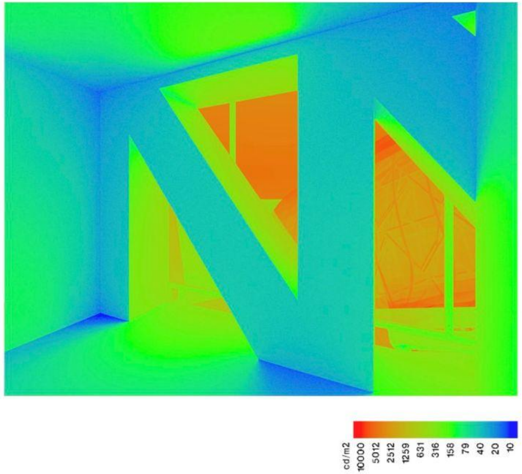


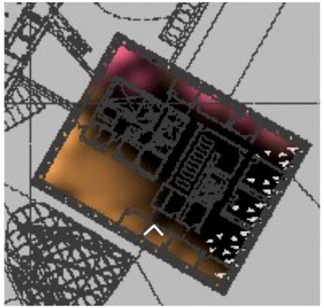
Level 1

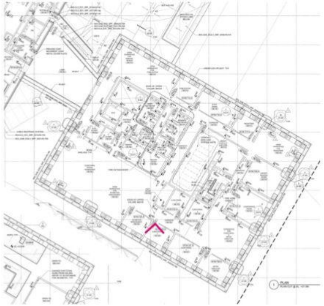
LOISOS + UBBELOHDE
ARCHITECTURE . ENERGY . LIGHT

Using the final BSDF in Reflection Studies









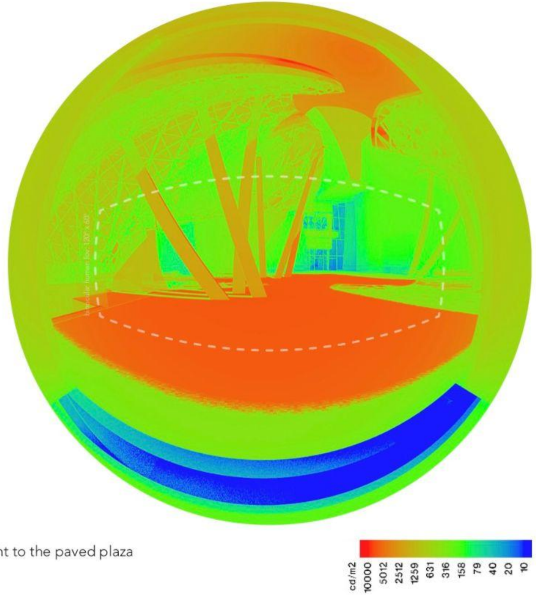
Level 1 Mezzanine

Shard Reflections

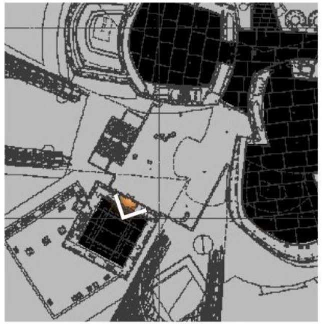
Cone Reflections

The brightest cone reflections in this location are likely to happen when sun angles are glancing off the top of the cone in the afternoon - these are times when solar shades will likely be deployed anyways to mitigate direct sun in the office.

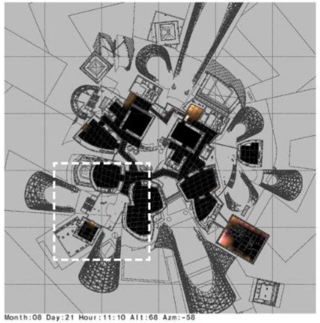
Using the final BSDF in Reflection Studies



The reflections from the cone are not excessively bright and are comparably bright to the paved plaza



Detail (indicated by dashed lines below)

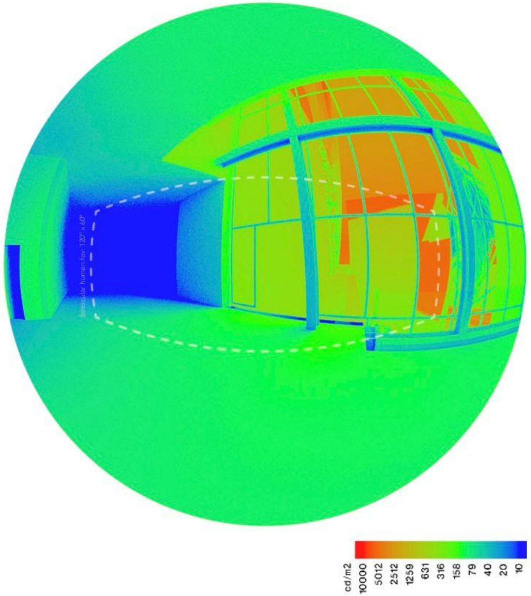


Level 2

Shard Reflections

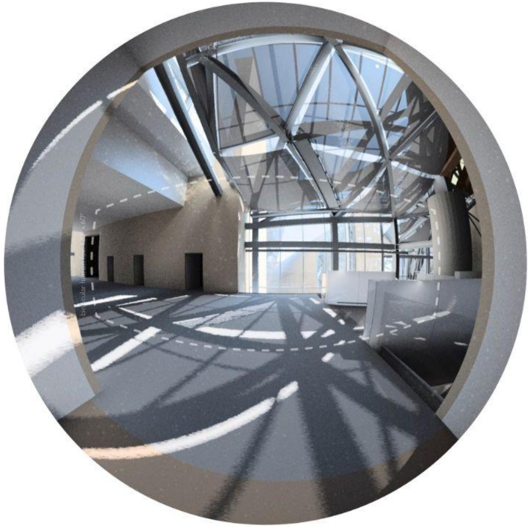
Cone Reflections

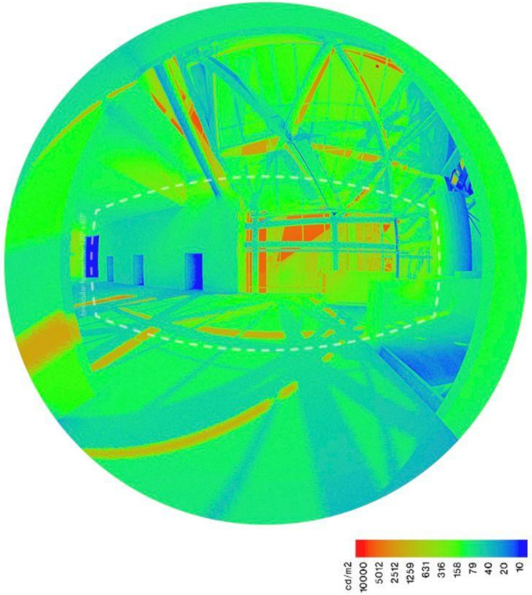
Using the final BSDF in Reflection Studies



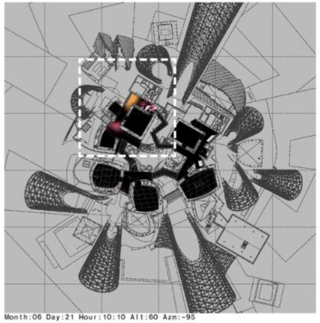
LOISOS + UBBELOHDE
ARCHITECTURE . ENERGY . LIGHT

Using the final BSDF in Reflection Studies





Detail (indicated by dashed lines below)

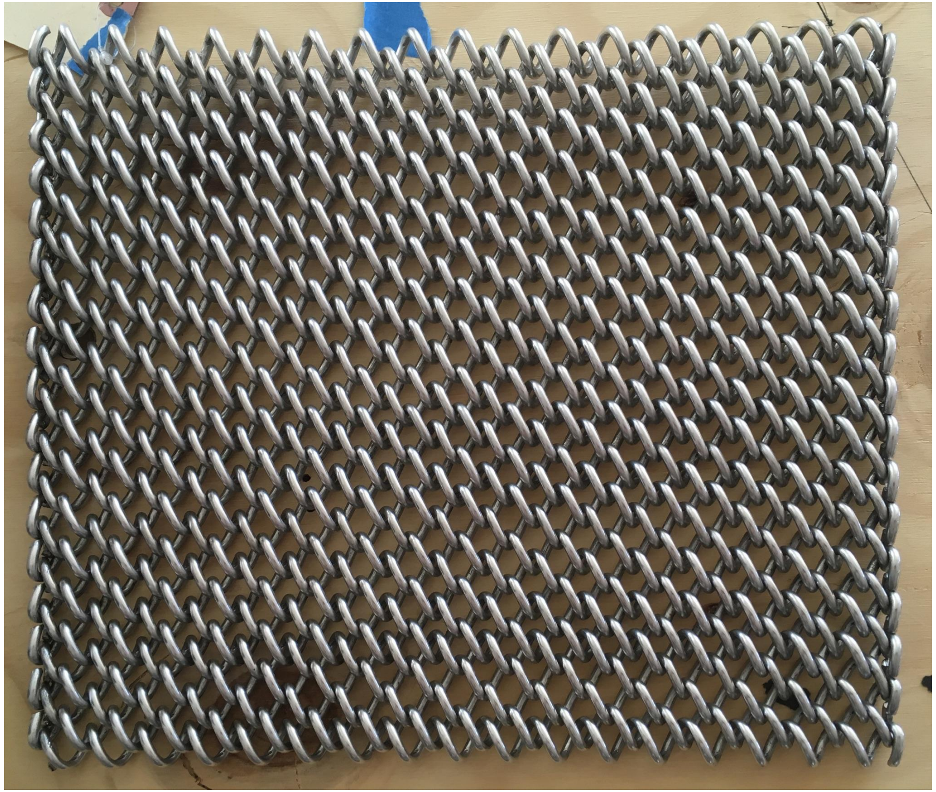


Level 3

Shard Reflections

Cone Reflections

The End



Thanks again to our collaborators on this project:

Tya Abe
Sangjin Joung
Jack Kay
Chloe Zhang

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