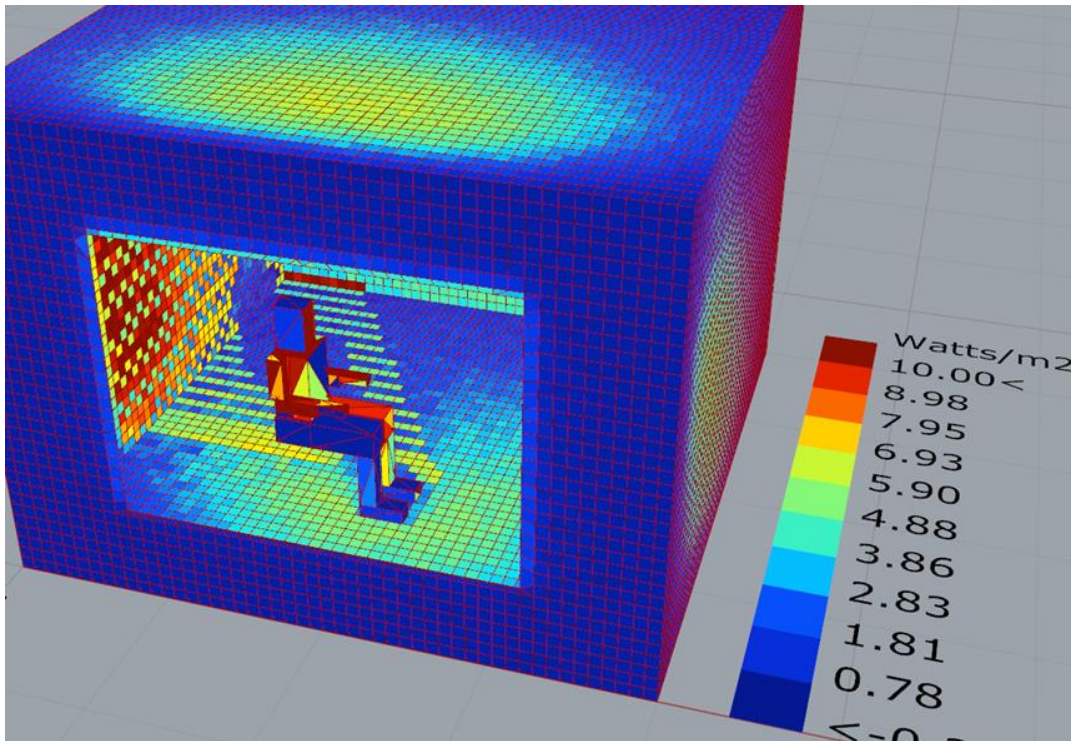


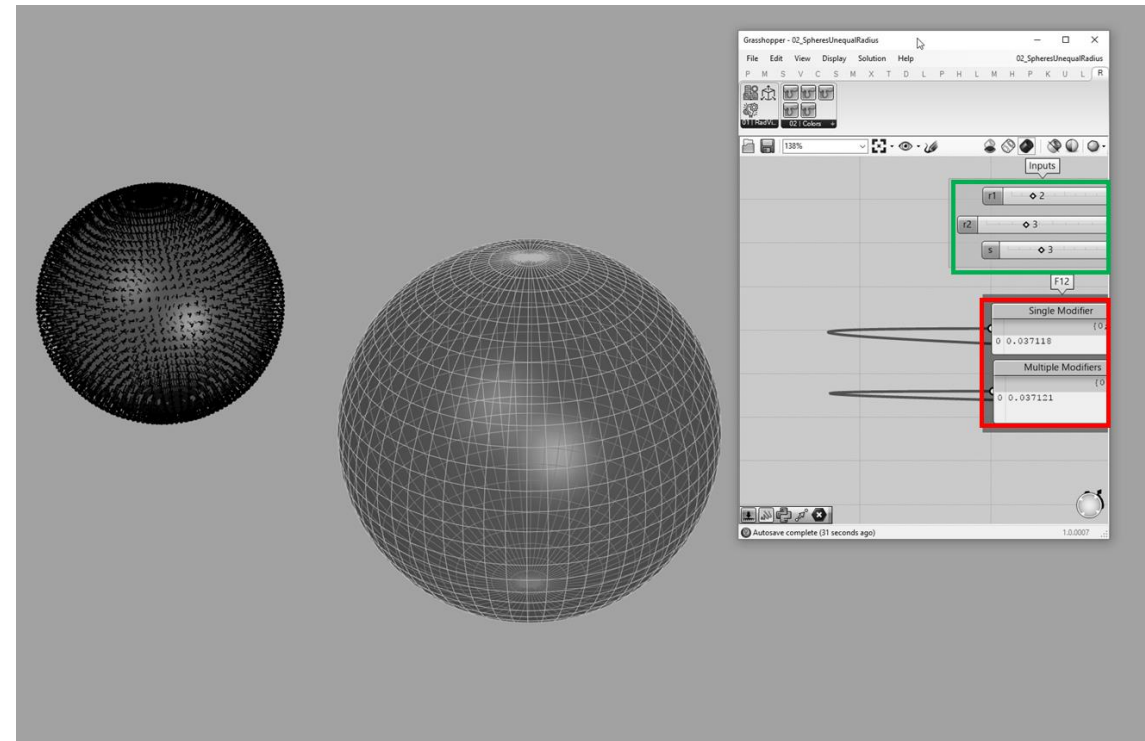
Employing Radiance in Heat Transfer Applications

Sarith Subramaniam

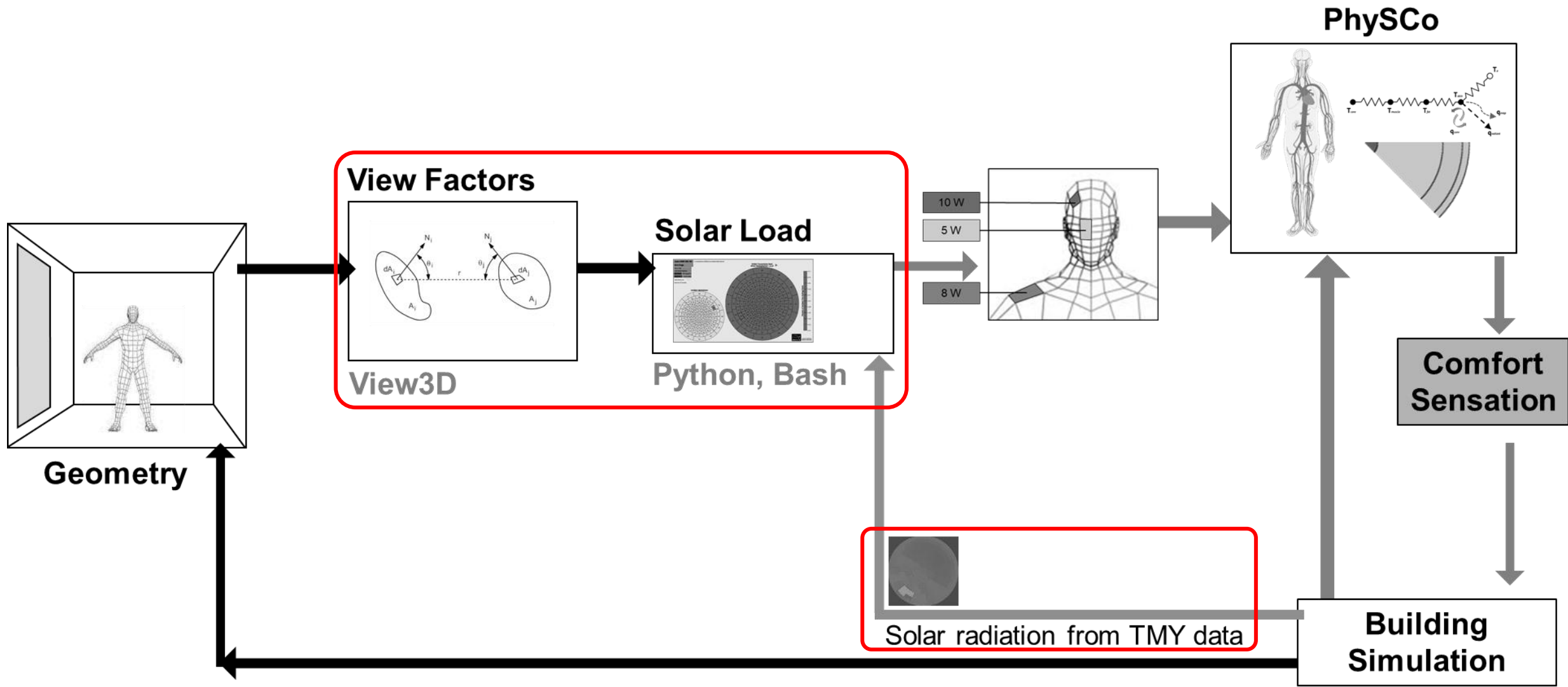
Department of Civil Engineering, TU Kaiserslautern, Germany



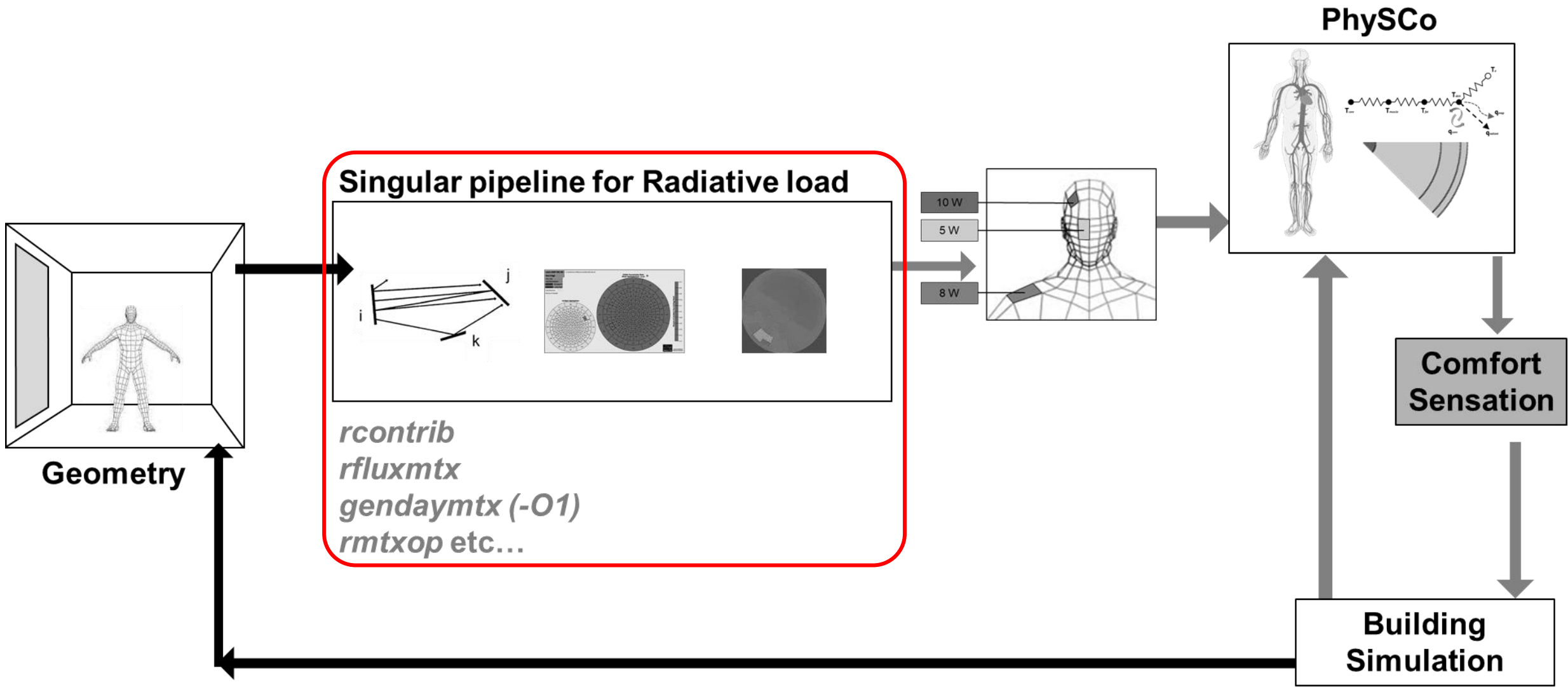
Solar load on human body



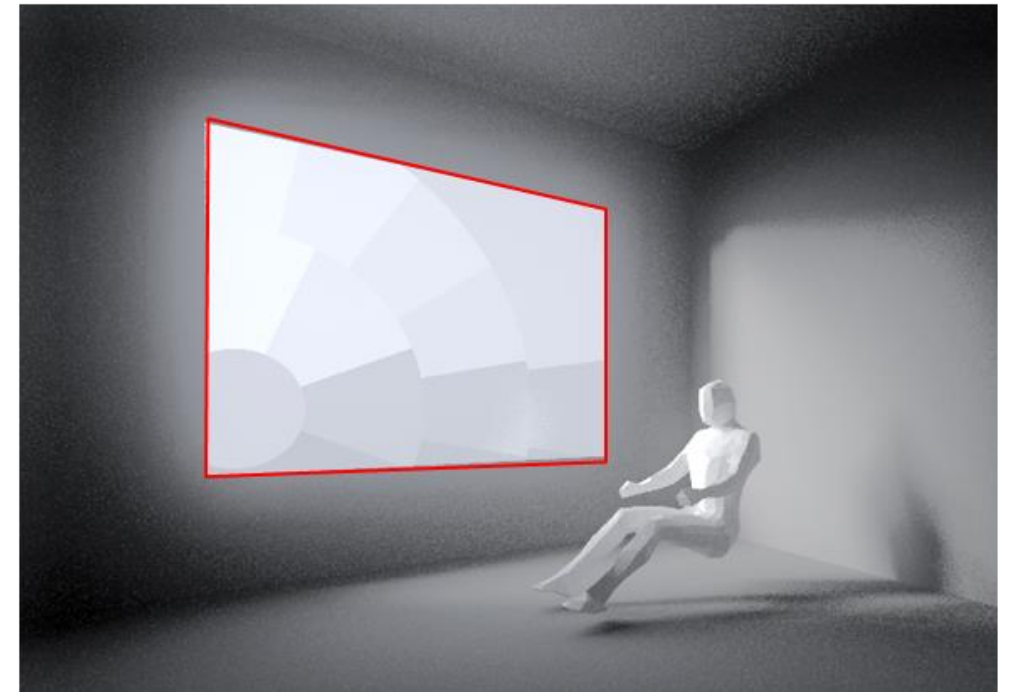
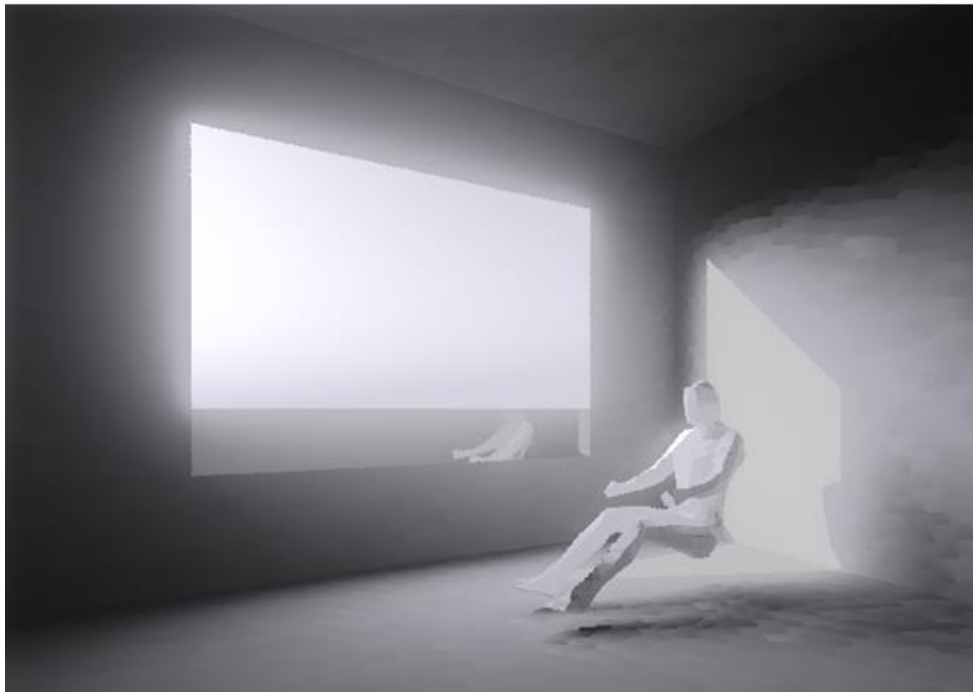
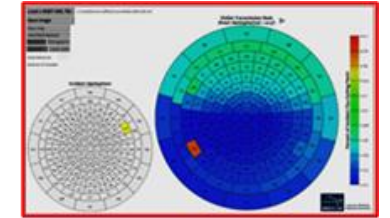
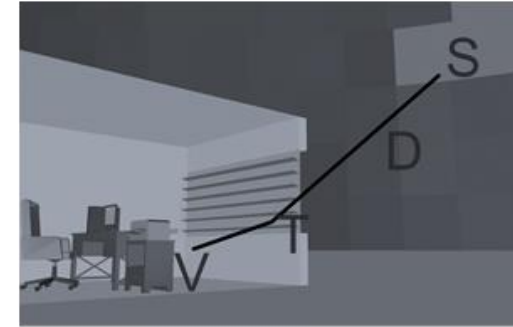
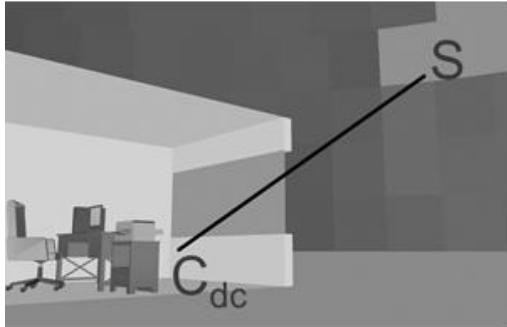
View Factors



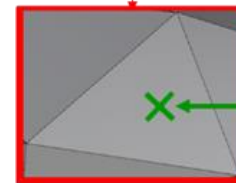
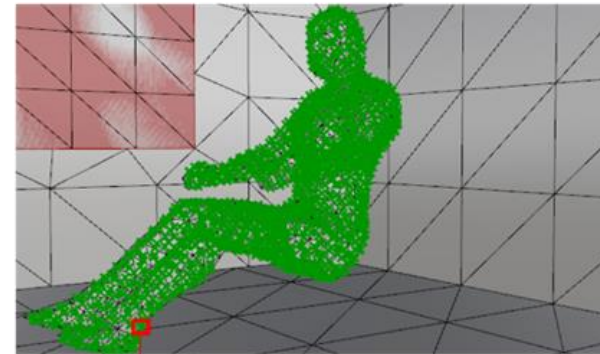
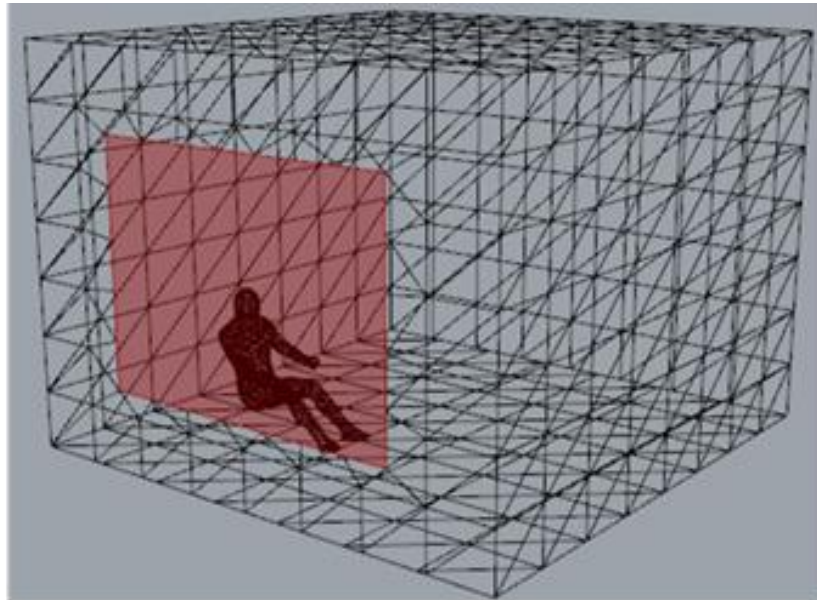
Background: Estimate short-wave radiation for Thermal Comfort Perception



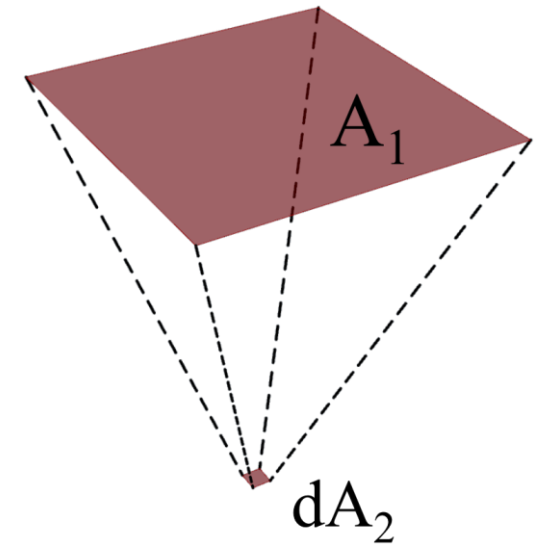
Initial work: Calculation of solar load on Manikin with and without CFS



Calculation of contribution factors for annual simulations (-ab 1)

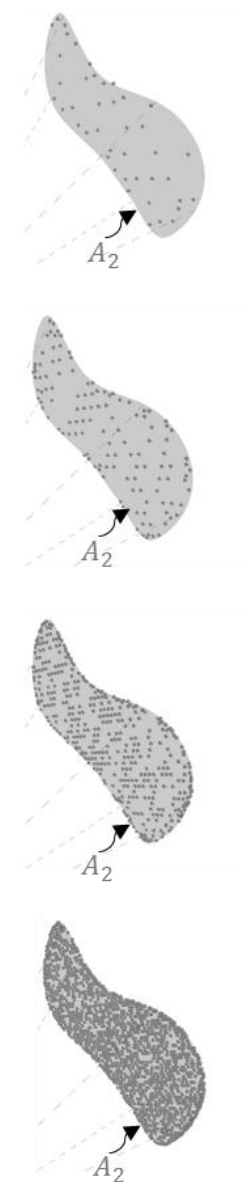
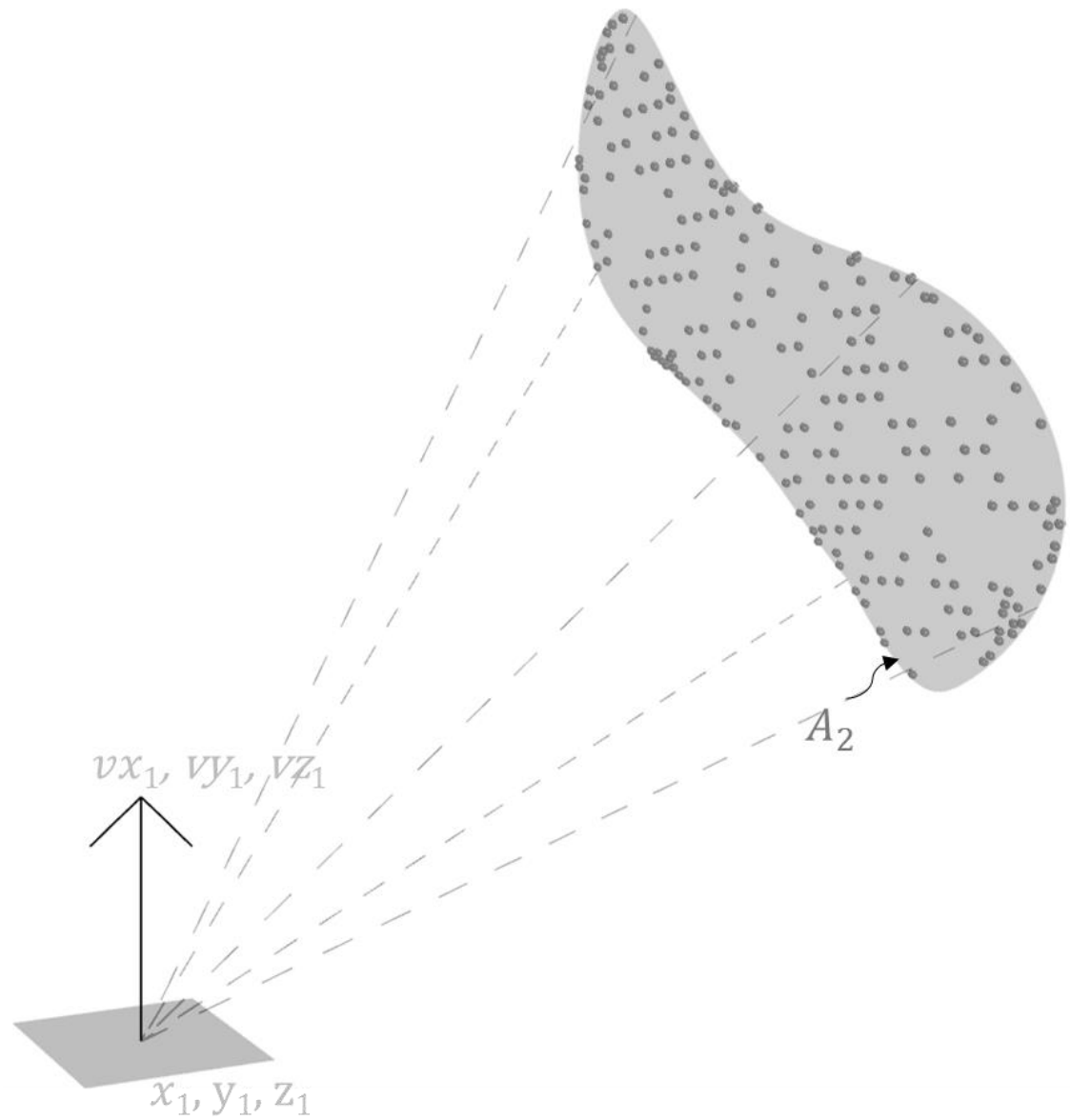


Ray origin for
sending surface



$$A_1 F_{1-d2} = dA_2 F_{d2-1}$$

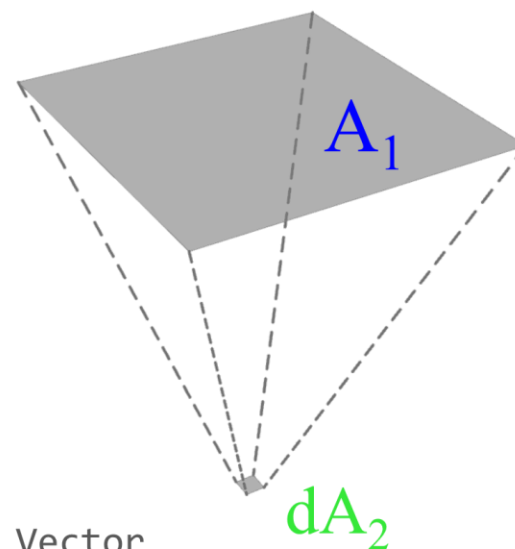
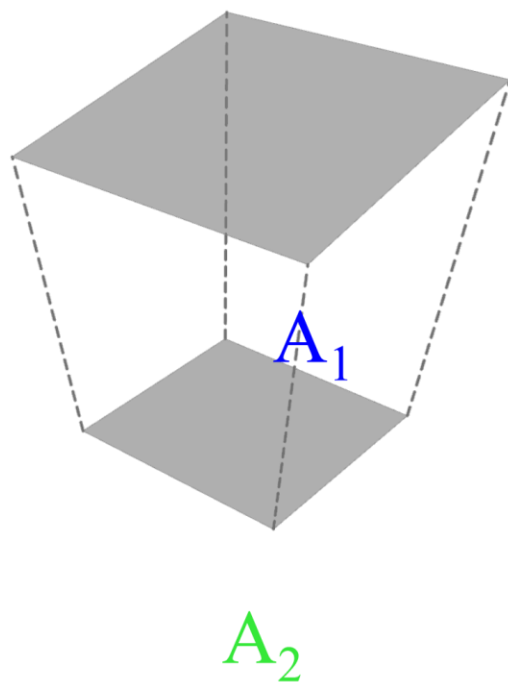
Using Monte Carlo Method to calculate View Factors



Higher sampling
for convergence

Workflow with rfluxmtx (Radiance | Sender | Receiver)

```
rfluxmtx A1.rad A2.rad > result.txt
```



Location Vector

$\underbrace{0 \ 0 \ 0}_{\text{Location}} \ \underbrace{0 \ 0 \ 1}_{\text{Vector}}$

```
 $\underbrace{0 \ 0 \ 0}_{\text{Location}} \ \underbrace{0 \ 0 \ 1}_{\text{Vector}} \mid$  rfluxmtx -I -ab 1 - A1.rad > result.txt
```


Workflow with rfluxmtx: Limitations and bottlenecks

Multiple modifiers are expanded in commandline while invoking rcontrib.

```
#?RADIANCE
oconv -f rec.rad
rcontrib -fo+ -h+ -ab 1 -ad 100000 -lw 1
1 -b if(-Dx*0-Dy*0-Dz*-1,0,-1) -m r12 -k
if(-Dx*0-Dy*0-Dz*-1,0,-1) -m r14 -bn 1 -
if(-Dx*0-Dy*0-Dz*-1,0,-1) -m r16 -bn 1 -
if(-Dx*0-Dy*0-Dz*-1,0,-1) -m r18 -bn 1 -
if(-Dx*0-Dy*0-Dz*-1,0,-1) -m r10 -bn 1
```

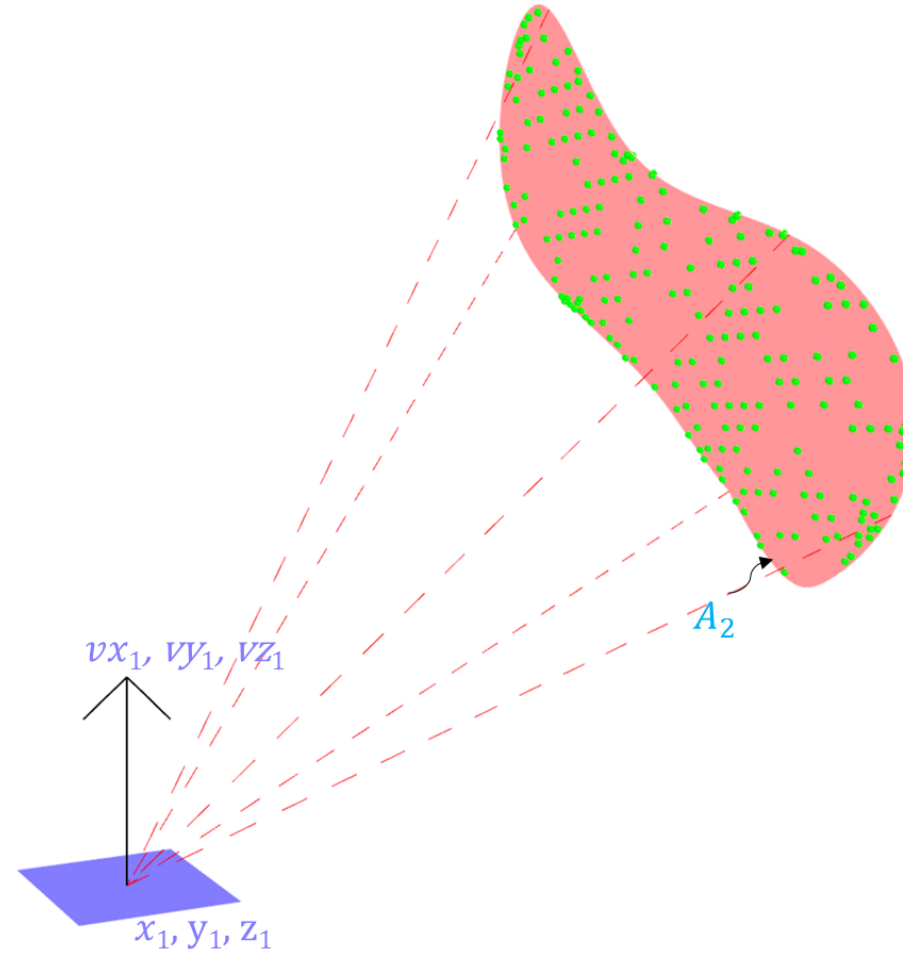
Single sending surface

```
rfluxmtx [ -v ] [ rcontrib options ] { sender.rad | - } receivers.rad [ -i system.oct ] [ system.rad .. ]
```

Need to assign rfluxmtx params.*

```
#@rfluxmtx h=u
void glw_receiver 0 0 4 1 1 1 0
```

View Factors → Monte Carlo Method ← Rcontrib



$$rcontrib = I - ad N - lw \frac{1}{N} - m \text{ surfaceIdentifier } \text{ surfaceGeometry } < \text{ point(s) } > \text{ ViewFactor } \times \pi$$

View Factor with rcontrib: Simple(st) use-case: Point to Parallel Surface



SurfaceGeometry (sen.rad)

```
void plastic rectangle 0 0 5 1 1 1 0 0
rectangle polygon object 0 0 12
0 0 1 1 0 1 1 1 1 0 1 1
```

point (pts.txt)

```
0 0 0 0 0 1
```

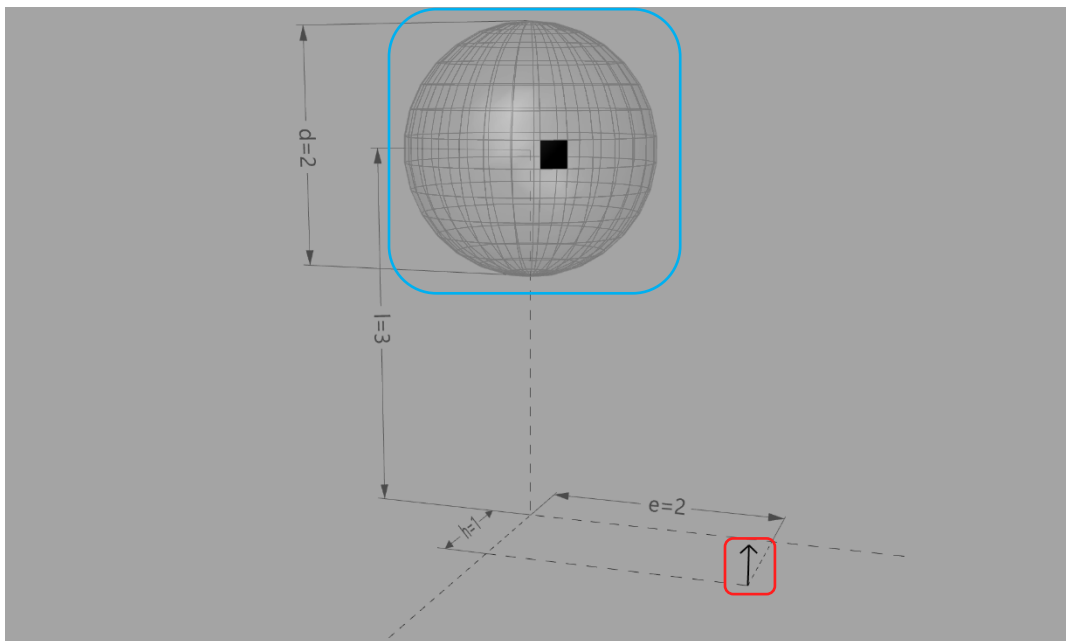
```
D:\>oconv sen.rad > geo.oct
```

```
D:\>rcontrib -h -w -I -ad 1000 -lw 0.001 -m rectangle geo.oct <pts.txt
```

```
4.325826e-01 4.325826e-01 4.325826e-01
```

Three Channel Output
(ViewFactor = $0.4325826/\pi$)

surfaceIdentifier

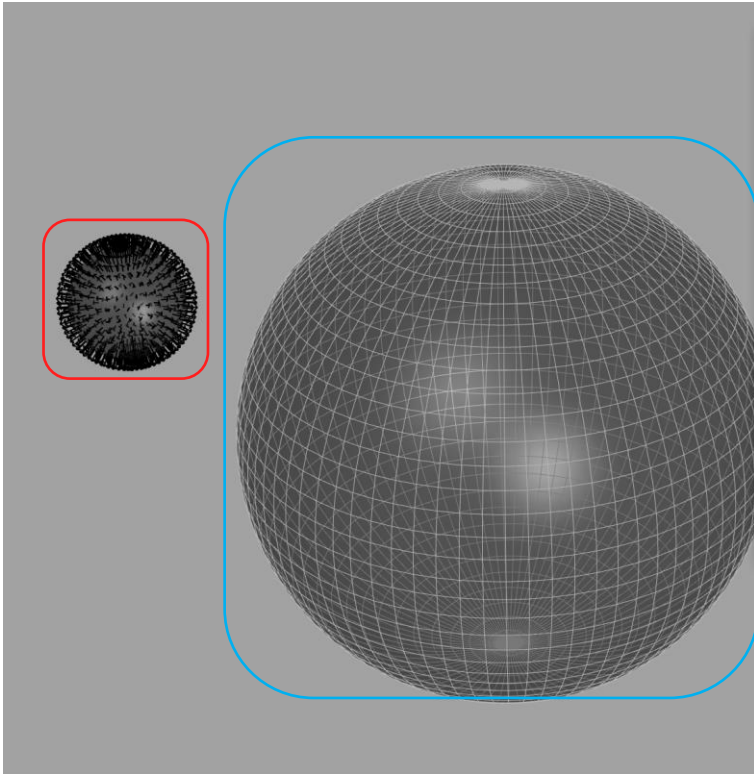


“The view factor from a surface I to a surface j is equal to the sum of the view factors from surface i to the parts for surface j”

$$F_{i-j} = F_{i-j_1} + F_{i-j_2} + F_{i-j_3} + \dots + F_{i-j_N}$$

rcontrib - I - ad N - lw $\frac{1}{N}$ - m *surfaceIdentifier* *surfaceGeometry* < *point(s)* > **ViewFactor** × π

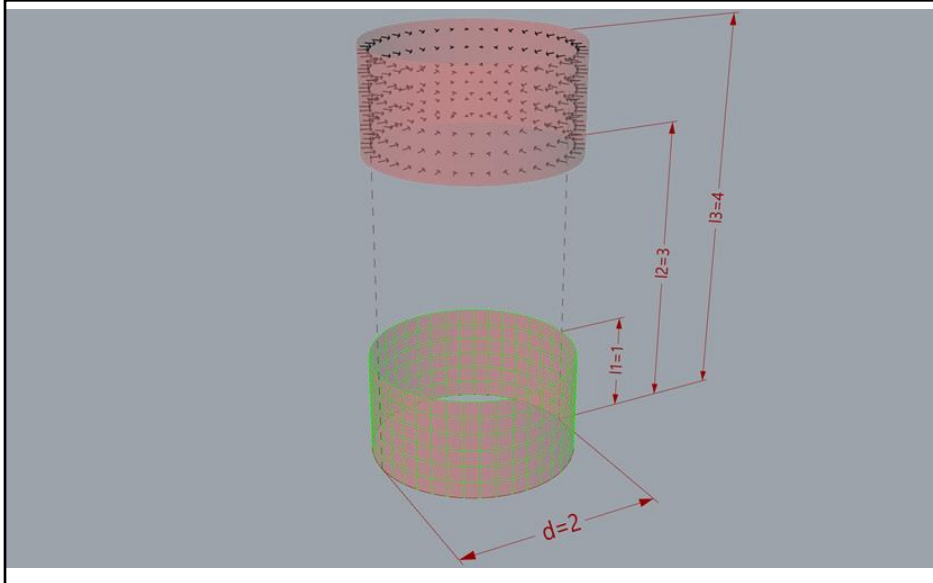
View factor between multiple curved surfaces



$$F_{i,j+k} = \frac{A_i F_{ik} + A_j F_{jk}}{A_i + A_j}$$

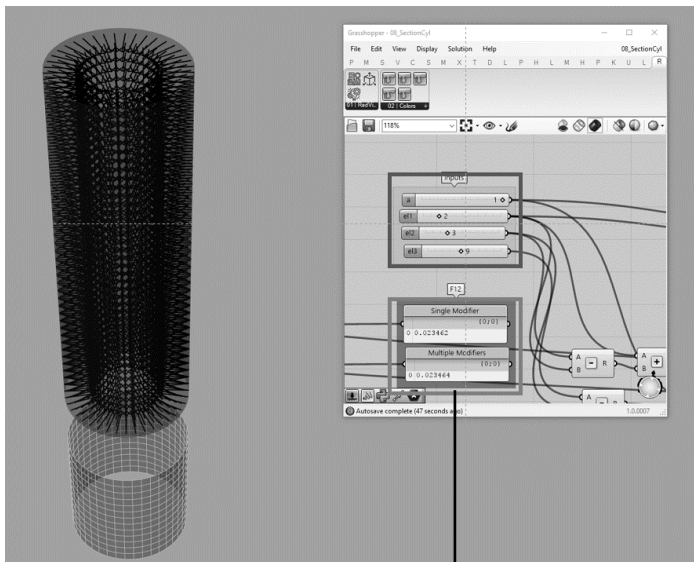
rcontrib -l -ad N -lw $\frac{1}{N}$ -m *surfaceIdentifier* *surfaceGeometry* < *point(s)* > *ViewFactor* × π

Validation against known analytical solutions



$$a = \frac{d}{2}; L = \frac{l}{a}; X(L) = \sqrt[2]{L^2 + 4}$$

$$F_{1-2} = \frac{1}{4(L_3 - L_2)} \left[\begin{aligned} &2L_1(L_3 - L_2) + (L_3 - L_1)X(L_3 - L_1) - \\ &(L_2 - L_1)X(L_2 - L_1) - L_3X(L_3) + L_2X(L_2) \end{aligned} \right]$$



C-87: Finite section of right circular cylinder to separated finite section.

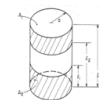
Warning: The scripts may not work correctly with the Internet Explorer!

a	=	1	, e1	=	2
e2	=	3	, e3	=	9

L1	=	2	, L2	=	3
L3	=	2			

F12	=	0.02356062325
-----	---	---------------

Reference: Hushman and Pittman

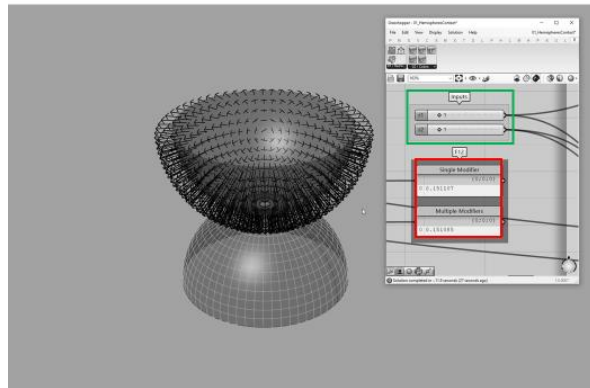


Definitions:

0.02356 (Analytical)

0.02346 (Radiance)

Validation against known analytical solutions



C-154: Two hemispheres in contact.

Warning: The scripts may not work correctly with the Internet Explorer!

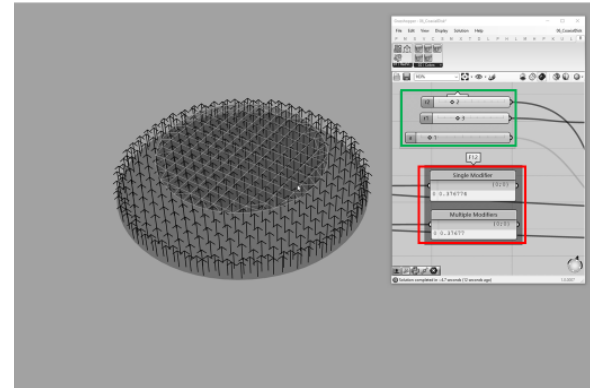
$x1 = 1$ $x2 = 0$

$R = 0$

F12 = 0.001

Reference: Hibbs, Kato and Eberle

Definitions:
R = radi



C-41: Disk to parallel coaxial disk of unequal radius.

$x1 = 0$
 $x2 = 0$
 $x3 = 0$

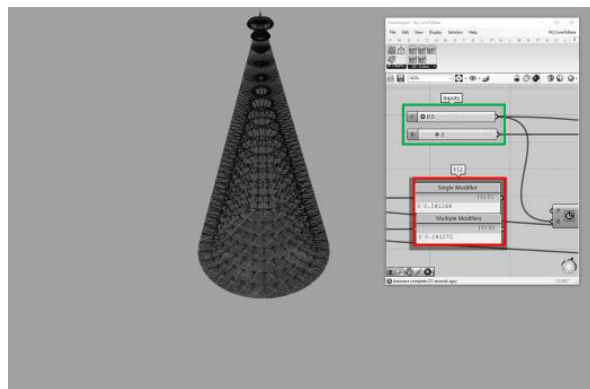
$R1 = 0$ $R2 = 0$ $N = 0.000000000$

F12 = 0.000000000

Reference: Koenig Hornig (1971), Frenkel (1975), Lammert and Pinner, Hainke and Meppan; See also Strahl and Wörz, for use of non-coaxial disks in parallel planes.

Definitions: $R = r_0$, $N = 1 + (1 - R_0^2/R_1^2)$

Governing equation:
$$x = \frac{1}{2} \sqrt{2R_1^2 - R_2^2 - N^2}$$



C-109: Interior of right circular cone to base.

Warning: The scripts may not work correctly with the Internet Explorer!

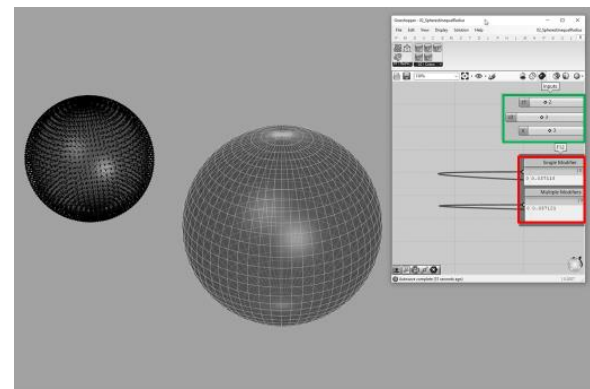
$a = 1.5$ $b = 2$

$R = 0$

F12 = 0.000000000

Reference: Berezowski, Bore, Buzdakov and Zilber

Definitions:
R = h0



C-137: Two spheres of unequal radius.

Warning: The scripts may not work correctly with the Internet Explorer!

$x1 = 0$ $x2 = 0$ $x3 = 0$

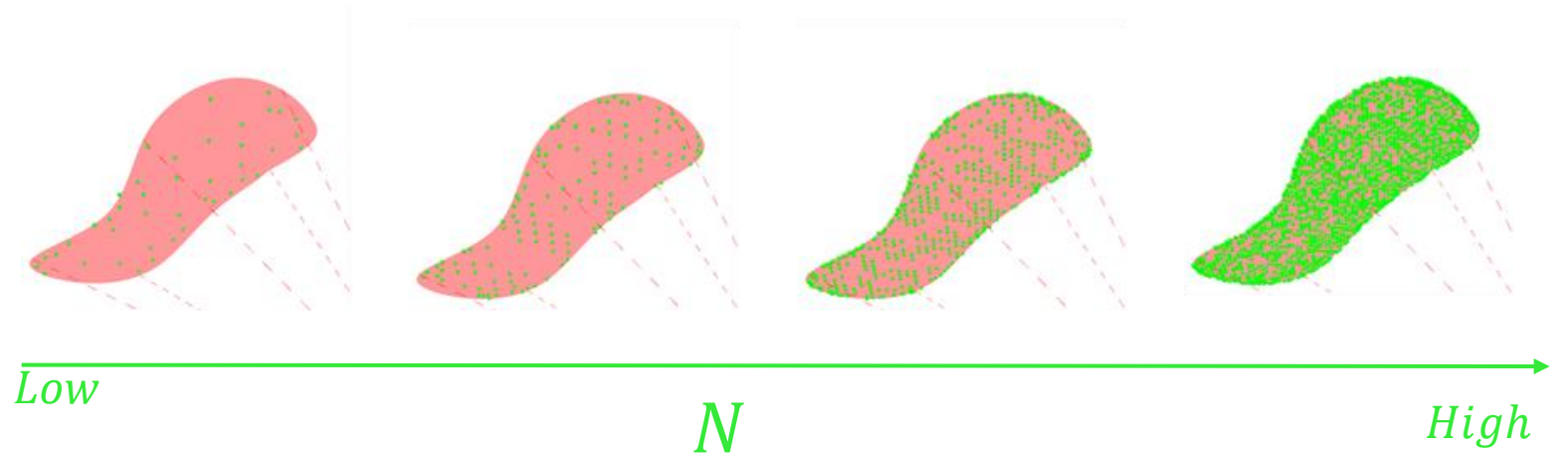
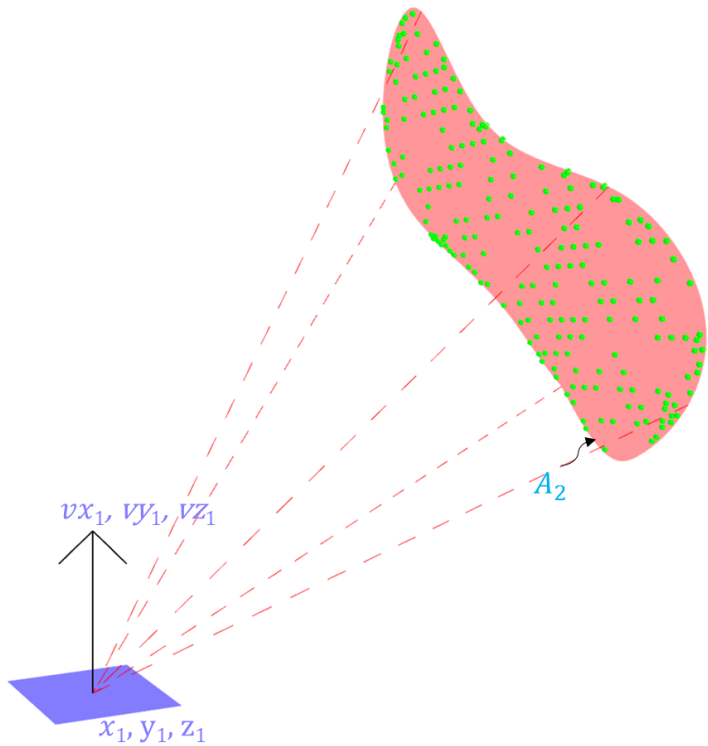
$R = 0.000000000$ $N = 0$

F12 = 0.000000000

System is not in equilibrium!
In region R1 F12 = 0.000000000.
In any region F12 = 0.000000000

From the table: F12_table = [0.000000000] (not available for the values at the boundary)

Reference: Jod (1975), Frenkel (1975), Cheng and Shoukri-Gross-Campbell and McCord; Frenkel's Error

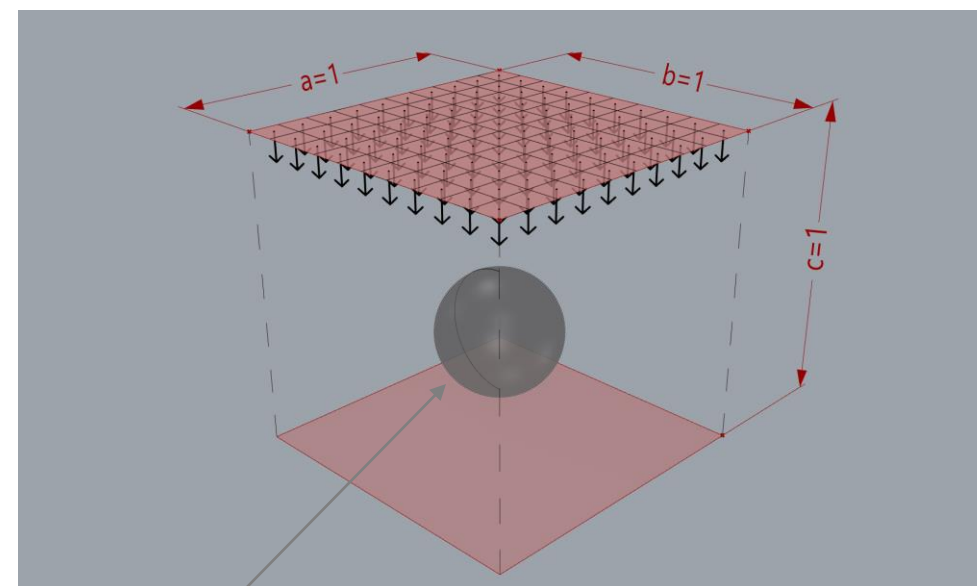
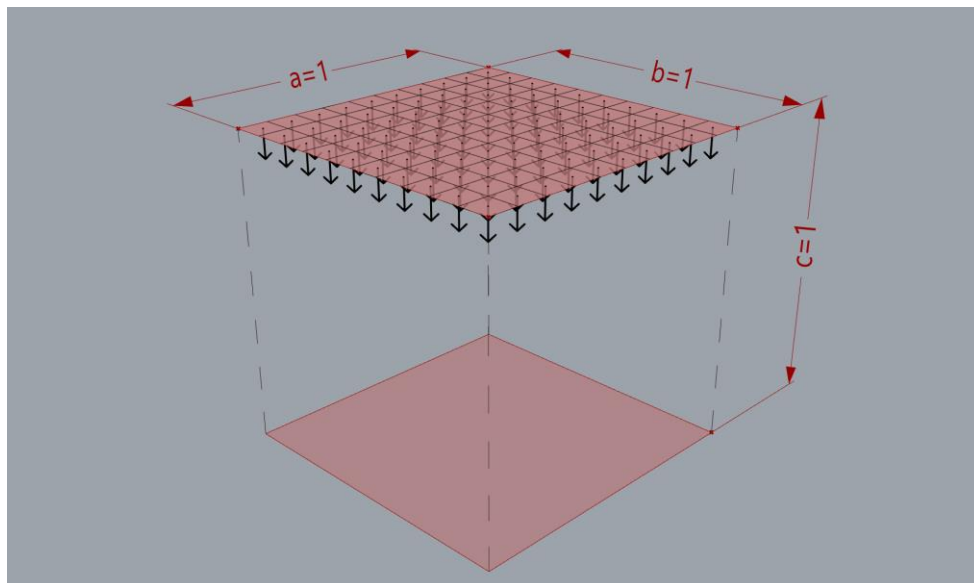


$$rcontrib = I \left[-ad N - lw \frac{1}{N} \right] m \text{ surfaceIdentifier } \text{ surfaceGeometry } < \text{ point(s) } > \text{ ViewFactor } \times \pi$$

$$-ad N - lw \frac{1}{N}$$

Obstructed view factor calculation

$$r_{contrib} = I - ad N - lw \frac{1}{N} - m \text{ surfaceIdentifier}(s) \quad \text{octree} \quad \text{surfaceGeometry} < \text{point}(s) > \text{ViewFactor} \times \pi$$

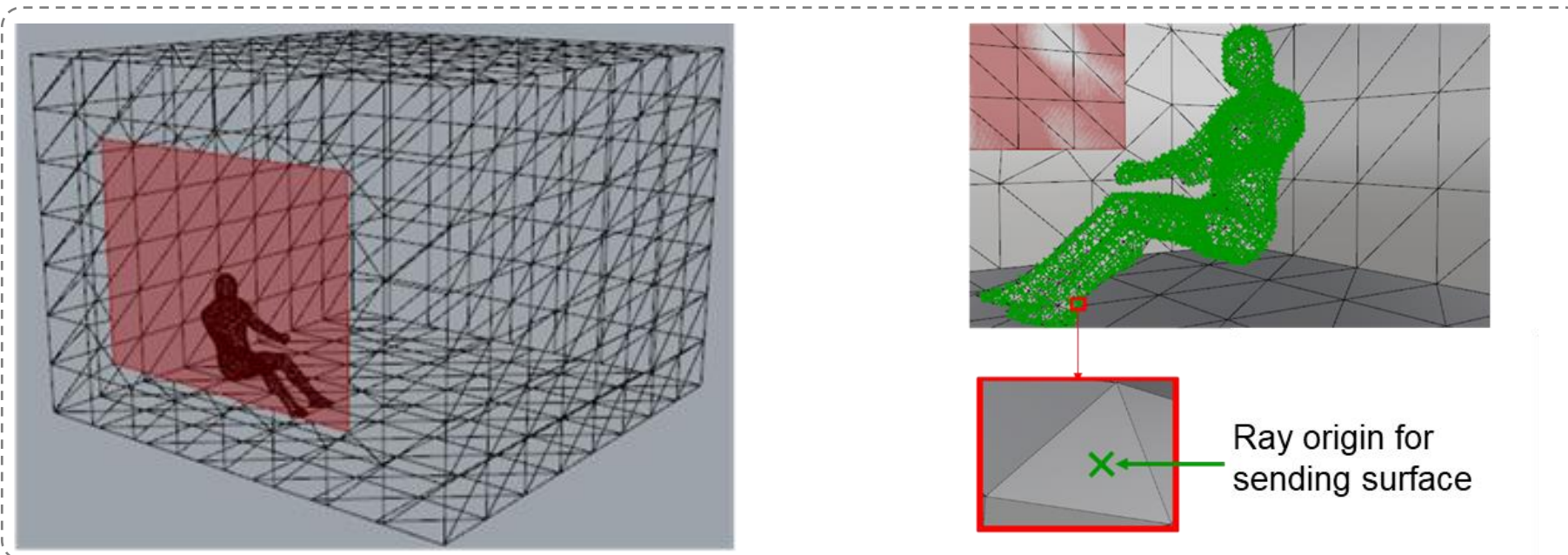


$$r_{contrib} = I - ad N - lw \frac{1}{N} - m \text{ surfaceIdentifier}(s) \quad \text{octree} \quad \text{surfaceGeometry} + \text{obstructing geometry} < \text{point}(s) > \text{ViewFactor} \times \pi$$

octree

Comparisons with a standard tool (View3D)

Incident radiation from fenestration to manikin



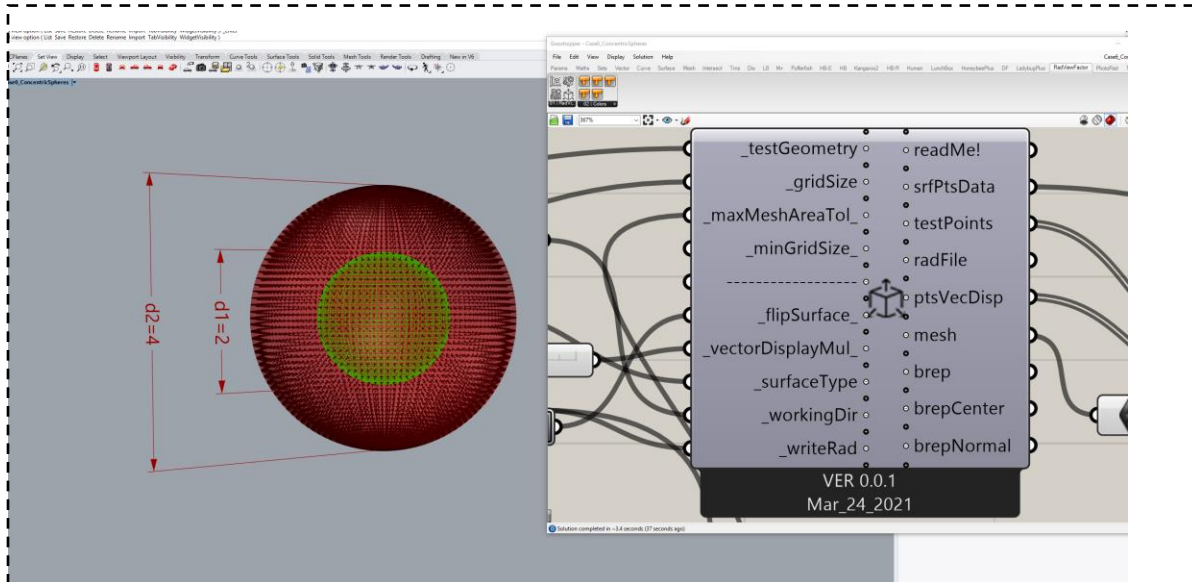
Average Simulation time (seconds)





	View3D	Radiance
Total mesh faces	2126	
Mesh faces (manikin)	1336	
View factors (to be calculated)	1336	
View factors (considered)	4519876	1336

Average Simulation time (seconds)

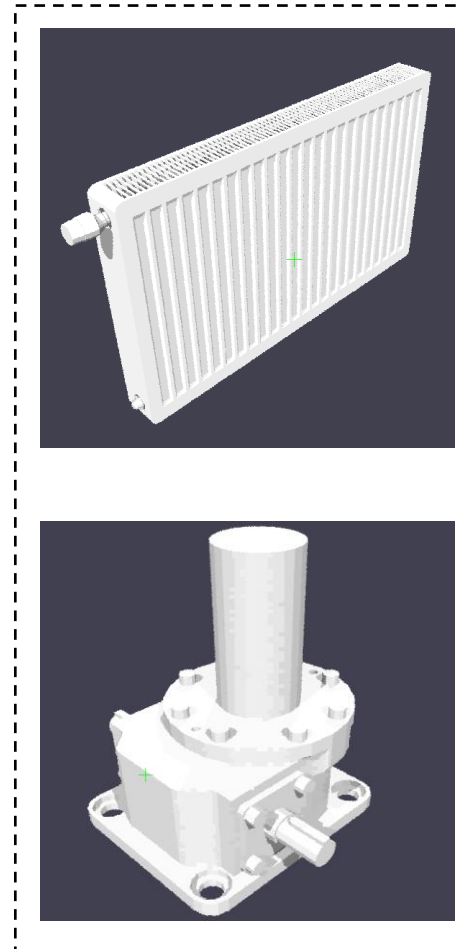
	1 Proc.	2 Proc.	4 Proc.
View3D	322.5	N.A.	N.A.
Radiance	14.2	7.8	4.1

Rhino/Grasshopper Plugin To Handle Geometry/Radiance



-  RadViewFactor Estimate Grid Size
-  RadViewFactor Project Dictionary
-  RadViewFactor Project Manager
-  RadViewFactor Surface Points

Practical Applications in Thermal Engineering



Thank you! Questions or comments?

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