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First steps of numerical simulation using Artificial Intelligence

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First Steps of Numerical Simulation using Artificial Intelligence

Vincent Vadez

Dorea

François Brunetti

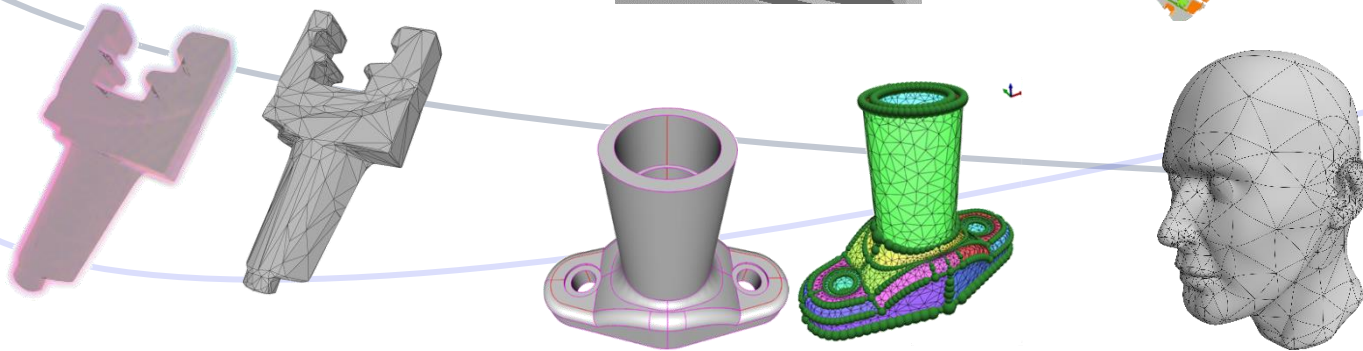
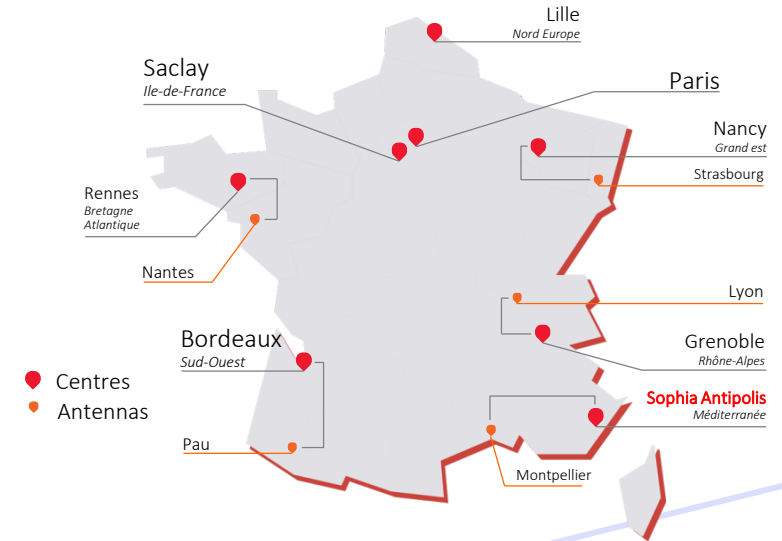
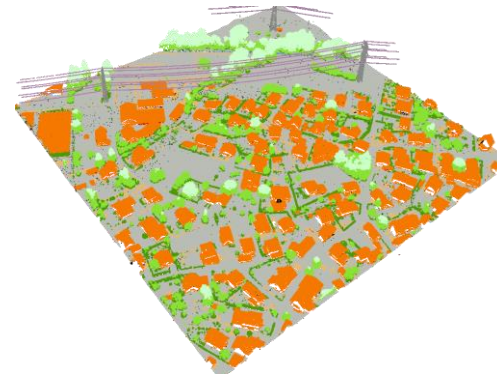
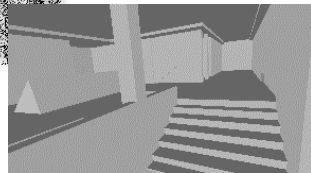
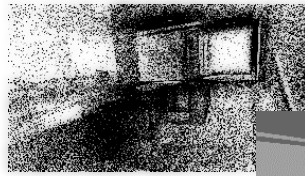
Dorea

Pierre Alliez

Inria Sophia Antipolis - Méditerranée

▶ Geometric modeling of 3D scenes from measurement data

- ▶ Analysis, reconstruction, approximation
- ▶ Computational geometry, geometry processing, machine learning



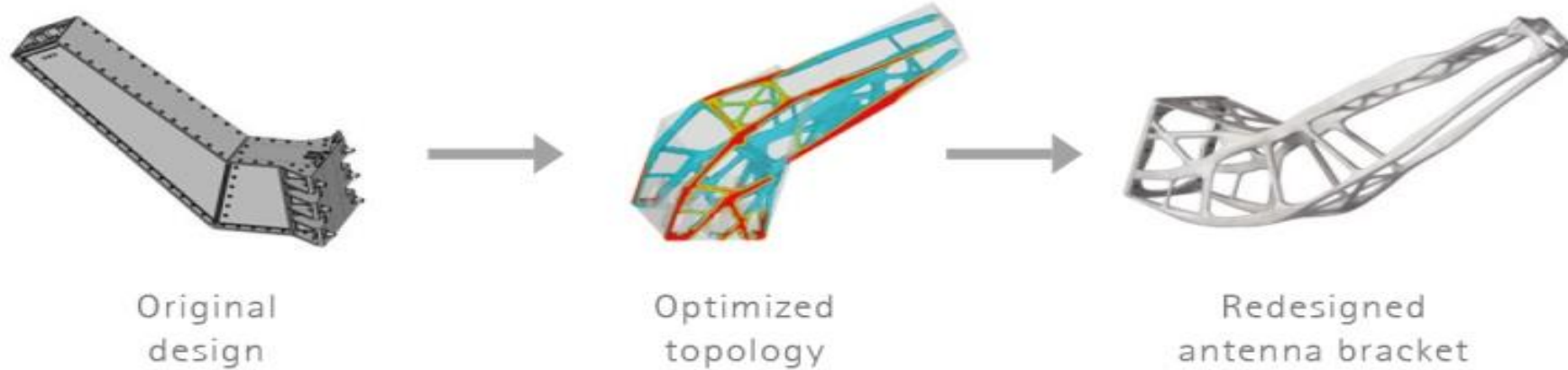


Image from
www.eos.info

- ▶ **Additive manufacturing yields increasingly complex objects**
 - ▶ Reduced weight via topology optimization
 - ▶ Many more facets elements are required to describe these free-form shapes, which are later added to the full satellite model.

- ▶ **Context of real-time simulation & sensibility**
 - ▶ Radiative thermal simulation is time-consuming: $O(n^2)$ complexity for the view factors, with n the number of faces of the mesh.
 - ▶ Full simulation intractable on the complete satellite model, in a reasonable time.
 - ▶ A thermal-aware geometric approximation process is required, allowing real-time simulation and beyond (multi-physics simulation and predictions).

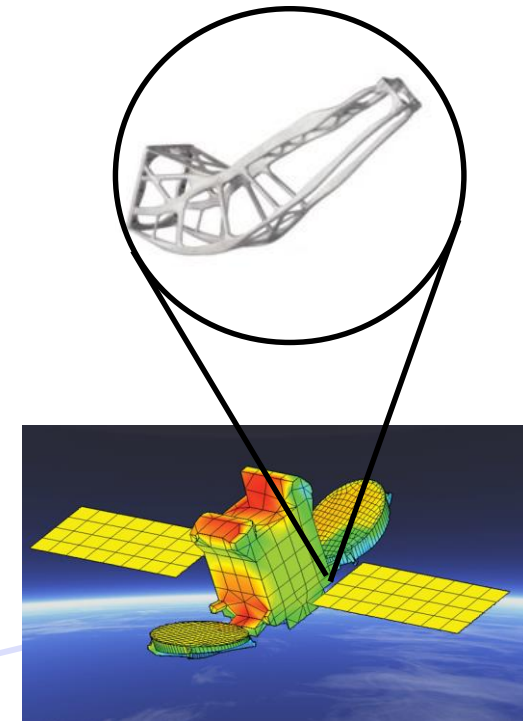


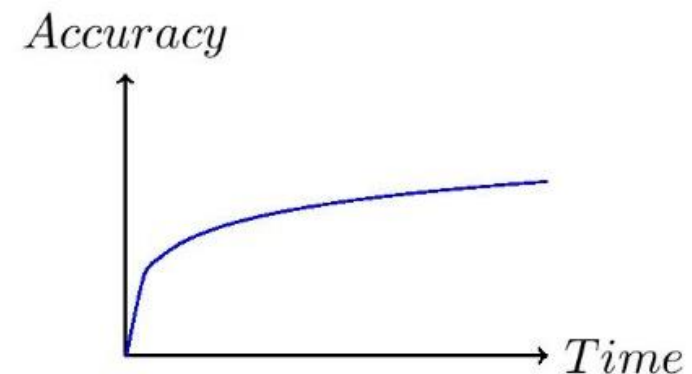
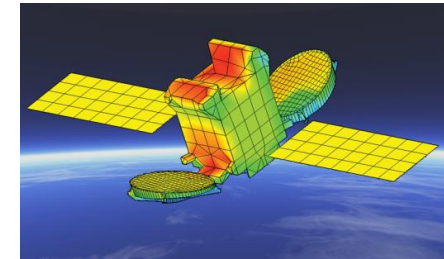
Image from www.ata-e.com

PROBLEM STATEMENT

- ▶ **Input:** Complex surface mesh (many facets and occlusions, created by a CAD software)
- ▶ **Output:** Approximated model respecting the view factors of the thermal nodes
- ▶ **Guarantees:** Error bounds under wide range of configurations and conditions
- ▶ **Goal:** Optimize trade-off between accuracy and time



SOLIDWORKS
CATIA



- ▶ **Topic of Ph.D. thesis:** Design a geometric approximation method preserving a *simulation-aware* error metric rather than a *geometric* error metric.
- ▶ **Application to space thermal analysis:** view factor computation and model reduction
- ▶ **Goals:**
 - ▶ Compute reference view factors
 - ▶ Compare with approximated view factors
 - ▶ Evaluate simulation with approximation
 - ▶ Utilize supervised machine learning to automate the reduction process, leveraging a large training dataset.

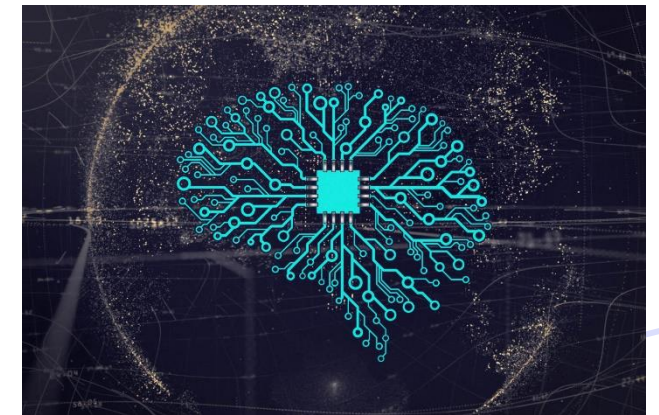


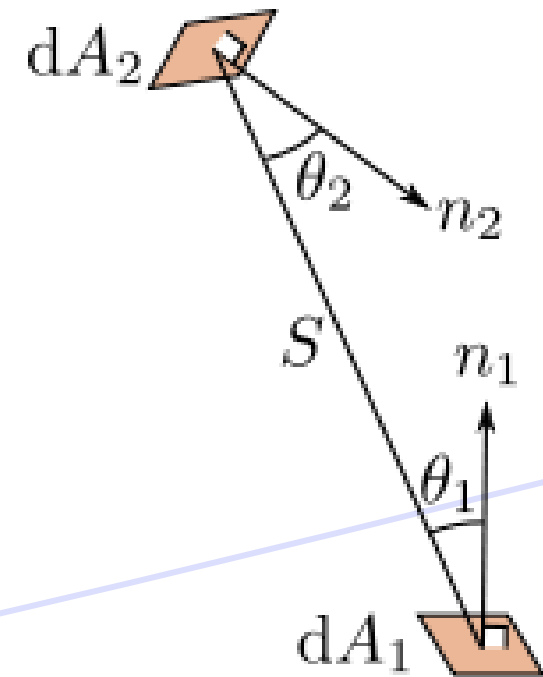
Image from www.warontherocks.com

$$F_{1 \rightarrow 2} = \frac{1}{A_1} \int_{A_1} \int_{A_2} \frac{\cos \theta_1 \cos \theta_2}{\pi s^2} dA_2 dA_1$$

$$dF_{1 \rightarrow 2} = \frac{\cos \theta_1 \cos \theta_2}{\pi s^2} dA_2$$

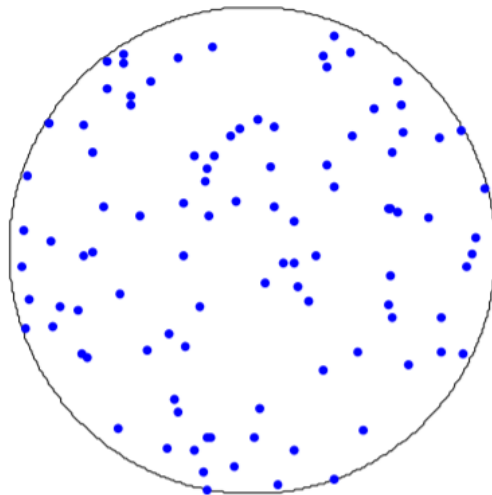
View factors depend on 3 components:

- area of the faces
- distance between them
- orientation

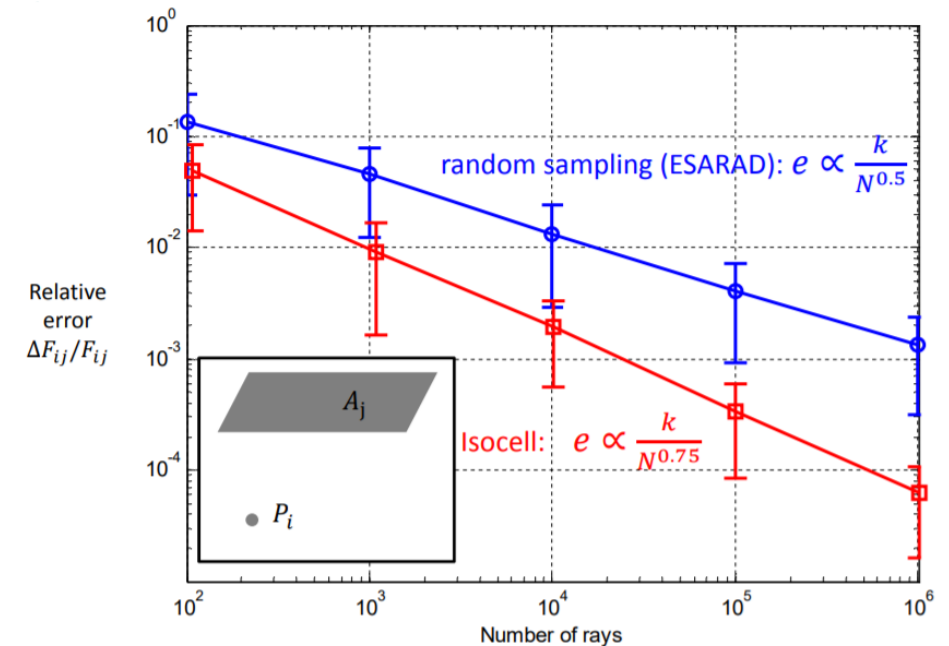
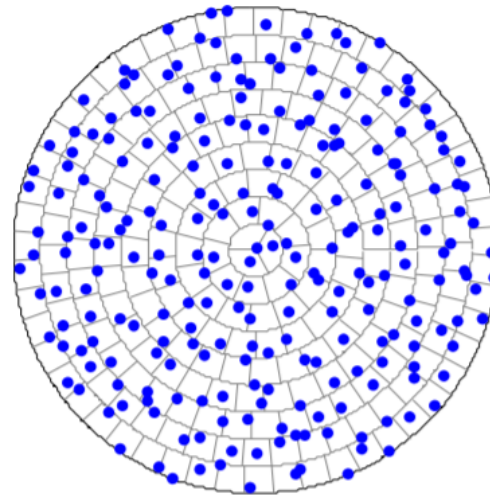


- ▶ **Accelerating computation of view factors**
 - ▶ **Jacques, Masset, Kerschen:** Ray tracing enhancement for space thermal analysis: isocell method, 27th Space Thermal Analysis Workshop, ESTEC.

Random (classic) sampling



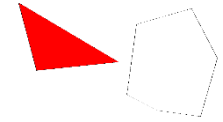
Isocell sampling



- ▶ **Schröder, Hanrahan:** *On the Form Factor between Two Polygons.* Proceedings of ACM SIGGRAPH 1993.

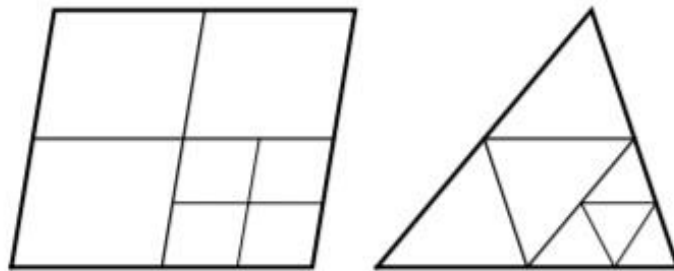
→ Closed form solution for the view factor between two convex polygons

- ▶ **Walton:** *Calculation of Obstructed View Factors by Adaptive Integration.* NIST Report, 2002.

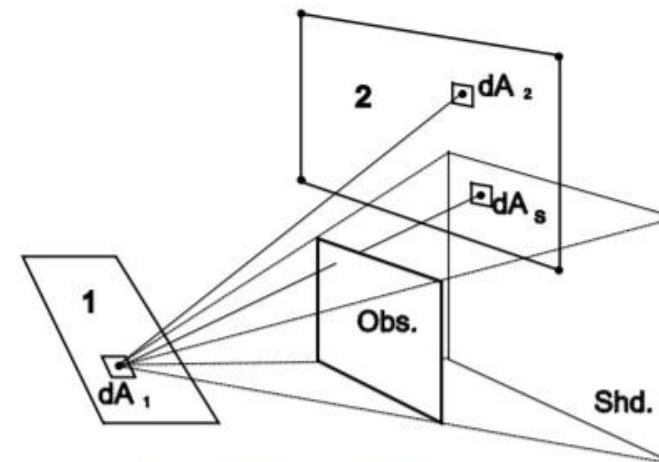


$$\begin{aligned}
 L(b|y) &= \int^a f^2(1-f)^{-3} \ln(b+f) dt = \frac{1}{b} \left[\frac{-b \ln(b-1)}{b-1} - \frac{b \ln(1+b)}{1+b} + \left(\frac{2b^2 - 3b + 1}{(b-1)^2(b+1)} \right) \ln \frac{b-1}{1+b} + \ln \frac{b-1}{1+b} \right] \\
 &\quad + \frac{2b-3}{(b-1)^2(b+1)} + \text{Li}_2 \left(\frac{1-b}{1+b} \right) \\
 M(y) &= \int^a f^2(1-f)^{-3} dt = \frac{1}{b} \left[4y(y^2-1)^{-2} + 2y(y^2-1)^{-1} + \ln \frac{y+1}{y-1} \right] \\
 G(q|y) &= \int^a \ln q(t) dt = \frac{x_1^2 q_0}{2a} \ln q(y) - 2y + \frac{2}{a} \tan^{-1} \frac{x_1^2 q_0}{2a} \\
 H(q|y) &= \int^a t \ln q(t) dt = \left(\frac{x_1^2}{2a} + \frac{2y}{a} - \frac{y^2}{2a^2} \right) \ln q(y) - \frac{y \ln y - y}{2a} - \frac{2y}{2a^2} \tan^{-1} \frac{x_1^2 q_0}{2a}
 \end{aligned}$$

Closed form
(without obstruction)

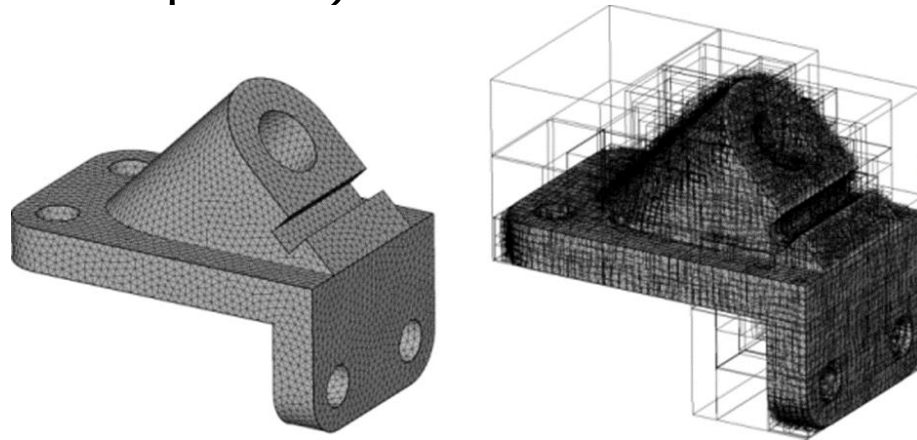


Adaptive Division of Polygons



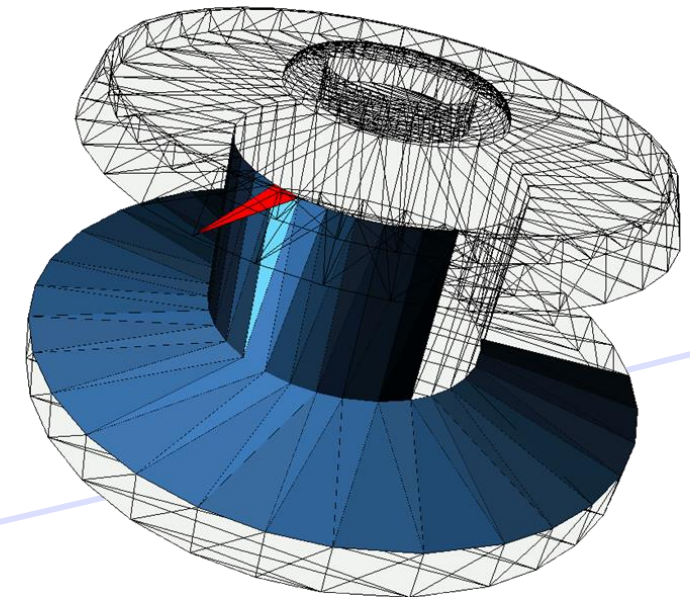
Partially Obstructed View

- ▶ **Hierarchical geometric data structure: AABB-tree** (fast intersection queries)



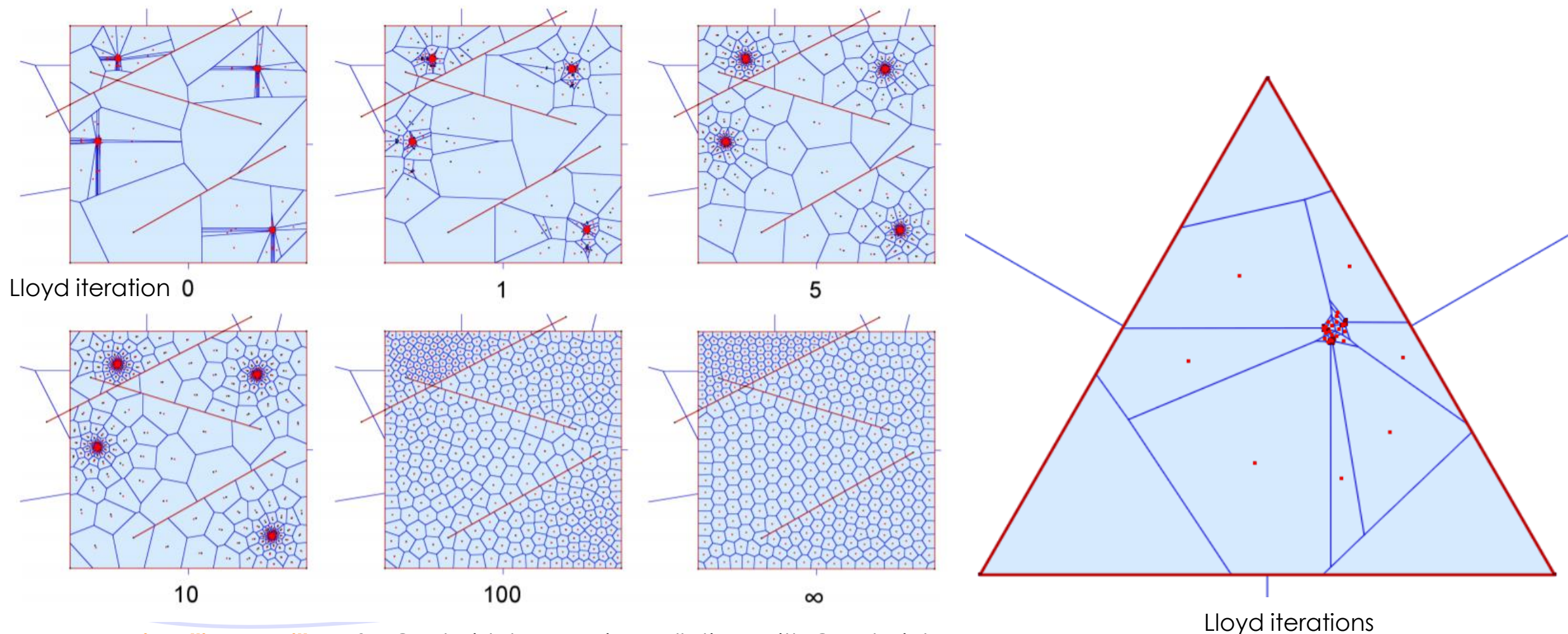
CGAL

- ▶ **Closed form solution** when full visibility (**Schröder**)
- ▶ **Quadrature in the presence of occlusions:**
 - ▶ Point-based (via bounded centroidal Voronoi diagrams)
 - ▶ Triangle-based (recursive longest bisection)



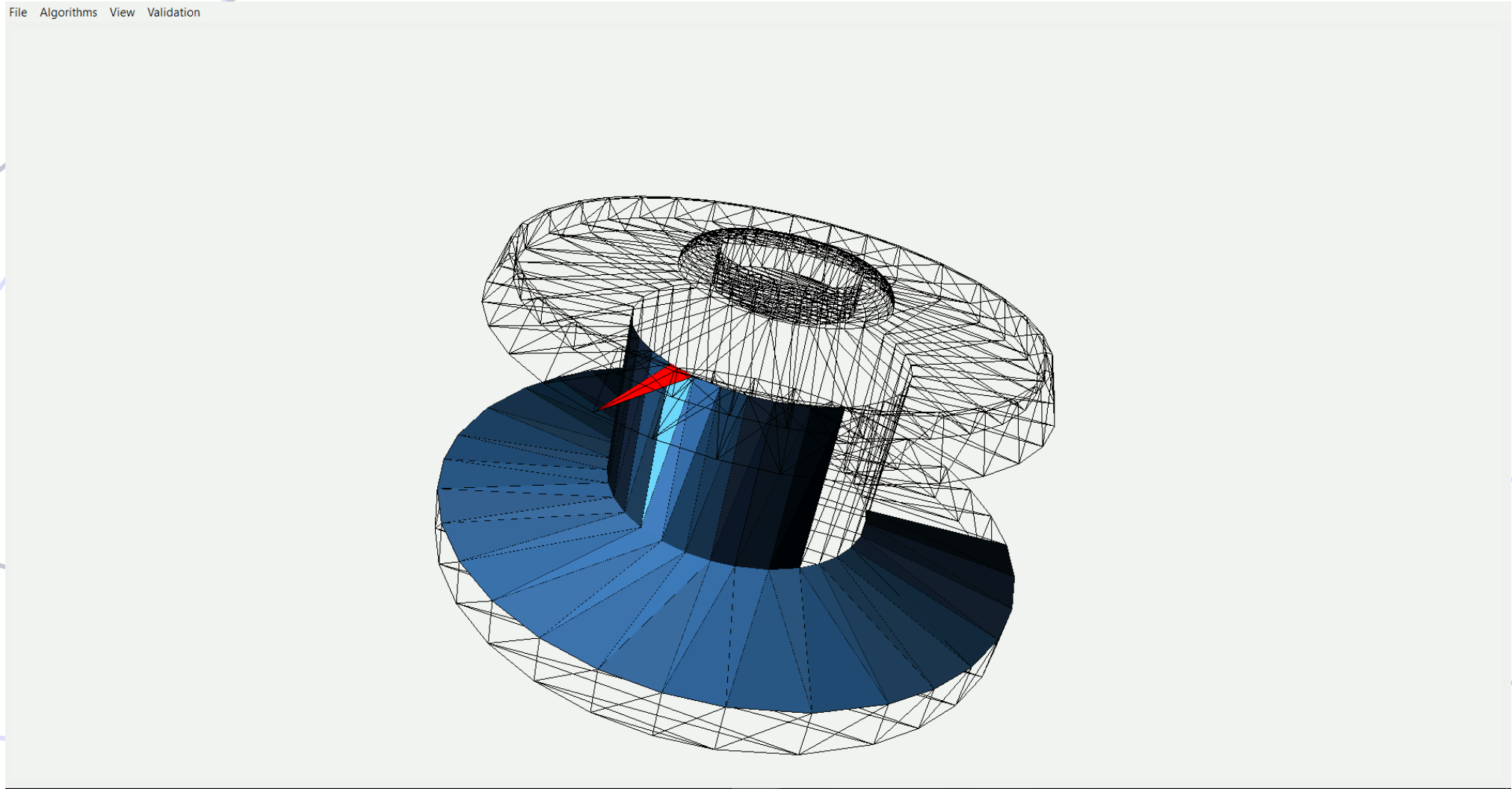
Reference view factors

Bounded Centroidal Voronoi Diagrams (CVD)



Tournois, Alliez, Devillers: *2D Centroidal Voronoi Tessellations with Constraints.*

VIEW FACTORS (VF)

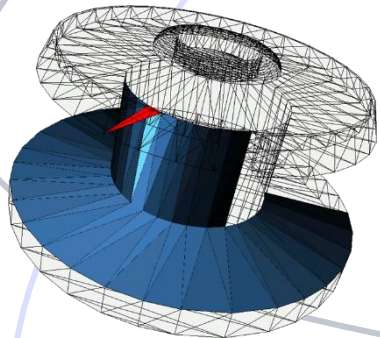
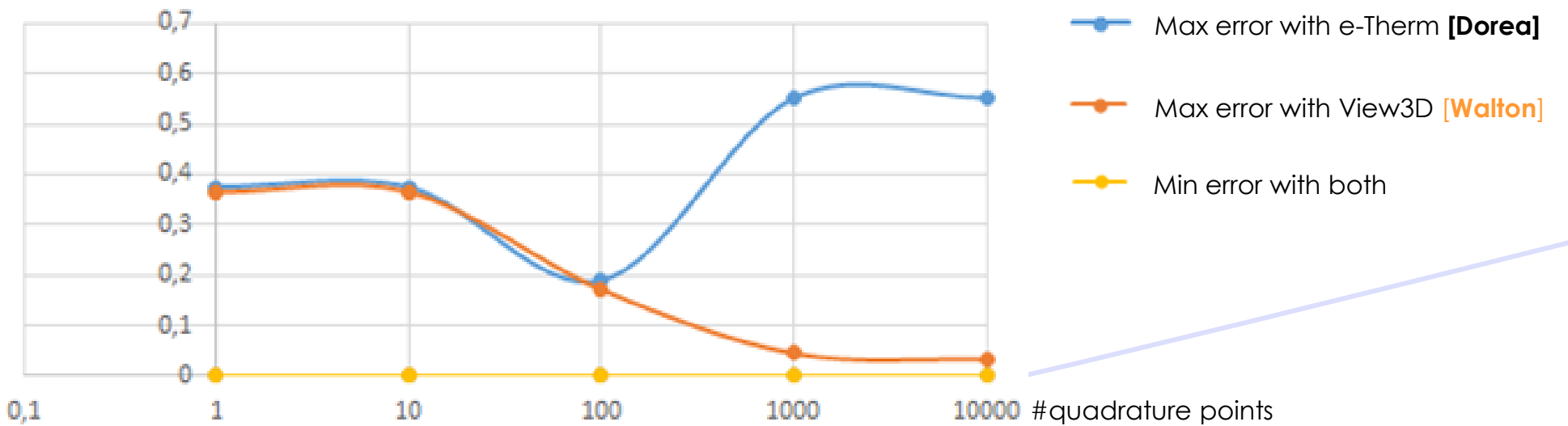


Emitter



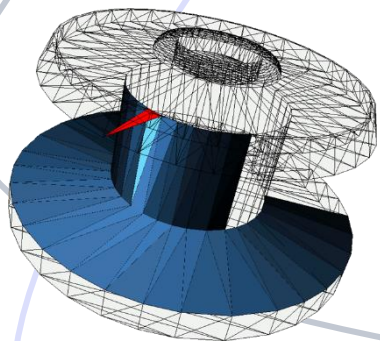
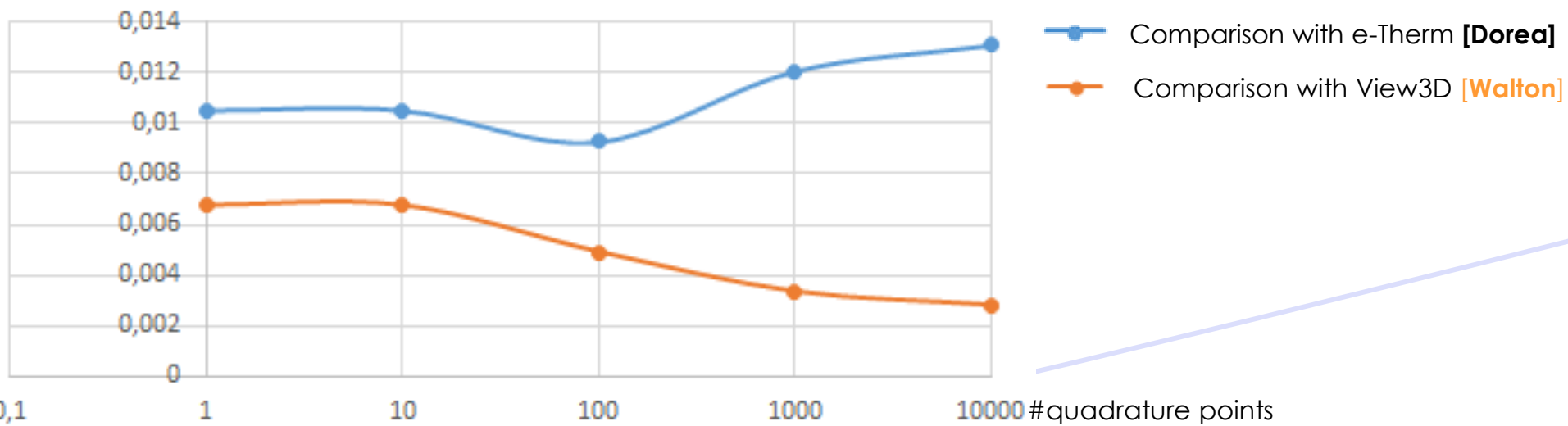
COMPARISONS

Maximum
difference of
view factors



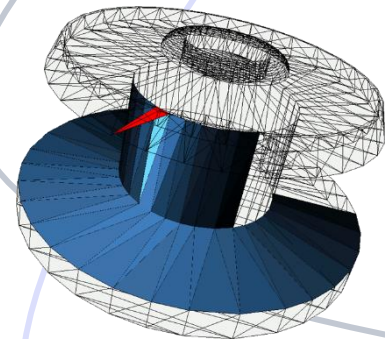
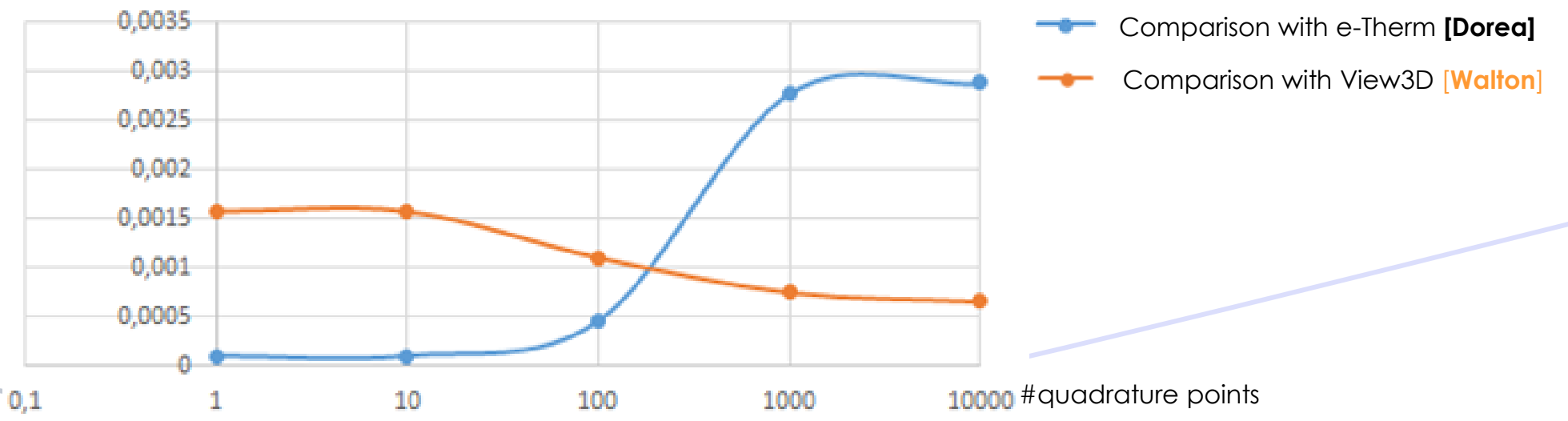
COMPARISONS

Standard deviation of view factor



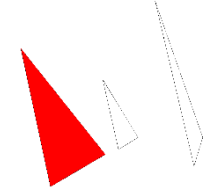
COMPARISONS

Average error of view factor



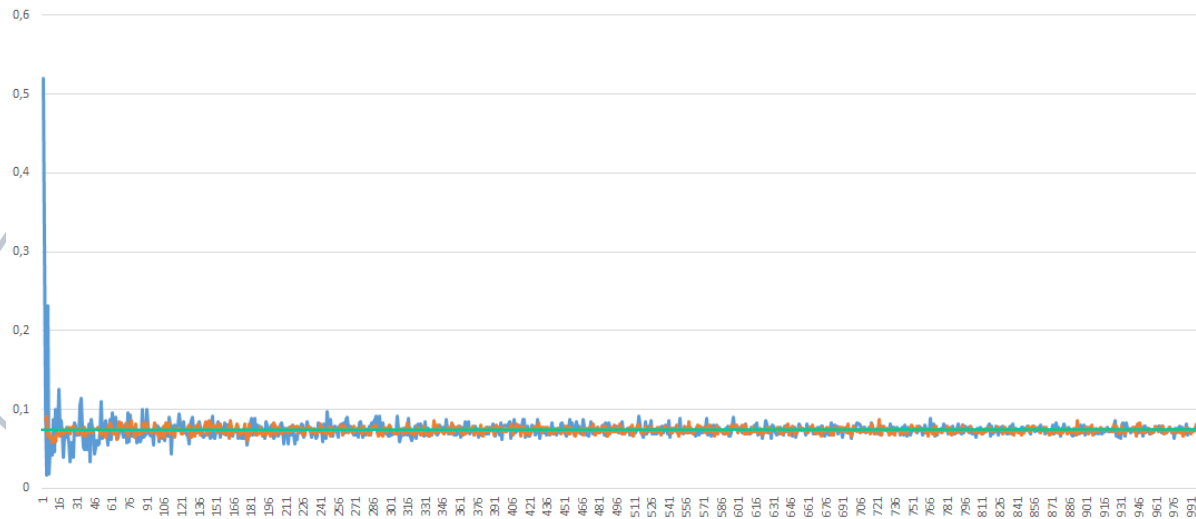
RANDOM SAMPLING VS CVD

Results with two random triangles configuration and an obstacle between them

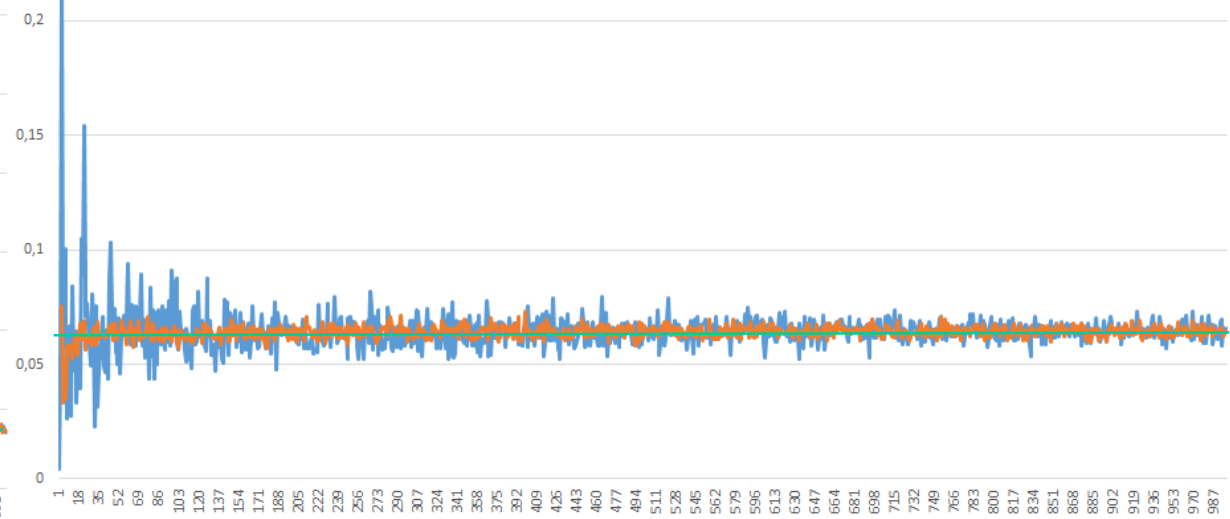


View factor value

Lloyd 100 obstacle 2



Lloyd 100 obstacle 3

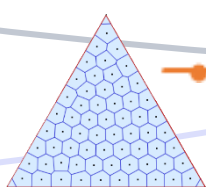
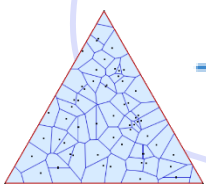


#quadrature points

—●— Random uniform sampling

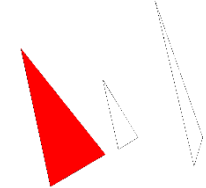
—●— Bounded Centroidal Voronoi

— View factor exact value



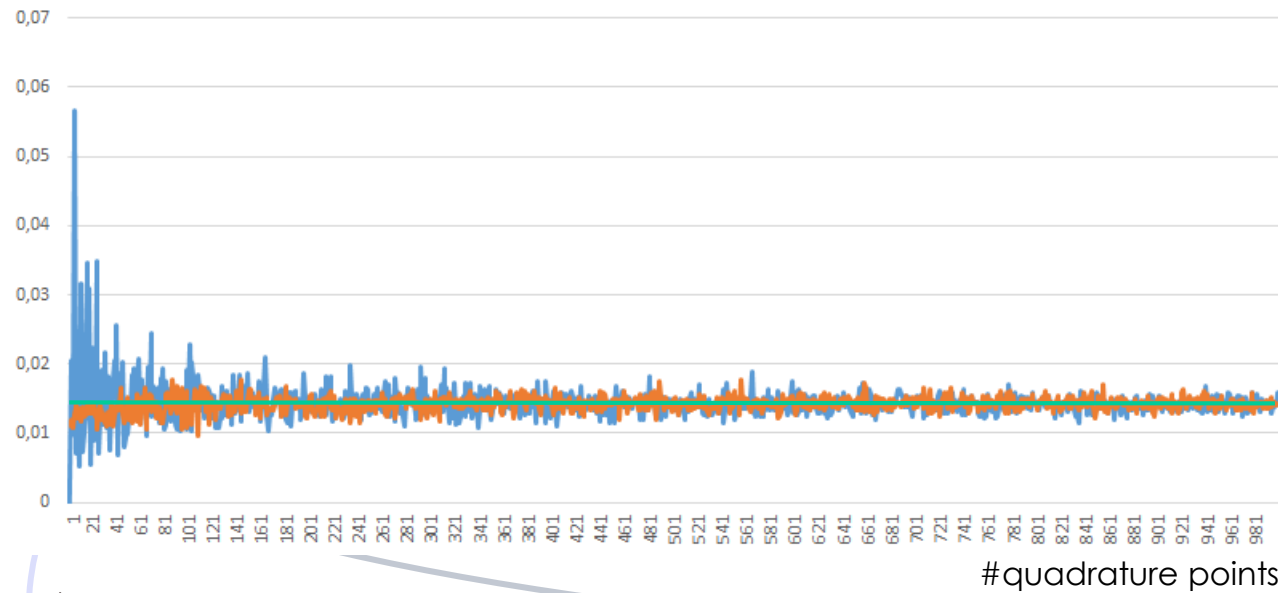
RANDOM SAMPLING VS CVD

Results with two random triangles configuration and an obstacle between them

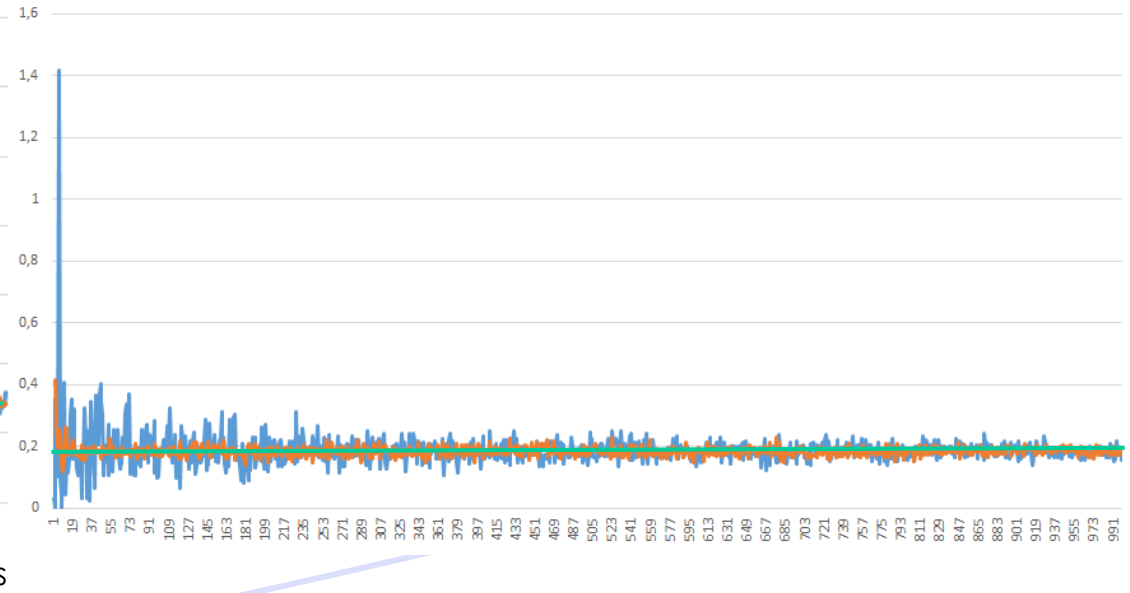


View factor value

Lloyd 100 obstacle 4



Lloyd 100 obstacle 5



#quadrature points

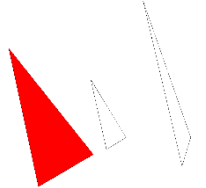
—●— Random uniform sampling

—●— Bounded Centroidal Voronoi

— View factor exact value

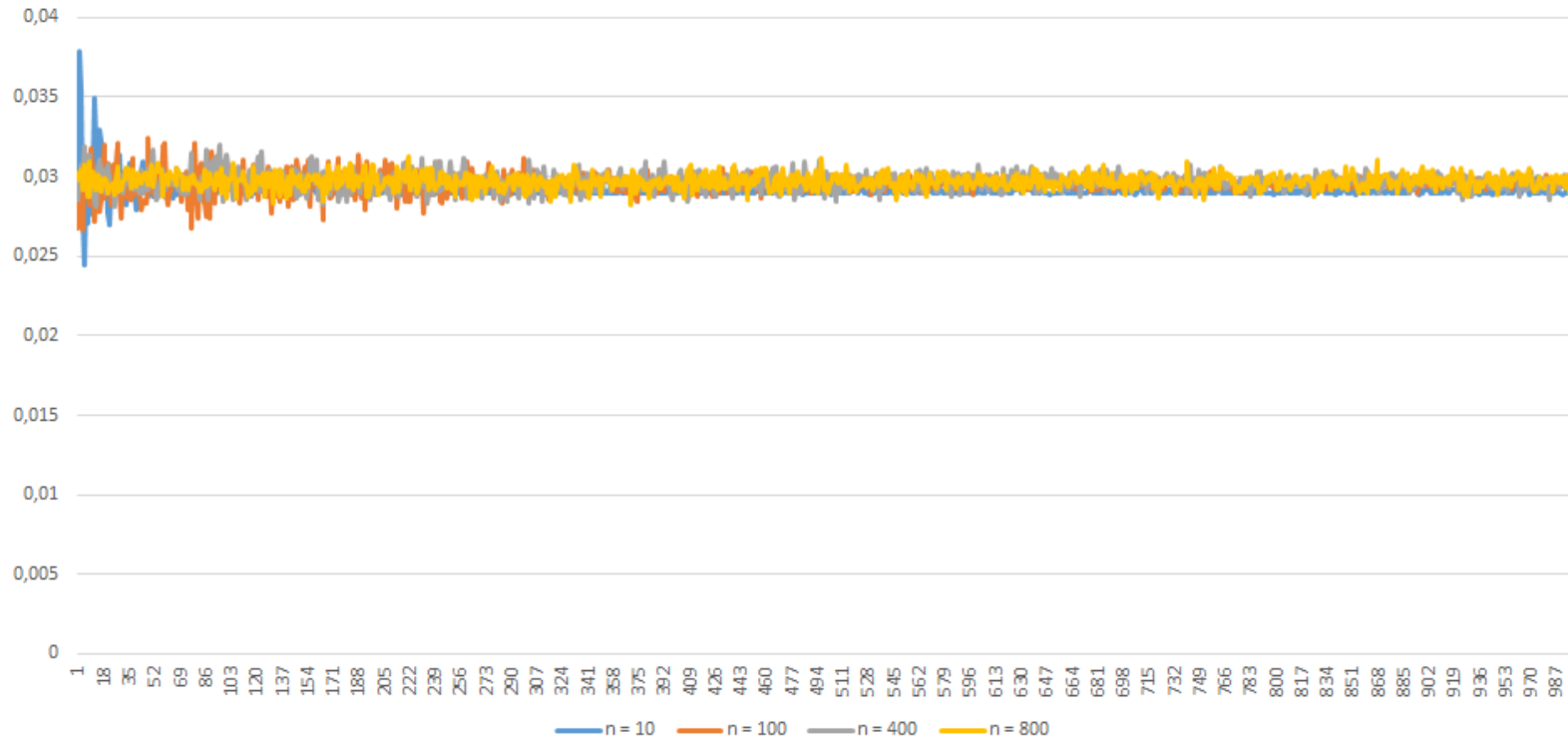
VARYING #LLOYD ITERATIONS

Results with two random triangles configuration and an obstacle between them



View factor value

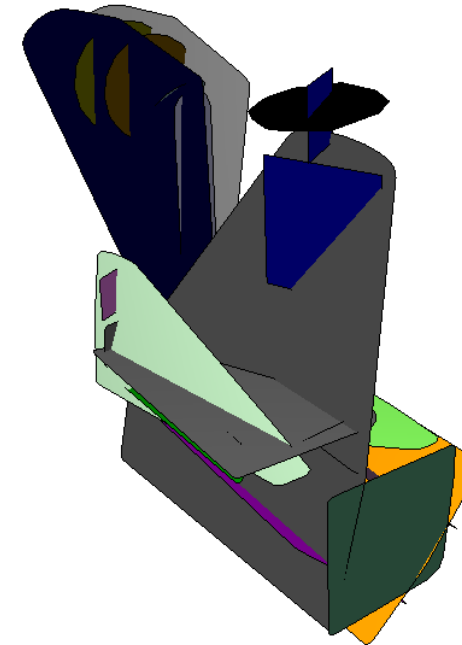
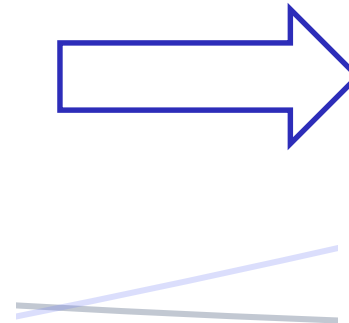
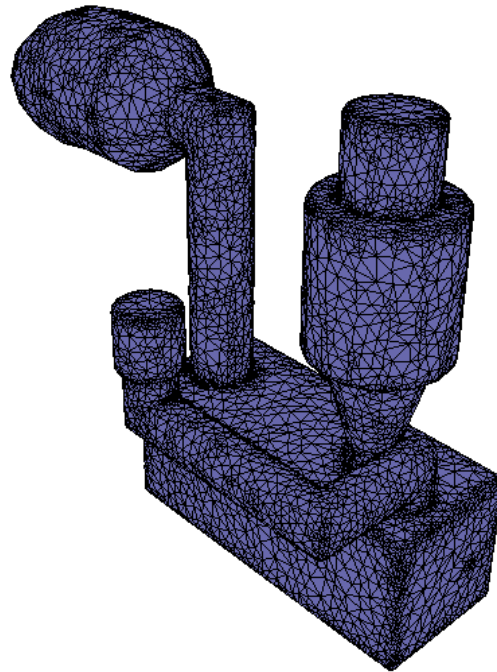
Fixed quad points, incrementing Lloyd iterations (with obstacle)



#Lloyd iterations

Approximation method guided by preservation of the view factors. We keep the constraint of the thermal nodes in order to compare the matrices of the radiative surfaces per nodes.

	1	2	3	4	5	6	7	8
1	11	12	0	0	0	0	0	0
2	0	22	0	0	0	0	0	0
3	31	32	33	0	0	0	0	0
4	41	42	43	44	0	0	0	0
5	0	0	0	0	55	56	0	0
6	0	0	0	0	0	66	67	0
7	0	0	0	0	0	0	77	78
8	0	0	0	0	0	0	0	87 88



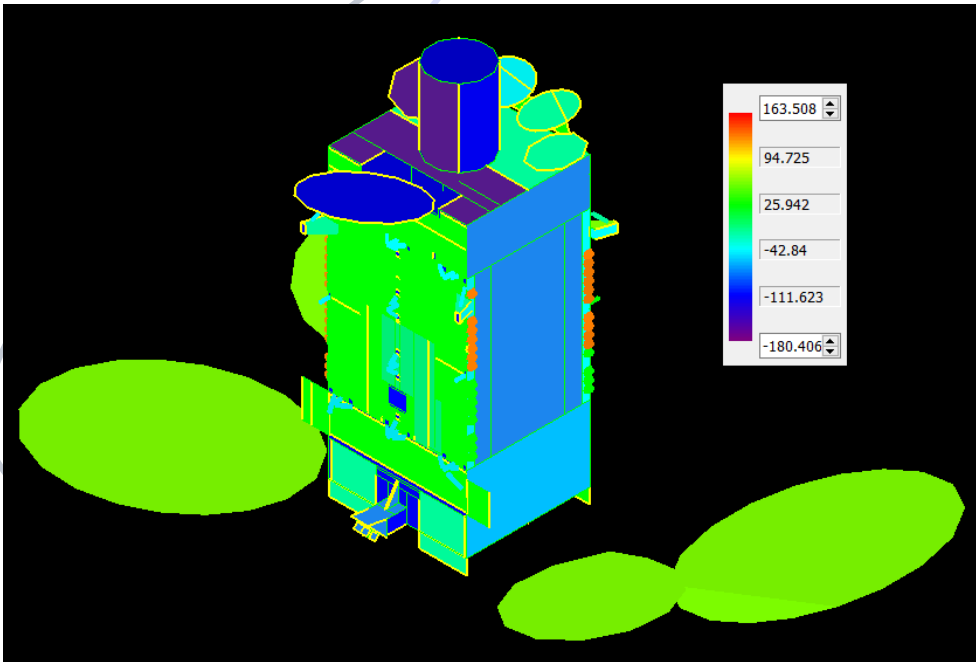
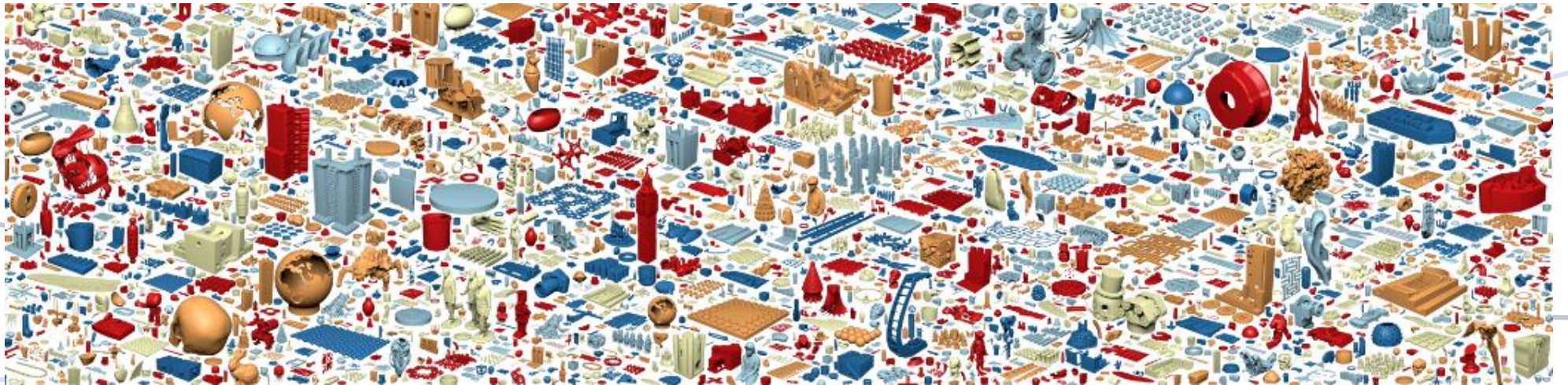


Illustration of the thermal nodes with e-Therm

- ▶ **Simplification** via face clustering in order to best approximate the thermal nodes.
- ▶ **Comparison with the reference calculation thanks to thermal nodes:**
 - ▶ Main idea: compare the radiative surfaces by node matrices from the reference calculation case and the approximation one



- ▶ **Goal:** learn geometric error metric able to govern an automatic approximation algorithm so that the resulting thermal simulation is as accurate as possible to a reference calculation.
- ▶ Constraints = thermal nodes, so we can compare the radiative surfaces of each node before and after approximation.



[[Jacobson](#)] Thingie10K (training dataset)

THANK YOU



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 - ▶ francois.brunetti@dorea.eu