Influence of geometrical levels of detail and inaccurate material optical properties on daylight simulation results

Nima Forouzandeh , Eleonora Brembilla,
Liangliang Nan, Jantien Stoter, Alstan Jakubiec

TU Delft Department of Architectural Engineering +Technology
BK Bouwkunde

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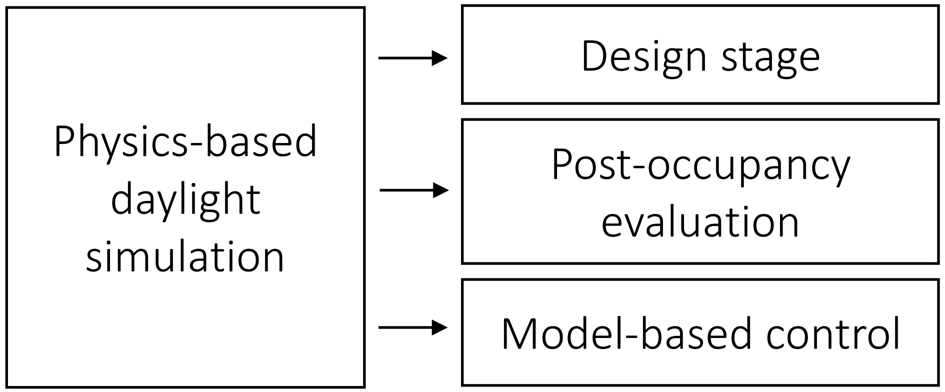
Greetings from Delft
“The only town with a statue to BSDFs”
– John

overview

- Introduction
- Research questions
- Definition of geometrical levels of detail (GLOD) and material classes of accuracy (MCOA)
- Influence of varying GLODs, MCOA on annual daylight results

Introduction



- Uncertainties caused by inaccurate definition of material and geometry

Introduction - Related works

- **Brembilla et al. >** sensitivity of CBDM results to the reflectance of different semantics, e.g., walls, floors.
- **Sadeghi and Mistrick >** model the exterior geometry in six different levels of detail by the inclusion of different semantics based on size at each LOD
- **Biljecki >** propagation of positional errors in the estimation of the solar irradiation of building roofs based on TU Delft's LODs jointly with varying XY/Z accuracy levels

- Definitions of indoor geometrical LODs are suited for:

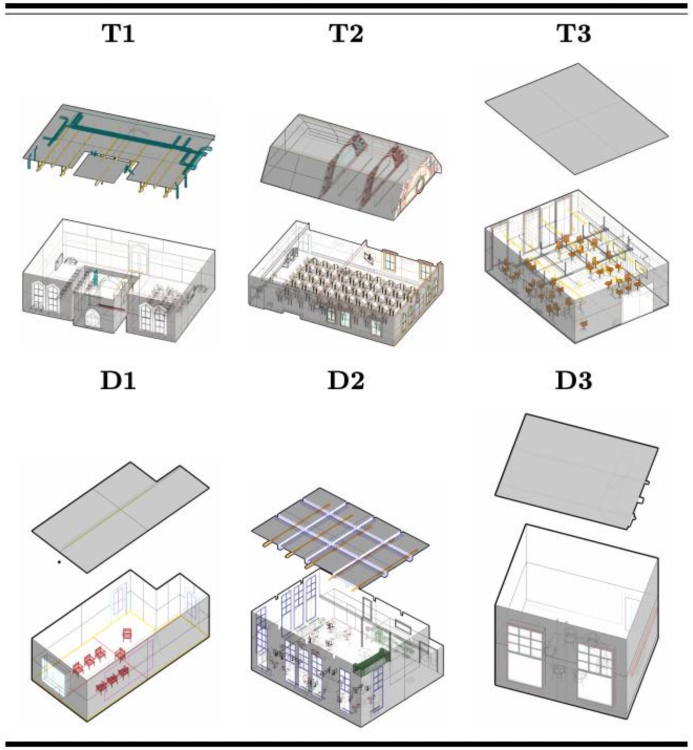
1. Natural disaster management
2. Area determination
3. Route visualization

Introduction - **Questions**

- How to standardize the geometry and material inputs for CBDM?
- Impact of incomplete geometry on CBDM results?
- Impact of inaccurate material definition on CBDM results?

Methodology - **Case study spaces**

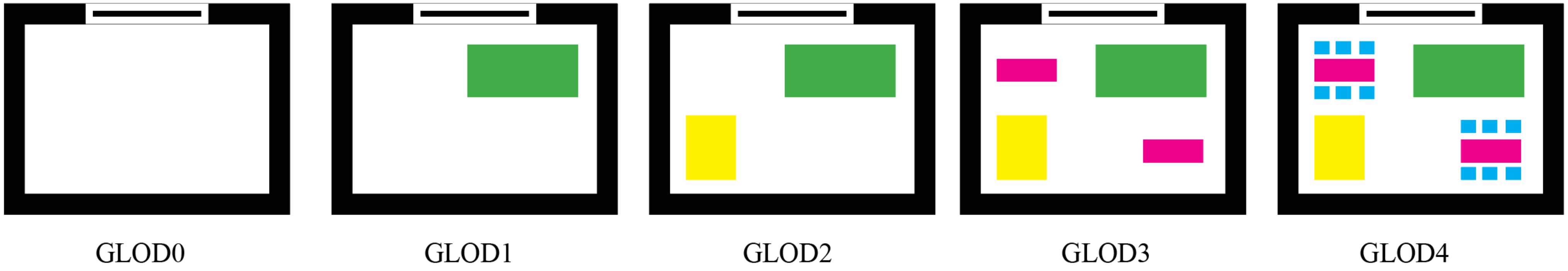
Case study spaces – 3D representation



Case study spaces - general information

Space ID	Location	Space type	Dimensions [m*m*m]	WFR [%]
T1	Toronto, CA	Classroom	14.5 * 9.7 * 3	9.6
T2	Toronto, CA	Classroom	16.6 * 10.6 * 3.5-6.7	9.1
T3	Toronto, CA	Classroom	11.7 * 8.3 * 4.0	14.1
D1	Delft, NL	Meeting room	5.8 * 4.4 * 5.8	9.1
D2	Delft, NL	Open office	12 * 9.8 * 5.8	29.4
D3	Delft, NL	Meeting room	7.2 * 3.4 * 2.6	40.9

Methodology - **Geometrical Level of Detail (GLOD)**



Methodology - **Geometrical Level of Detail (GLOD)**

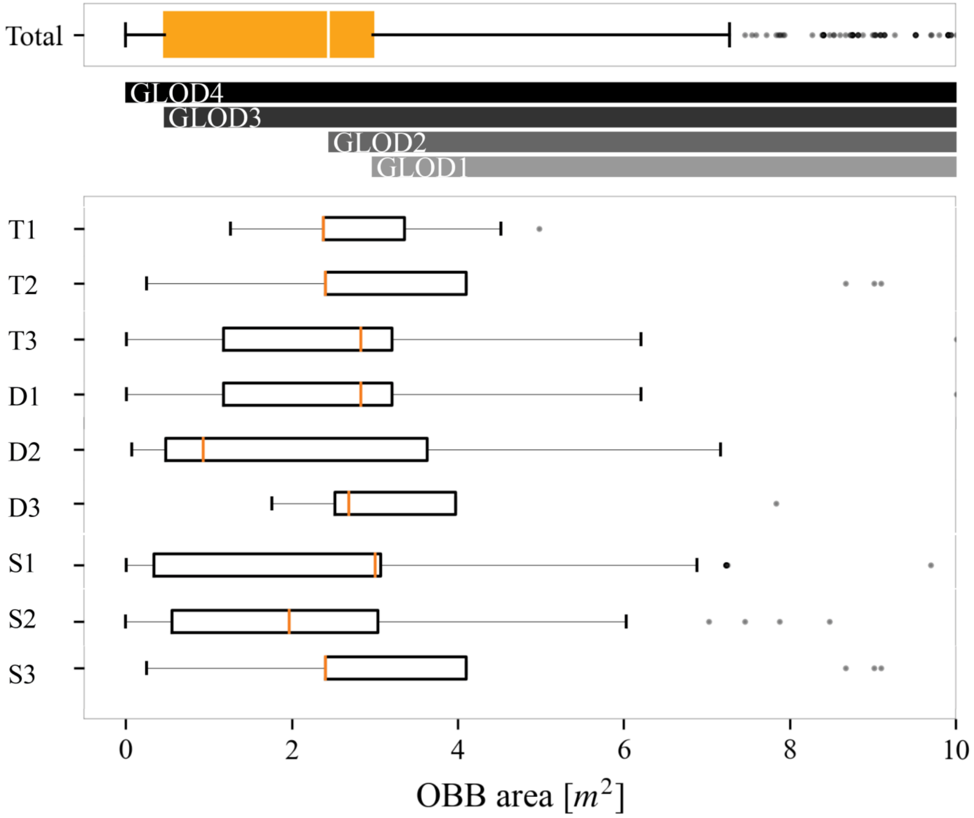
What measure for size?

Surrounding Sphere | Axis-aligned bounding box

Oriented Bounding Box(OBB) | Convex hull

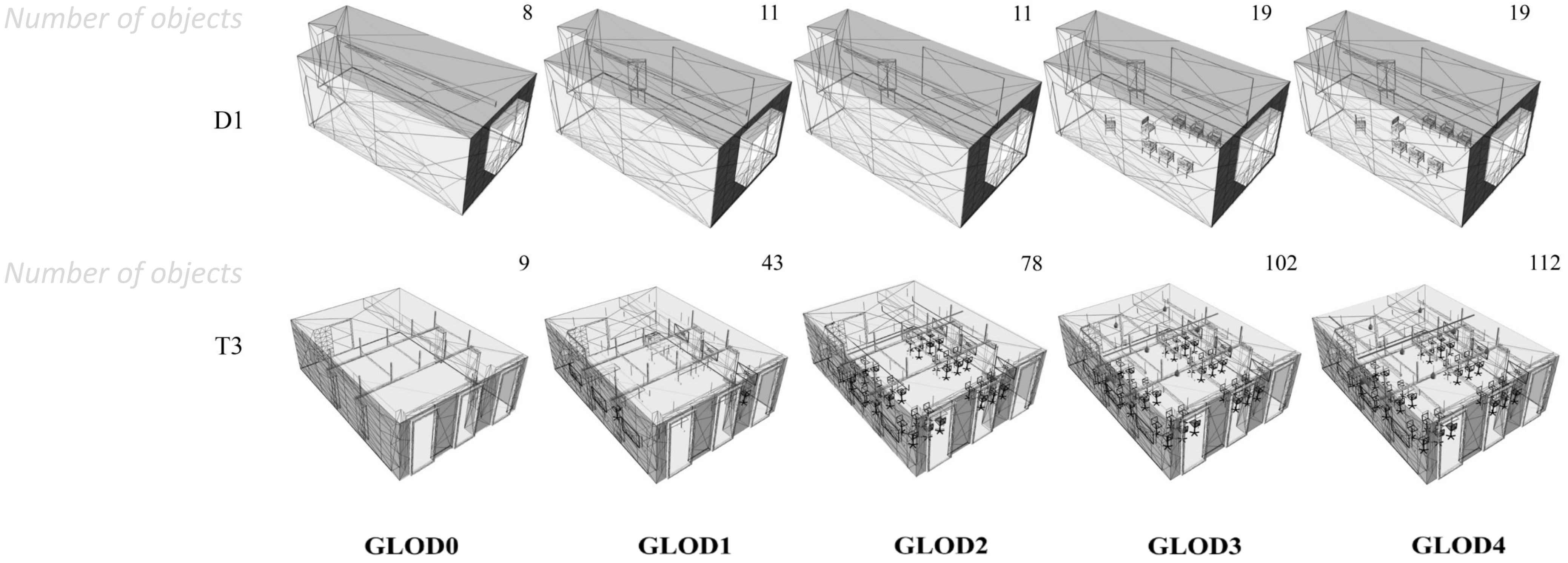
Bounding geometries

What thresholds to pick?



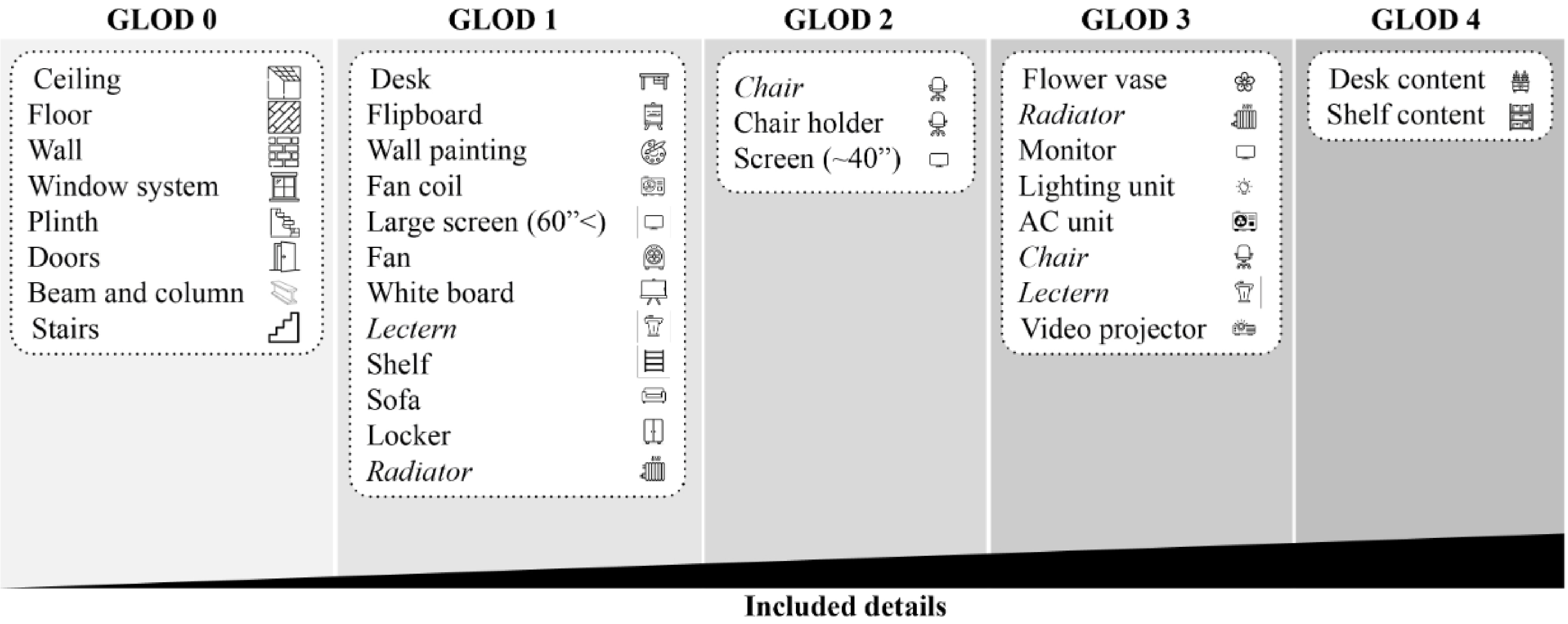
Summary of object sizes in the case study spaces

Methodology - **Geometrical Level of Detail (GLOD)**



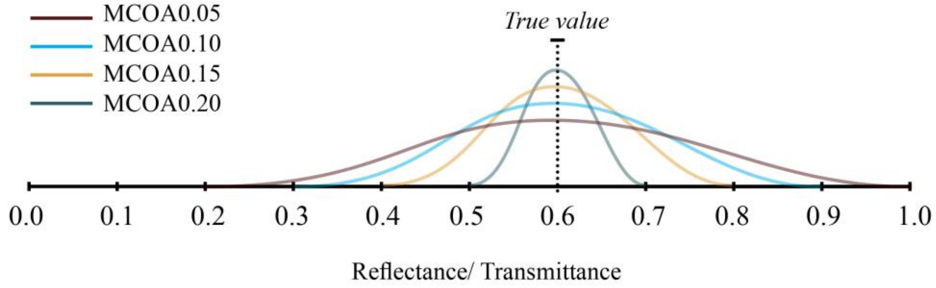
3D representation of spaces in multiple GLODs

Methodology - **Geometrical Level of Detail (GLOD)**

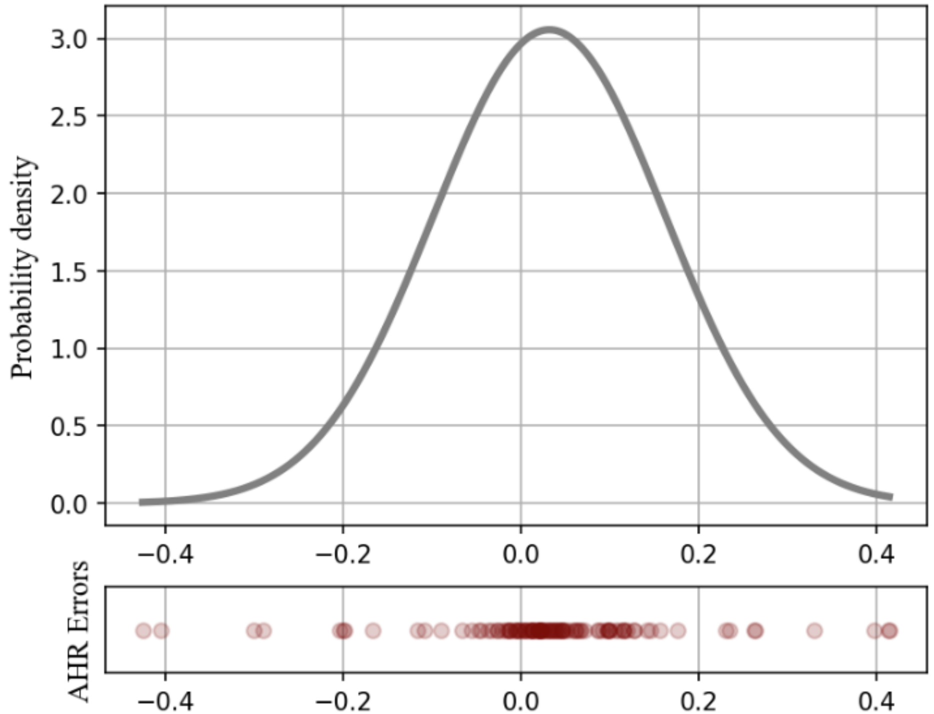


The GLOD where each semantic first appears in the models.

Methodology - **Material classes of accuracy (MCOA)**



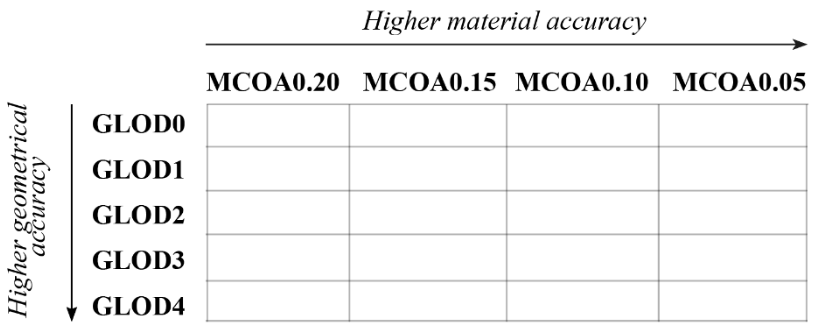
An example of four MCOAs used in the Monte Carlo simulation. In this example the ground truth is 0.6



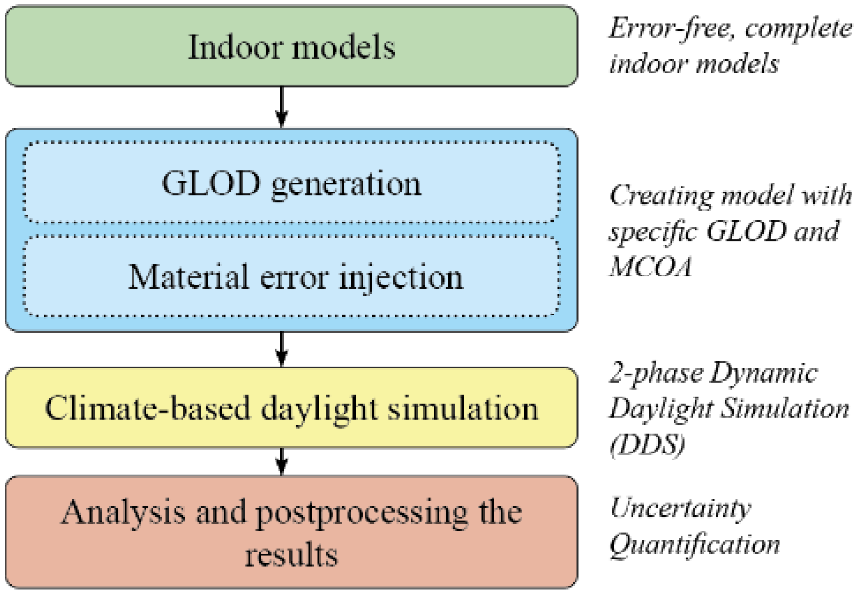
Bell curve fitted to AHR errors, when compared against measurement from a reflectance spectrophotometer

Methodology - **Monte Carlo simulation**

- Dynamic daylight Simulation(DDS) method
- 500 simulations for each cell in the matrix with varying optical properties

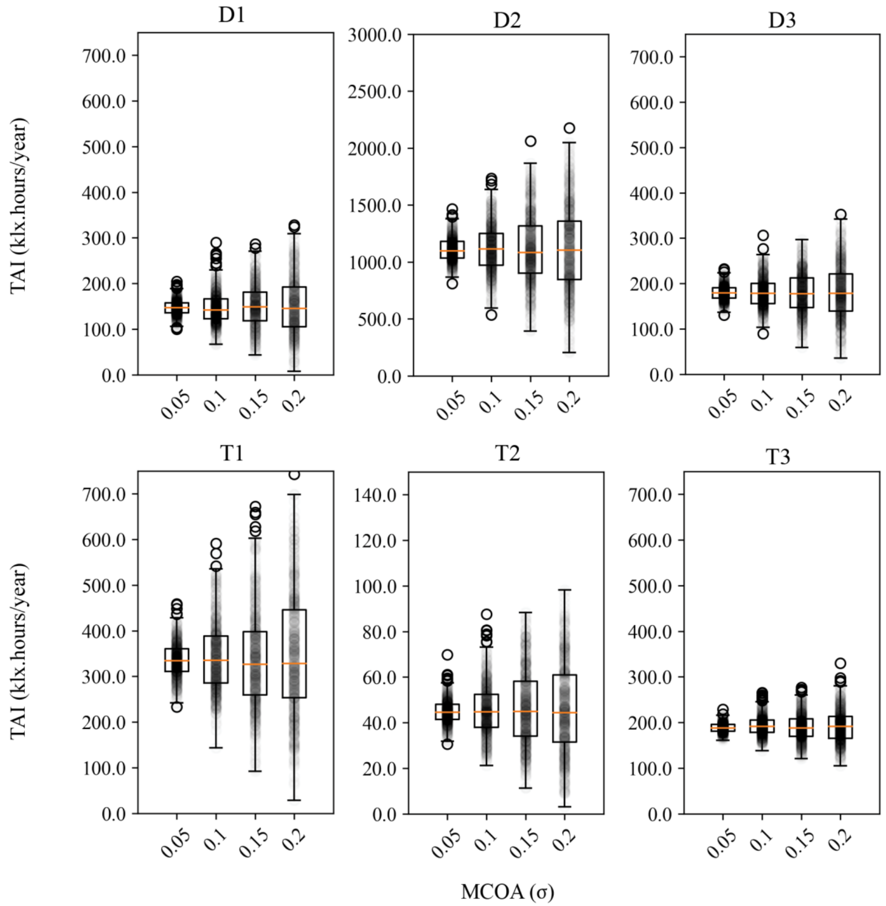


The GLOD-MCOA matrix

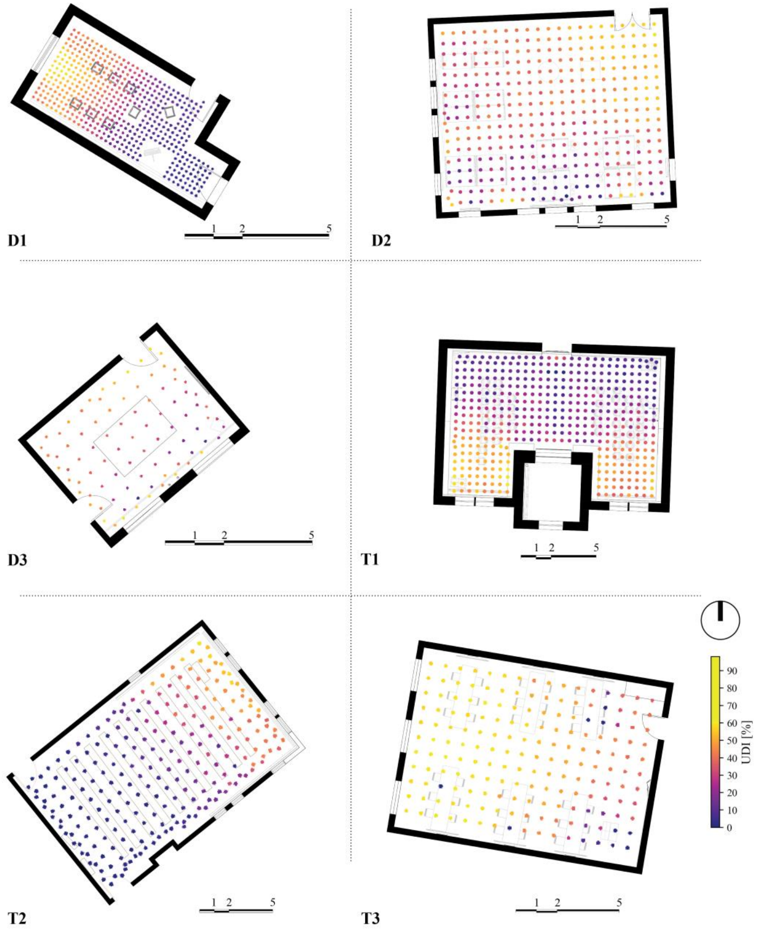


Workflow of the uncertainty quantification study

Results - **Daylight availability in the studied spaces**

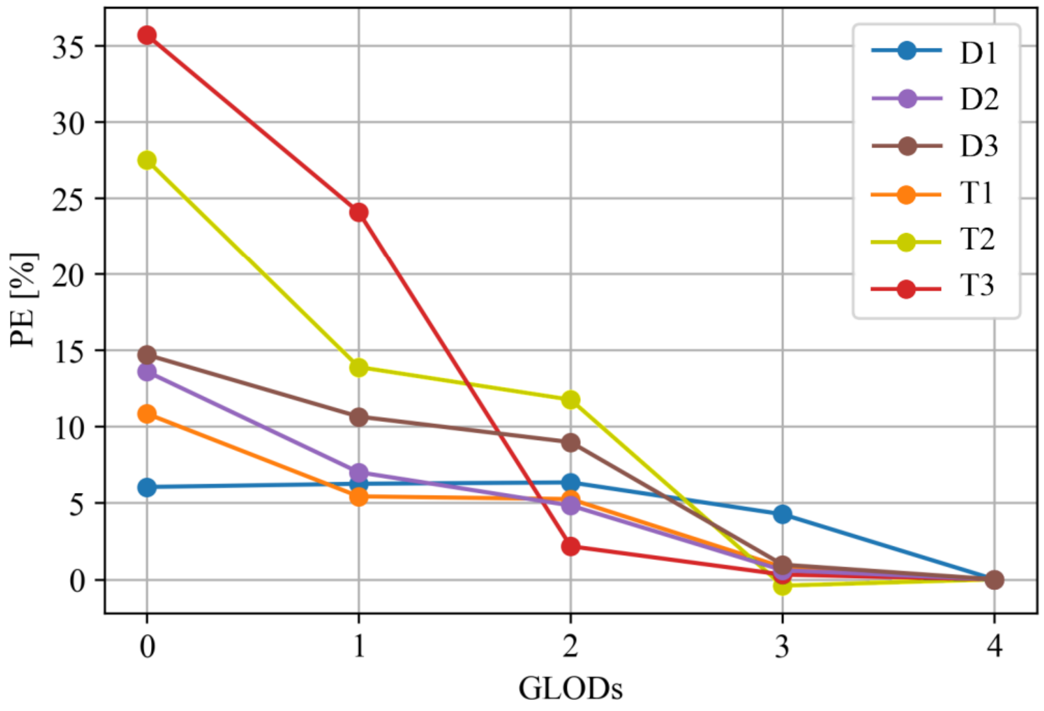


TAI results, all in GLOD 4. Boxplots show the interquartile values for one GLOD-MCOA combination.



UDI Heat maps

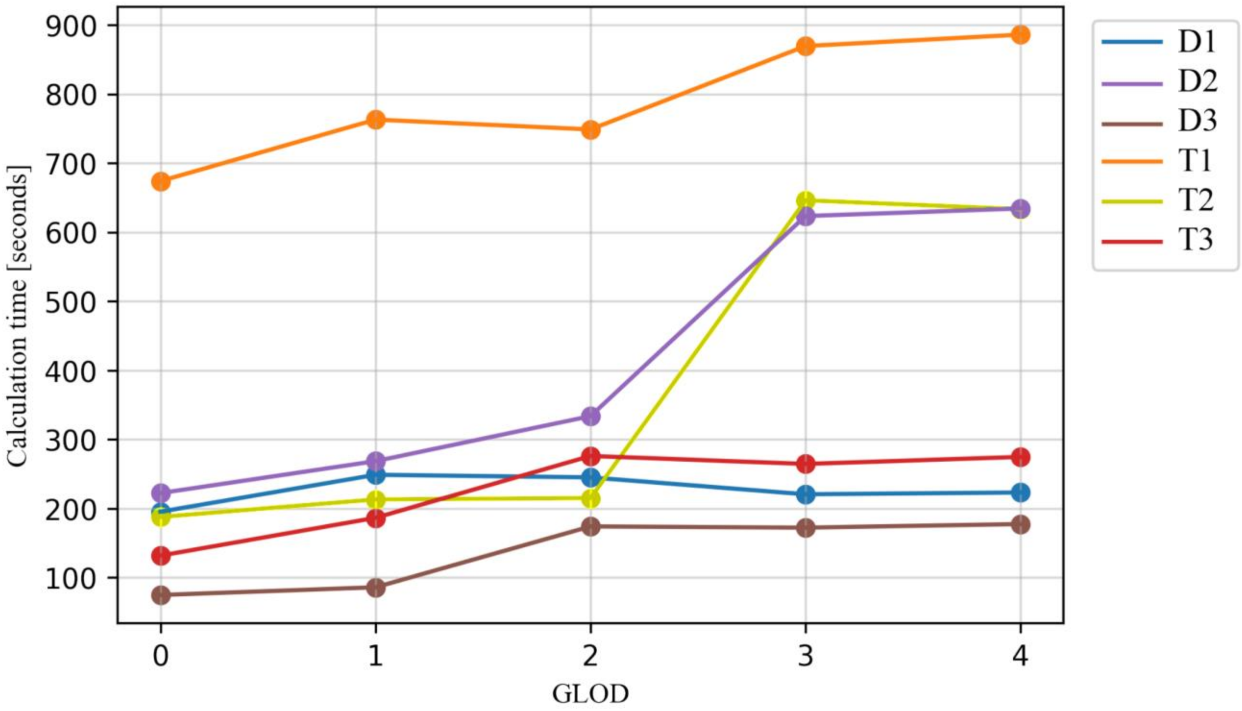
Results - **Influence of varying GLODs, accuracy**



Influence of geometrical resolution on annual illuminance predictions

	GLOD0	GLOD1	GLOD2	GLOD3
		PE [%]		
min	6.04	5.42	2.16	0
max	35.67	24.07	11.75	4.25
mean	18.05	11.21	6.55	1.08
		RMSE [*lx*]		
min	57	894	50	44
max	949	51	876	841
mean	320	302	292	279

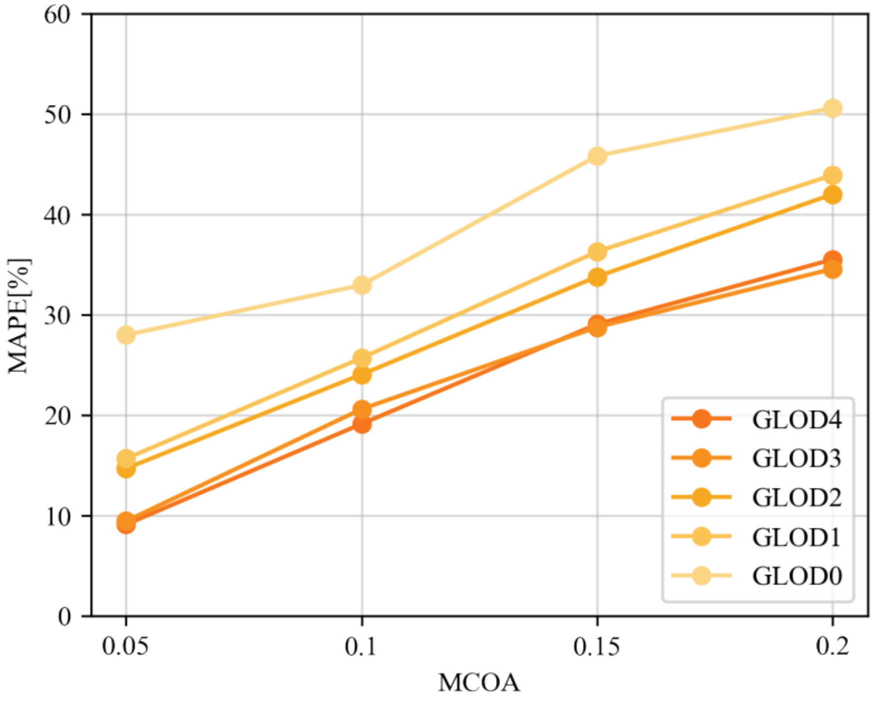
Results - **Influence of varying GLODs, simulation time**



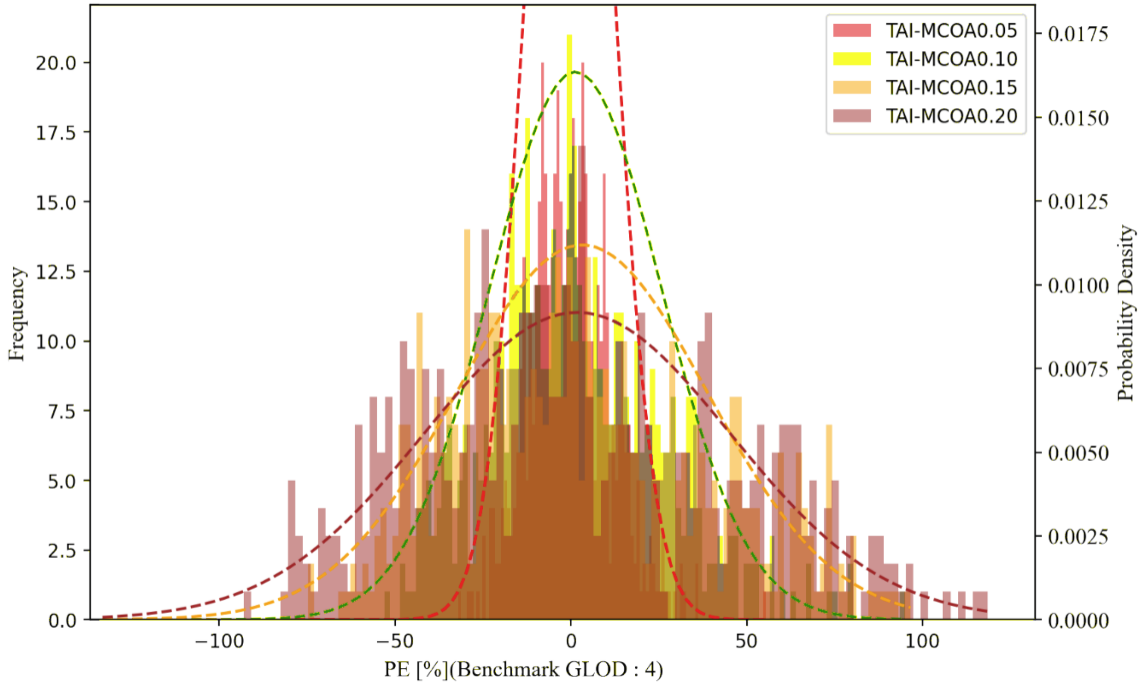
Influence of geometrical resolution on simulation times

- The simulation time can decrease by 200%.
- Model complexity.

Results - **Influence of varying MCOAs**

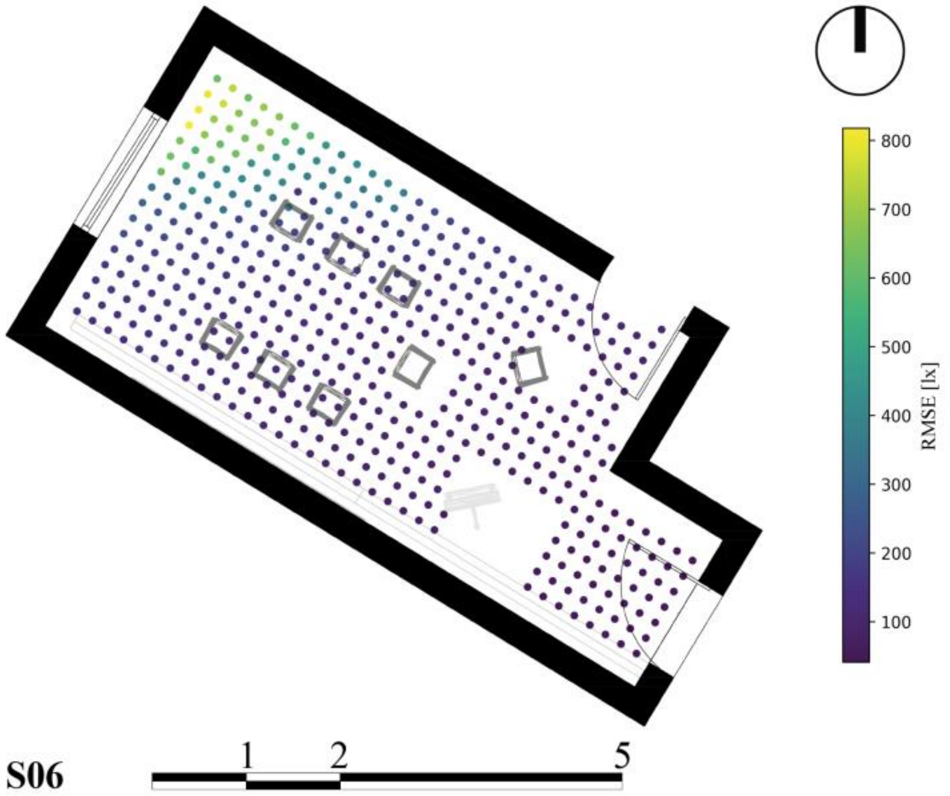


Influence of varying MCOA



Distribution of errors in the estimation of the TAI for space T2 with the four different MCOA and the fitted normal probability density functions for each one (T2)

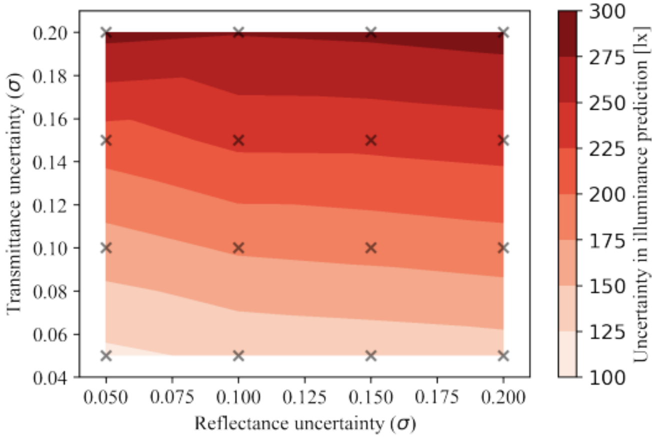
Results - **Influence of varying MCOAs – spatial distribution**



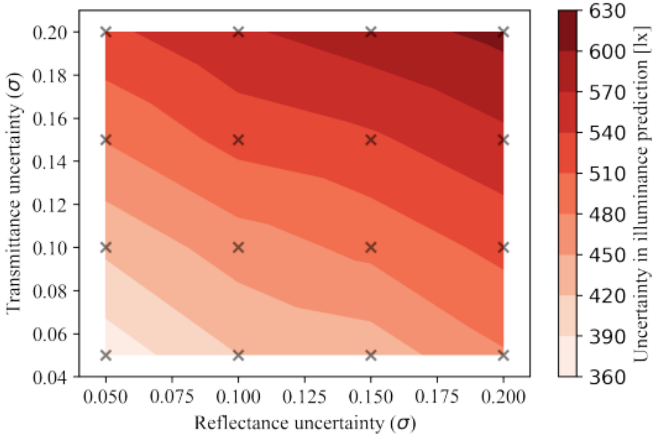
Spatial distribution of prediction errors caused by inaccurate material definition (MCOA0.2-GLOD4–D1)

- The uncertainty is pronounced around the windows.
- What is the relative importance of transmittance and reflectance?

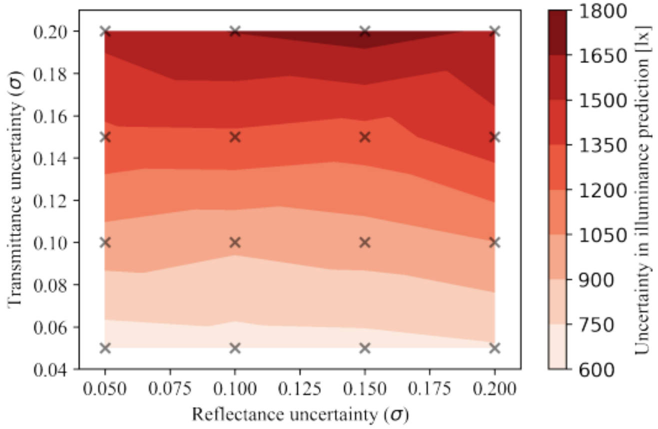
Results - **Influence of varying MCOAs – Error isolation**



(a) *S06* (WFR: 9.1%)



(b) *S09* (WFR: 14.1%)



(c) *S11* (WFR: 40.9%)

Uncertainty in the calculation of annual grid-based illuminance values, gradient colors represents the interpolated uncertainty across the 2D domain of 0.05-0.20 reflectance-transmittance independent uncertainties

Discussion/limitations

- Focus on non-permanent objects.
- 2 ways for GLOD definition: inclusion/exclusion approach vs. Mesh simplification approach.
- We ignore the influence of proximity to windows and object orientation.
- MCOAs and generalizability to other measurement approaches/ maintenance factors.

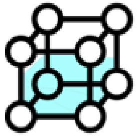
Conclusion

- Exclusion of non-permanent objects in GLOD3-GLOD0 causes on average 1.08, 6.55, 11.21, and 18.05 % errors in the output TAI values
- Excluding the non-permanent objects is shown to make the simulation run up to threefold faster
- The errors arising from inaccurate definitions of material optical properties exhibit a normal distribution.
- The uncertainty in measurements linearly increases with higher levels of input material uncertainty by 10-30% depending on the space.
- The uncertainty is more pronounced around the openings. This can be attributed to the fact that the overall uncertainty is primarily influenced by the uncertainty in the transmittance of materials.

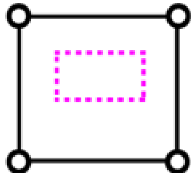
Work in progress

- Semi-automatic reconstruction of indoor spaces from point clouds

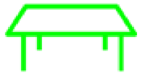
Watertight
(permanent structures)

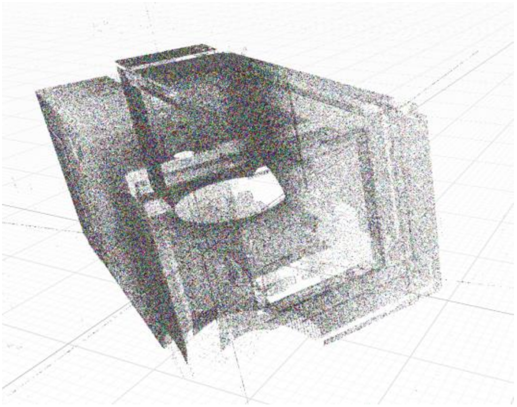


Window boundaries

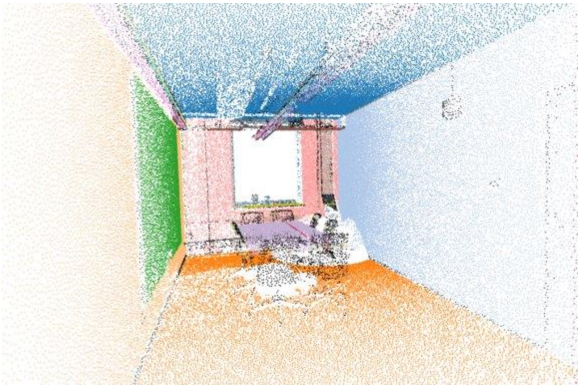


Major furniture pieces

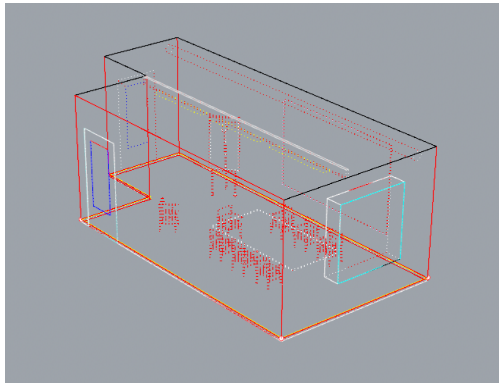




Point cloud acquisition



Segmentation



Surface Reconstruction

Thank you for your attention,

Questions and comments are welcome!

n.forouzandeh@tudelft.nl