

Thermoxels

A voxel-based method to generate simulation-ready 3D thermal models

Etienne Chassaing 

cetiennech@yahoo.com

EPFL

Florent Forest 

florent.forest@epfl.ch

EPFL

Olga Fink 

olga.fink@epfl.ch

EPFL

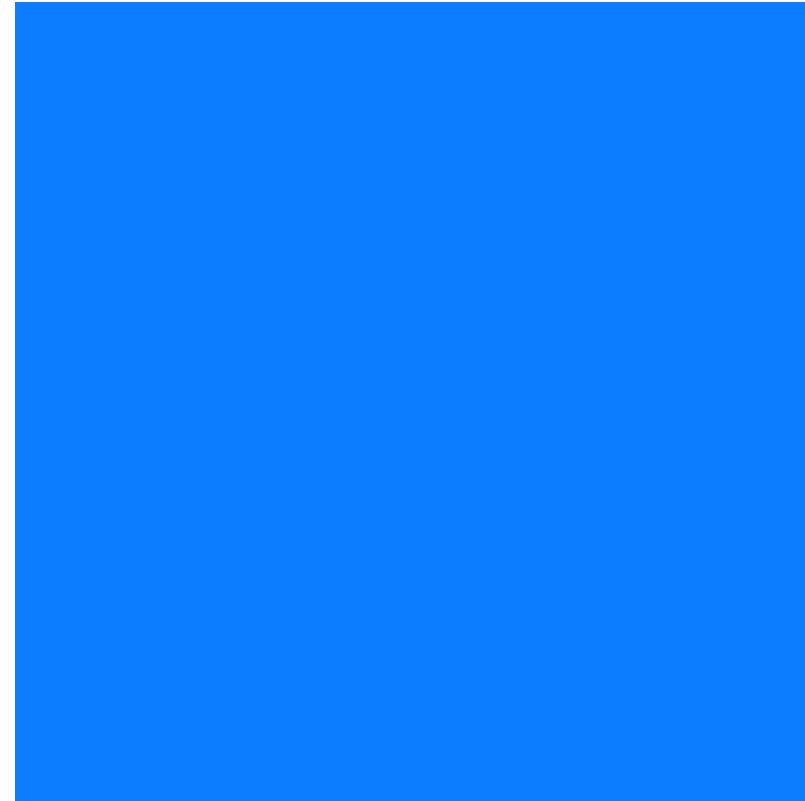
Malcolm Mielle 

malcolm.mielle@schindler.com

Schindler EPFL Lab

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Building (energy consumption) statistics



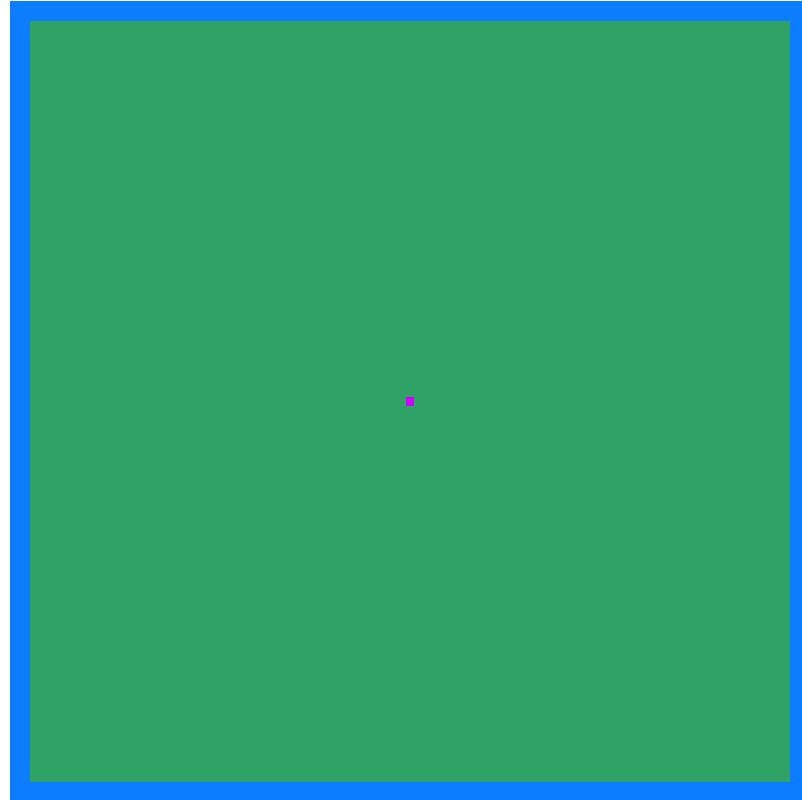
Building (energy consumption) statistics

- 85 to 95% still standing by 2050



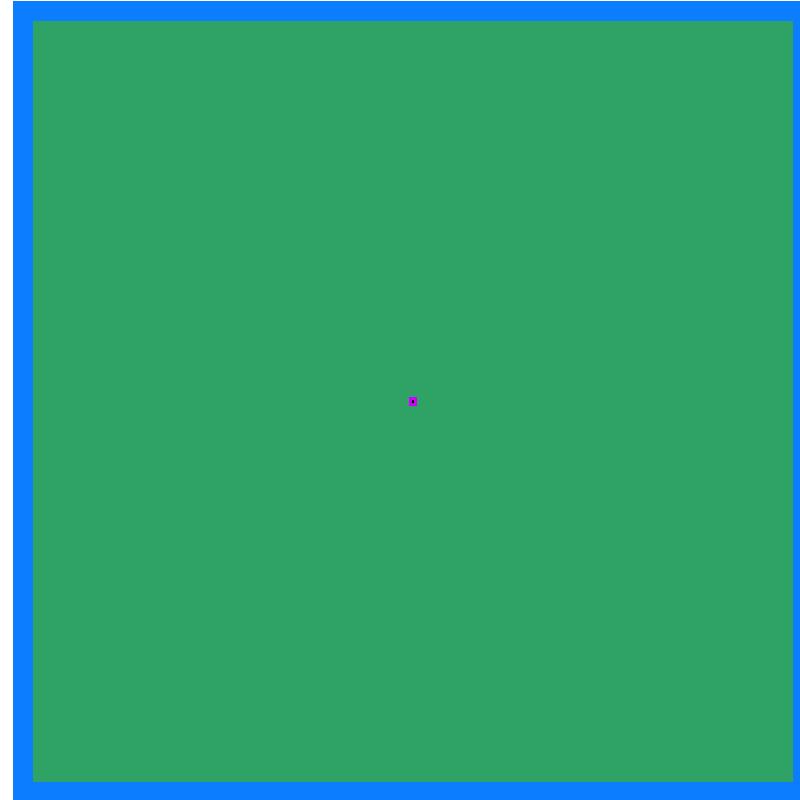
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- Weighted annual energy renovation rate: 1%



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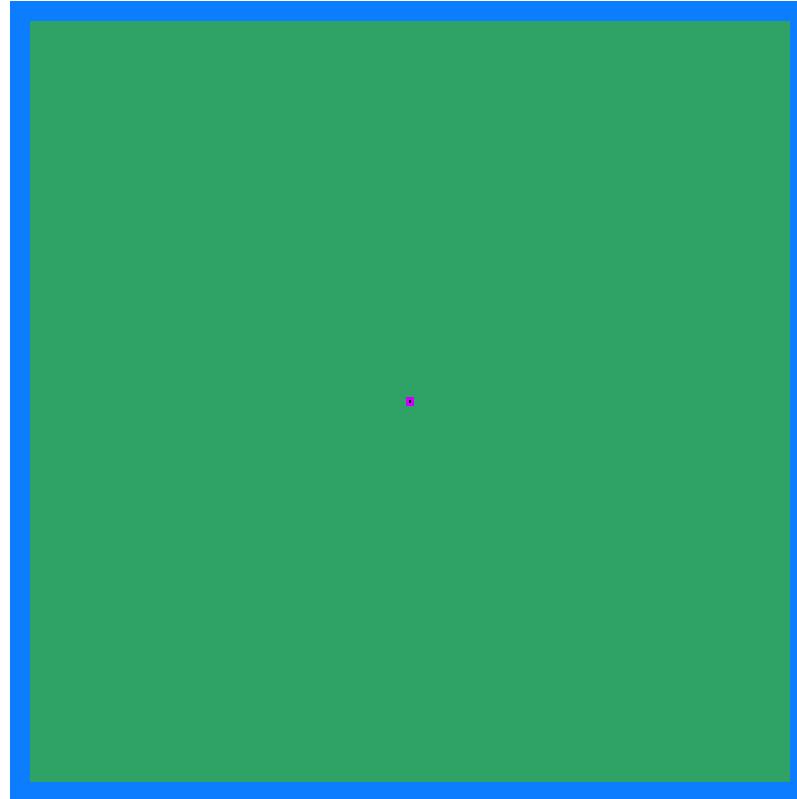
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- Weighted annual energy renovation rate: 1%
- Deep renovation: 0.2%



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Need tools for targeting and monitoring of renovations.

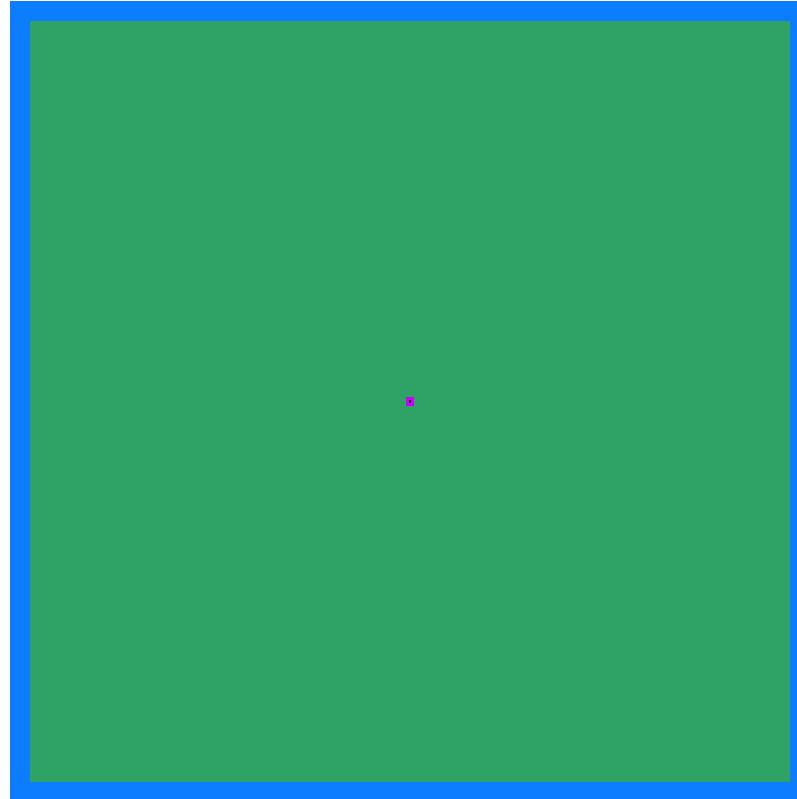


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Finite Element Analysis (FEA) for heat forward problem simulation.



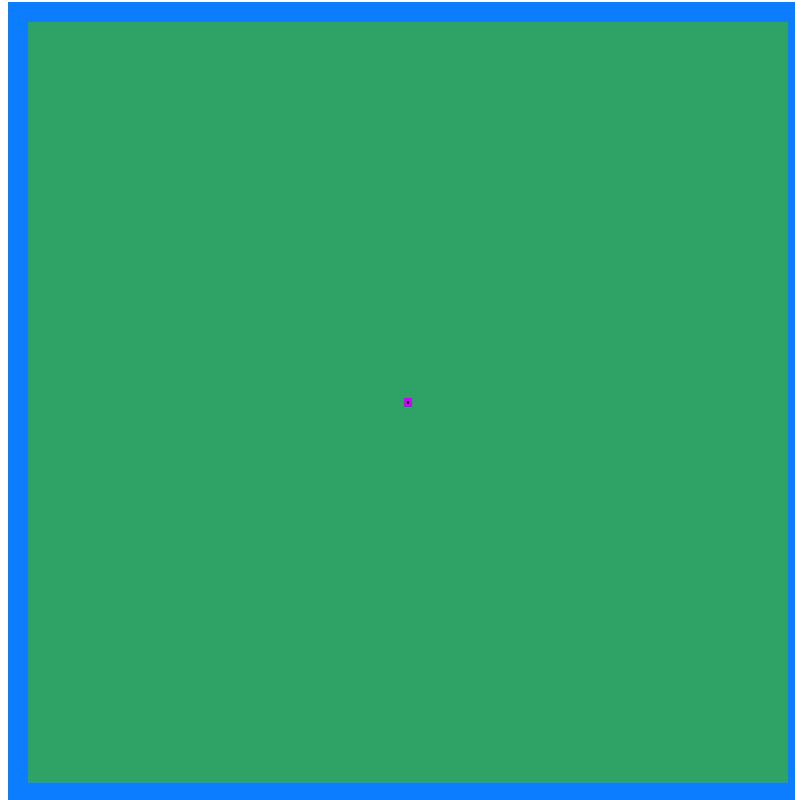
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Finite Element Analysis (FEA) for heat forward problem simulation.

- Tedious and error-prone modeling



Aim



Aim

Simplify data collection and model generation



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Research Question



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Research Question

Is it possible to use computer vision to simplify the generation of volumetric 3D models for Finite-Element Analysis (FEA)?



Existing 3D RGB+Thermal reconstruction

Take a sparse set of images of a building and estimate

1. Hassan et al. 2025, ThermoNeRF: A multimodal neural radiance field for joint RGB-thermal novel view synthesis of building facades, Advanced Engineering Informatics ↵

2. Chen et al. 2025, Thermal3D-GS: Physics-induced 3D gaussians for thermal infrared novel-view synthesis, Computer vision – ECCV 2024 ↵

3. Fridovich-Keil et al. 2022, Plenoxels: Radiance fields without neural networks, Proceedings of the IEEE/CVF conference on computer vision and pattern recognition ↵

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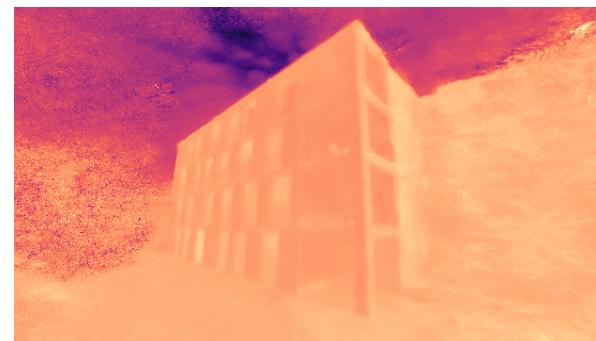
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Not possible to simulate using FEA



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Thermoxels

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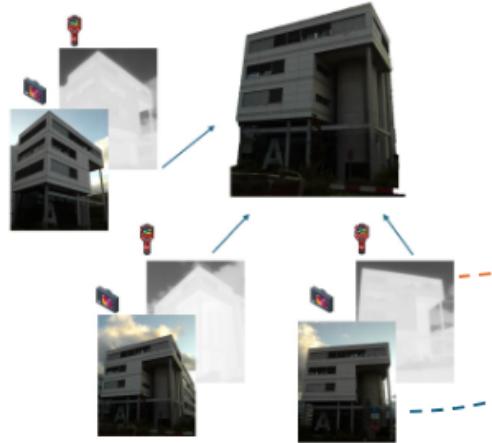


Thermoxels

First method to generate volumetric meshes compatible with FEA from a sparse set of RGB+Thermal images

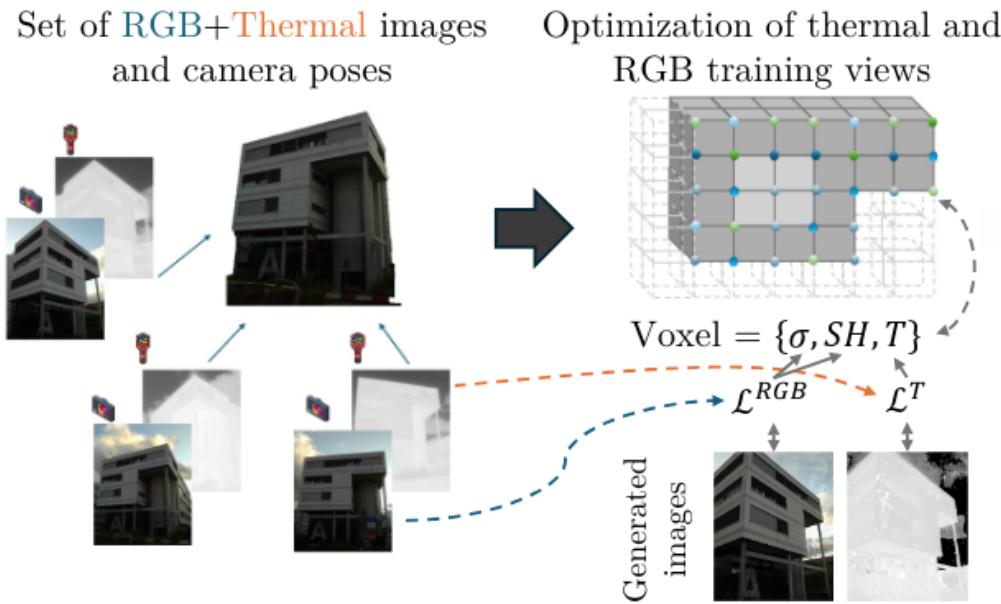
Pose extraction

Set of **RGB+Thermal** images
and camera poses



```
1 # Find poses on RGB with COLMAP
2 poses = COLMAP(images_rgb)
```

Voxel optimization

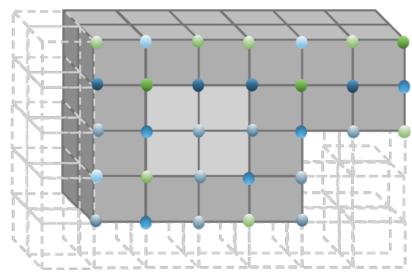


```

1 poses = COLMAP(images_rgb)
2 # optimize color and temperature on voxels
3 thermoxels = Voxels(scene_size)
4 while i <= max_iteration:
5     rgb, temperature = thermoxels(images_rgb, images_thermal, poses)
6     loss = Loss(rgb, temperature, rgb_gt, temperature_gt)
7     thermoxels.optimize(loss)

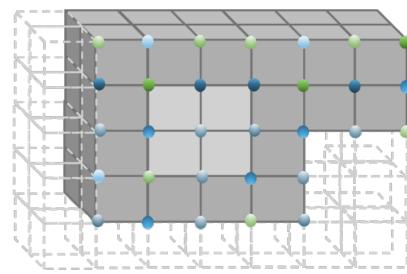
```

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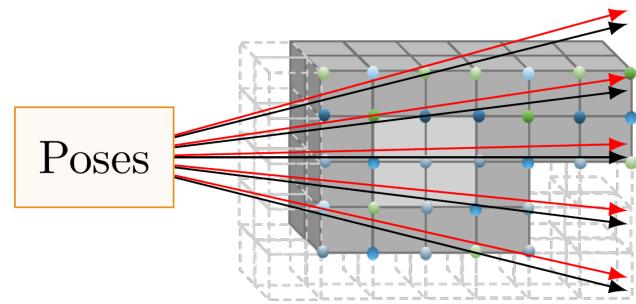


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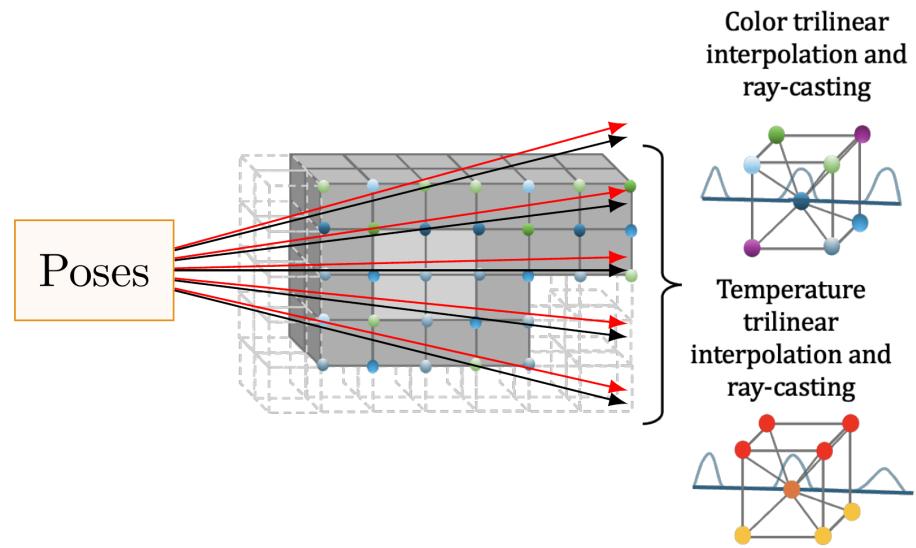
Poses



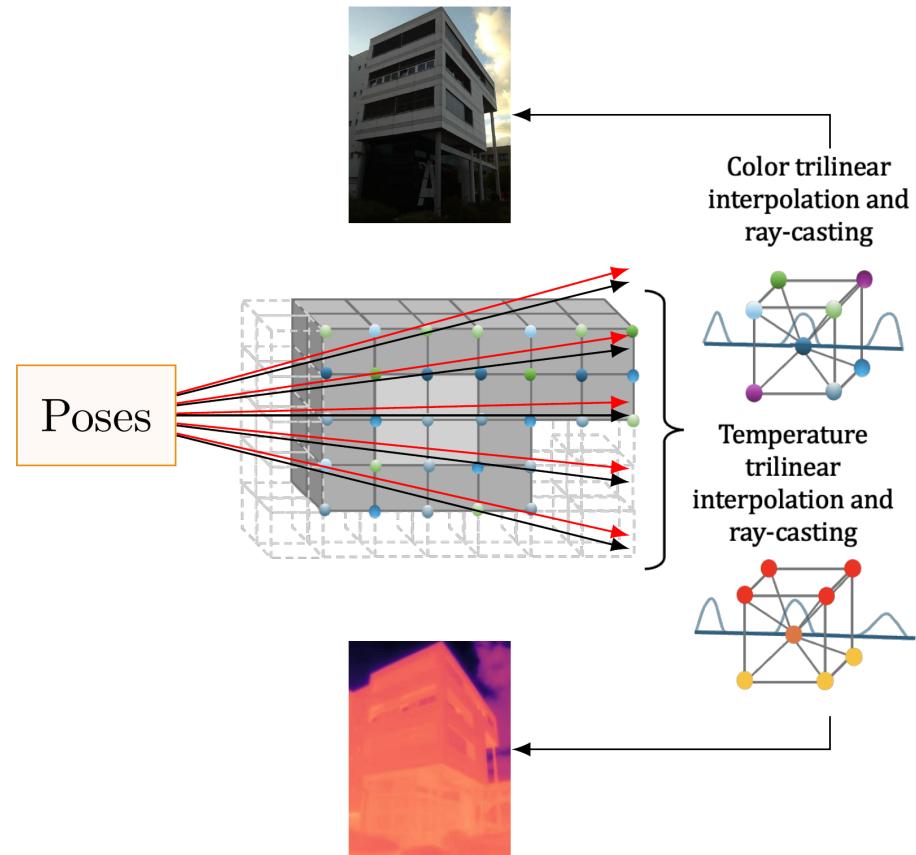
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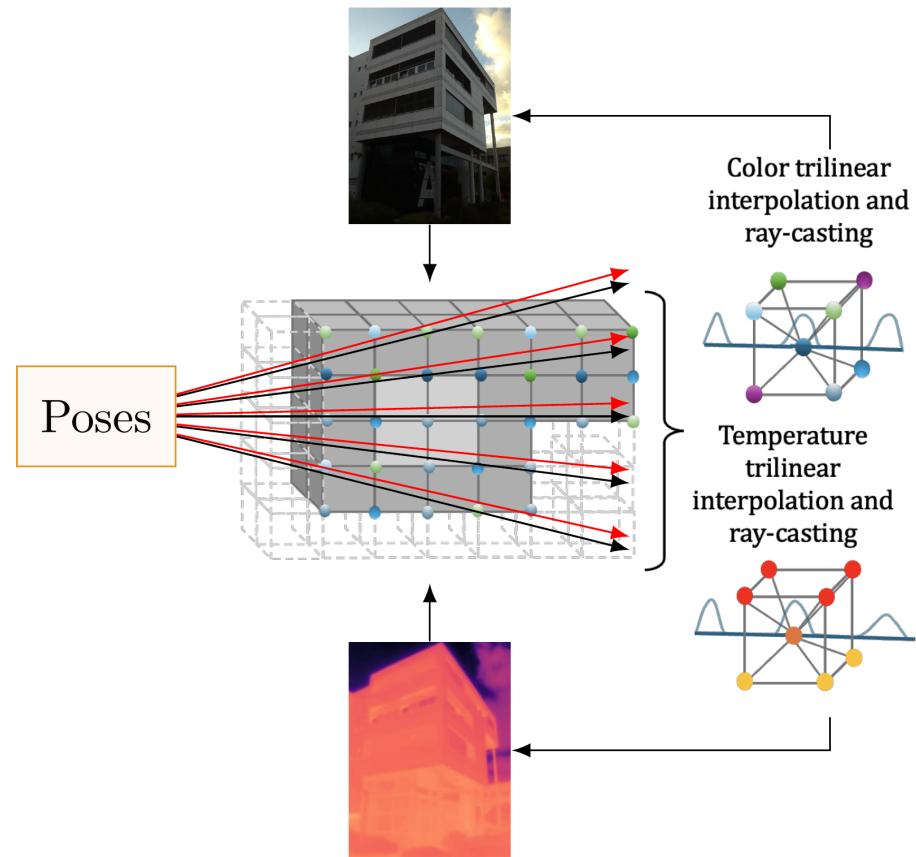
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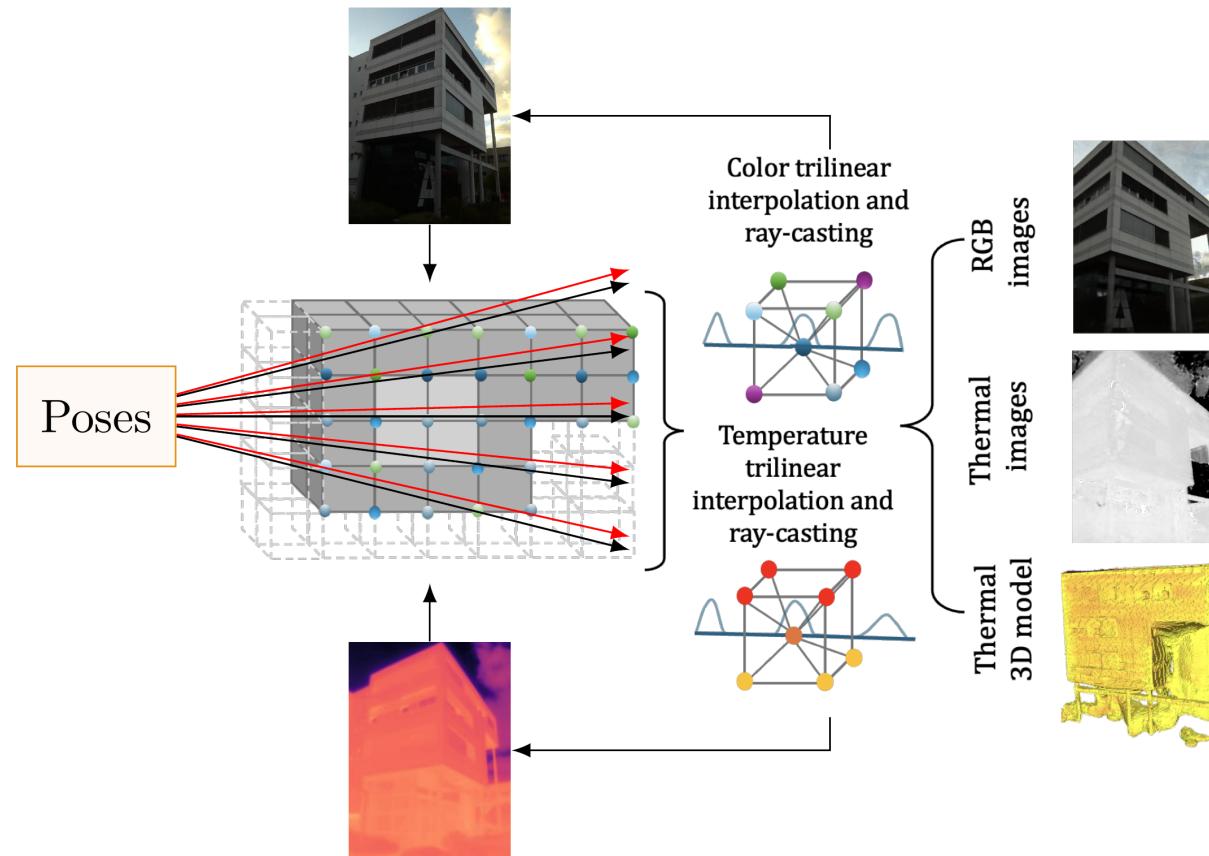
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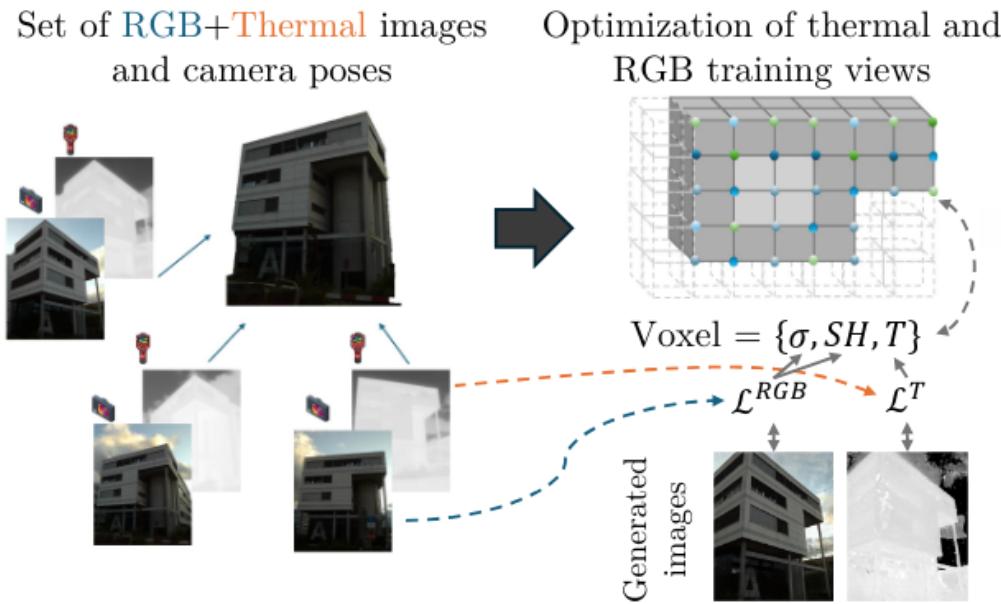
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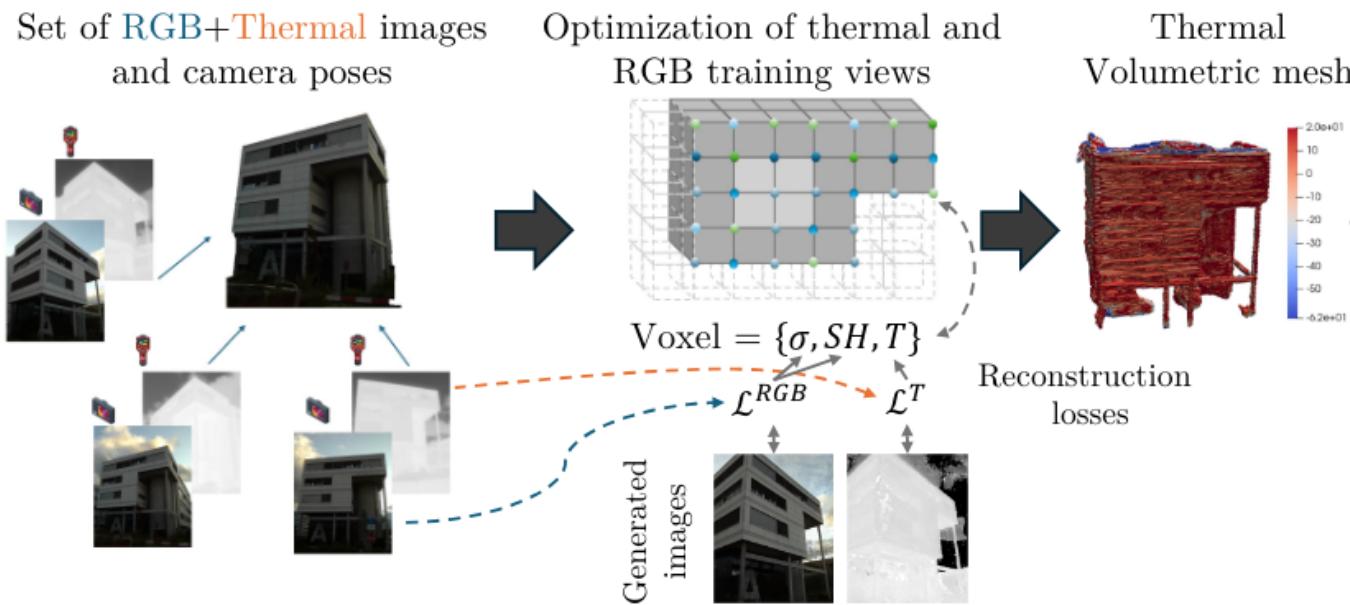


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```

Volumetric Mesh Extraction

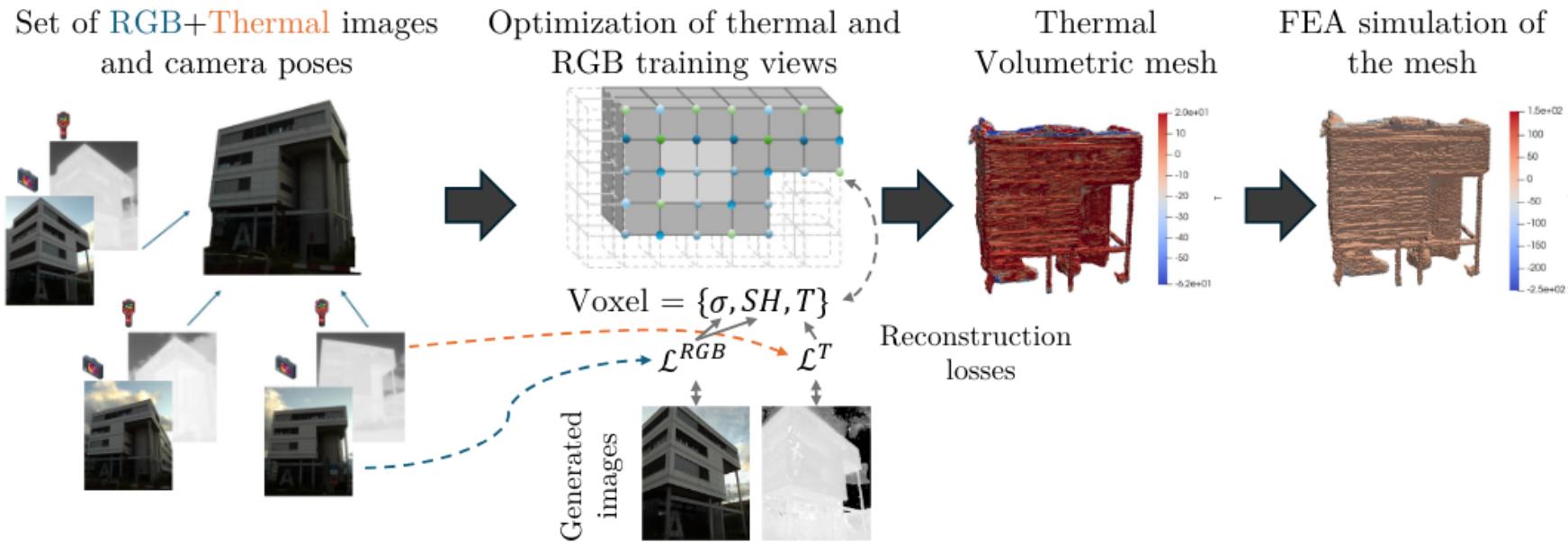


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3 while i <= max_iteration:
4     rgb, temperature = thermoxels(images_rgb, images_thermal, poses)
5     loss = Loss(rgb, temperature, rgb_gt, temperature_gt)
6     thermoxels.optimize(loss)
7 # Reconstruct thermal volumetric mesh
8 vol_mesh, surface_temperature = filtering(voxels, threshold)

```

Finite-Element Analysis



```

1 poses = COLMAP(images_rgb)
2 thermoxels = Voxels(scene_size)
3 while i <= max_iteration:
4     rgb, temperature = thermoxels(images_rgb, images_thermal, poses)
5     loss = Loss(rgb, temperature, rgb_gt, temperature_gt)
6     thermoxels.optimize(loss)
7     vol_mesh, surface_temperature = filtering(voxels, threshold)
8     # Run FEA simulation
9     simulation = FEA(vol_mesh, surface_temperature, env_conditions)

```

Results



Reconstruction Metrics

Method	Heated Water Cup	Heated Water Kettle	Melting Ice Cup	Building (spring)	Building (winter)	Double robot	Exhibition Building	Dorm 1	Dorm 2
ThermoNeRF									
Plenoxels_t									
Thermoxels									

Figure 1: PSNR ↑

Reconstruction Metrics

Method	Heated Water Cup	Heated Water Kettle	Melting Ice Cup	Building (spring)	Building (winter)	Double robot	Exhibition Building	Dorm 1	Dorm 2
ThermoNeRF	32.05	34.04	32.24	26.63	28.75	30.75	33.79	34.10	29.94
Plenoxels_t	31.93	34.40	42.05	35.24	34.62	33.29	27.50	39.24	35.50
Thermoxels	29.78	30.37	19.99	19.84	22.56	24.16	18.78	10.79	13.85

Figure 2: PSNR ↑

Reconstruction Metrics

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Figure 2: PSNR ↑

ThermoNeRF	0.92	0.94	0.98	0.92	0.88	0.95	0.97	0.96	0.95
Plenoxels_t	0.92	0.98	0.96	0.96	0.93	0.92	0.97	0.98	0.97
Thermoxels	0.83	0.92	0.88	0.90	0.82	0.75	0.86	0.60	0.72

Figure 3: SSIM ↑

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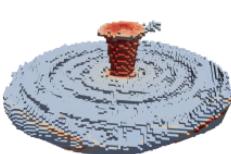
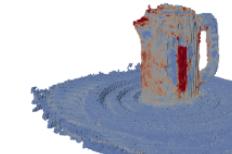
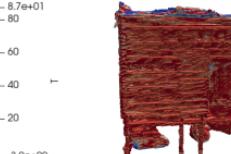
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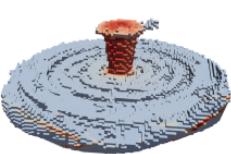
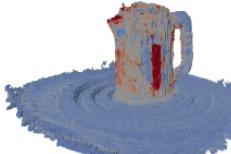
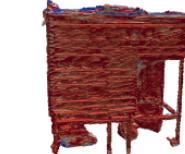
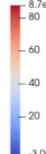
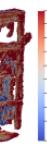
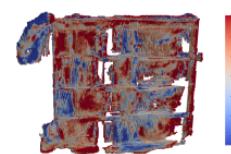
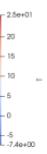
ThermoNeRF	2.10	2.76	1.57	1.88	0.66	0.91	0.31	0.38	0.75
Plenoxels_t	0.87	1.41	0.11	1.36	0.40	0.49	1.00	0.32	0.39
Thermoxels	0.99	1.15	1.74	5.29	1.27	0.74	1.29	8.87	4.21

Figure 4: MAE ↓

Simulation-ready models

Scene	Cup	Kettle	Building A spring	Dorm 1	Dorm 2
Thermoxels (Ours)					

Simulation-ready models

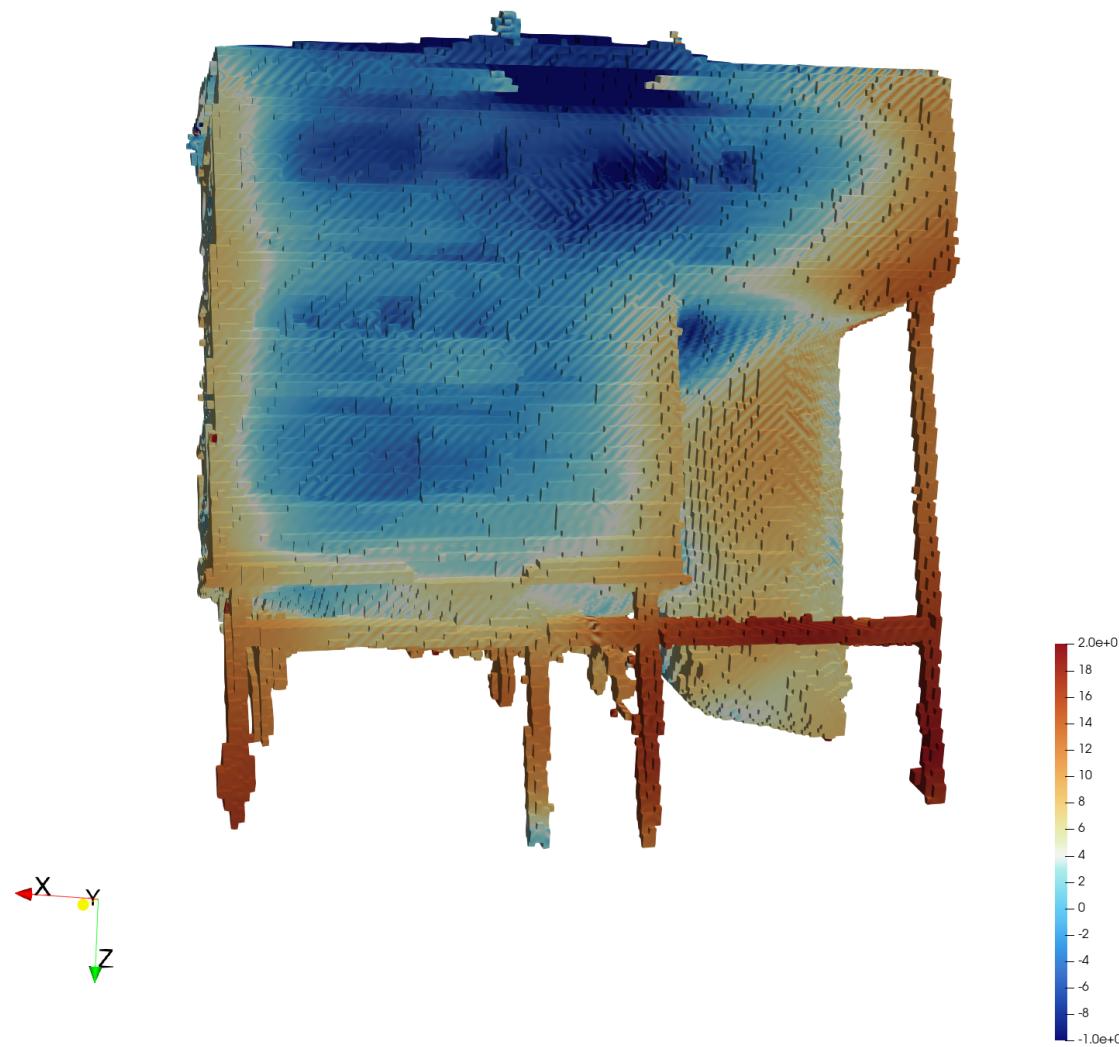
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Simulation-ready models

Scene	Cup	Kettle	Building A spring	Dorm 1	Dorm 2
Plenoxels _t					
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Thermoxels After FEA					

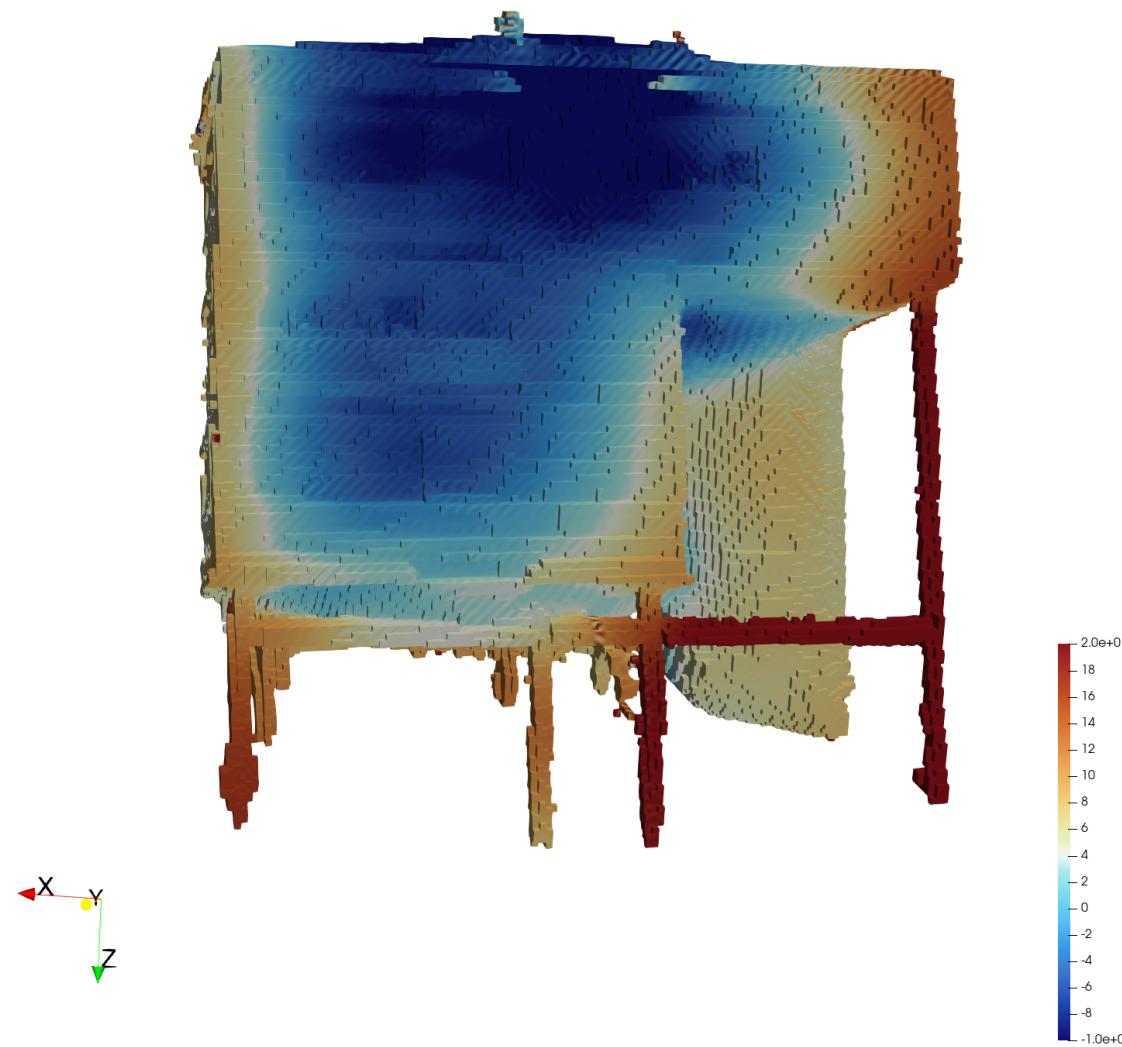
Thermoxels temperature as initial condition

Simulation



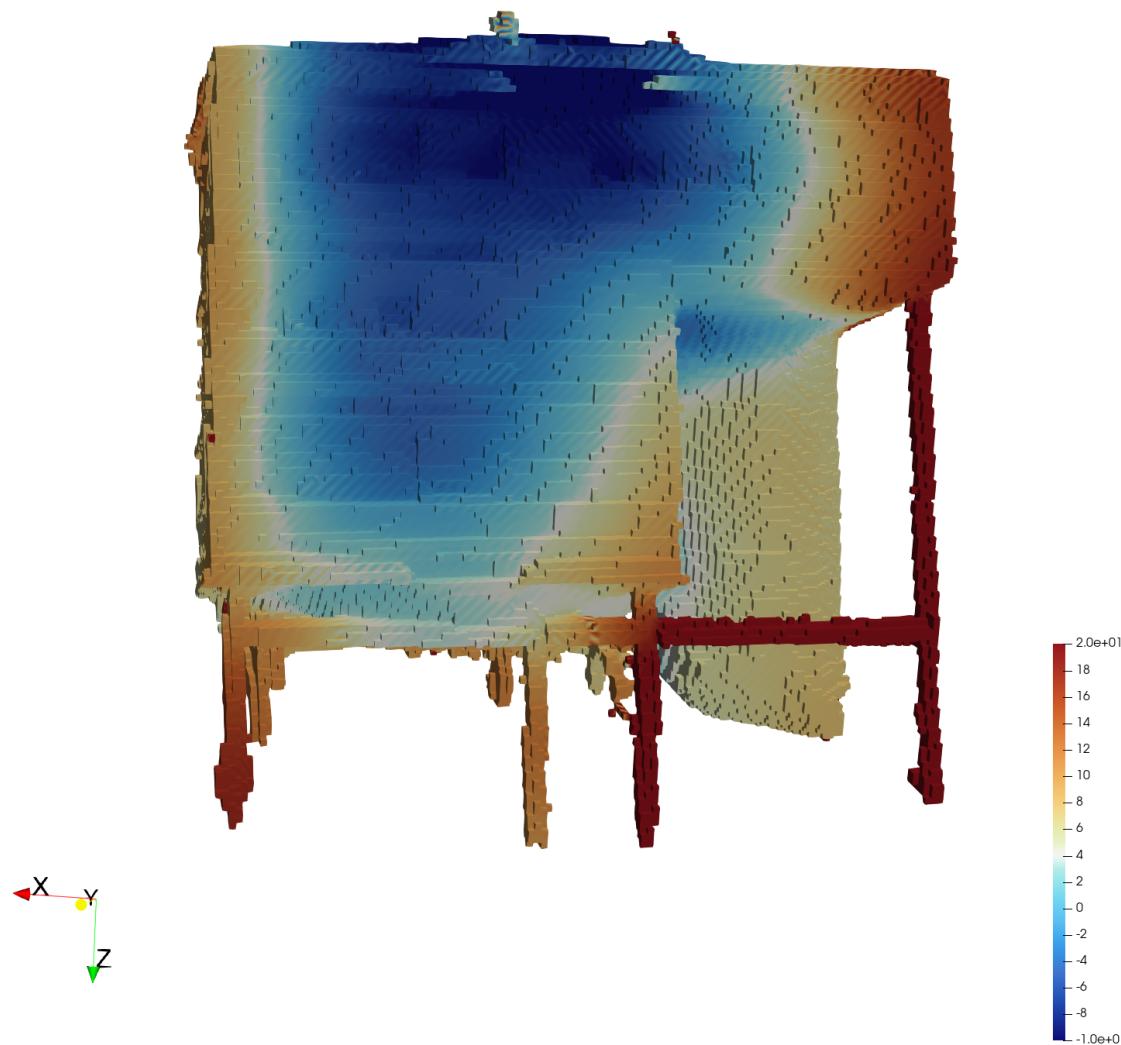
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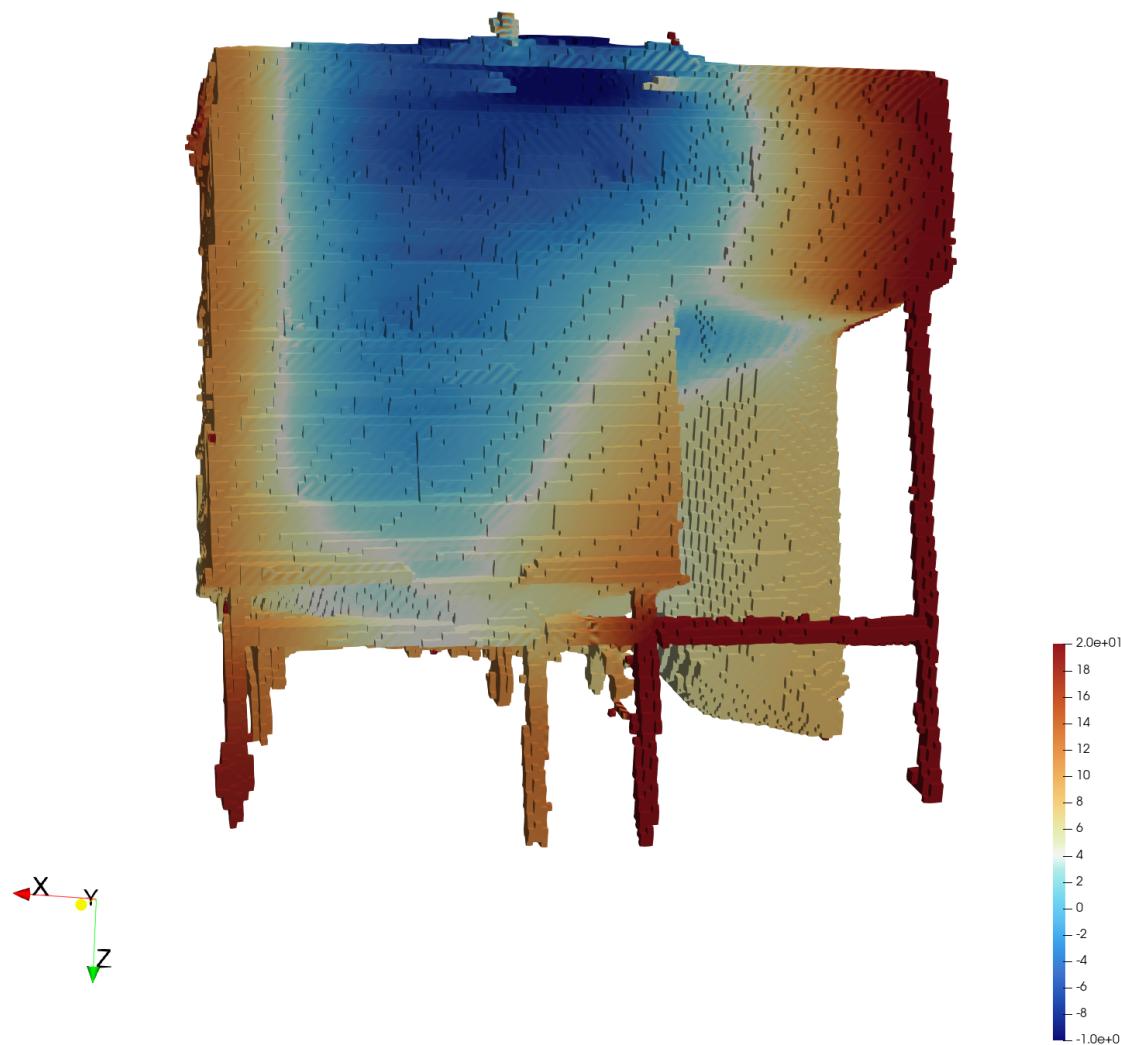
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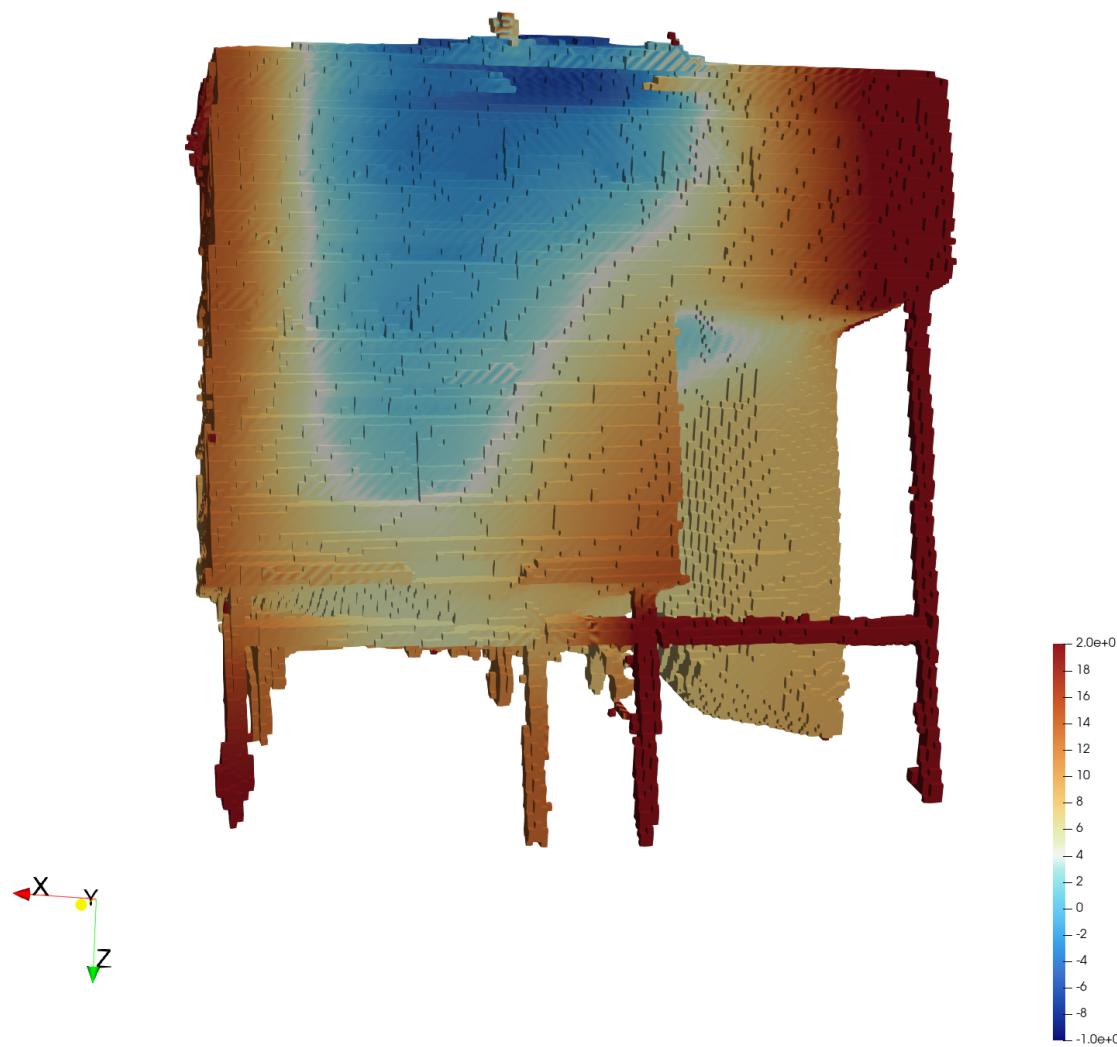
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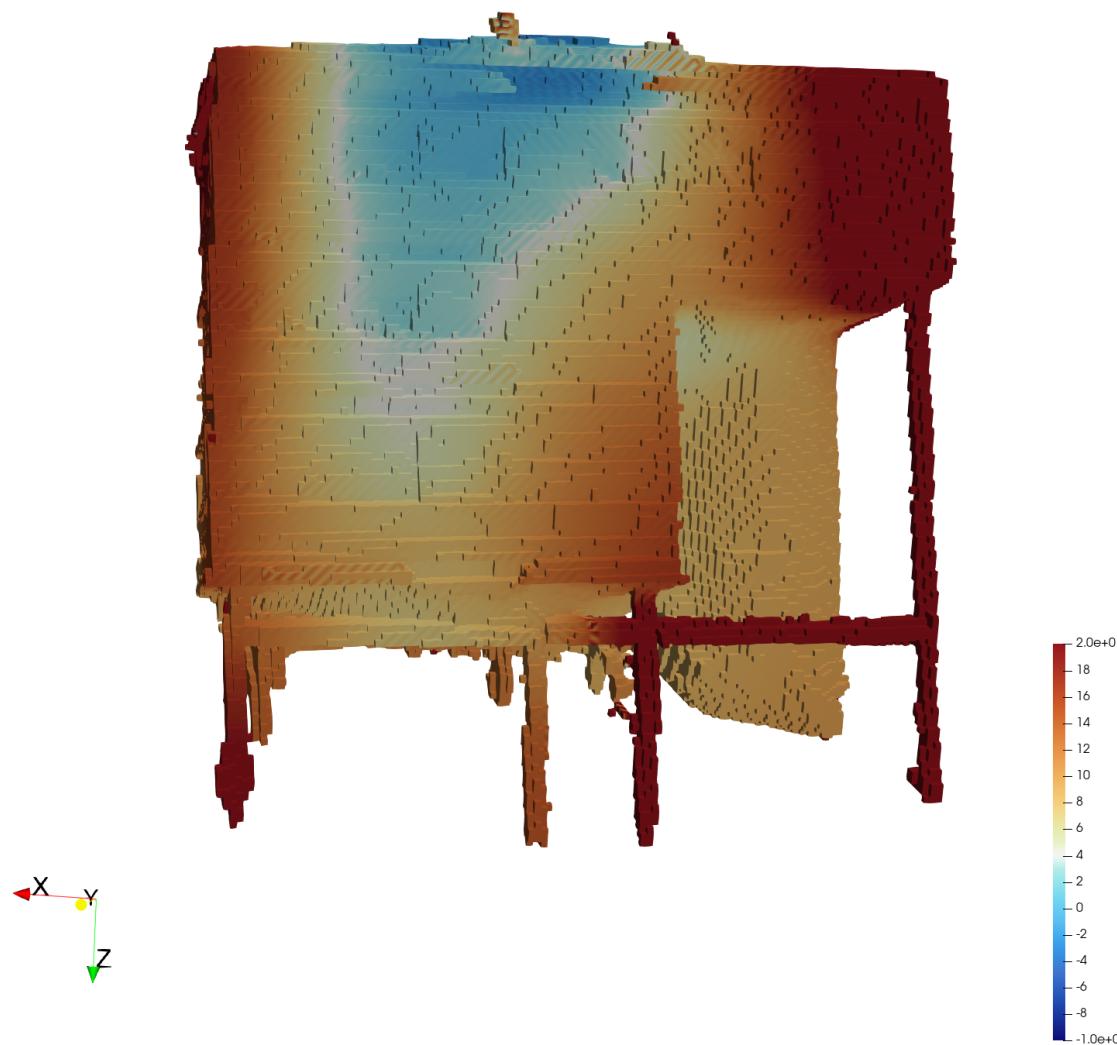
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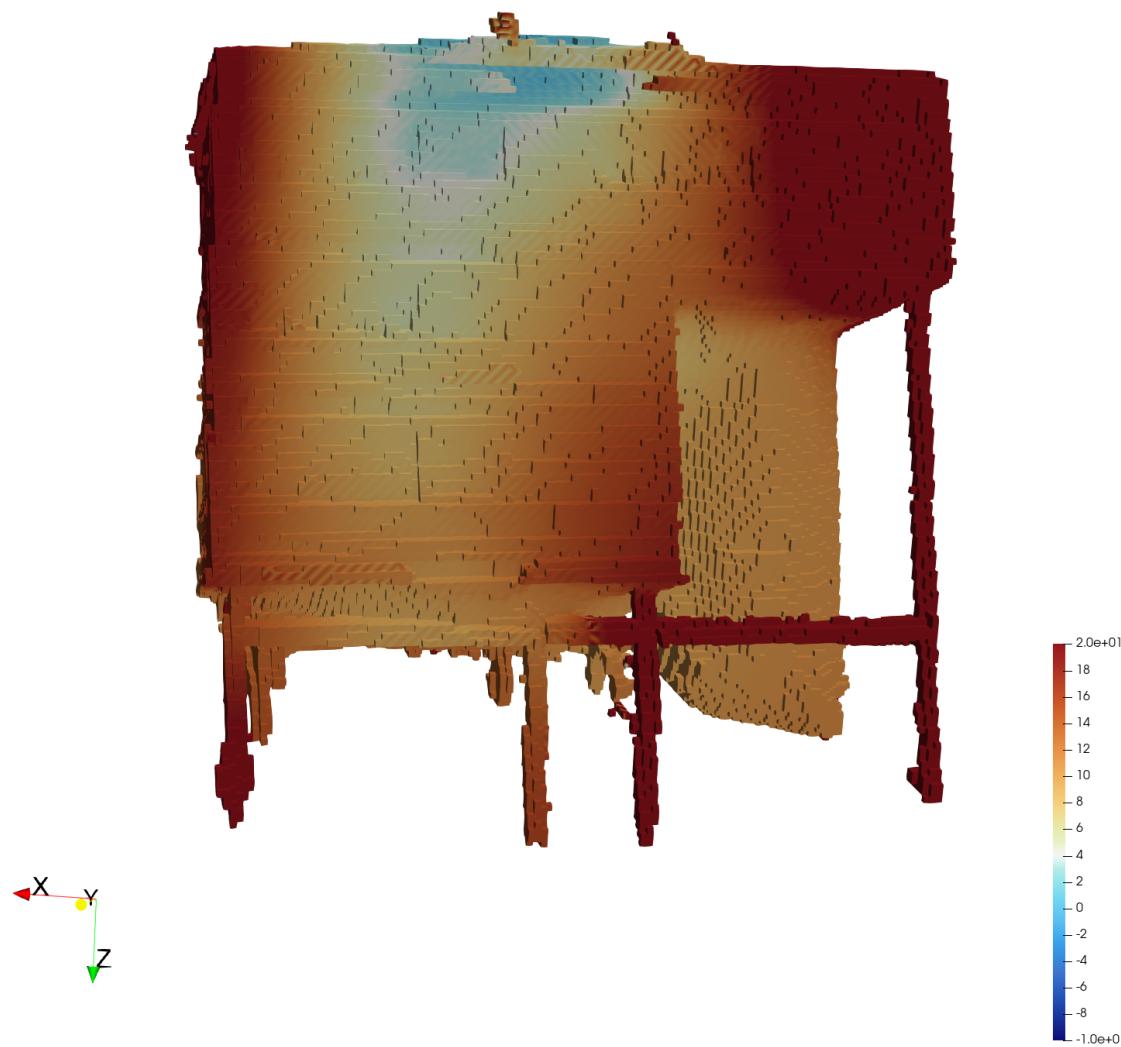
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Simulation



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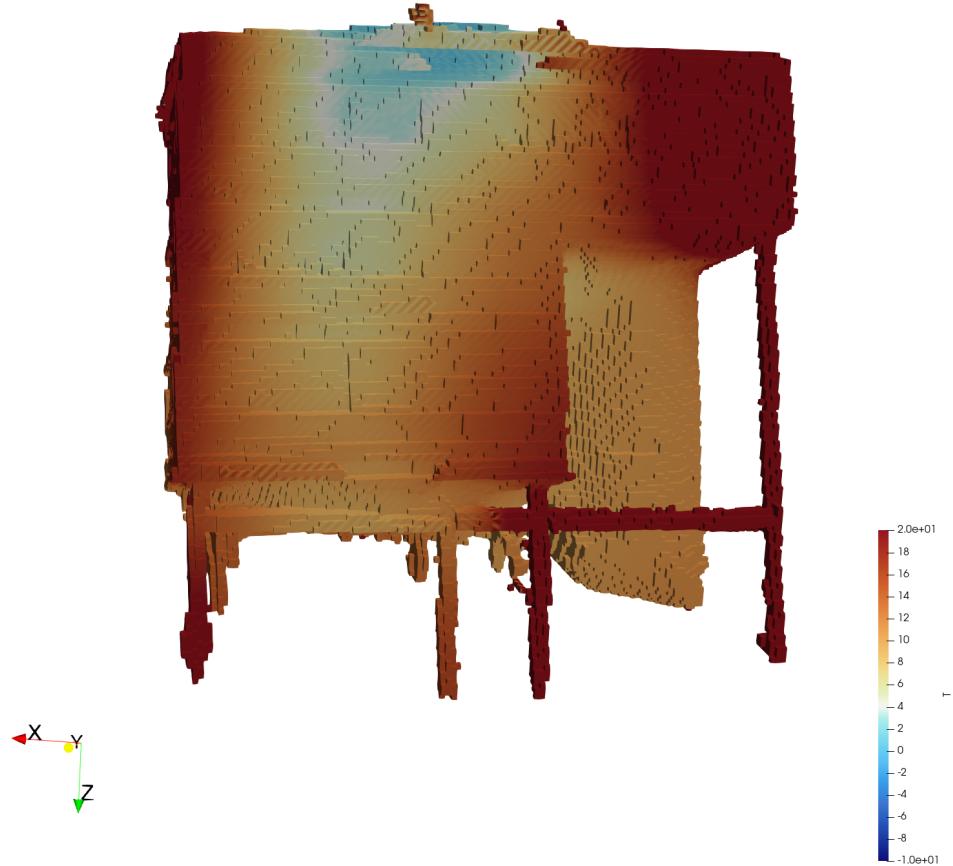
Simulation



Schindler - We elevate

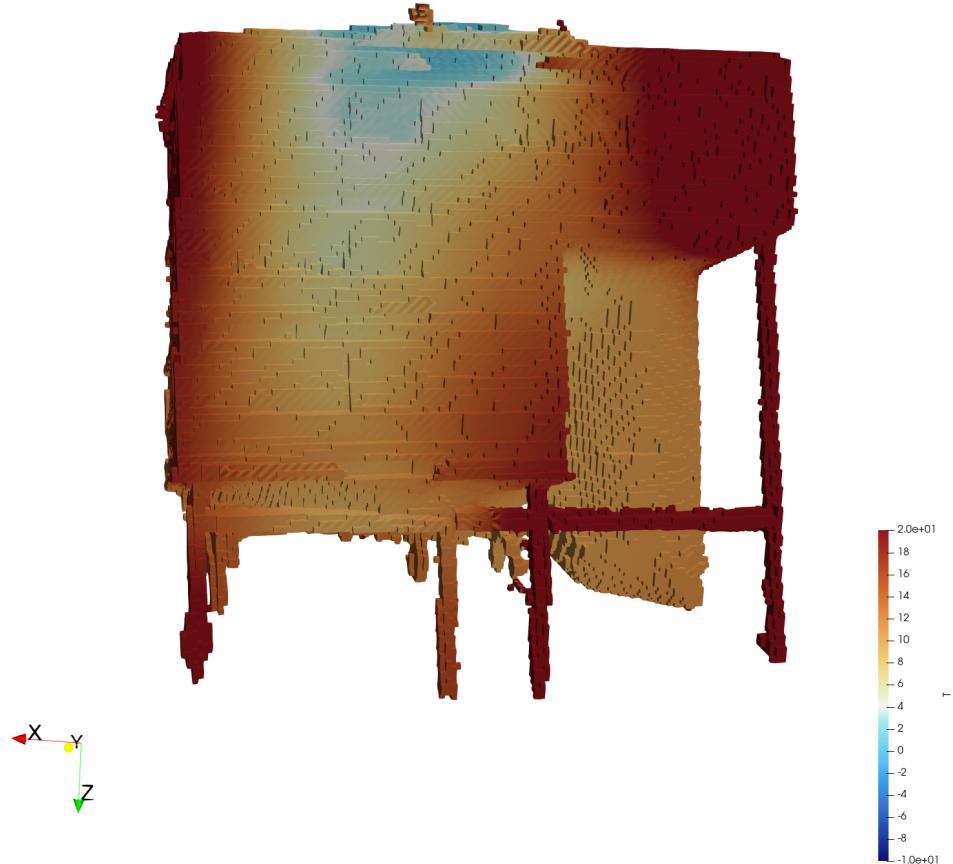
Conclusion and Future Work

- The first method able to build 3D models compatible with FEA using sparse RGB images.



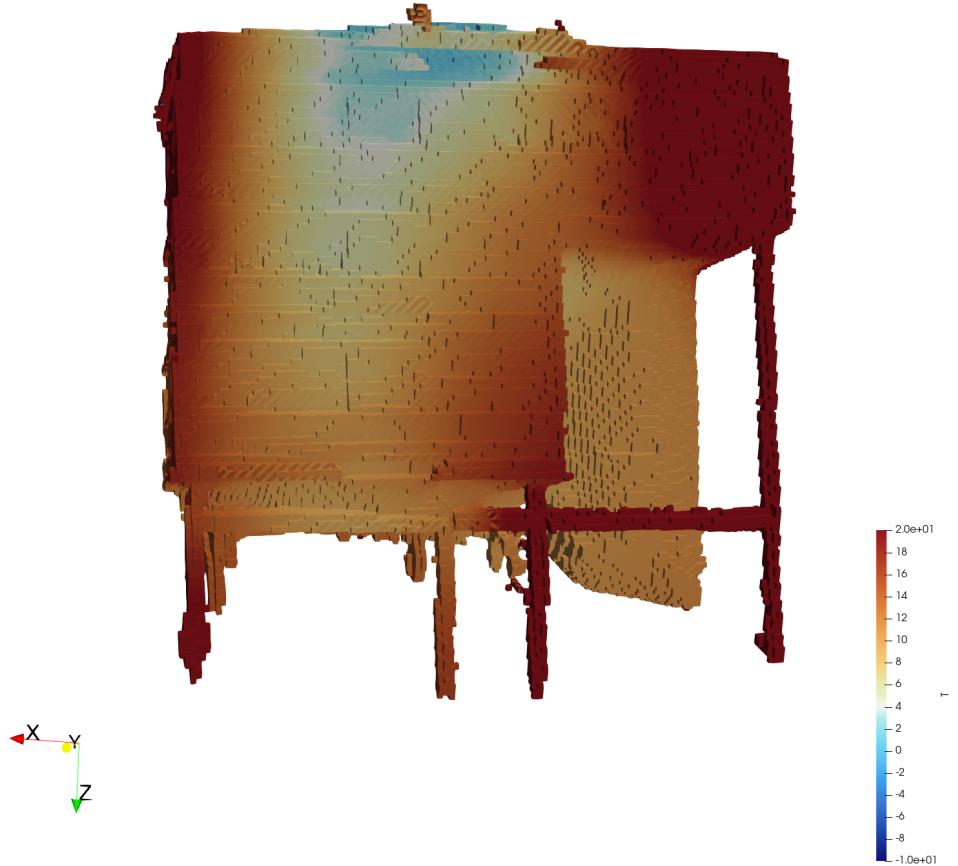
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- The first method able to build 3D models compatible with FEA using sparse RGB images.
- Metrics do not capture mesh quality.



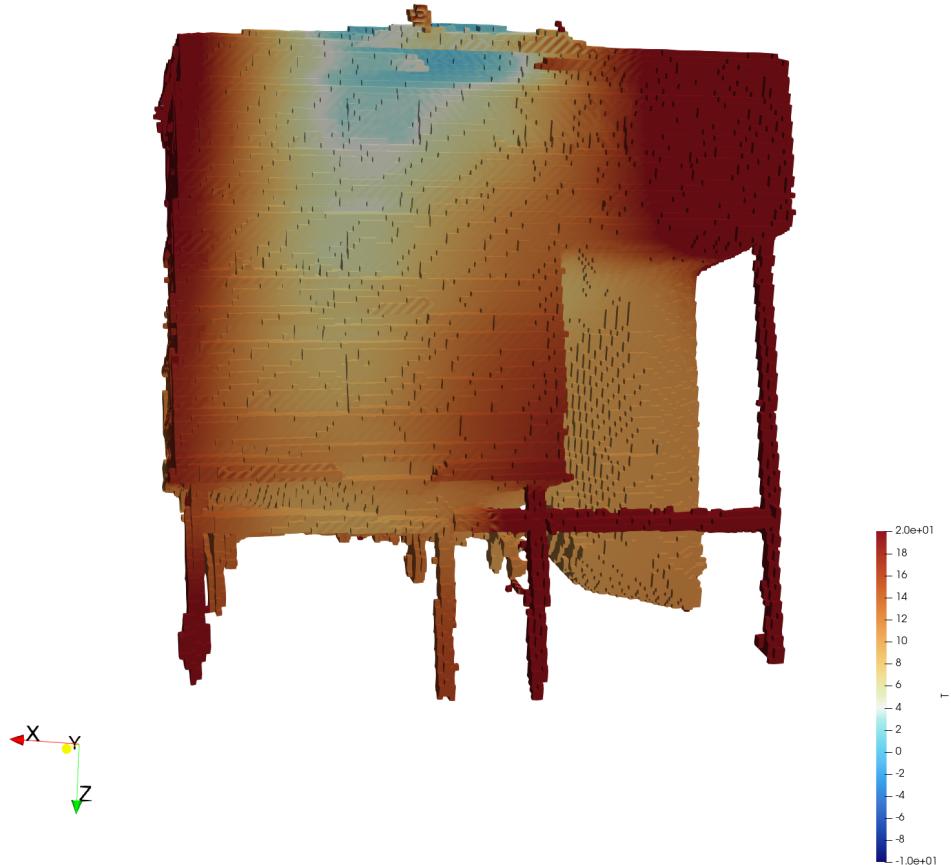
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- Future works:



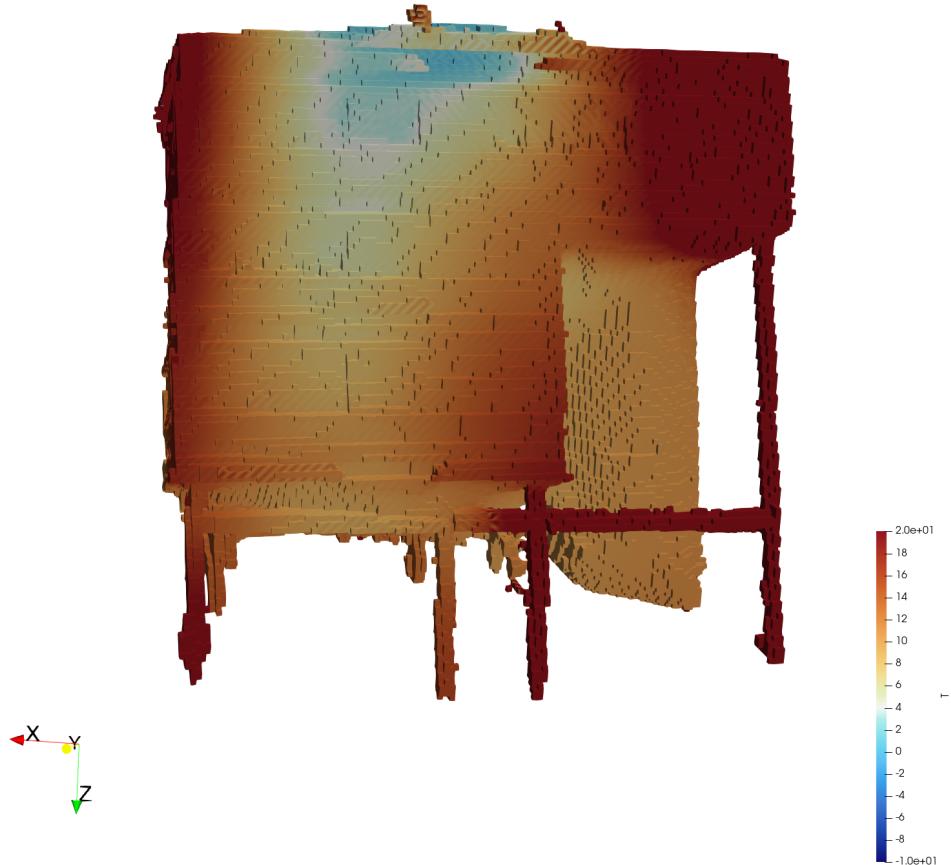
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- Metrics do not capture mesh quality.
- Future works:
 - Improve surface approximation.
 - Integrate material properties.



References

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