The American University in Cairo

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Evaluating the Effectiveness of Four-Sided Wind Towers for Daylighting:

Daylight Performance Study of a Complex Fenestration System Using Radiance

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Introduction

Research Abstract

Wind towers have a long, traceable history in the MENA Region and can be found in their first preliminary forms in Ancient Egyptian architecture and in more complex forms in today's architecture. They have always been used to direct wind towards desired indoor areas, leading hereby to improved ventilation and passive cooling. Nowadays, given the rising trend of environmentally sustainable design and given the current urge to study and optimize the performance of buildings for reduced energy consumption and operating costs, studying the multifold merits of wind towers is of evident interest and clear importance. In this respect, aim of this paper is to study and optimize the daylight performance of a four-sided wind tower, so that it doesn't only act for passive cooling, but also for improved daylighting. Hence, the paper examines the daylight performance of a four-sided wind tower at The American University in Cairo and discusses the potential optimization of its louver system through multiple iterations in the number, material and form of louver system slats. Modelling of the architectural geometry is done using the software program "Rhinoceros 7". Behavior of the louver system is studied using the Bidirectional Scattering Distribution Function (BSDF) for simulating Complex Fenestration Systems (CFS) with "Radiance". Annual daylight simulations are conducted using two different Methods through Grasshopper's Ladybug Tools "Honeybee" and "Honeybee[+]". Spatial Daylight Autonomy (sDA) & Useful Daylight Illuminance (UDI) values are examined.

Keywords: Wind Towers, Building Performance, Climate-Based Daylight Modelling (CBDM), Complex Fenestration System (CFS), Bi-directional Scattering Distribution Function (BSDF), Five-Phase Method, Spatial Daylight Autonomy (sDA), Useful Daylight Illuminance (UDI), Honeybee, Radiance

Main Research Objectives

- Study the daylight performance of an actual wind tower (to optimize it)
- Carry out systematic evaluation and benchmarking of multiple state-of-the-art CBDM techniques which all use RADIANCE (all on the wind tower application)

with the aim to understand the flexibility and limitations of each tool with regards to input parameters and output metrics, and to study the effect of certain inputs on the output

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    - Geometry Preparation of Louver System
    - Geometry Preparation of Architectural Building
    - Annual Daylight Simulation Recipe
  - Approach 2: **Ladybug Legacy Tools Honeybee[+] 0.0.06** ***(Surface- Based Approach, 5-Phase Method)***
    - Geometry Preparation of Architectural Building
    - Annual Daylight Simulation Recipe
  - Quick Comparison of 2 Approaches, Tools & Workflows
- Preliminary Design Iterations + Future Optimization Workflow & Plan
- Conclusion with Current Limitations & Further Research Plan

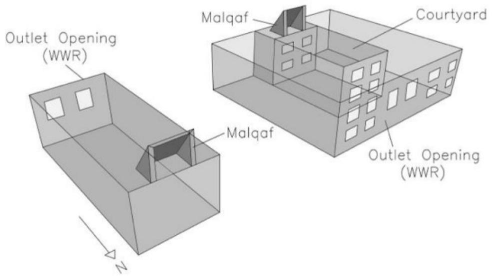
Introduction

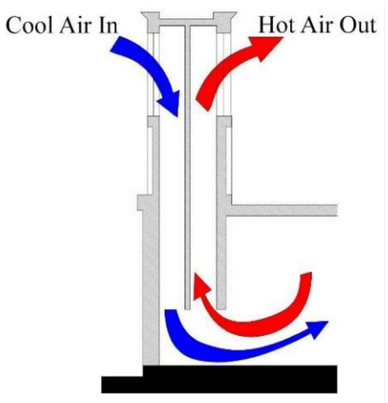
About Wind Towers

- Wind Towers, also known as wind catchers or “malqaf” (in Arabic), are
  - architectural elements in the form of chimney-like tower structures constructed on top of buildings and used for natural ventilation & passive cooling in countries with severe hot climates.

- They work due to
  - difference in pressure & buoyancy;
    rising of warm air and lowering of cold air.

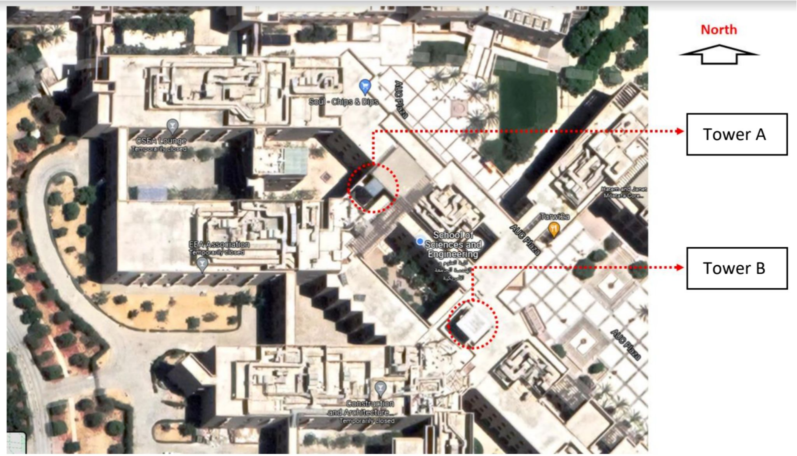
- There are different types of wind towers:
  - uni-directional
  - bi-directional
  - multi-directional
  - cylindrical etc.

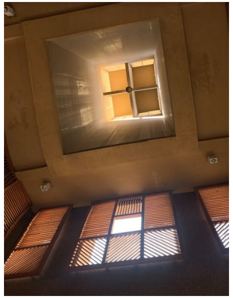




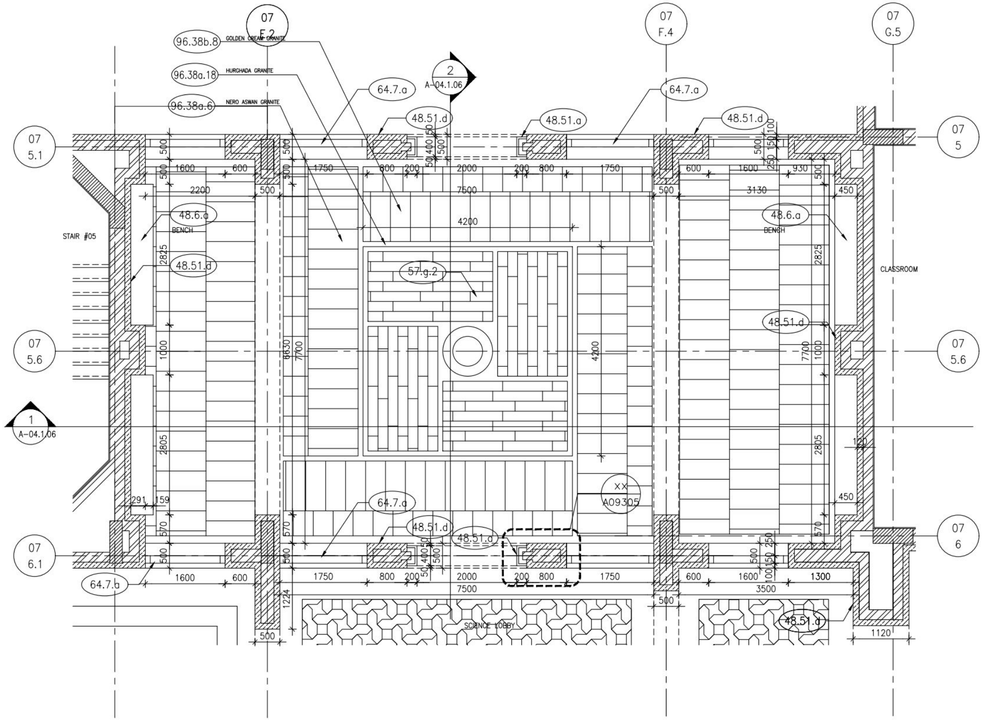
Reference: Nessim, M., Elshabshiri, A., Bassily, V., Soliman, N., Tarabieh, K., Goubran, S. (2023). The Rise and Evolution of Wind Tower Designs in Egypt and the Middle East. MDPI. Sustainability in Heritage & Urban Planning. Retrieved from https://doi.org/10.3390/su151410881

Description of AUC Wind Tower A

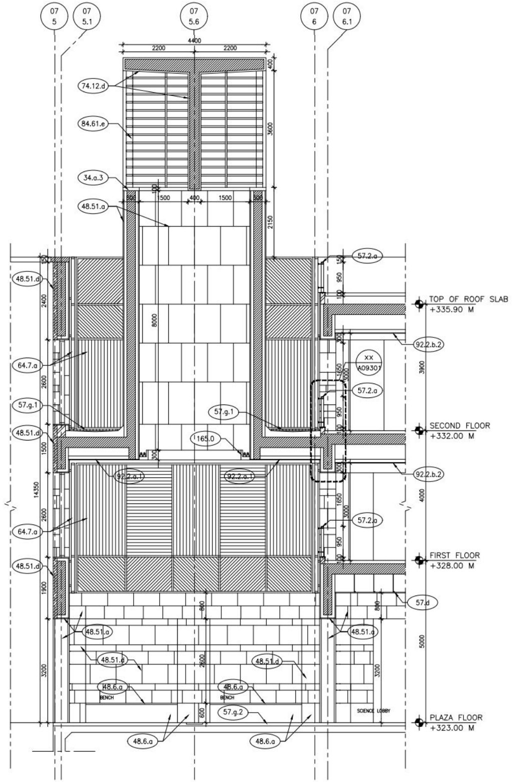




Construction Drawings of AUC Wind Tower A



Enlarged Plaza Floor Plan



Section 2-2

Reference: AUC Campus Planning Office

Overview on Approaches, Methods, Tools & Workflows

What do we want to study?			
Research Objective	Studying the Daylight Performance of the Wind Tower Openings & the Wind Tower Louver System		
What tool should we use?			
Tool	RADIANCE		
How can we use it?			
Method	Climate Studio	Ladybug Tools Honeybee	Radiance
	user interface	visual programming	Command line

How to decide?

Introduction About Climate-Based Daylight Modelling (CBDM)

Traditional Methods for the Indoor Daylight Performance Assessment Becoming **Increasingly Insufficient**

Combination of existing theoretical models and improvements in the computer simulation field

The Rise of New Simulation Techniques Grouped under the Name **"Climate-Based Daylight Modelling" (CBDM)**

Taking the Following Factors into Consideration:

- Sky Conditions
- Local Climate
- Building Orientation
- Geometry & Surface Properties of a Space
- Increasingly Complex Fenestration Systems (CFS) & Window Technologies

Reference: Brembilla, E. (2019). Applicability of Climate-Based Daylight Modelling. Retrieved from: https://repository.lboro.ac.uk/articles/thesis/Applicability_of_climate-based_daylight_modelling/9455126

Introduction About Climate-Based Daylight Modelling (CBDM)

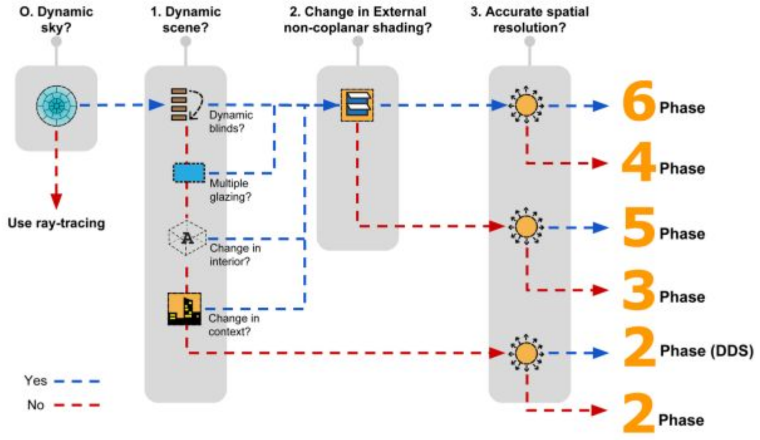
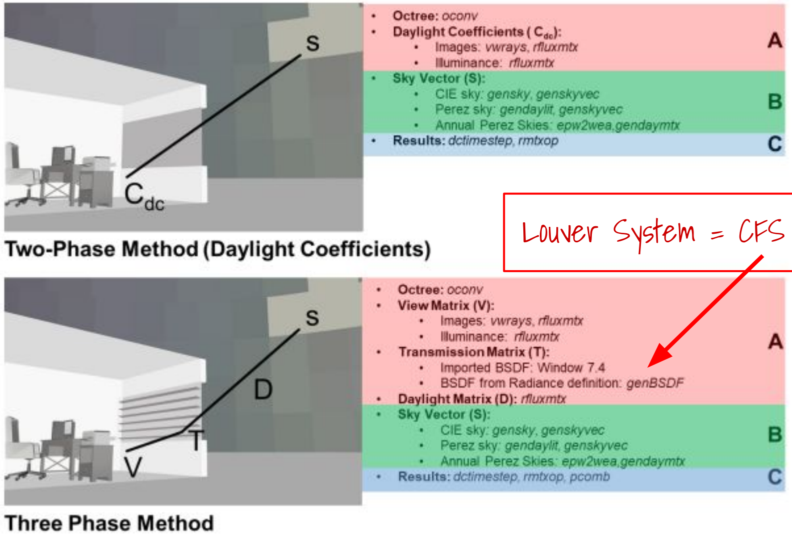


Figure 1. A simple decision tree for determining the appropriate type of simulation. The names of the simulations are mentioned on the right as 2 Phase, 3 Phase and so on. The questions above each of the grey boxes represent decisions. Accurate spatial resolution is obtained by an accurate calculation of direct-sun radiation and the use of high resolution Bidirectional Scattering Distribution Functions (BSDFs). For example, to simulate a model with dynamic skies and accurate spatial resolution, one would choose a 2 Phase (DDS) simulation. (Image Credit: Mostapha Sadeghipour Roudsari)

Reference: Subramaniam, S. (2017). Daylighting Simulations with Radiance using Matrix-Based Methods. Retrieved from: https://www.radiance-online.org/learning/tutorials/matrix-based-methods



Louver System = CFS = BSDF

- **A:** Flux-transfer calculations
- **B:** Sky-vector calculations
- **C:** Calculation of results

Figure 2. Schematic overview of the Two-Phase Method, Three-Phase Method and the Four-Phase Method. The italicized terms such as *oconv*, *vwrays* and *genskyvec* refer to Radiance programs required for that particular aspect of the simulation. For example, Step A in the case of the Daylight Coefficient method involves the use of *oconv* to create an octree, *vwrays* and *rfluxmtx* to generate matrices for image-based simulation and *rfluxmtx* alone for illuminance-based simulation.

Approach #1: Ladybug Tools Honeybee 1.6.0

Workflow Overview

- **Stage I: Preparation of Louver System Geometry (Radiance BSDF XML File)**
- Stage II: Preparation of Architectural Building Geometry (Rhino + LBT 1.6.0 Honeybee)
- Stage III: Preparation & Running of Annual Daylight Recipe (Honeybee-Radiance)

Stage 1: Preparing Louver System Geometry

Understanding CFS and BSDF

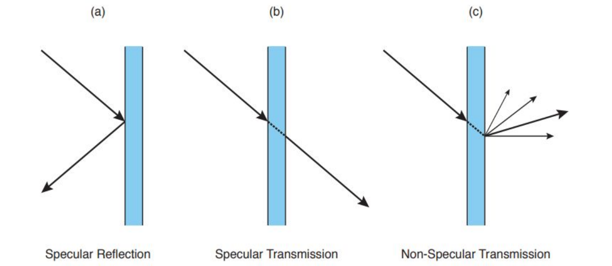
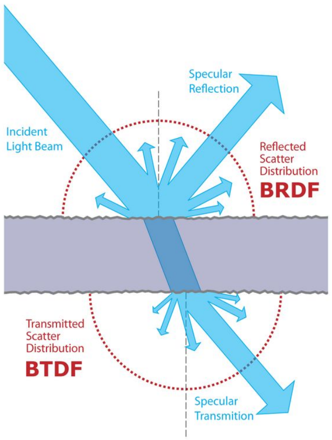


Figure 2.6: Schematic illustration of the difference in directionality of the emerging light resulting from the same incident direction ray. A specular reflection(a) causes the ray to be bounced back towards the symmetrical direction, but in the same hemisphere of the incident one; a specular transmission (b) happens when the ray passes through the glazing system without modifying its original direction; a non-specular transmission (c), typical of CFS, originates when the system re-direct the incident ray towards a different direction than the specular one.



Complex Fenestration System (CFS): entirety of any optically complex window system, comprised of parts exhibiting non-specular transmittance properties

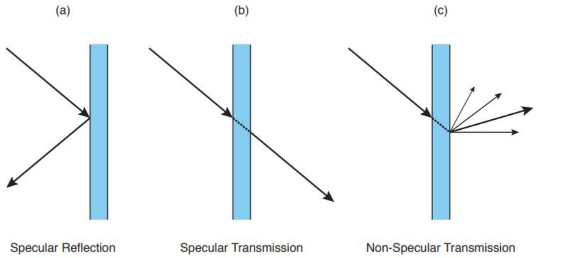
Bidirectional Scattering Distribution Function (BSDF): a set of hemispherical luminous coefficients defined by paired incident and outgoing angles to characterize the solar-optical & daylighting performance of CFS, where "scattering" is the combination of

- transmittance (BTDF)
- reflectance (BRDF)

1. *Brembilla, E. (2019). Applicability of Climate-Based Daylight Modelling. Retrieved from: https://repository.lboro.ac.uk/articles/thesis/Applicability_of_climate-based_daylight_modelling/9455126*
2. *Lee, E. (2017). Complex Fenestration Modeling Tools: Radiance. Retrieved from: https://www.energy.gov/sites/default/files/2017/04/f34/6_35515b_Lee_031617-1130.pdfhttps://www.energy.gov/sites/default/files/2017/04/f34/6_35515b_Lee_031617-1130.pdf*
3. McNeil, A., Jonsson, J.C., Ward, G., Lee, E.S. (2013). A Validation of a Ray-tracing Tool used to Generate Bi-Directional Scattering Distribution Functions for Complex Fenestration Systems. Retrieved from: DOI:10.1016/j.solener.2013.09.032

Stage 1: Preparing Louver System Geometry

Understanding CFS, BSDF & Wind Tower A Louver System



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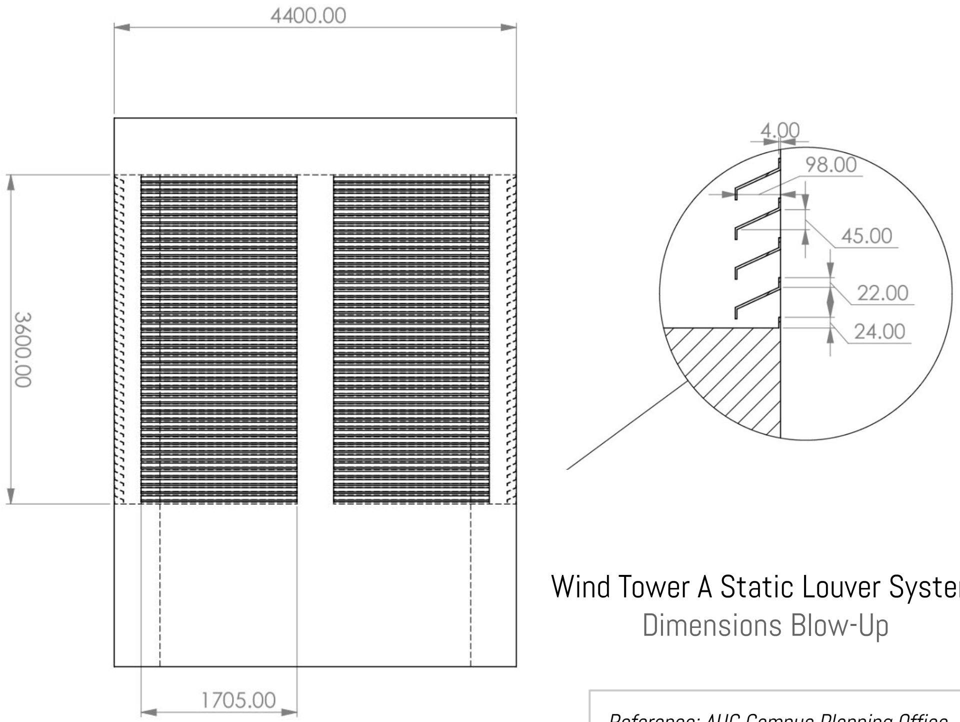
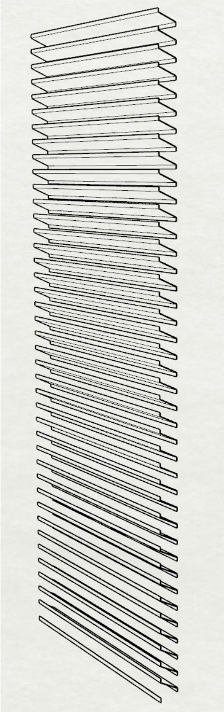


Wind Tower A Static Louver System
Dimensions Blow-Up

Reference: AUC Campus Planning Office

Preparing Louver System Geometry

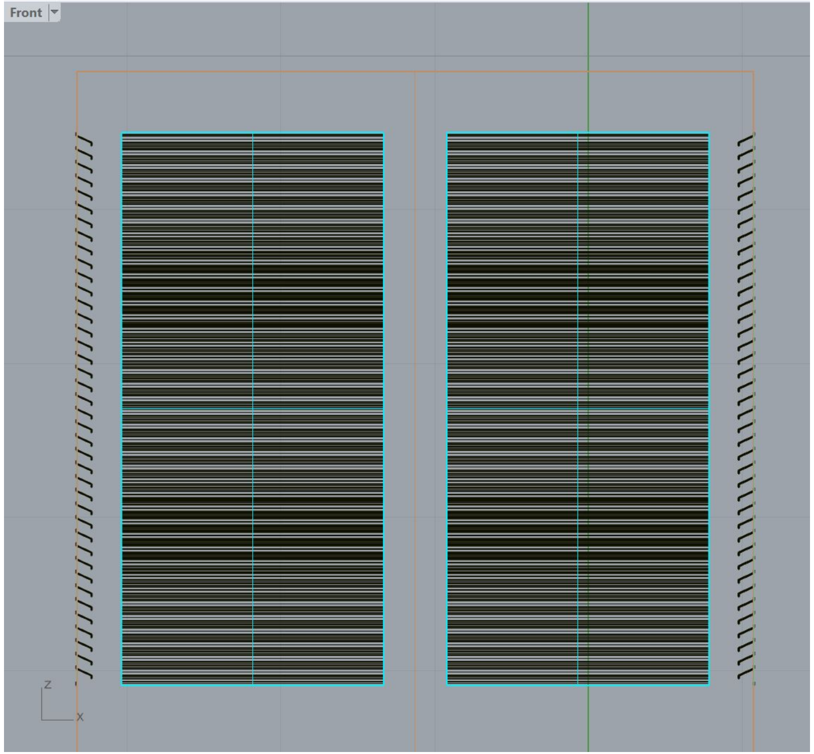
Workflow from Rhino to Radiance to Honeybee

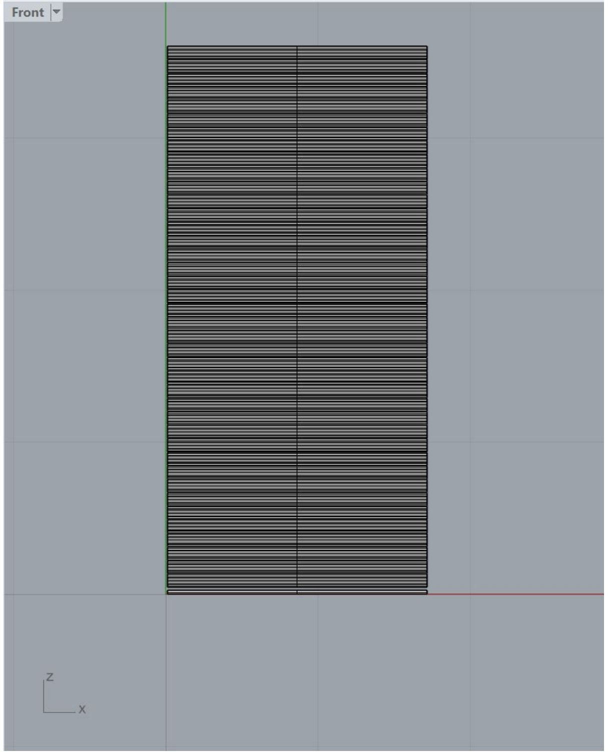


1. Creating Louver System Geometry on Rhino & Adjusting Orientation to Export OBJ File
2. **Creating RAD File using "obj2rad.exe"**
3. Checking RAD Model Orientation using "getbbox.exe"
4. Adding Material Properties to RAD File
5. **Generating BSDF XML File using "genbsdf.exe"**
6. Checking BSDF XML File using "BSDF Viewer"
7. Integrating BSDF XML File in Honeybee Code after Architectural Geometry Preparation

Preparing Louver System Geometry

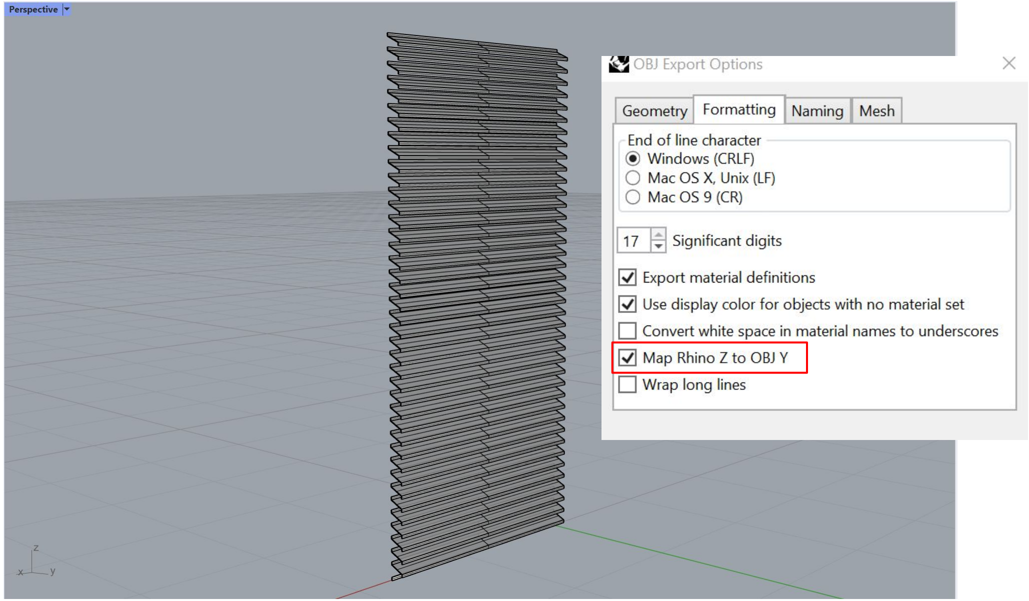
Creating Louver System Geometry on Rhino





Preparing Louver System Geometry

Adjusting Louver System Model Orientation in Rhino & Exporting OBJ File



Checking correct orientation of louver system later from RAD & XML files:

checking RAD model orientation:

getbbox.exe BaseCaseLouvers.rad
pause

xmin	xmax	ymin	ymax	zmin	zmax
.0107467	1.71577	0.00024712	3.60025	-0.110624	-0.0086242

checking correct model dimensions in XML file:

<Thickness unit="meter">0.1019998</Thickness>
<Width unit="meter">1.7050233</Width>
<Height unit="meter">3.60000288</Height>

Preparing Louver System Geometry

Creating RAD File, Adding Material Properties & Generating BSDF XML File

creating RAD File using "obj2rad.exe":

obj2rad.exe BaseCaseLouvers.obj > BaseCaseLouvers.rad
pause

adding material properties to RAD file:
RGB reflectance values, specularity & roughness for metals

Reference: https://help.iesve.com/ve2021/6__materials_in_radiance.htm

```
# obj2rad BaseCaseLouvers.obj
# Rhino

void metal diffuse_0
0
0
5 0.8 0.8 0.8 0.7 0.1

diffuse_0 polygon unnamed.1
0
0
9
      1.78669130802    -0.100537784398     -1.00068378448
      1.78669130802    -0.100537784398      1.00069367886
      1.76281154156    -0.100537784398      1.00069367886
```

generating BSDF XML File using "genbsdf.exe":

genbsdf.exe **-geom meter** BaseCaseLouvers.rad > BaseCaseLouvers.xml
pause

BSDF XML File Generation takes almost 60 min using **default parameters.*

- behind.dat
- bsender.rad
- device.oct
- device.rad
- face.dat
- fsender.rad
- receivers.rad

Temporary files created in temporary directory (User > AppData > Local > Temp > genBSDF), from which the final XML File gets generated & from which one can track progress of genBSDF

Preparing Louver System Geometry

Understanding "genBSDF" & "rfluxmtx" Parameters & Options

Table 1. Command line options for generating Klems basis BSDFs with genBSDF.

Command Line Option	Description
-c Nsamp	Sets the number of sample rays per Klems division. The default is 2000 samples per Klems division.
-n Nproc	Sets the number rtrace processes to run. This option allows users to make use of multiple processors to reduce computation time. The default is 1.
-r '*rtcontrib* opts...'	Set simulation options passed to rtcontrib (-ab, -ad, -ss, -lw etc.)
+b (-b)	Create a BTDF and BRDF for back (indoor) surface of CFS.
+f (-f)	Create a BTDF and BRDF for front (outdoor) surface of CFS.
{+|-}mgf	Specifies the input model format. The default for input model format is Radiance (-mgf). MGF can be used with +mgf.
{+|-}geom unit	Geometry will be included in the resulting XML file if +geom is set (this is the default). Geometry is excluded with -geom. The length unit must be given in either case, and must be one of meter, foot, inch, centimeter, or millimeter. Output geometry is MGF regardless of input format.
-dim Xmin Xmax Ymin Ymax Zmin Zmax	Normally, "emitting" rectangles are positioned according to the bounding box of the model. This option allows the user to specify a different bounding box.

rfluxmtx parameters	Default setting	Description
-ab	5	The number of bounces traced. Once a ray tree gets to the specified number of bounces, no further rays are spawned.
-ad	700	The number of rays spawned at each surface intersection (contingent on the ray weight being above the lw setting). This is similar to 'ray splitting' parameters used in other raytracing software.
-lw	3e-6	The limit weight sets the minimum weight of a ray that is traced. Each traced ray is weighted according to its contribution to the result. At a ray intersection if 700 ambient division rays are spawned, the weight of each of those rays is 1/700th * the diffuse reflectance of the intersected material. If the weight of the spawned rays would be less than the limit weight, fewer than 700 are traced.
-lr	-10	The reflection limit determines how many specular reflections are traced. A negative value indicates that Russian roulette termination is used after the limit is reached.
-ss	1.0	The number of samples sent to sample highlights of rough specular materials.
-st	0.15	The threshold for specular sampling. If the specular reflection or transmission of a material is below this value, specular sampling will not occur.

-t{3|4} *Nlog2*	Tells genBSDF to create a tensor tree BSDF (rather than a Klems Basis BSDF). The 3 or 4 immediately follows the 't' (no space) and tells genBSDF what rank of tensor tree to create. A rank three tensor tree can be used for an isotropic system (has radial symmetry). For non-isotropic systems rank four tensor tree is required. The Nlog2 specifies the finest resolution of patch considered.

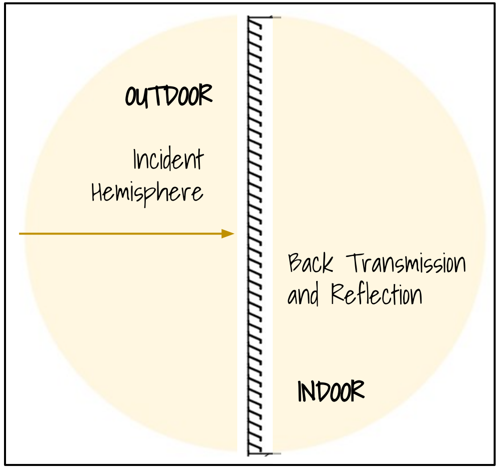
Additional "genBSDF" Parameter For TensorTree BSDF instead of Full Klems Basis BSDF

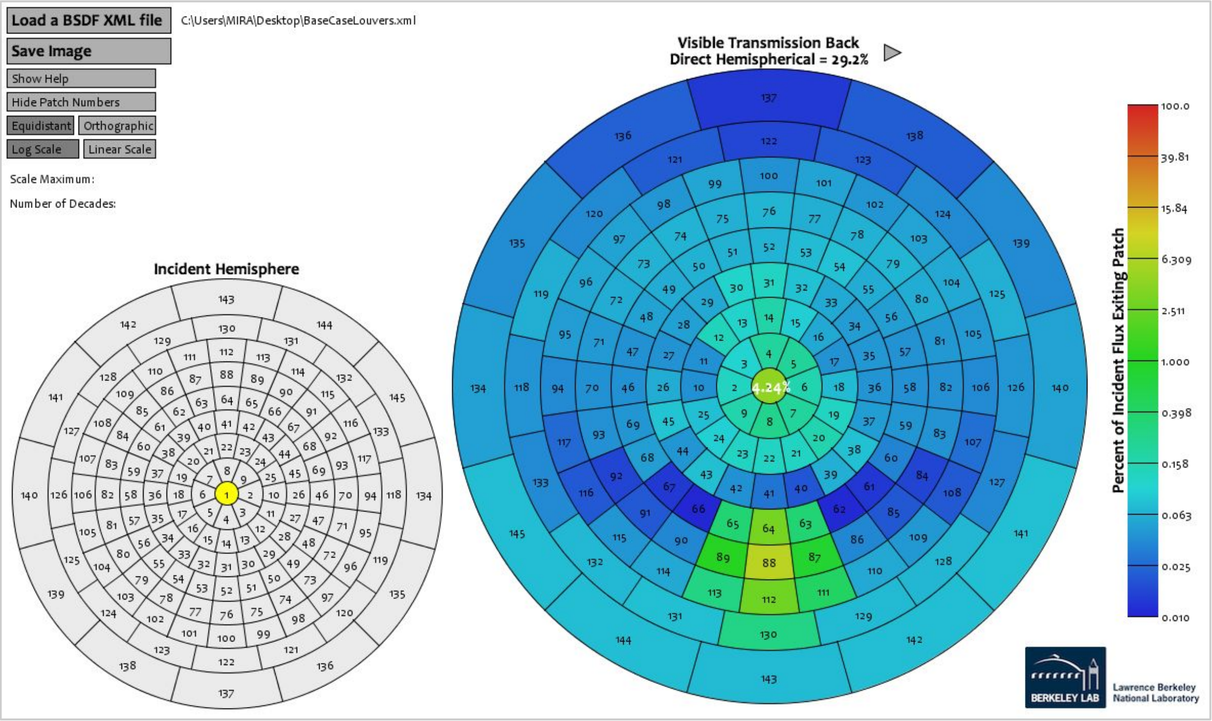
1. *McNeil, A., Jonsson, J.C., Ward, G., Lee, E.S. (2013). A Validation of a Ray-tracing Tool used to Generate Bi-Directional Scattering Distribution Functions for Complex Fenestration Systems. Retrieved from: DOI:10.1016/j.solener.2013.09.032*
2. McNeil, A. (2015). Radiance genBSDF Tutorial. Retrieved from https://www.radiance-online.org/learning/tutorials/Tutorial-genBSDF_v1.0.1.pdf

Preparing Louver System Geometry

Checking Louver System BSDF Behavior with “BSDFViewer.exe”

This is just a rough conceptual sketch to visualize incident angle.





Preparing Louver System Geometry

Checking Louver System BSDF Behavior with "BSDFViewer.exe"

How to understand BSDF Viewer Full Klems Angle Basis Output?

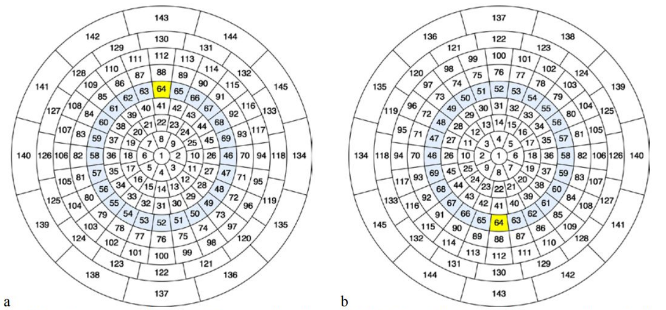
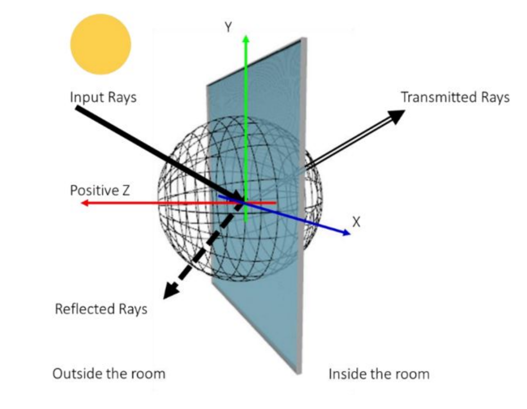
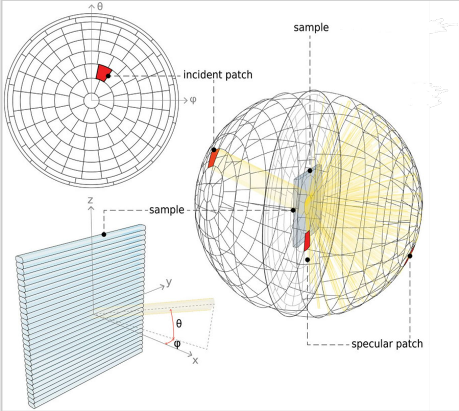


Fig. 1. Angular projection of Klems angle basis viewed from the incident side for (a) incident (normal direction out of the page) and (b) transmitted hemispheres (normal direction into the page). The blue shaded regions indicate a Klems "theta band" which is all the patches with the same theta angles. A "phi division" is a single patch in the theta band (eg shaded in yellow). Note that the numbering scheme of the patches is different for the two hemispheres. This numbering is chosen to allow a specular beam to be described by the same patch number for incident, reflected and transmitted directions.

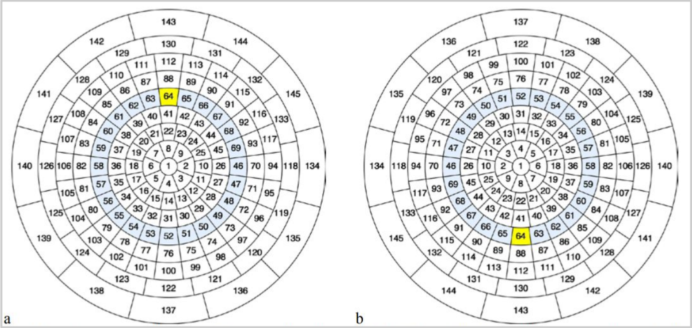




1. McNeil, A., Jonsson, J.C., Ward, G., Lee, E.S. (2013). *A Validation of a Ray-tracing Tool used to Generate Bi-Directional Scattering Distribution Functions for Complex Fenestration Systems*. Retrieved from: DOI:10.1016/j.solener.2013.09.032
2. Mashaly, I. (2016). *A Sustainable Complex Fenestration System using Recycled Plastics*. ResearchGate. Retrieved from: DOI:10.13140/RG.2.1.1965.3364
3. Piccioni, V., Leschok, M., Grobe, L.O., Wasilewski, S., Seshadri, B., Hischier, I., Schlüter, A. (2023). *Tuning the Solar Performance of Building Facades through Polymer 3D Printing: Toward Bespoke Thermo-Optical Properties*. Advanced Materials Technologies, Wiley. Retrieved from: https://doi.org/10.1002/admt.202201200

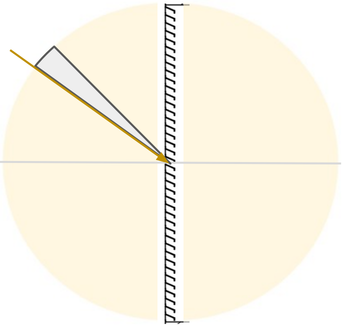
Preparing Louver System Geometry

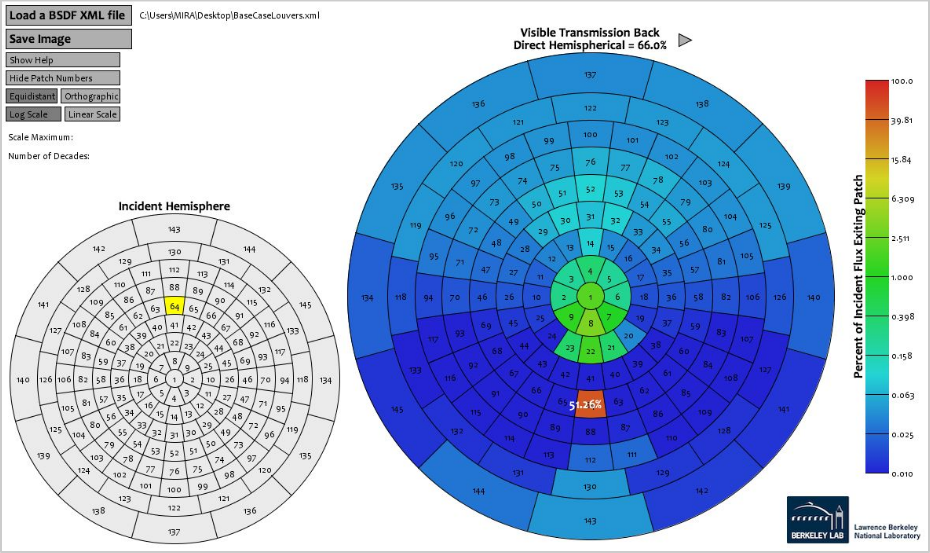
Checking Louver System BSDF Behavior with “BSDFViewer.exe”



Theta Band	Patch Numbers	Theta Range	Number of Phi Divisions	Solid Angle
1	1	0°-5°	1	0.0239
2	2-9	5°-15°	8	0.0238
3	10-25	15°-25°	16	0.0234
4	26-45	25°-35°	20	0.0274
5	46-69	35°-45°	24	0.0293
6	70-93	45°-55°	24	0.0293
7	94-117	55°-65°	24	0.0395
8	118-133	65°-75°	16	0.0643
9	134-145	75°-90°	12	0.1355

Theta range = 35-45 degrees





Preparing Louver System Geometry

Checking Louver System BSDF Behavior with “BSDFViewer.exe”

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5	46-69	35°-45°	24	0.0293
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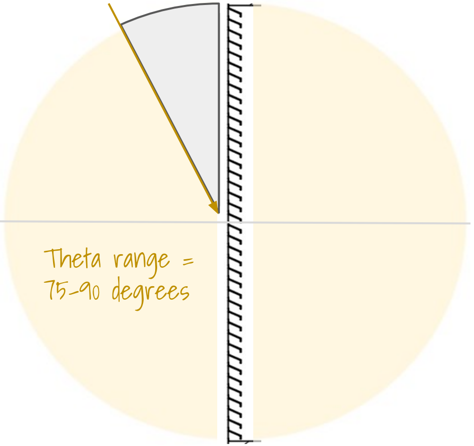

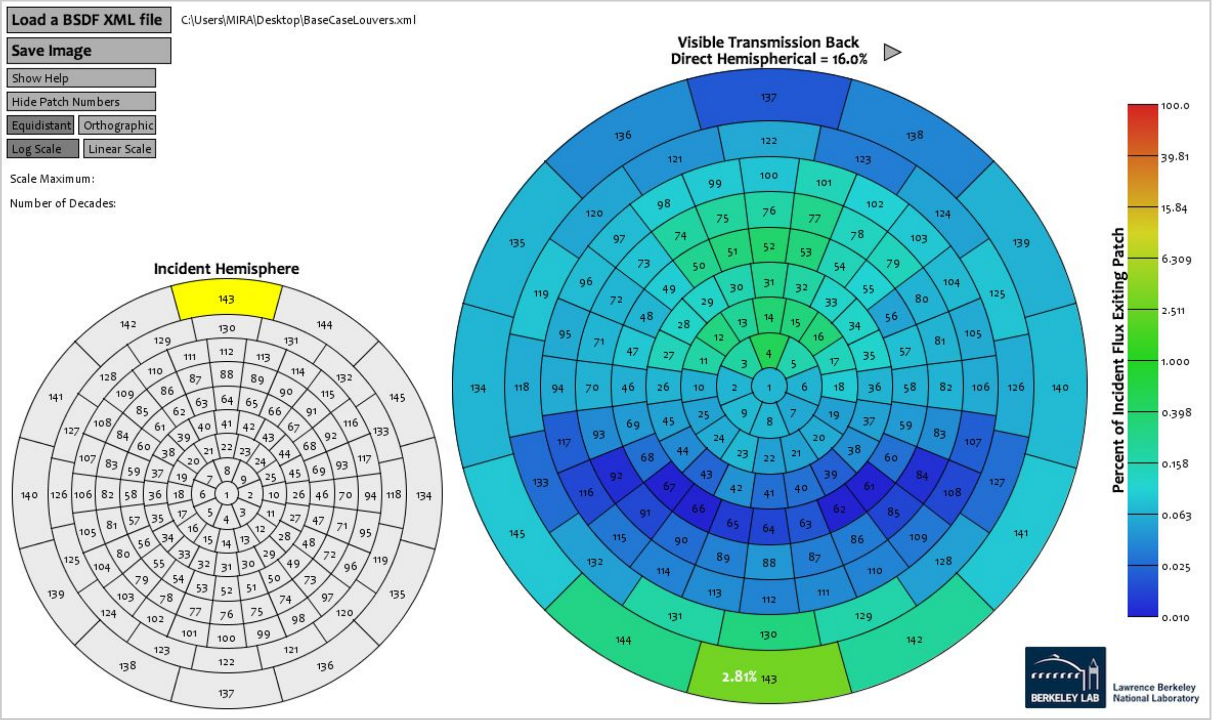

Preparing Louver System Geometry

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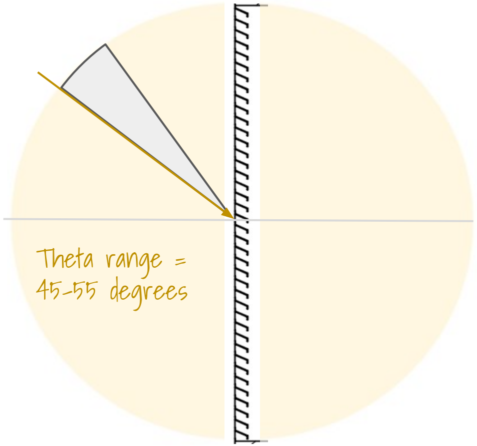
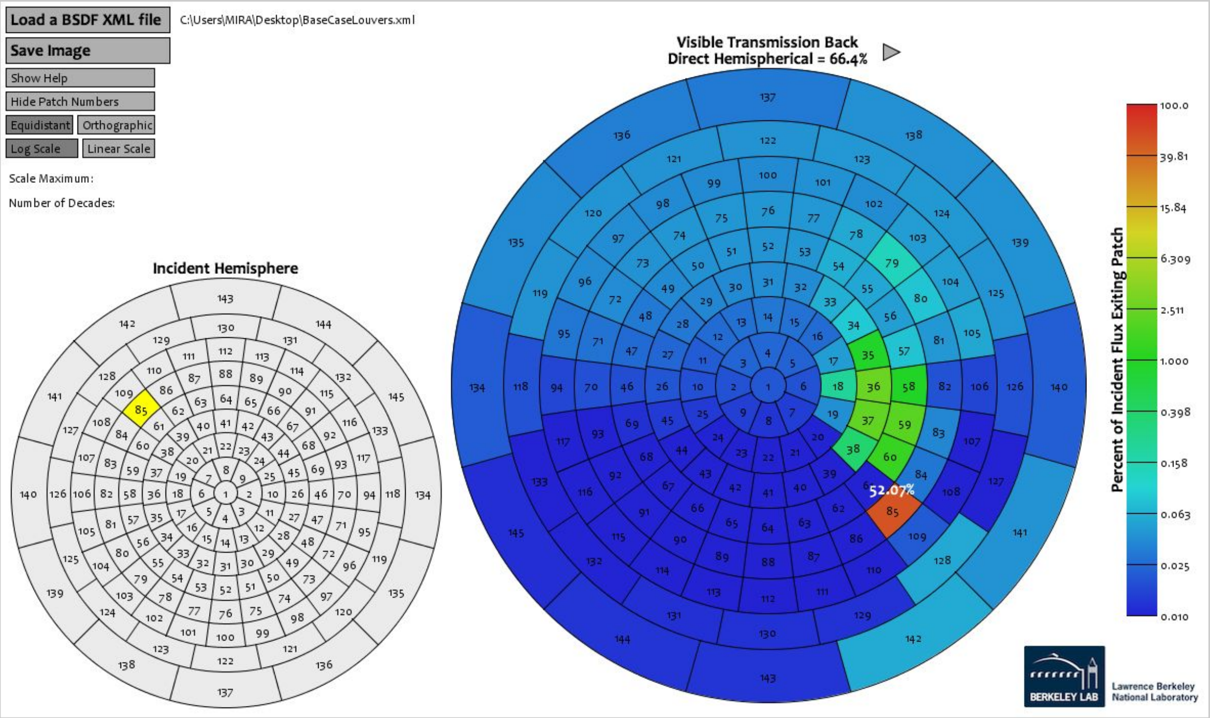
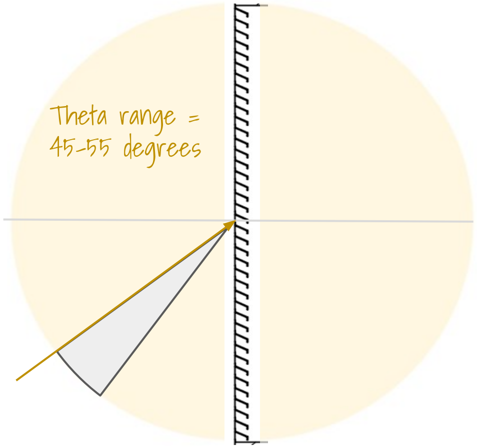


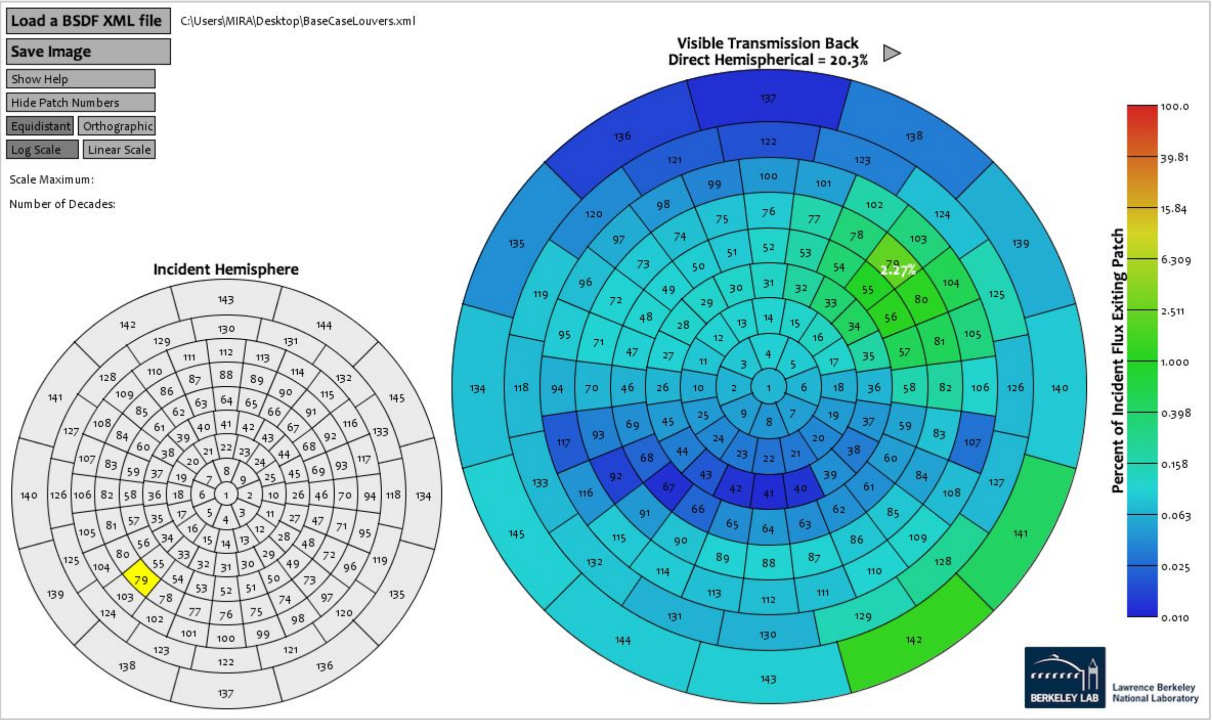


Preparing Louver System Geometry

Checking Louver System BSDF Behavior with “BSDFViewer.exe”

Theta Band	Patch Numbers	Theta Range	Number of Phi Divisions	Solid Angle
1	1	0°-5°	1	0.0239
2	2-9	5°-15°	8	0.0238
3	10-25	15°-25°	16	0.0234
4	26-45	25°-35°	20	0.0274
5	46-69	35°-45°	24	0.0293
6	70-93	45°-55°	24	0.0293
7	94-117	55°-65°	24	0.0395
8	118-133	65°-75°	16	0.0643
9	134-145	75°-90°	12	0.1355





Preparing Louver System Geometry

Checking Louver System BSDF Behavior with "BSDFViewer.exe"

Theta Band	Patch Numbers	Theta Range	Number of Phi Divisions	Solid Angle
1	1	0°-5°	1	0.0239
2	2-9	5°-15°	8	0.0238
3	10-25	15°-25°	16	0.0234
4	26-45	25°-35°	20	0.0274
5	46-69	35°-45°	24	0.0293
6	70-93	45°-55°	24	0.0293
7	94-117	55°-65°	24	0.0395
8	118-133	65°-75°	16	0.0643
9	134-145	75°-90°	12	0.1355

Theta Band	Patch Number	Theta Range	BSDF Visible Transmission Back	BSDF Visible Transmission at Specular Patch
1	1	0°-5°	29.2%	4.24%
2	8	5°-15°	39.0%	24.19%
3	22	15°-25°	49.7%	42.72%
4	41	25°-35°	66.4%	64.37%
5	64	35°-45°	66.0%	51.26%
6	88	45°-55°	53.7%	14.55%
7	112	55°-65°	45.6%	2.45%
8	130	65°-75°	33.1%	3.07%
9	143	75°-90°	16.0%	2.81%

Workflow Overview

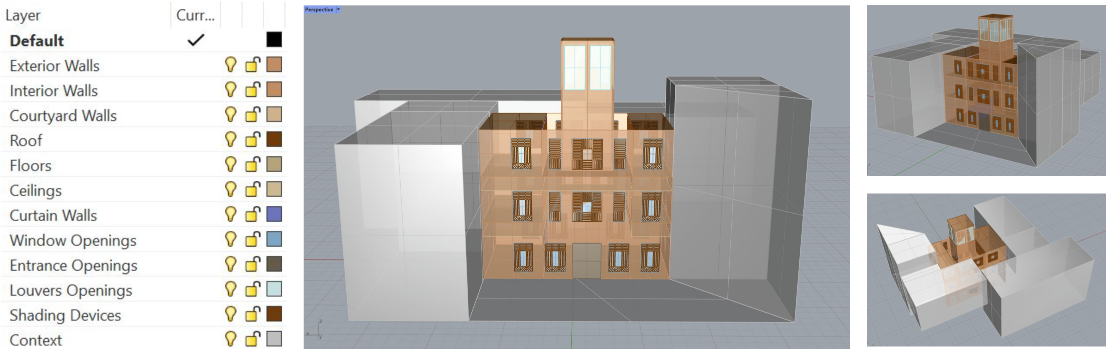
- Stage I: Preparation of Louver System Geometry (Radiance BSDF XML File)
- **Stage II: Preparation of Architectural Building Geometry (Rhino + LBT 1.6.0 Honeybee)**
- Stage III: Preparation & Running of Annual Daylight Recipe (Honeybee-Radiance)

Stage 2: Preparing Architectural Building Geometry

Geometry Preparation Workflow from Rhino to Honeybee

Model
Creation
Workflow

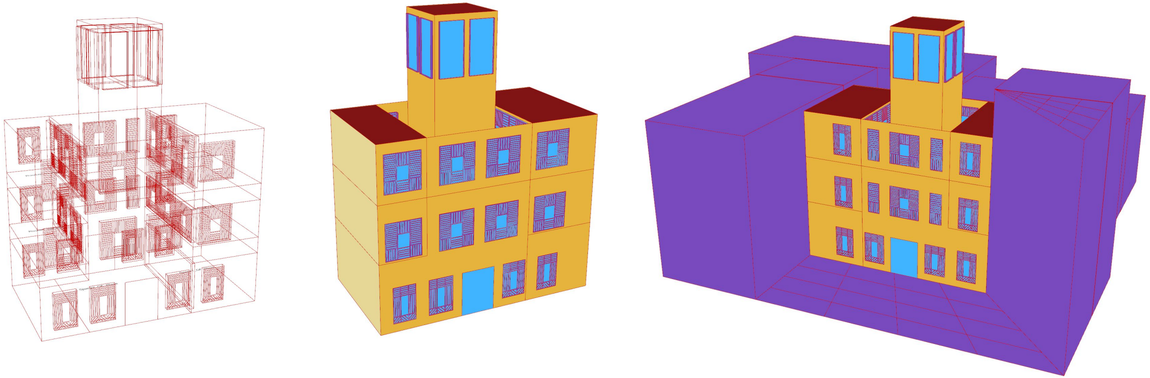
(from Rhino ...)



↓

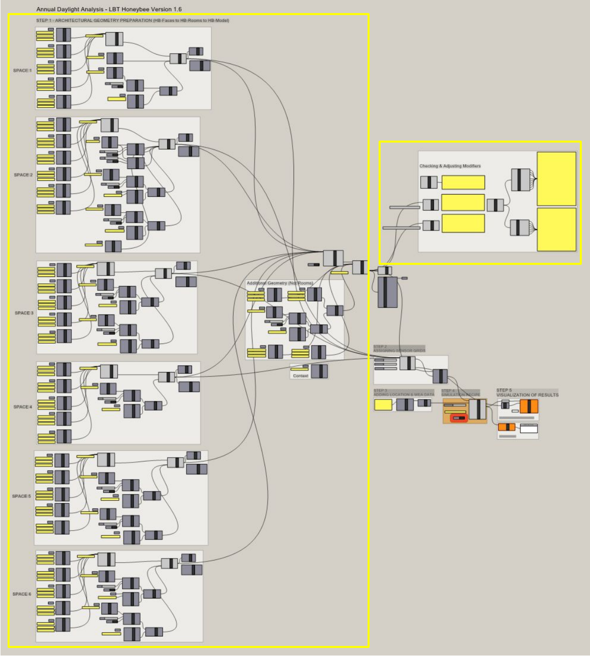
Model
Creation
Workflow

(... to LBT 1.6.0 Honeybee-Radiance)



Stage 2: Preparing Architectural Building Geometry

Geometry Preparation Workflow from Rhino to Honeybee

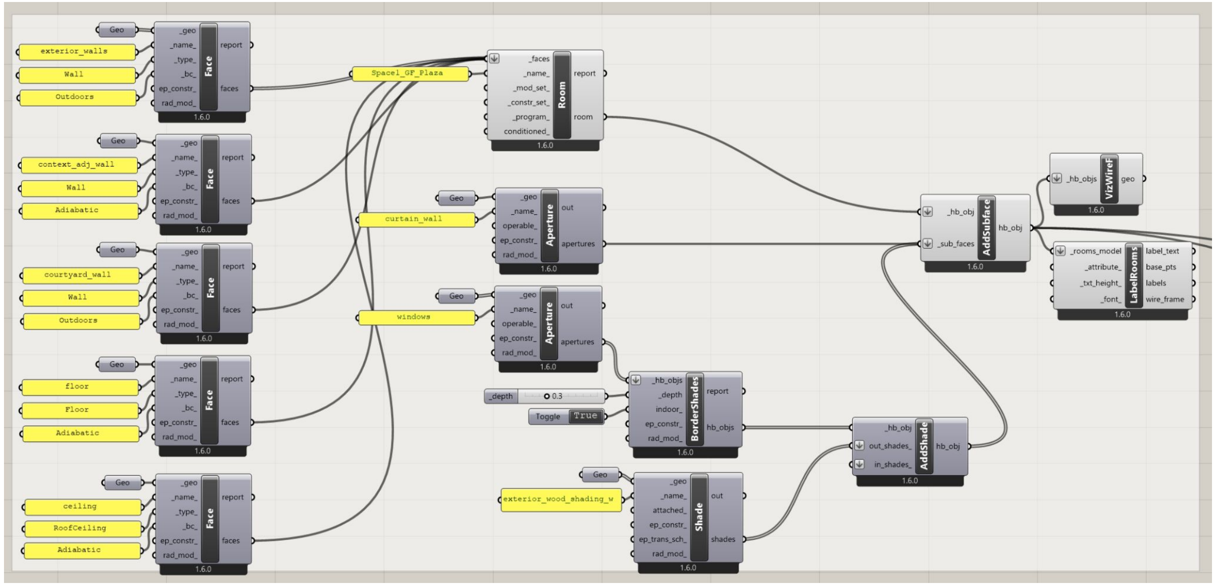


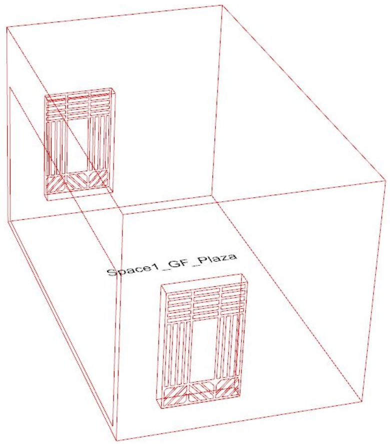
Rhino Surfaces → HB-Faces → HB-Rooms + Solving Adjacency → HB Model

1. Create a Rhino-Model based on **overlapping surfaces with no holes for apertures** (faces & overlapping sub faces) + Assign **types & boundary conditions**
2. Create HB-Model from **HB-Rooms** based on HB-Faces + Solve **room adjacency**
3. Add **context** to the HB-Model
4. Check HB-Model with **"HB Visualize by Type" component**
5. Check assigned generic **HB-Radiance modifier sets** & apply material modifications

Preparing Architectural Building Geometry

Creating HB-Model from HB-Faces based on Rhino-Surfaces



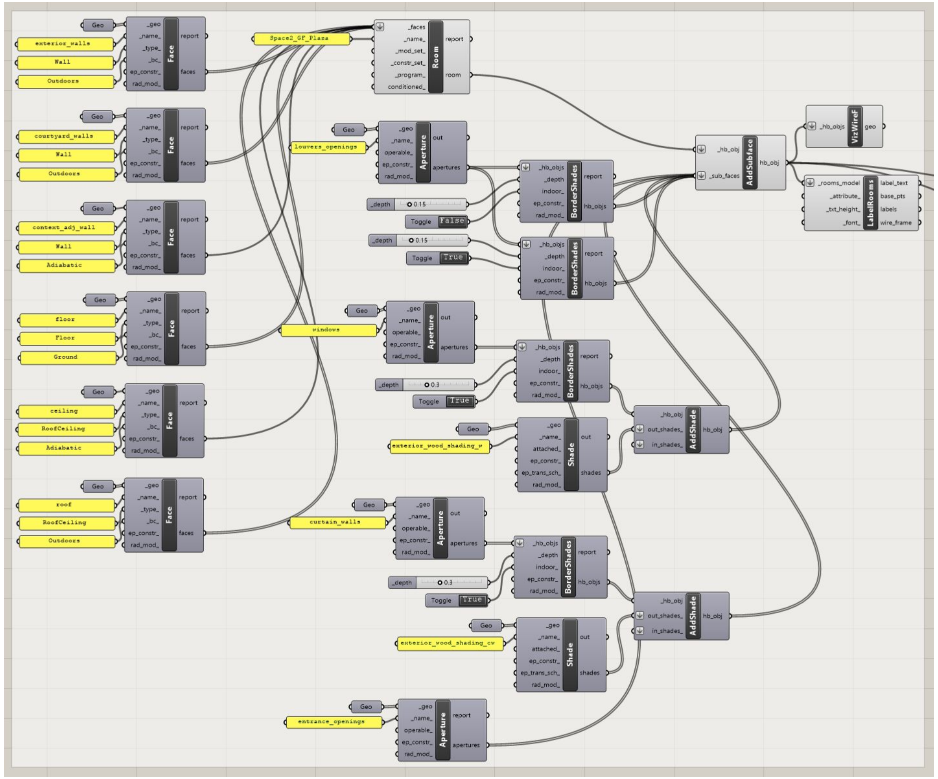


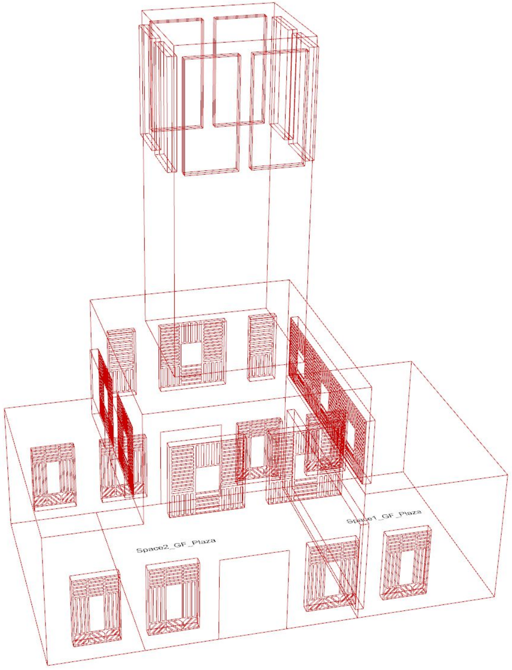
**Note: Each room has to be totally closed. Any additional surfaces in the room create "Room not closed" warning.*

Space 1

Preparing Architectural Building Geometry

Creating HB-Model from HB-Faces based on Rhino-Surfaces

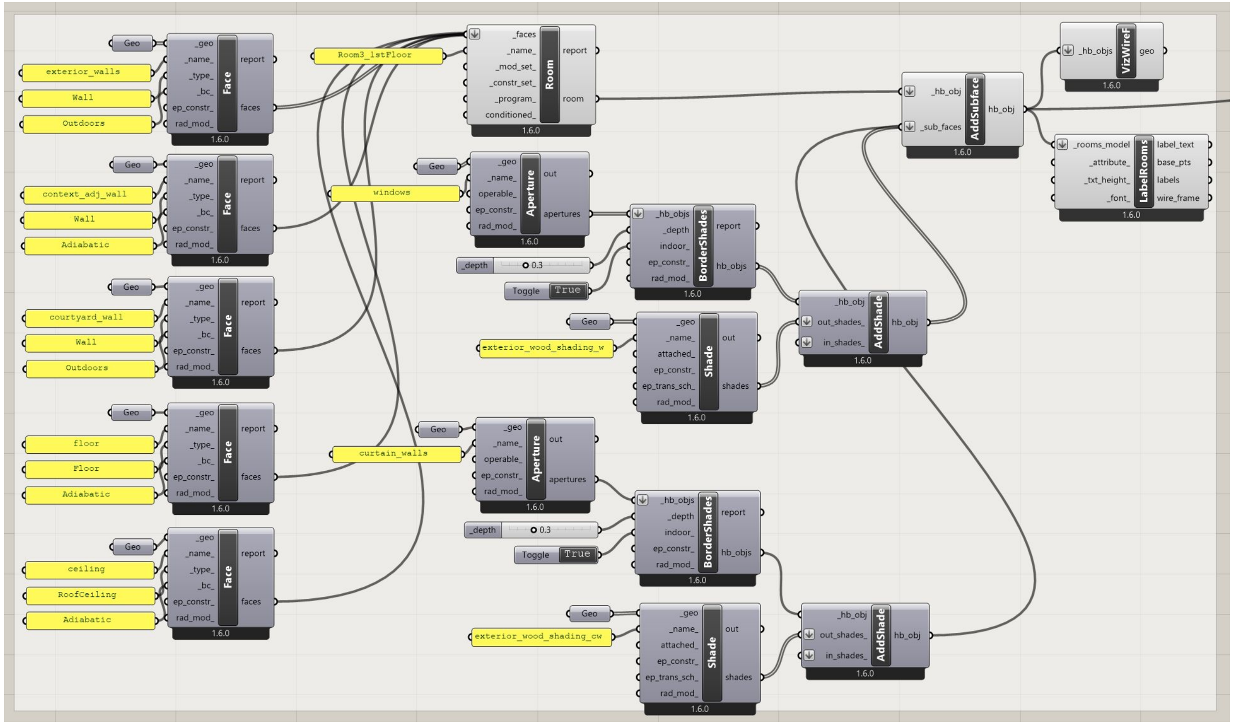


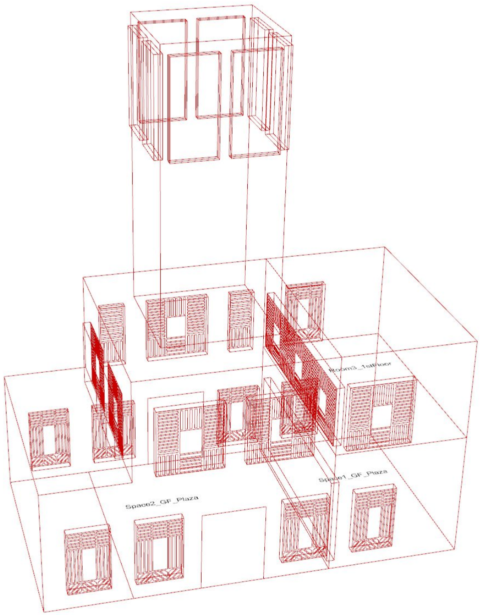


Space 2

Preparing Architectural Building Geometry

Creating HB-Model from HB-Faces based on Rhino-Surfaces

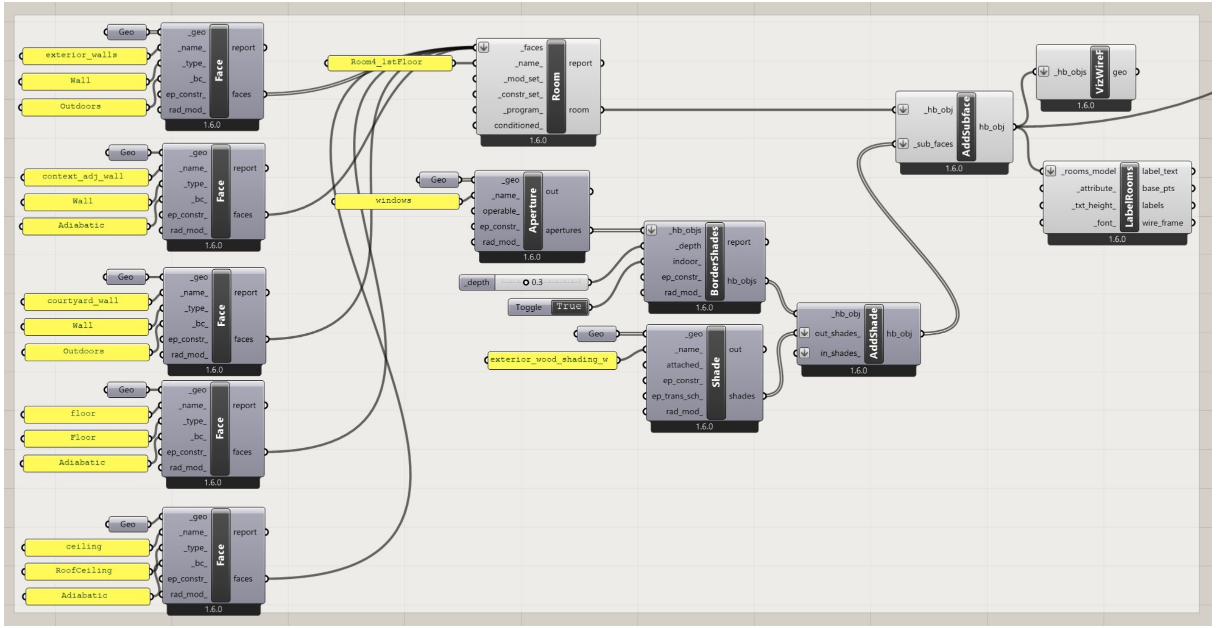


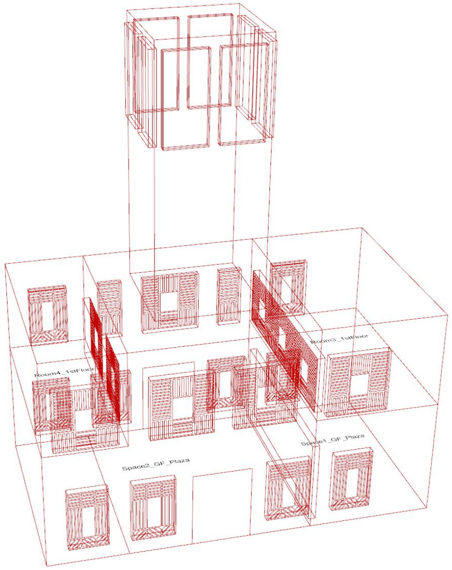


Space 3

Preparing Architectural Building Geometry

Creating HB-Model from HB-Faces based on Rhino-Surfaces

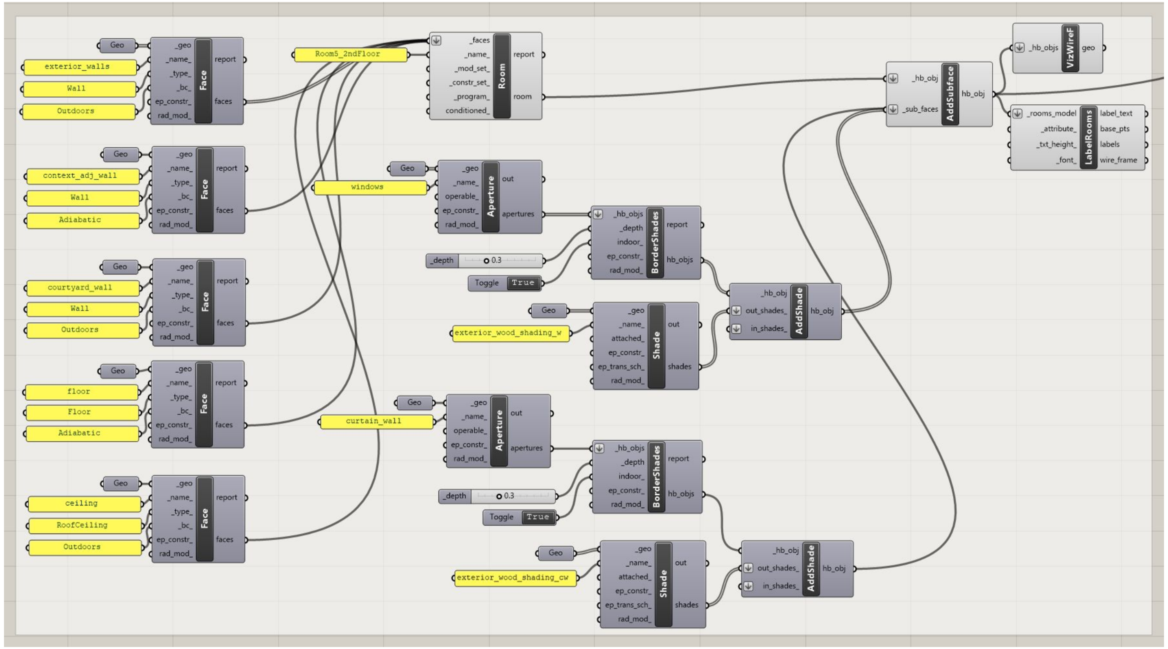


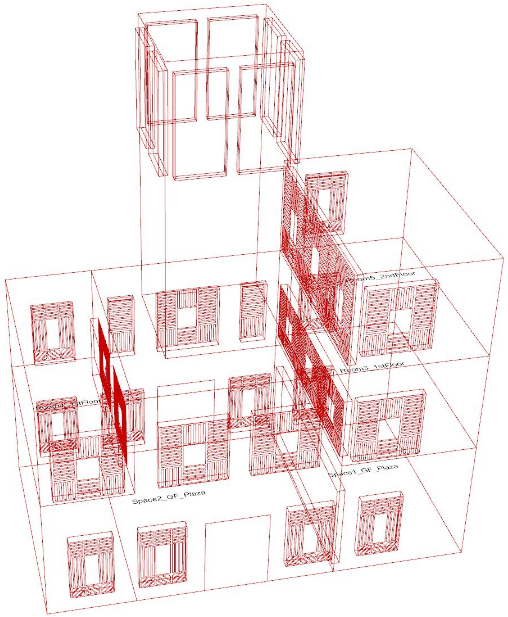


Space 4

Preparing Architectural Building Geometry

Creating HB-Model from HB-Faces based on Rhino-Surfaces

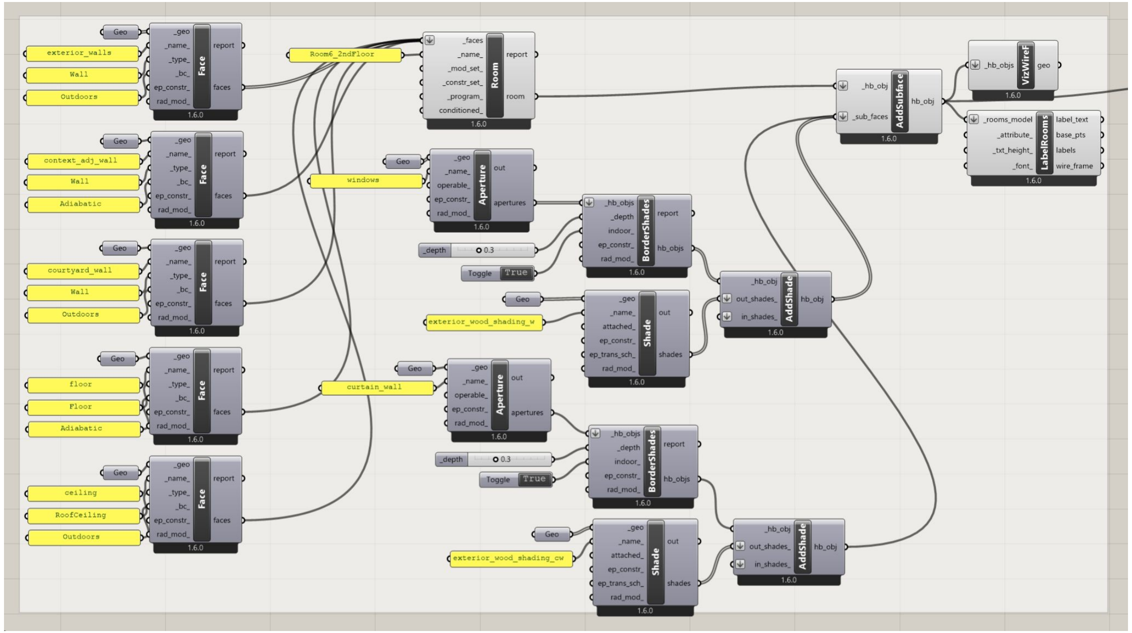


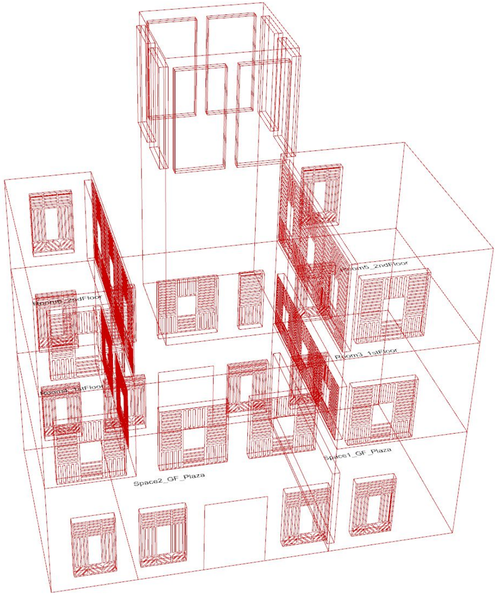


Space 5

Preparing Architectural Building Geometry

Creating HB-Model from HB-Faces based on Rhino-Surfaces

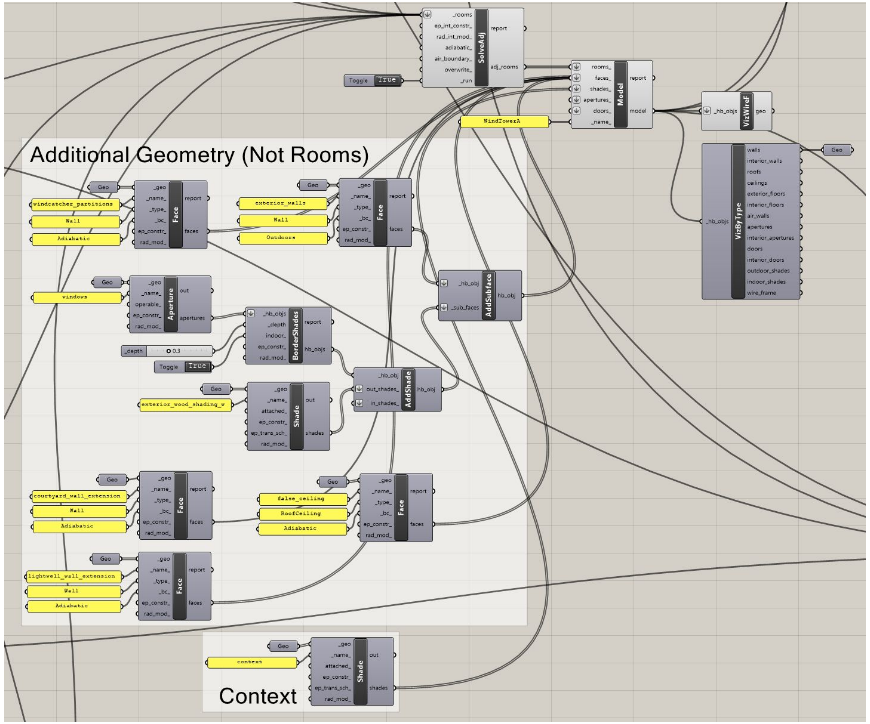


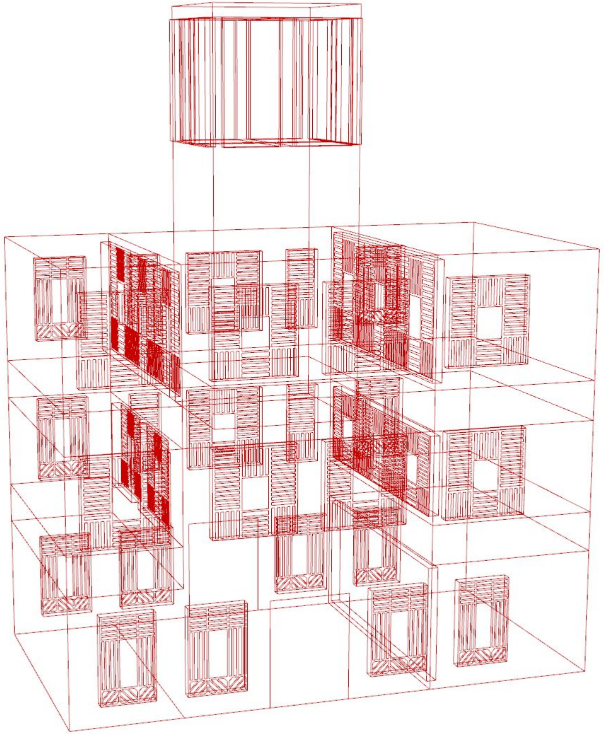


Space 6

Preparing Architectural Building Geometry

Creating HB-Model from HB-Faces based on Rhino-Surfaces

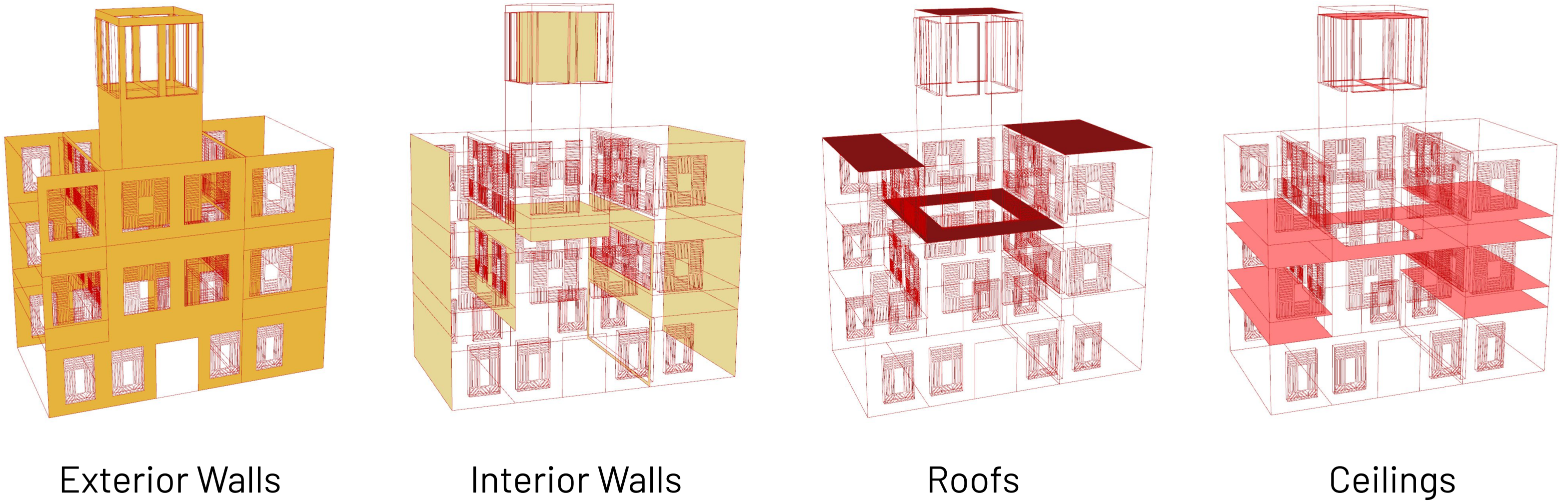




Complete Wind Tower Model

Preparing Architectural Building Geometry

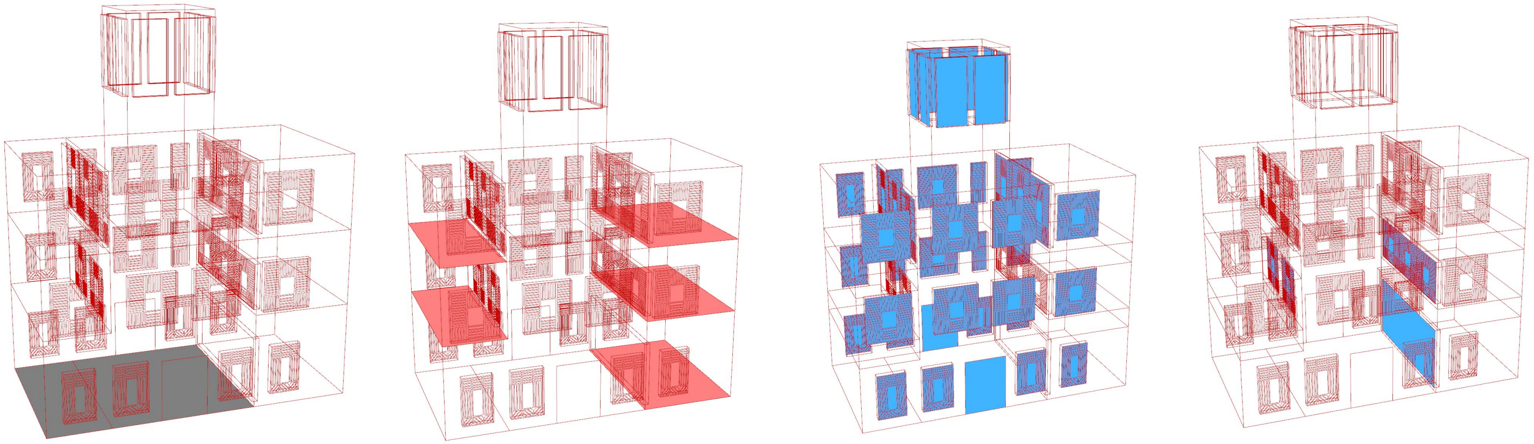
Checking HB-Model with “HB Visualize by Type” Component



Limitations: 1- Wall thicknesses are not considered. Modeling surfaces to represent them & integrating these into the HB code is a bit tedious.

Preparing Architectural Building Geometry

Checking HB-Model with “HB Visualize by Type” Component

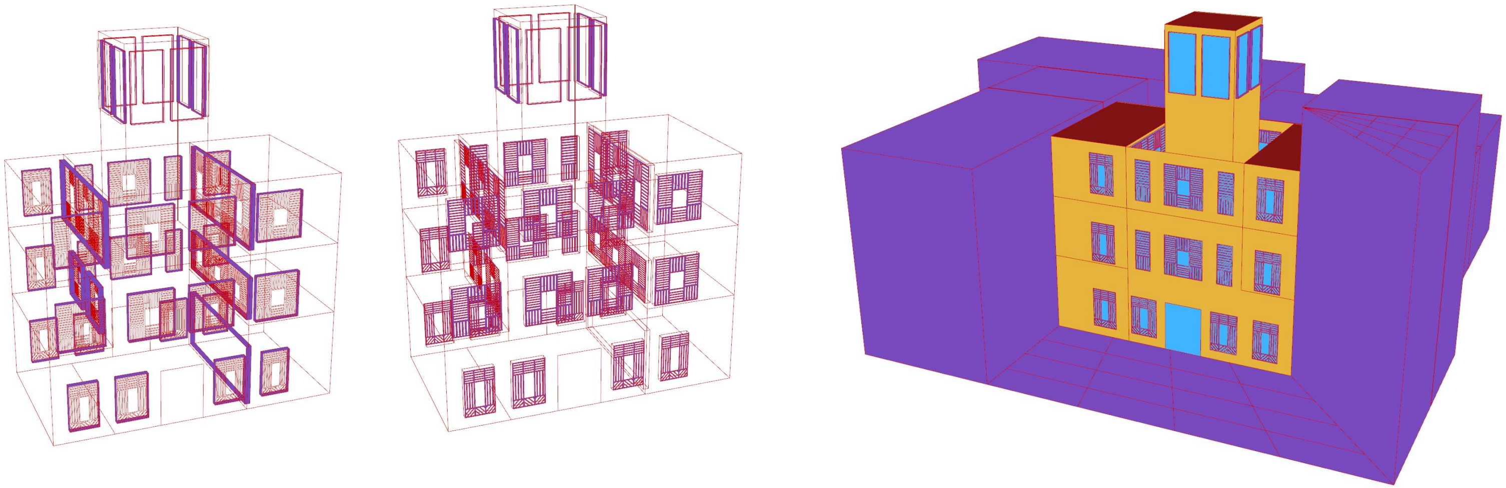


Exterior Floors | Interior Floors | Exterior Apertures | Interior Apertures

Limitations: 2- Some of the facade apertures are actual openings (holes in the wall; e.g. entrances). Here they're automatically getting a default glass modifier.

Preparing Architectural Building Geometry

Checking HB-Model with "HB Visualize by Type" Component



Indoor Shades

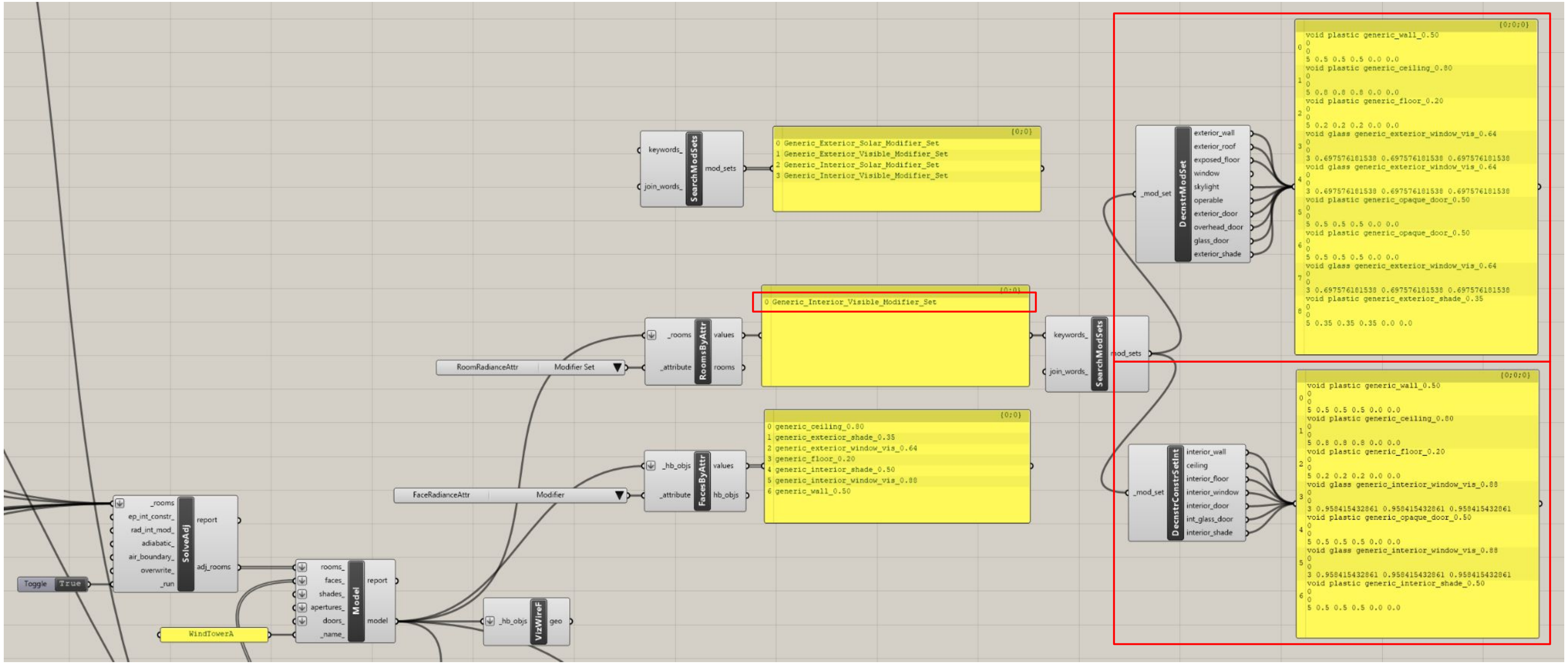
Outdoor Shades (without Context)

Complete Model (with Context)

Limitations: 3- Thickness of wooden shading devices is not considered.

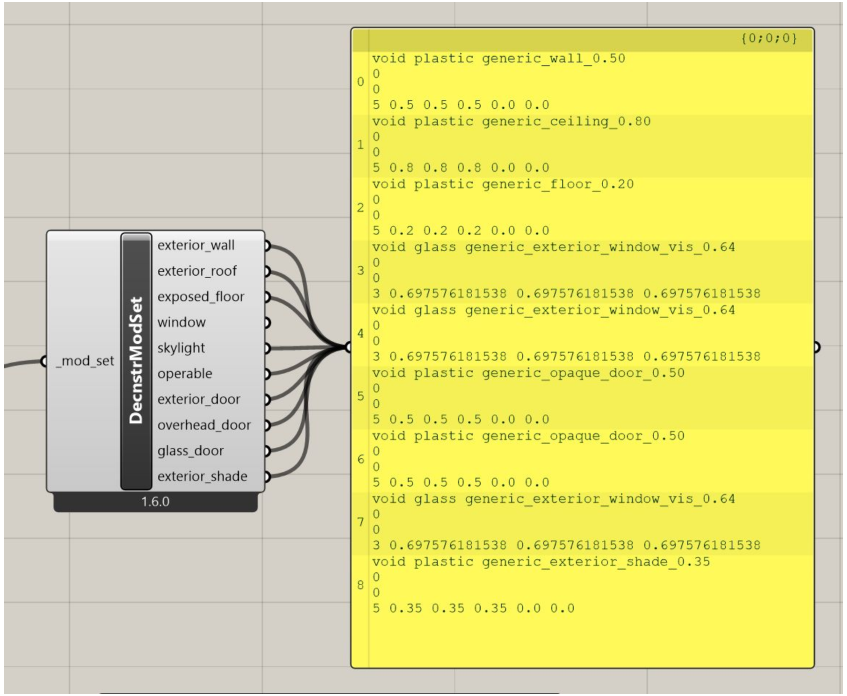
Preparing Architectural Building Geometry

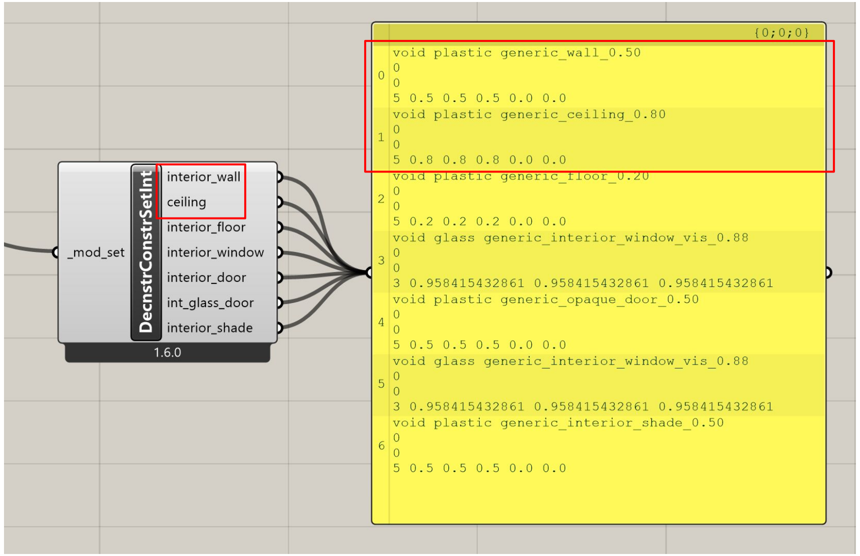
Checking Assigned Generic HB-Radiance Modifiers & Applying Modifications



Preparing Architectural Building Geometry

Checking Assigned Generic HB-Radiance Modifiers & Applying Modifications



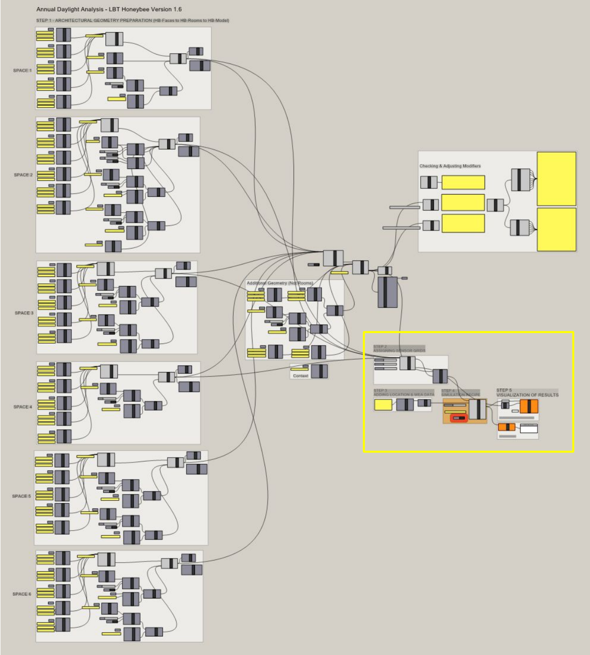


Workflow Overview

- Stage I: Preparation of Louver System Geometry (Radiance BSDF XML File)
- Stage II: Preparation of Architectural Building Geometry (Rhino + LBT 1.6.0 Honeybee)
- **Stage III: Preparation & Running of Annual Daylight Recipe (Honeybee-Radiance)**

Stage 3: Preparing & Running Annual Daylight Simulation Recipe

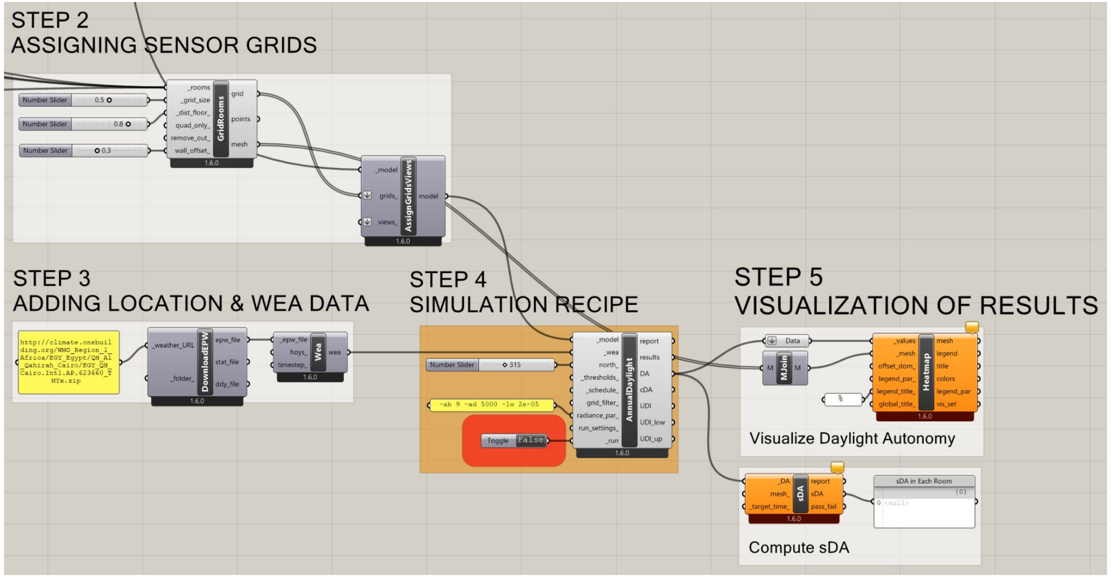
Workflow from Honeybee to Radiance

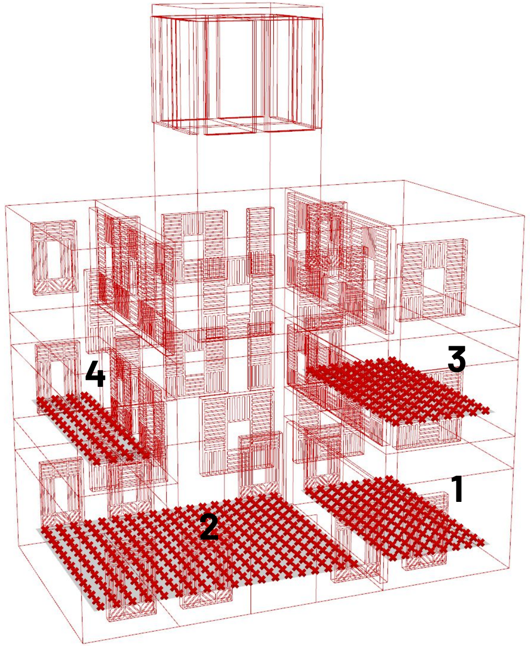


1. Assigning HB & Radiance Sensor Grids to Rooms
2. Adding Location, Climate & Weather Data
3. **Running Annual Daylight Simulation Recipe**
4. Visualizing Results

Stage 3: Preparing & Running Annual Daylight Simulation Recipe

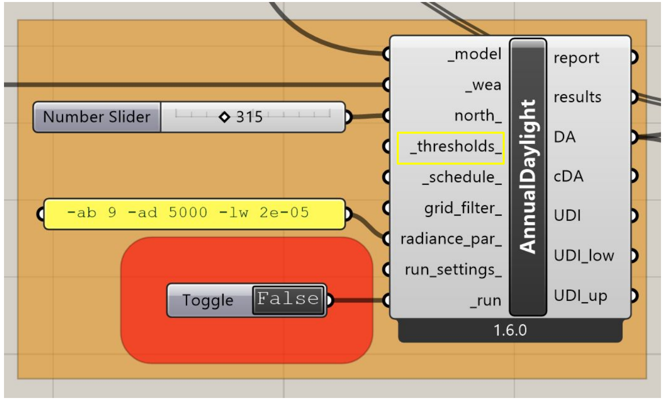
Workflow from Honeybee to Radiance





Preparing & Running Annual Daylight Simulation Recipe

Understanding Simulation Recipe Parameters & Results



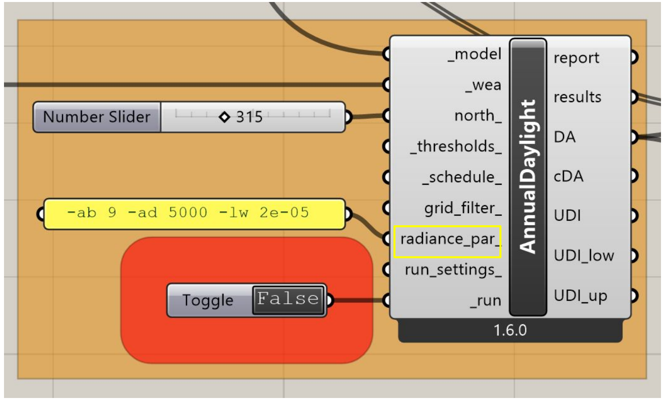
Annual Daylight Metrics & Thresholds

- **Daylight Autonomy (DA in %):** percentage of occupied hours where each sensor receives equal or more than the illuminance threshold of 300 lux
- **Spatial Daylight Autonomy (sDA in %):** percentage of floor area achieving at least 300 lux for at least half of the analysis hours (8 am - 6 pm); acceptable percentage is 55 % & optimum target percentage is 75%
- **Useful Daylight Illuminance (UDI in %):** percentage of occupied hours where illuminance falls between minimum & maximum thresholds of 100 & 3000 lux

Annual Daylight Thresholds left to **default values: -t 300 -lt 100 -ut 3000*

Preparing & Running Annual Daylight Simulation Recipe

Understanding Simulation Recipe Parameters & Results



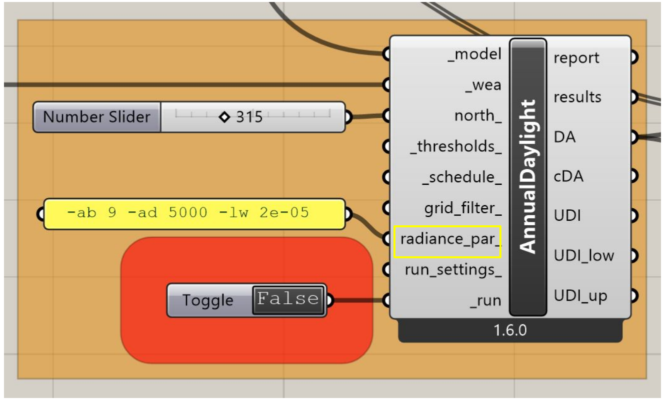
Radiance Ray Tracing Parameters

- **-ab (ambient bounces):**
  number of bounces traced
- **-ad (ambient divisions) :**
  number of rays spawned at each surface intersection
- **-lw (limit weight):**
  minimum weight of a ray that is traced

HB-Radiance** *default raytracing parameters for Annual Daylight Recipe (-ab 2 -ad 5000 -lw 2e-05)* ***adjusted first to *-ab 9 -ad 5000 -lw 2e-05* ***and then to*** *-ab 15 -ad 10 000 -lw 2e-05.*

Preparing & Running Annual Daylight Simulation Recipe

Understanding Simulation Recipe Parameters & Results



HB-Radiance default raytracing parameters for Annual Daylight Recipe -ab 2 -ad 5000 -lw 2e-05* ***adjusted first to* *-ab 9 -ad 5000 -lw 2e-05* ***and then to*** *-ab 15 -ad 10 000 -lw 2e-05.*

Radiance Ray Tracing Parameters

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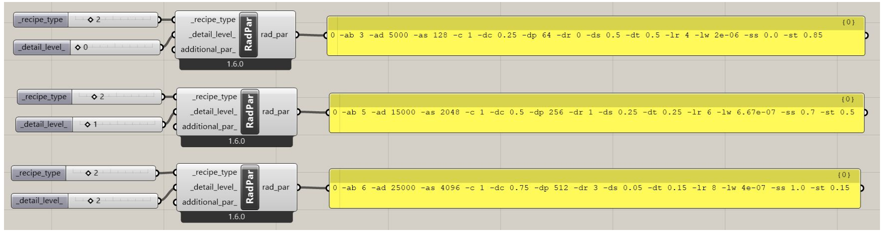


Additional ***"HB Radiance Parameter" component****, where* ***"recipe type"*** *could be decided (here: rfluxmtx) & parameters could be set based on* ***"detail level".***

Preparing & Running Annual Daylight Simulation Recipe

Understanding Simulation Recipe Parameters & Results

What happens when the code runs?

- GenerateSunpath, CreateSkyDome, CreateDirectSky, CreateTotalSky, CreateRadFolder, ParseSunUpHours (gendaymtx)
- **PrepareMultiPhase** (oconv, rcontrib)
- DirectSky, TotalSky, DirectSunlight, DirectSunlightToNpy
- OutputMatrixMath, RestructureTotalResults, RestructureDirectSunlightResults, CalculateAnnualMetrics

C:\Users\MIRA\ladybug_tools\python\Scripts\queenbee.exe

```
2023-08-20 17:17:41 INFO: Started running GenerateSunpath...
2023-08-20 17:17:41 INFO: gendaymtx: reading weather tape 'sky.wea'
2023-08-20 17:17:41 INFO: gendaymtx: location 'Cairo.Intl.AP'
2023-08-20 17:17:41 INFO: gendaymtx: (lat,long)=(30.1,-31.4) degrees north, west
2023-08-20 17:17:41 INFO: gendaymtx: outputting suns to file
2023-08-20 17:17:41 INFO: gendaymtx: rotating output 315 degrees
2023-08-20 17:17:41 INFO: gendaymtx: done.
2023-08-20 17:17:41 INFO: ...finished running GenerateSunpath in 0:00:00
2023-08-20 17:17:41 INFO: Started running CreateSkyDome...
2023-08-20 17:17:41 INFO: Started running CreateDirectSky...
2023-08-20 17:17:41 INFO: Started running CreateTotalSky...
2023-08-20 17:17:42 INFO: Started running CreateRadFolder...
```

Which Method is this?
2-Phase, 3-Phase or 5-Phase?

*According to "Honeybee-Radiance Primer" the simulation recipe uses an **enhanced 2-Phase Method**.*

DAY - [source code]

Run an annual daylight study for a Honeybee model to compute hourly illuminance for each sensor in a model's sensor grids.

This recipe uses an enhanced 2-phase method for daylight simulation which accurately models direct sun by tracing rays from each sensor to the solar position at each hour of the calculation.

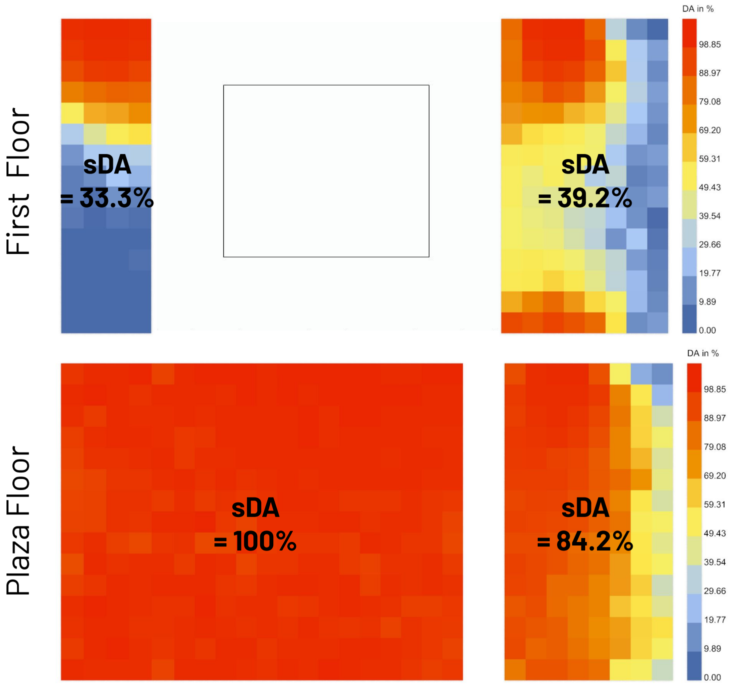
https://docs.ladybug.tools/hb-radiance-primer/components/3_recipes/annual_daylight

Preparing & Running Annual Daylight Simulation Recipe

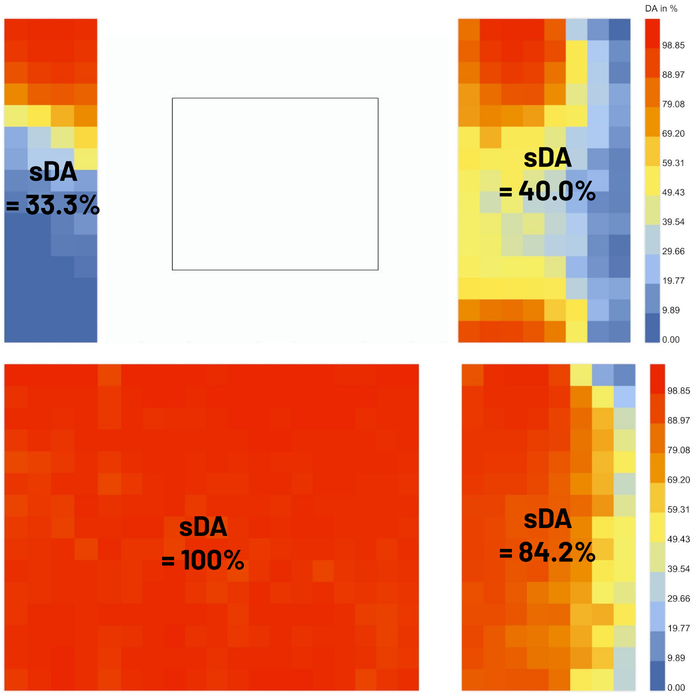
Measuring the Effect of Wind Tower Openings on Daylight Performance

-ab 9 -ad 5000 -lw 2e-05

Totally Closed Wind Tower Openings (Hypothetical)



Totally Opened Wind Tower Openings (Hypothetical)



Preparing & Running Annual Daylight Simulation Recipe

Measuring the Effect of Wind Tower Openings on Daylight Performance

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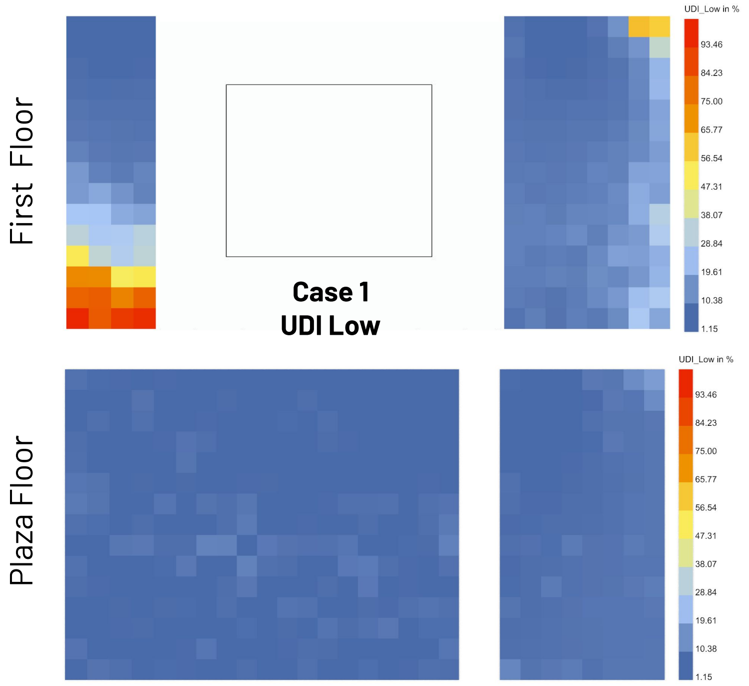
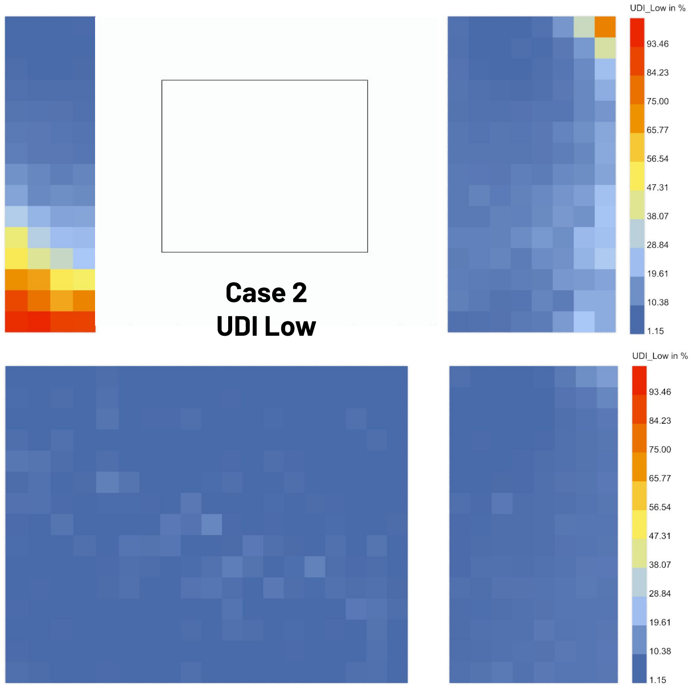
Totally Closed Wind Tower Openings (Hypothetical)



Totally Opened Wind Tower Openings (Hypothetical)



Preparing & Running Annual Daylight Simulation Recipe

Measuring the Effect of Wind Tower Openings on Daylight Performance

-ab 9 -ad 5000 -lw 2e-05

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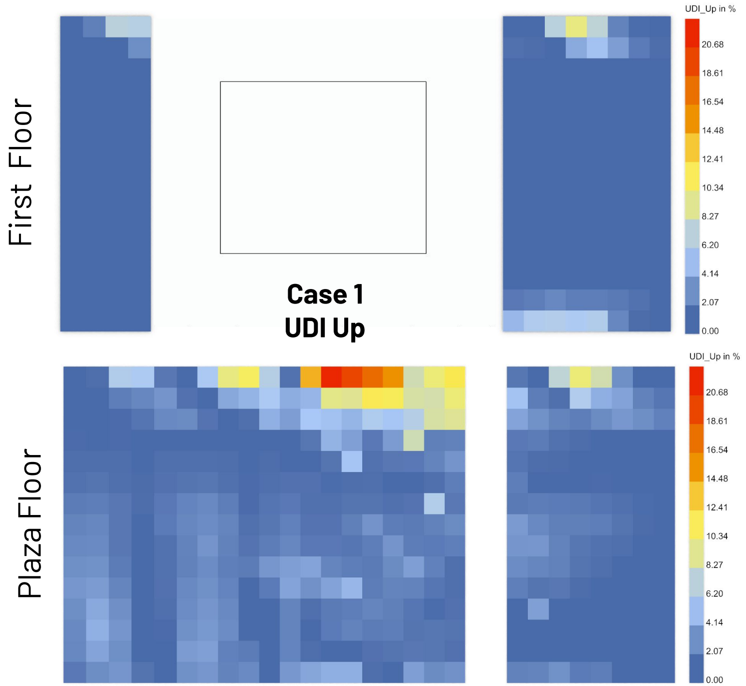
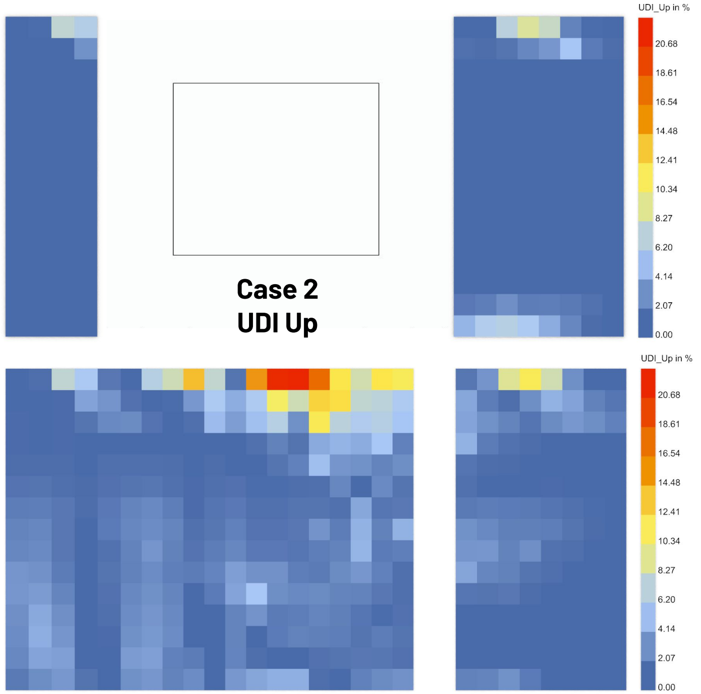
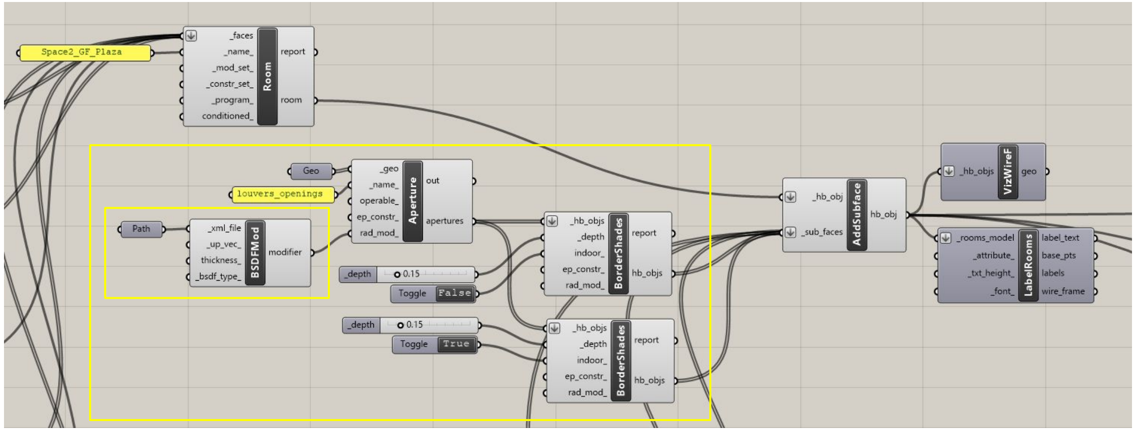


Totally Opened Wind Tower Openings (Hypothetical)

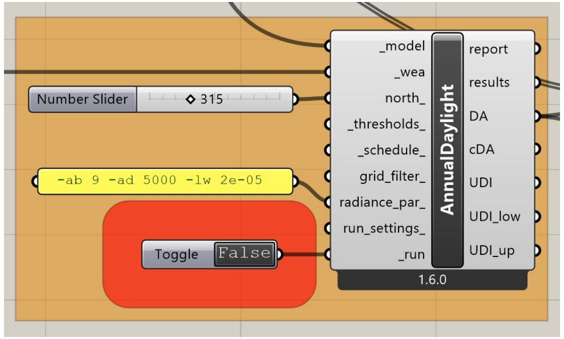


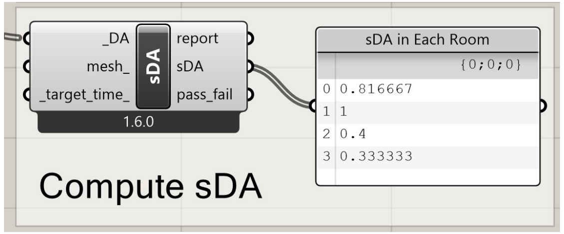
Preparing Louver System Geometry

Integrating BSDF XML File in Honeybee Code



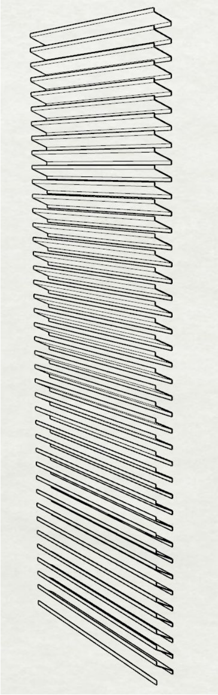
Annual Daylight Recipe takes around 20 min to generate results.

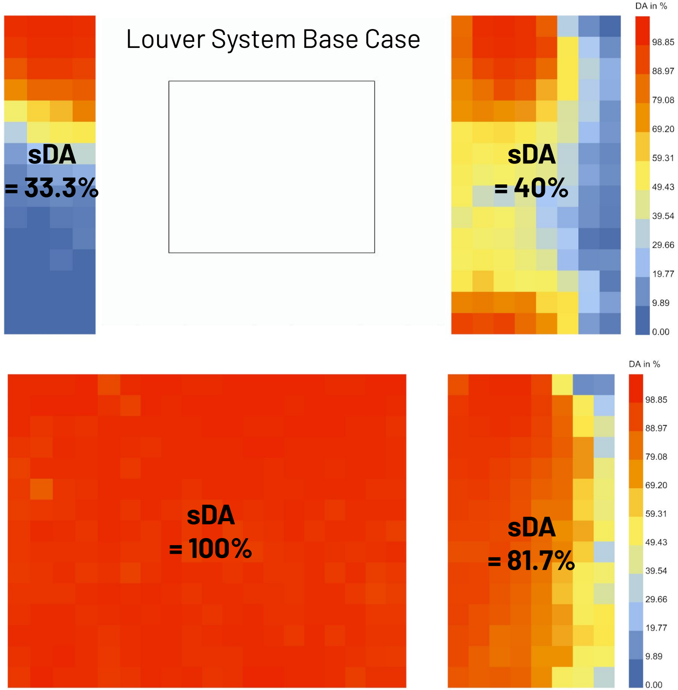




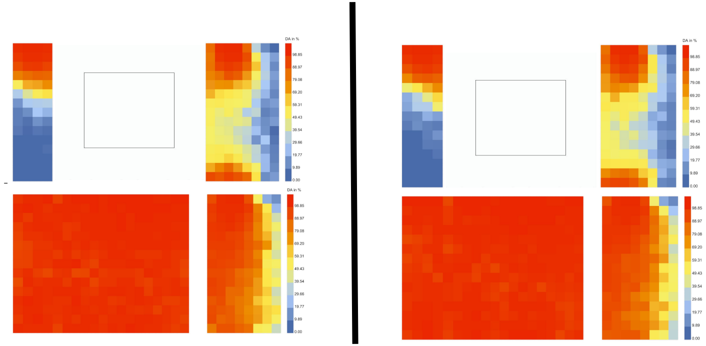
Preparing Louver System Geometry

Analyzing Annual Daylight Metrics Results after Integrating BSDF XML File in Honeybee Code





-ab 9 -ad 5000 -lw 2e-05



Totally Closed

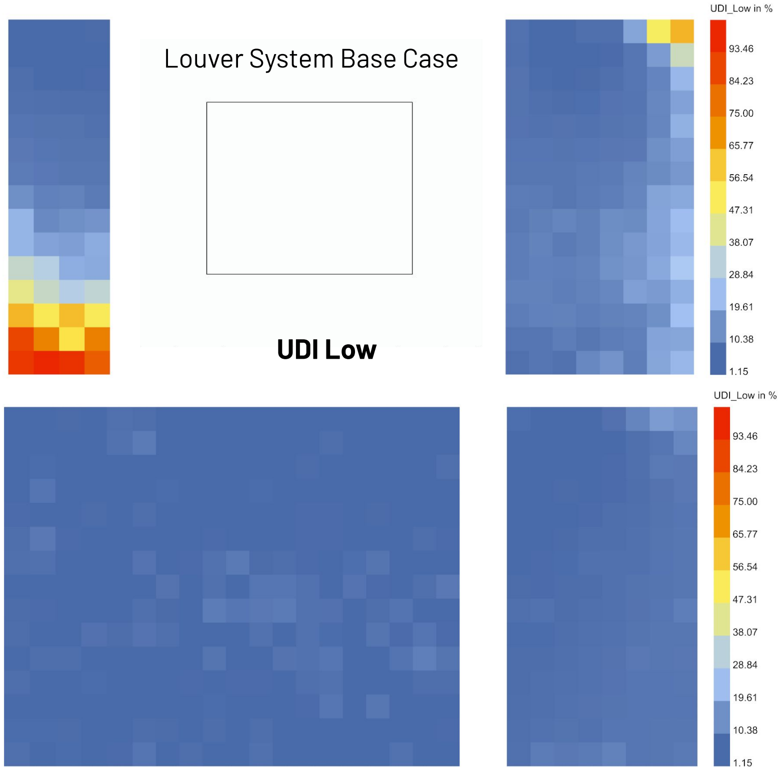
Totally Opened

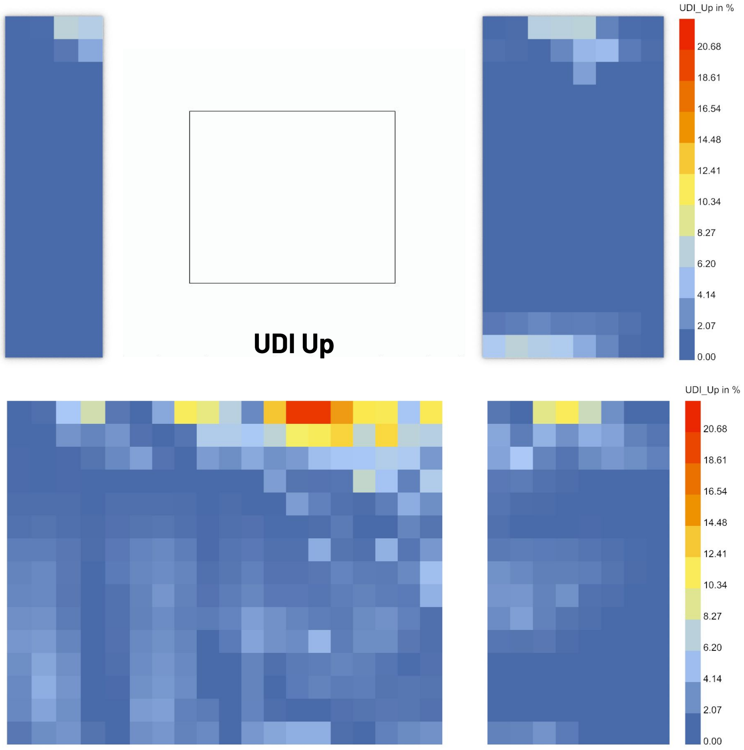
First Generic Cases

Preparing Louver System Geometry

Integrating BSDF XML File in Honeybee Code

-ab 9 -ad 5000 -lw 2e-05



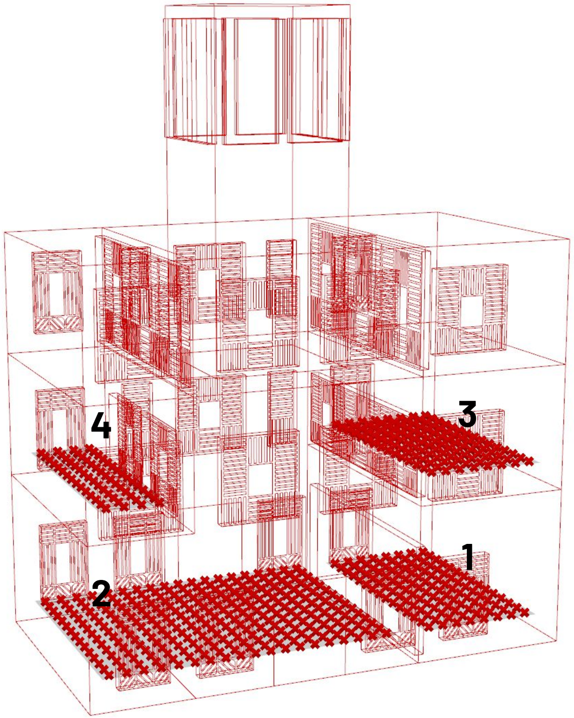


Preparing & Running Annual Daylight Simulation Recipe

Measuring the Effect of Wind Tower Openings on Daylight Performance

Analysis of sDA values for Round 1
Radiance Parameters for Simulation Recipe = -ab 9 -ad 5000 -lw 2e-05

Room Name	Totally Closed Wind Tower Openings	Base Case Scenario with Louver System BSDF	Totally Opened Wind Tower Openings
Room 1	84.2%	81.7%	84.2%
Room 2	100.0%	100.0%	100.0%
Room 3	39.2%	40.0%	40.0%
Room 4	33.3%	33.3%	33.3%



Conclusion for Optimization (according to all cases):

- Spaces 1 & 2 are already well lit.
- Rooms 3 & 4 need daylight performance optimization.

Preparing & Running Point-in-Time Simulation Recipe (Qualitative)

Point-In-Time Analysis for the 3 Cases for 21st September at 3 pm

Option A: Select values based on the Detail level

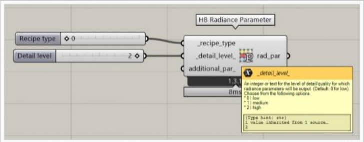
Given that the detail level that you select defines the radiance parameters for the simulation, you should choose it based on the complexity of your model. As a rule of thumb, we can say that:

0-Low level: Corresponds to a room with window without shading

1-Medium level: Can be used for the parametric analysis of the interior of a room with windows and simple shading.

2-High level: Can be used for the analysis of the interior of a deep room without shade or a normal room with complex shading.

In case you want to set an even higher level of detail (e.g. for a deep room with complex shading) or you want to further adjust the radiance parameters, you can hold a convergence test as described next.



Radiance parameters based on Detail level

Option B: Customize the values based on a convergence test

A 'convergence test' is always recommended to find the most suitable set of ambient parameters for a given scene (3D geometry and optical properties). The test consists of running multiple simulations and gradually increasing the 'resolution' of the ray-tracing process by changing one parameter at a time. The radiance ambient parameters that can be specified are:

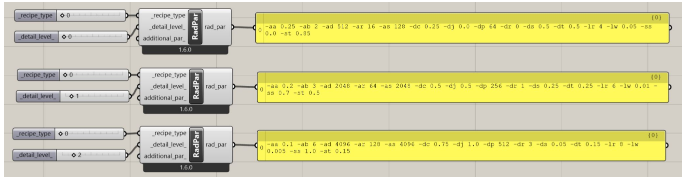
-ab: ambient bounces (number of inter-reflections to take into account)

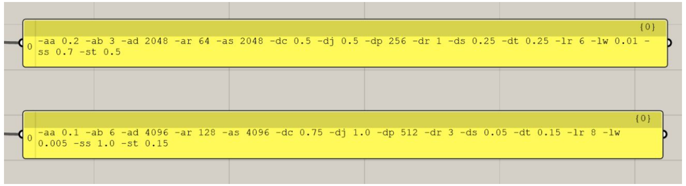
-aa: ambient accuracy (maximum error allowed in the ambient interpolation)

-ar: ambient resolution (density of sample points for detailed regions)

-ad: ambient divisions (number of rays in the sampling hemisphere)

-as: ambient super-samples (additional rays for highly varying regions)





References:
https://www.ladybug.tools/radiance/image-parameters#grid
http://wiki.bk.tudelft.nl/toi-pedia/Honeybee_Intermezzo_6:_Customized_set_of_radiance_parameters

Preparing & Running Point-in-Time Simulation Recipe (Qualitative)

Point-In-Time Analysis for the 3 Cases for 21st September at 3 pm

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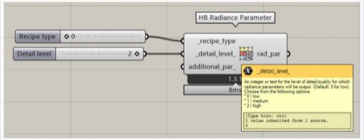

Radiance parameters based on Detail level

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-ar: ambient resolution (density of sample points for detailed regions)

-ad: ambient divisions (number of rays in the sampling hemisphere)

-as: ambient super-samples (additional rays for highly varying regions)

	→ Increasing accuracy of ambient calculation →				
-ab (ambient bounces)	1	2	3	4	5
-aa (ambient accuracy)	0.4	0.2	0.1	0.05	-
-ar (ambient resolution)	8	16	32	64	128
-ad (ambient divisions)	32	64	128	256	512
-as (ambient super-samples)	Set at most equal to -ad /2				

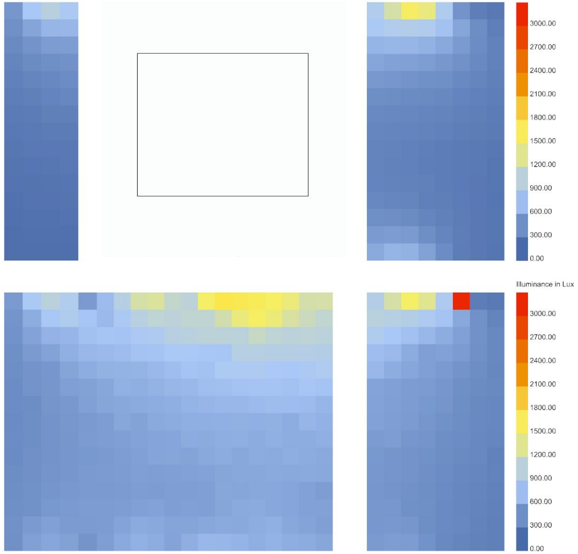
Systematically trying out different iterations of the input parameters till the outcome values stop changing significantly, showing stabilized results.

References:
https://www.ladybug.tools/radiance/image-parameters#grid
http://wiki.bk.tudelft.nl/toi-pedia/Honeybee_Intermezzo_6:_Customized_set_of_radiance_parameters

Preparing & Running Point-in-Time Simulation Recipe (Qualitative)

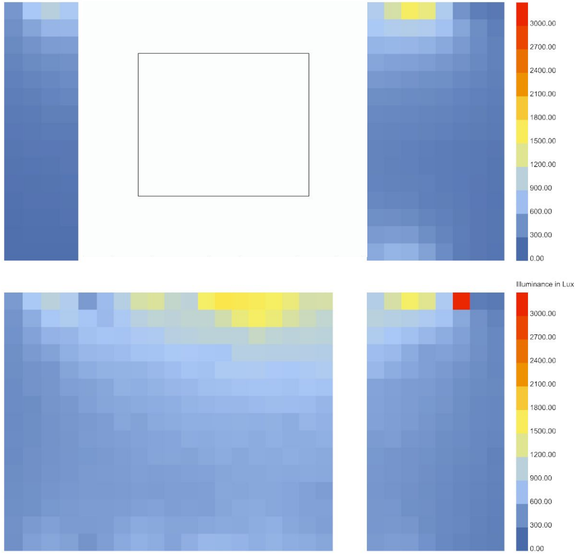
Point-In-Time Analysis for the 3 Cases for 21st September at 3 pm

Totally Closed WT Openings



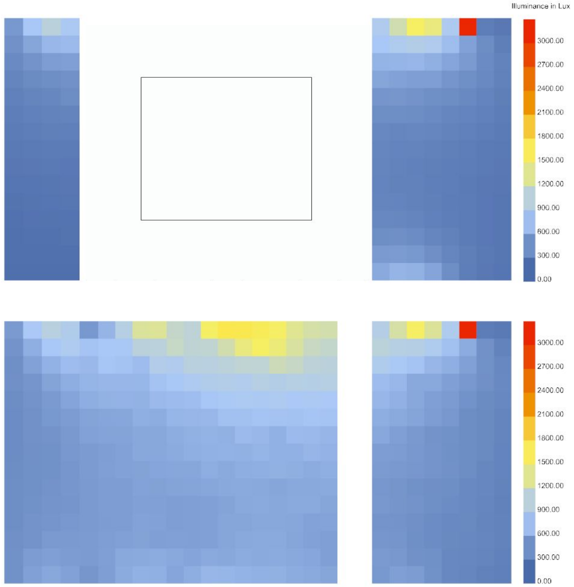
medium detail level; simulation time = 10 min

WT Openings with Base Case BSDF



high detail level; simulation time = 45 min

Totally Opened WT Openings

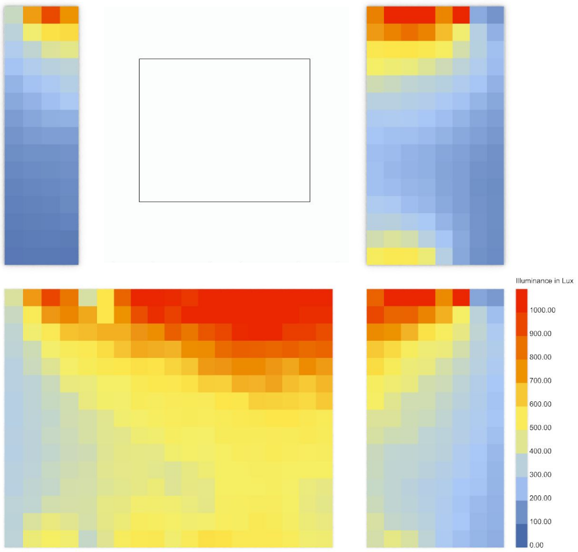


medium detail level; simulation time = 10 min

Preparing & Running Point-in-Time Simulation Recipe (Qualitative)

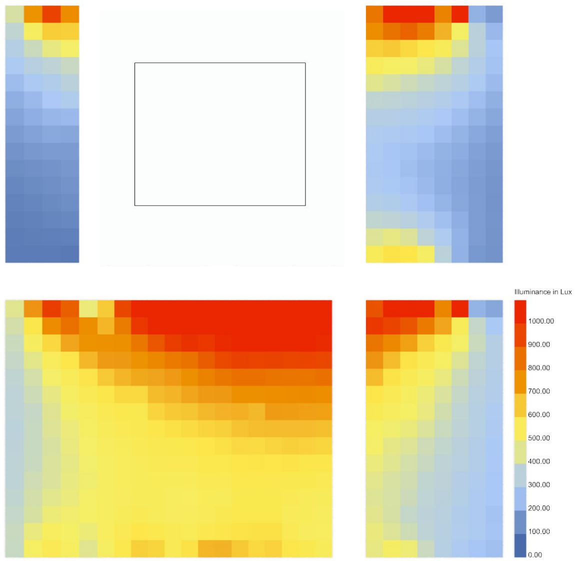
Point-In-Time Analysis for the 3 Cases for 21st September at 3 pm

Totally Closed WT Openings



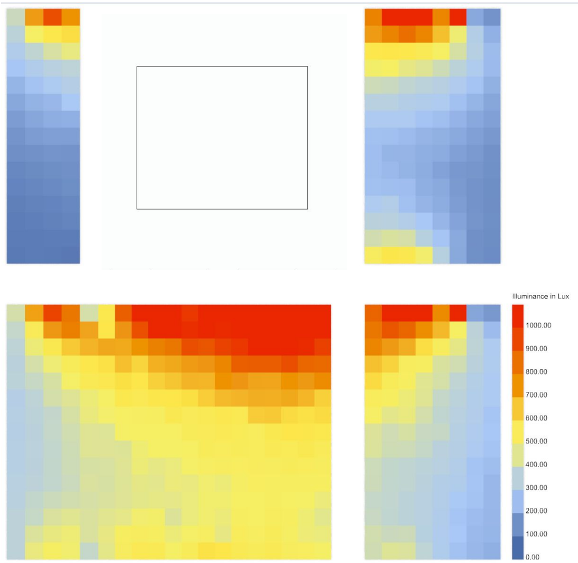
medium detail level; simulation time = 10 min

WT Openings with Base Case BSDF



high detail level; simulation time = 45 min

Totally Opened WT Openings



medium detail level; simulation time = 10 min

Approach #2: Ladybug Legacy Tools Honeybee[+] 0.0.06

Workflow Overview

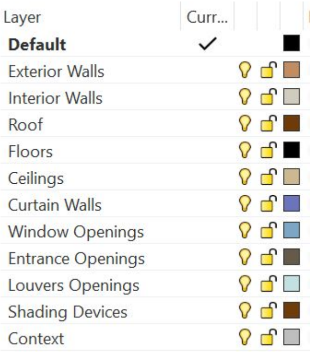
- Stage I: Preparation of Louver System Geometry (Radiance BSDF XML File)
- **Stage II: Preparation of Architectural Building Geometry (Rhino & LBT Honeybee[+] 0.0.06)**
- Stage III: Preparation & Running of Annual Daylight Recipe (Honeybee-Radiance)

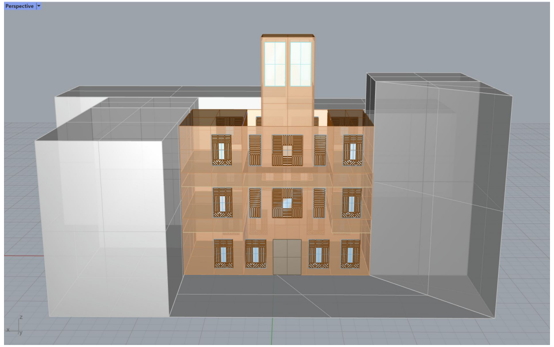
Stage 2: Preparing Architectural Building Geometry

Geometry Preparation Workflow from Rhino to Honeybee[+]

Model Creation Workflow

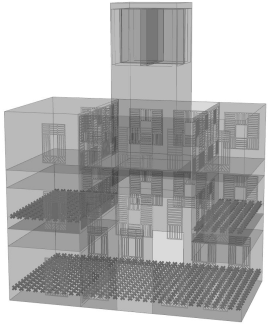
(from Rhino ...)

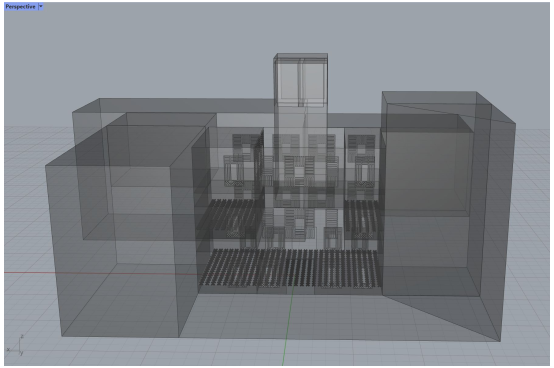




Model Creation Workflow

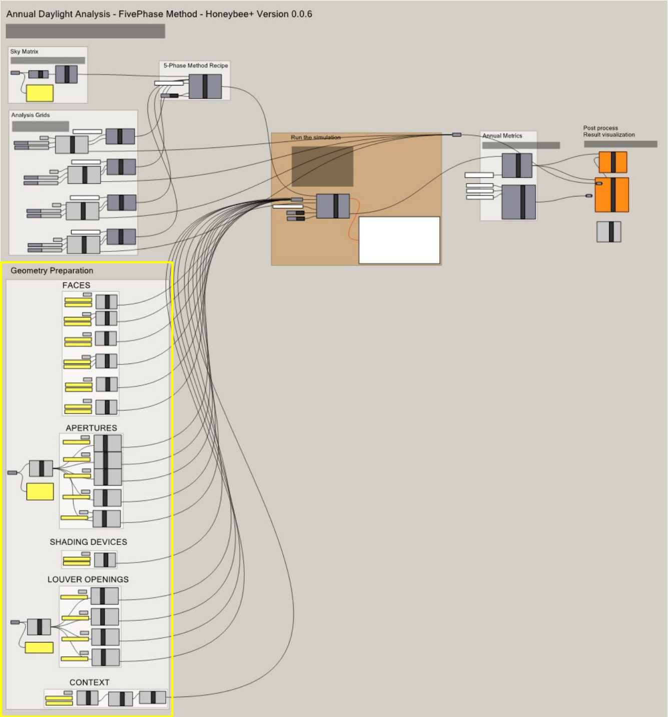
(... to LBT Honeybee[+] 0.0.06)





Stage 2: Preparing Architectural Building Geometry

Geometry Preparation Workflow from Rhino to Honeybee[+]

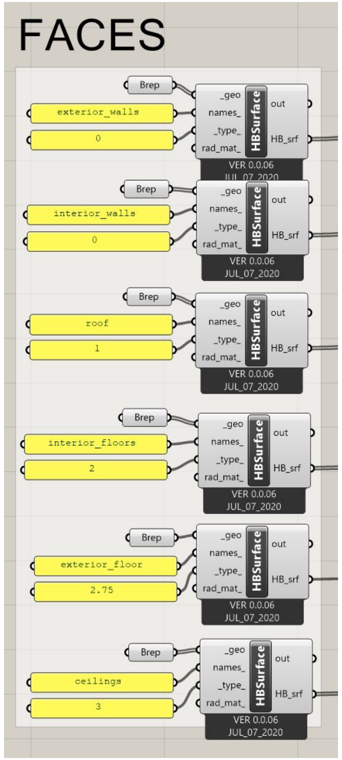


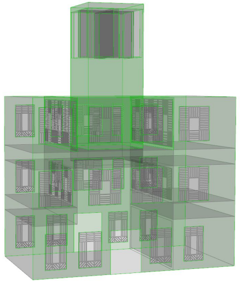
Rhino Surfaces → HB-Faces → HB-Objects

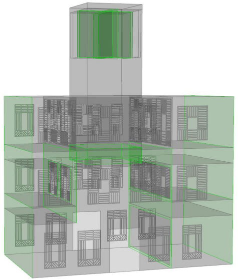
1. Create a Rhino-Model based on **surfaces with holes for apertures**
2. Assign **face types for default modifiers** to be assigned (walls, roofs, floors, ceilings, windows, context etc.)
3. Create **context & RAD scene**

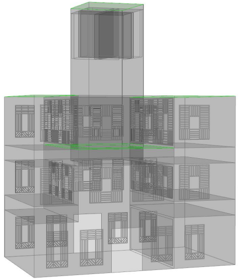
Stage 2: Preparing Architectural Building Geometry

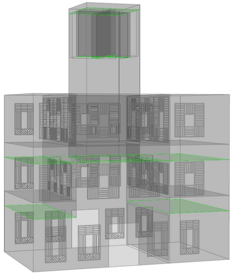
Geometry Preparation Workflow from Rhino to Honeybee[+]

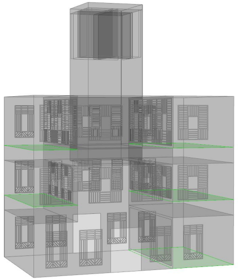


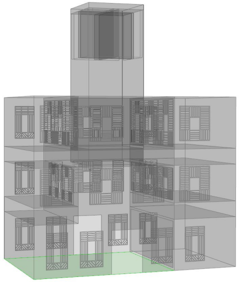

Exterior Walls

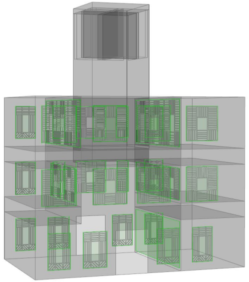

Interior Walls

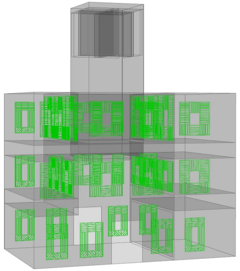

Roofs


Ceilings


Interior Floors

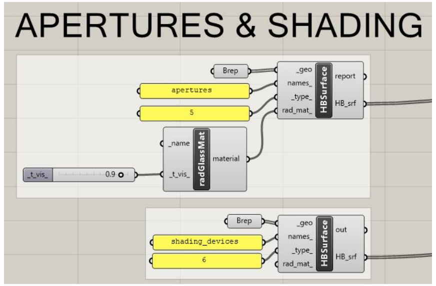

Exterior Floors

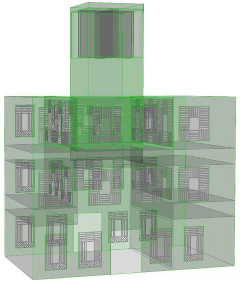

Windows

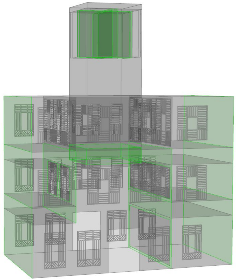

Window Shades

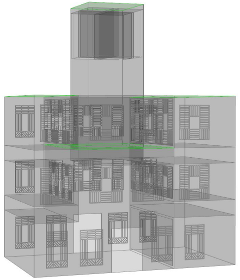
Stage 2: Preparing Architectural Building Geometry

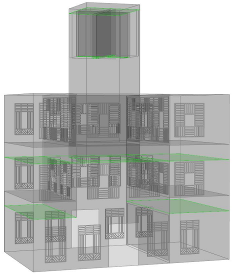
Geometry Preparation Workflow from Rhino to Honeybee[+]

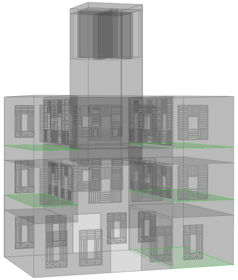


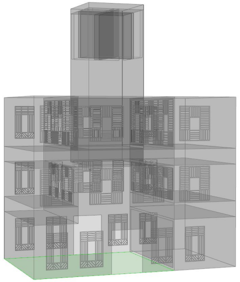

Exterior Walls

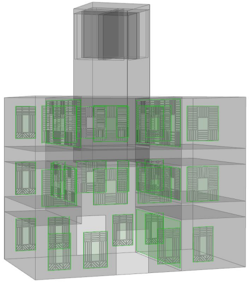

Interior Walls

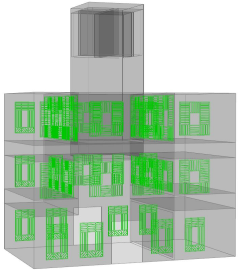

Roofs


Ceilings


Interior Floors

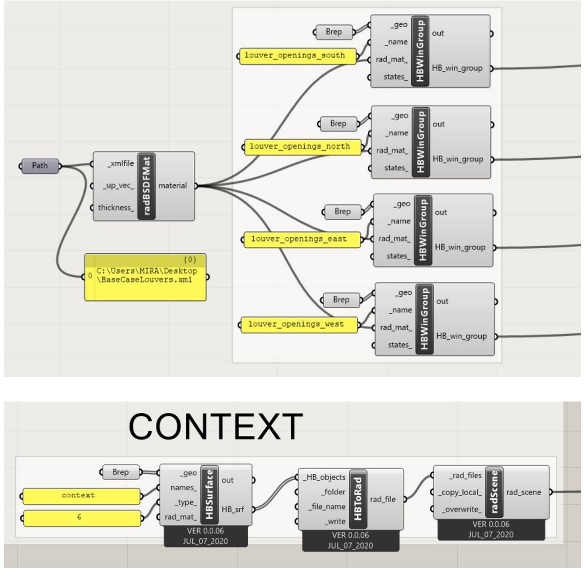

Exterior Floors

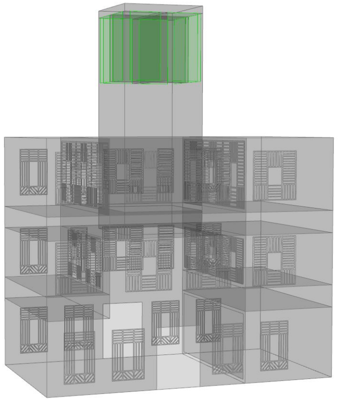

Windows


Window Shades

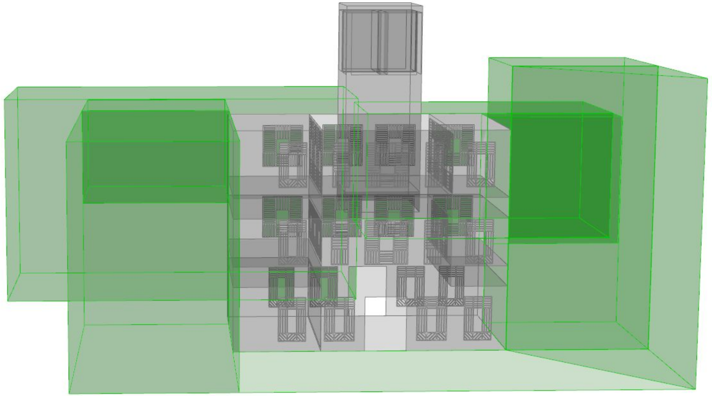
Stage 2: Preparing Architectural Building Geometry

Geometry Preparation Workflow from Rhino to Honeybee[+]





Louver Openings



Context

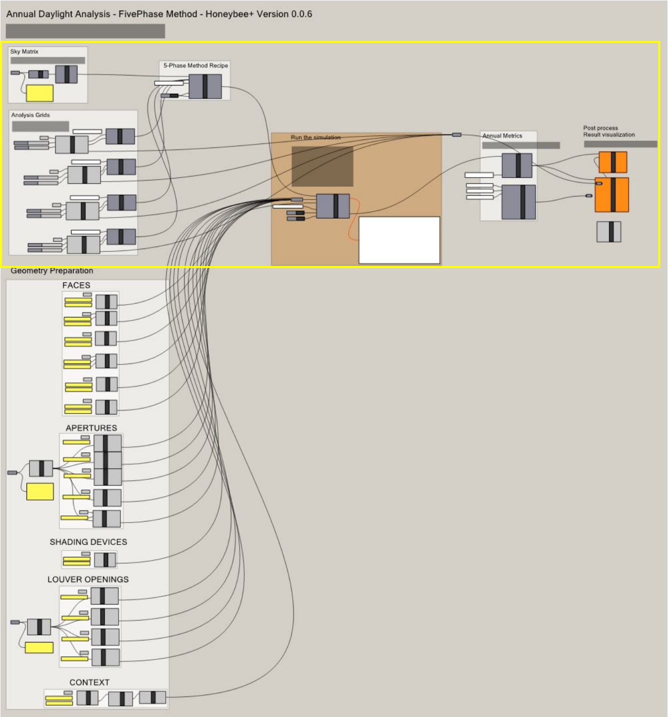
Approach #2: Ladybug Legacy Tools Honeybee[+] 0.0.06

Workflow Overview

- Stage I: Preparation of Louver System Geometry (Radiance BSDF XML File)
- Stage II: Preparation of Architectural Building Geometry (Rhino & LBT Honeybee[+] 0.0.06)
- **Stage III: Preparation & Running of Annual Daylight Recipe (Honeybee-Radiance)**

Stage 3: Preparing & Running Annual Daylight Simulation Recipe

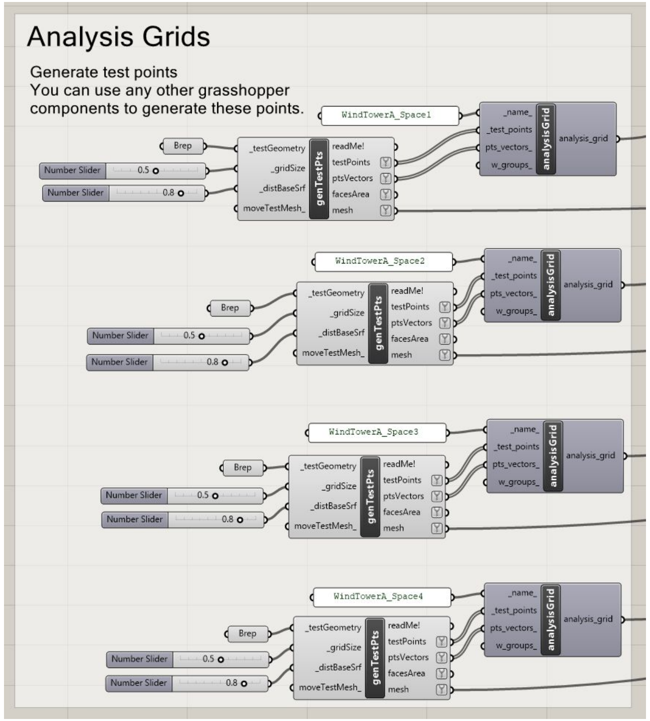
Understanding the 3- & 5-Phase Methods and Simulation Recipe

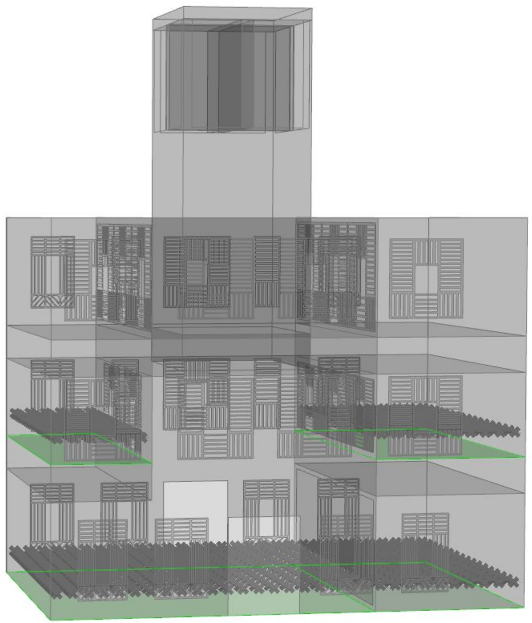


1. Assigning Radiance Analysis Grids to Surfaces
2. Adding Location, Climate & Weather Data for the **Sky Matrix**
3. Setting Up **3- or 5-Phase Method Component & Parameters**
4. **"Writing" Recipe Files** to Check for Errors before Running
5. Running Annual Daylight Simulation Recipe
6. Visualizing Results

Stage 3: Preparing & Running Annual Daylight Simulation Recipe

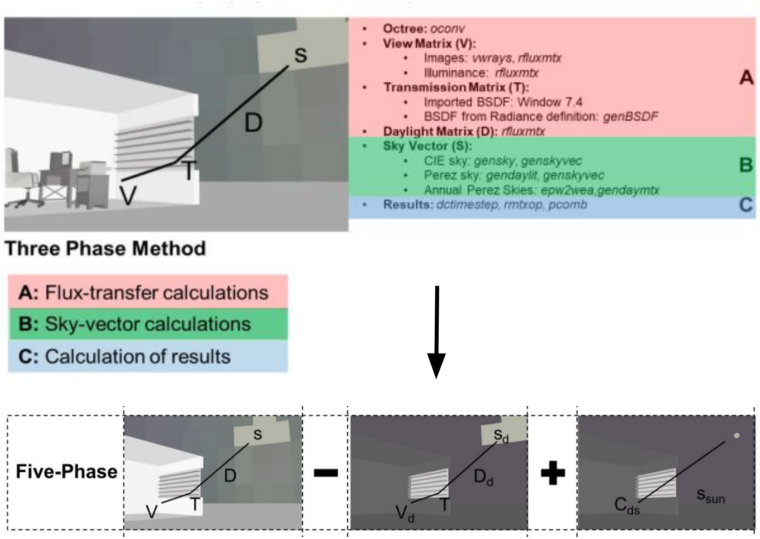
Understanding the 3- & 5-Phase Methods and Simulation Recipe





Stage 3: Preparing & Running Annual Daylight Simulation Recipe

Understanding the 3- & 5-Phase Methods and Simulation Recipe



Reference: Subramaniam, S. (2017). Daylighting Simulations with Radiance using Matrix-Based Methods. Retrieved from: [*https://www.radiance-online.org/learning/tutorials/matrix-based-methods*](https://www.radiance-online.org/learning/tutorials/matrix-based-methods)

The 3-Phase Method

- **Sky Vector Calculations**
  - Sky Vector (S)
- **Flux Transfer Calculations**
  - Daylight Matrix (D)
  - Transmission Matrix (T) from BSDF
  - View Matrix (V)
- **Calculation of Results**

*"The **5-Phase** Method seeks to **improve upon the results** generated through the 3-Phase Method by incorporating a **more accurate calculation for the direct-sun component** of the sky."*

Stage 3: Preparing & Running Annual Daylight Simulation Recipe

Understanding the 3- & 5-Phase Methods and Simulation Recipe

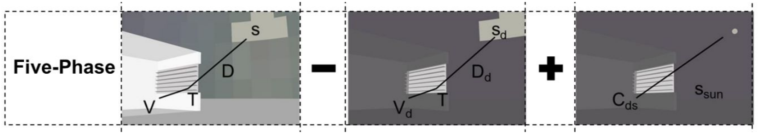
The 3-Phase Method

- **Sky Vector Calculations**
  - Sky Vector (S)
- **Flux Transfer Calculations**
  - Daylight Matrix (D)
  - Transmission Matrix (T) from BSDF
  - View Matrix (V)
- **Calculation of Results**

Examples of common input parameter values for dmtx & vmtx in 3- & 5-phase methods:

2-phase Method	-ab 5 -ad 100000 **-aa 0** -lw 1e-5
3-phase Method	vmx: -ab 12 -ad 50000 **-aa 0** -lw 2e-5 dmx: -ab 2 -ad 1000 **-aa 0** -lw 1e-3
5-phase Method	dsc: -ab 1 -ad 5000 **-aa 0** -lw 2e-4

[From Ladybug Forum]



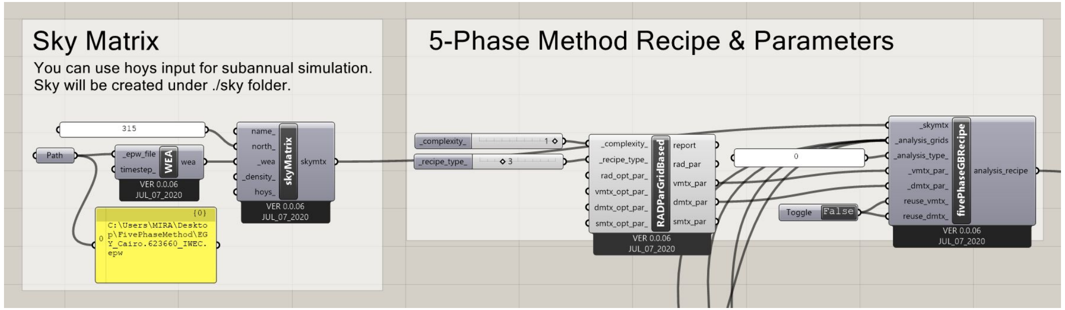
2-ph	-ab 5 -ad 89600 -lw 1e-5
3-ph (vmx)	-ab 5 -ad 22400 -lw 5e-5
3-ph (dmx)	-ab 2 -ad 22400 -lw 5e-5
5-ph	-ab 1 -ad 89600 -lw 1e-5 -dc 1 -dt 0 -dj 1 -st 1 -ss 0

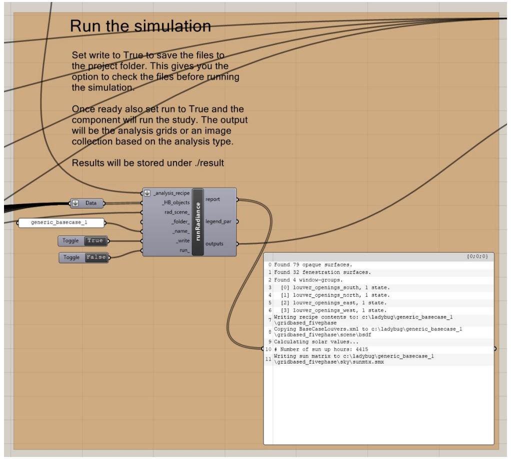
Subramaniam, S. (2017). Daylighting Simulations with Radiance using Matrix-Based Methods. Retrieved from: https://www.radiance-online.org/learning/tutorials/matrix-based-methods

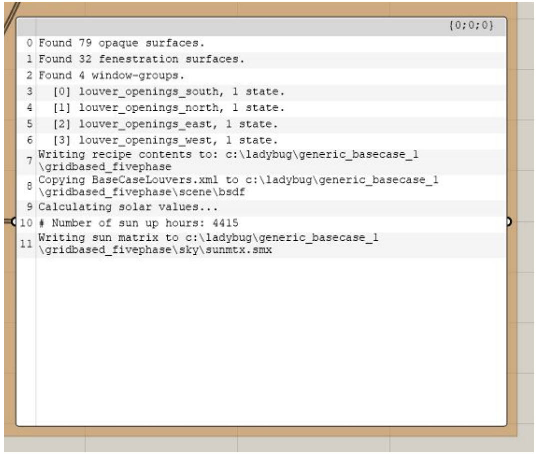
Brembilla, E. (2019). Applicability of Climate-Based Daylight Modelling. Retrieved from: https://repository.lboro.ac.uk/articles/thesis/Applicability_of_climate-based_daylight_modelling/9455126

Stage 3: Preparing & Running Annual Daylight Simulation Recipe

Understanding the 3- & 5-Phase Methods and Simulation Recipe







Results for this Method are still in PROGRESS

Adding more details in the model

Quick Comparison Between the Two Approaches

In Terms of Workflows and Flexibility & Limitations of Inputs: Characteristics, Pros & Cons

LBT Honeybee 1.6.0

- the possibility to **see & check** the correctness of the HB-Model before running the simulation
- **slightly more advanced/ detailed architectural geometry preparation process (room-based)** with a **variety of HB options** (HB-Face, HB-Subface, HB-Aperture, HB-Door, HB-Shade), allowing **more flexibility & parametric options related to adding shades, border shades** etc.
  - yet a bit time-consuming
  - & with the drawback of not considering wall thicknesses (only border shades)
- good control over modifiers + the ability to add **BSDF modifiers**
- adequate control over **Radiance parameters (Enhanced 2-Phase Method)**

Ladybug Legacy Tools Honeybee[+] 0.0.06

- the possibility to **check** files before running the simulation through "write files" option
- **relatively quick & efficient architectural geometry preparation process (surface-based)**
  - yet a bit primitive with **limited HB options** (HB-Surface, HB-Window, HB-Window Group only)
- good control over modifiers + ability to add **BSDF modifiers**
- high control control over **Radiance parameters for individual flux matrices, e.g. dmtx, vmtx etc. (3- & 5-Phase Methods)**

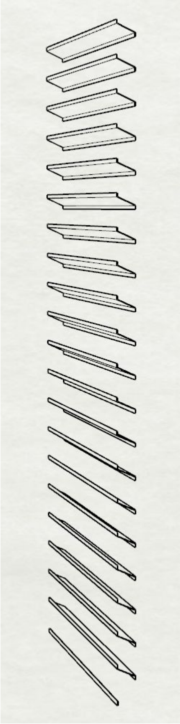
Optimization Workflow & Further Research Plan

Preliminary Design Iterations

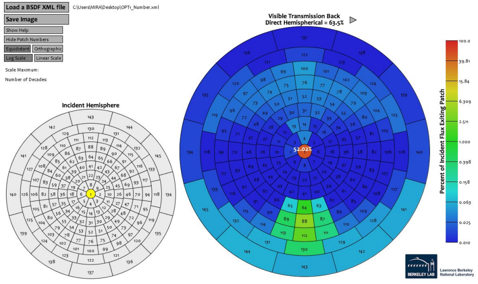
- Change in Number of Louvers
- Change in Material of Louvers
- Change in Form (Shape, Size, Depth, Inclination Angle etc.) of Louvers

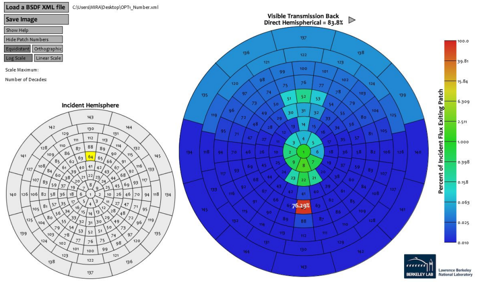
Preliminary Optimization Trials

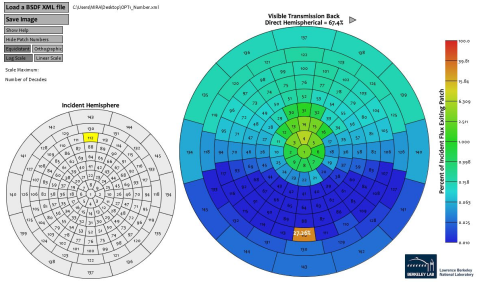
Examining BSDF Behavior: Less Number of Louvers

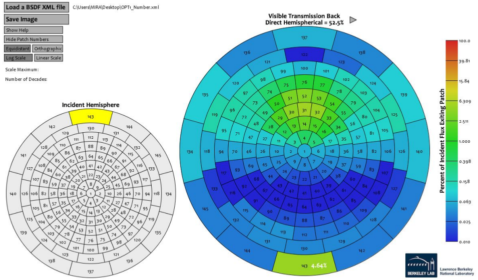


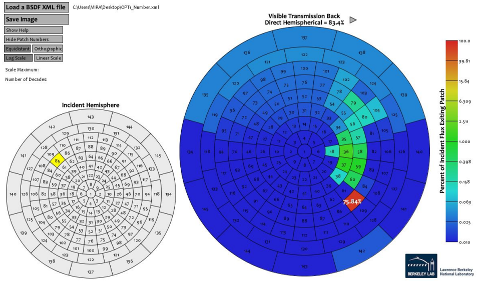
20 Louver Slats, Same Material

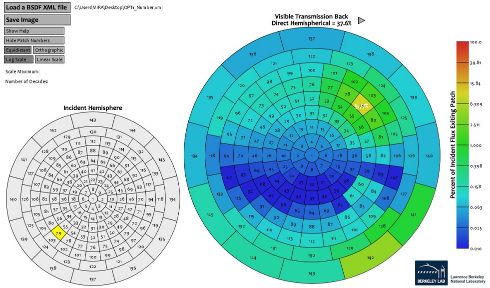






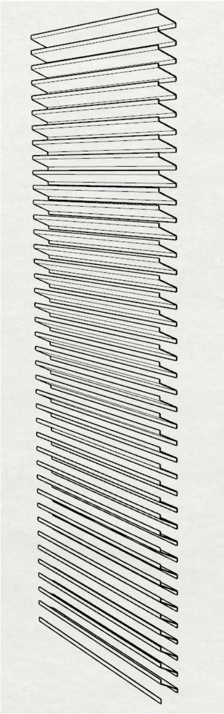






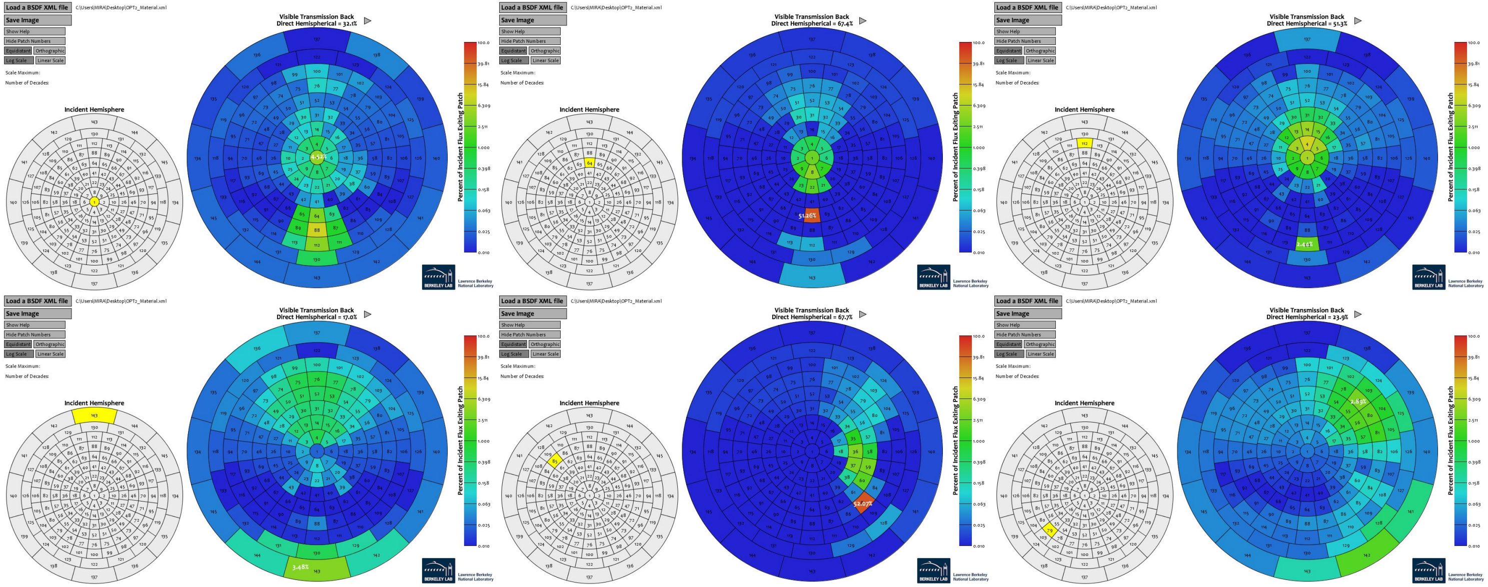
Preliminary Optimization Trials

Examining BSDF Behavior: Material with Higher Specularity



40 Louver Slats, Changed Material

```
void metal diffuse_0
0
0
5 0.8 0.8 0.8 0.9 0.1
```



Preliminary Optimization Trials

Comparing Different BSDF Behaviors

Base Case

Theta Band	Patch Number	Theta Range	BSDF Visible Transmission Back	BSDF Visible Transmission at Specular Patch
1	1	0°-5°	29.2%	4.24%
2	8	5°-15°	39.0%	24.19%
3	22	15°-25°	49.7%	42.72%
4	41	25°-35°	66.4%	64.37%
5	64	35°-45°	66.0%	51.26%
6	88	45°-55°	53.7%	14.55%
7	112	55°-65°	45.6%	2.45%
8	130	65°-75°	33.1%	3.07%
9	143	75°-90°	16.0%	2.81%

20 Louver Slats, Same Material

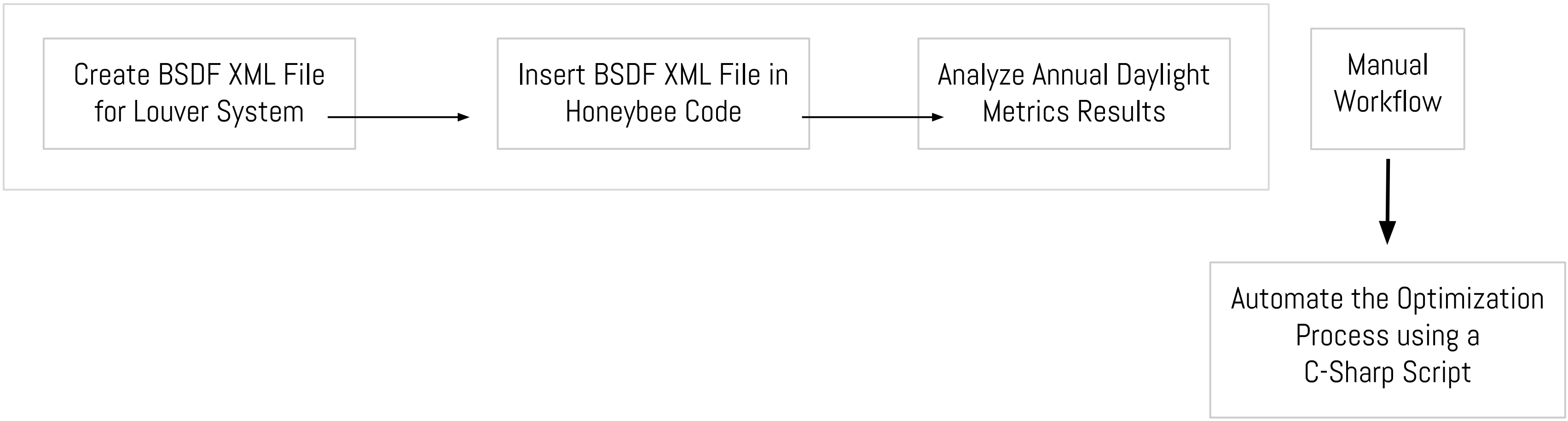
BSDF Visible Transmission Back	BSDF Visible Transmission at Specular Patch
63.5%	52.02%
65.3%	60.50%
72.6%	71.27%
82.0%	81.10%
83.8%	76.29%
78.0%	57.64%
67.4%	27.26%
59.8%	5.39%
52.5%	4.64%

40 Louver Slats, Changed Material

BSDF Visible Transmission Back	BSDF Visible Transmission at Specular Patch
32.1%	4.52%
39.6%	24.56%
50.2%	42.85%
66.4%	64.39%
67.4%	51.26%
58.2%	14.55%
51.3%	2.44%
35.1%	3.02%
17.0%	3.48%

Proposed Optimization Workflow

Workflow from Rhino to Radiance to Honeybee



Conclusion with Limitations & Further Research Plan

Current Limitations of Modelling & Simulation Processes for the Wind Tower:

- Wall thicknesses not included.
- Thickness & behavior of wooden shading devices not included.
- No furniture included.
- Default material modifiers applied.
- Glare not studied.

Preliminary Conclusion regarding Wind Tower Daylight Performance & Optimization:

- Optimization of louver system alone is probably not sufficient. There's need for additional re-design/ optimization decisions (e.g. material treatment of wind tower inner walls/ addition of reflective surfaces etc.) considering a better redirection of the light entering from the WT openings to reach the lower spaces.

Open Questions & Further Areas of Development:

- Best practices in terms of workflow for this case (high level of accuracy + reasonable modelling & simulation times)
- Choice of case-specific, adequate parameters (considering the relationship between type & scale of project, simulation recipe type & needed level of simulation recipe detail)

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Thank you.