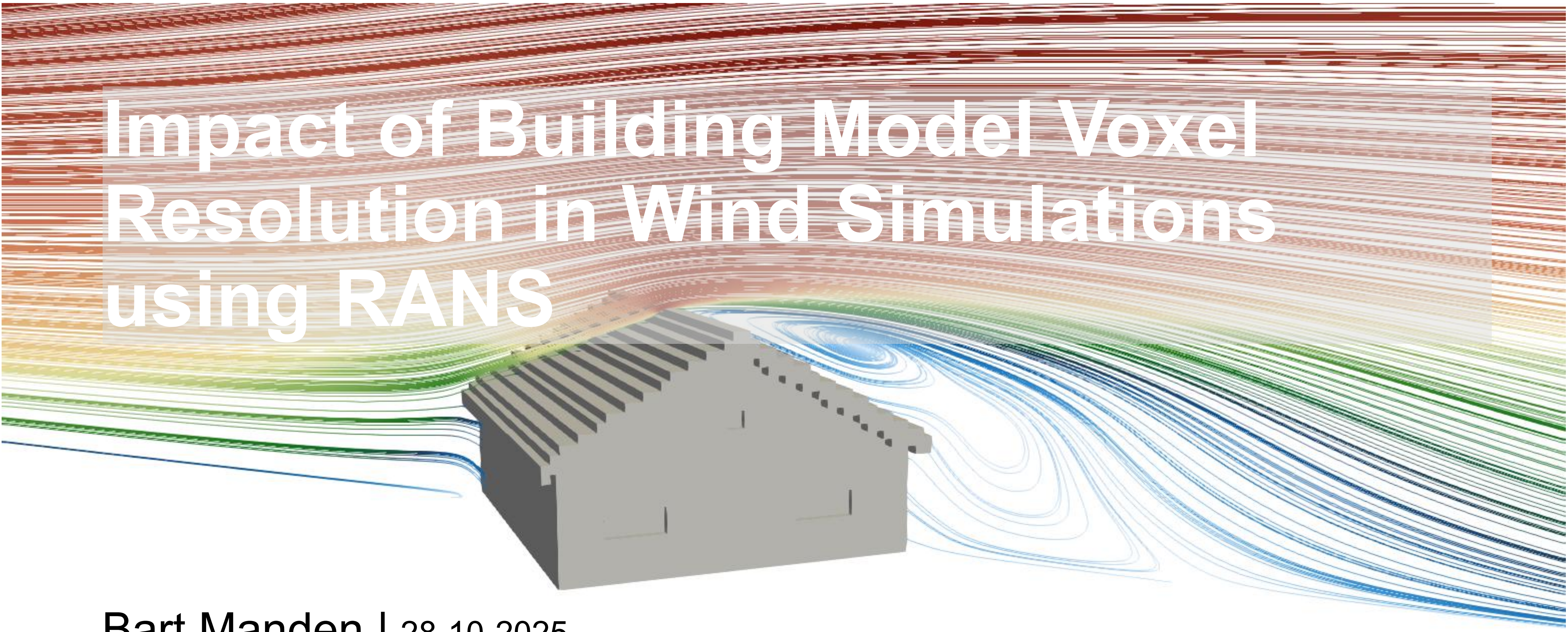
Impact of Building Model Voxel Resolution in Wind Simulations using RANS



Bart Manden | 28-10-2025

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Co-reader: Nadine Hobeika

Delegate: Edward Verbree

TU Delft

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- Methodology
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Motivation

- Cities impact local meteorology
- Urban CFD analyses this impact

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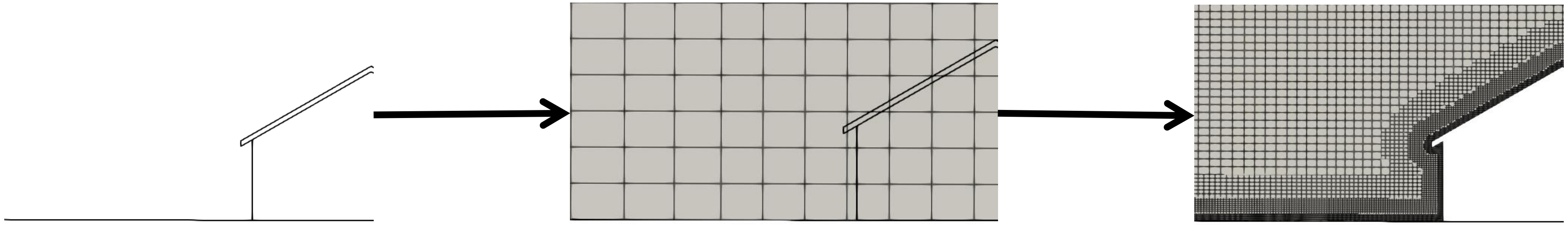
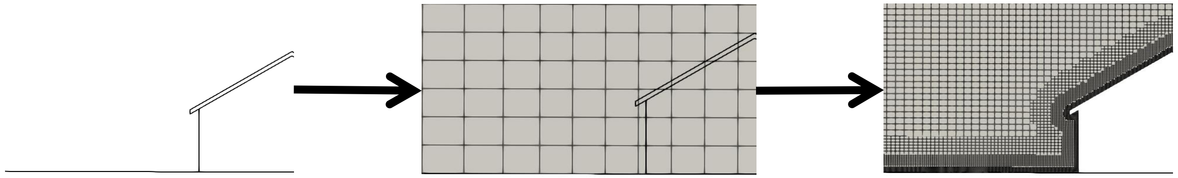
- Non-uniform data
- Large time investment



Motivation

- Reducing the meshing times



Motivation

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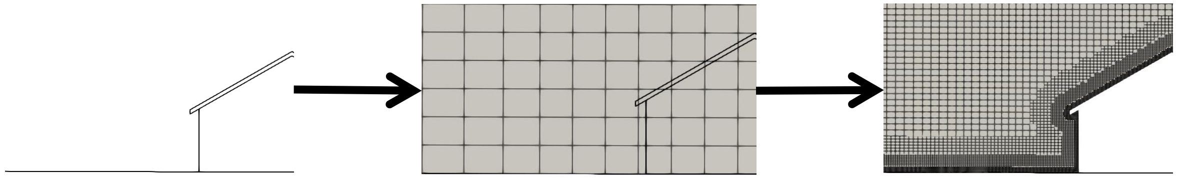
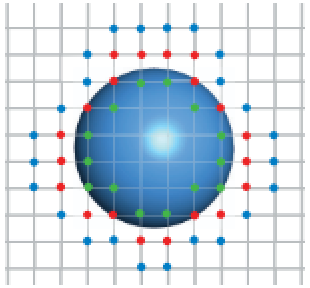


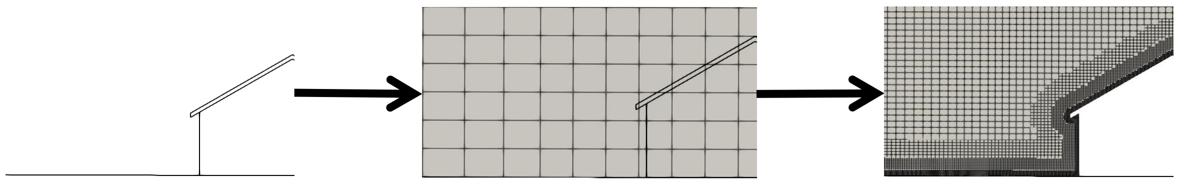
- Immersed boundary method

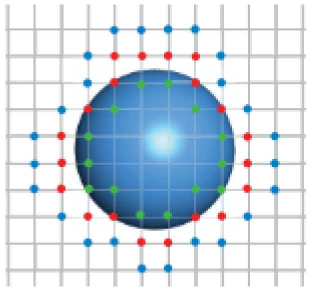


(Verzicco, 2023)

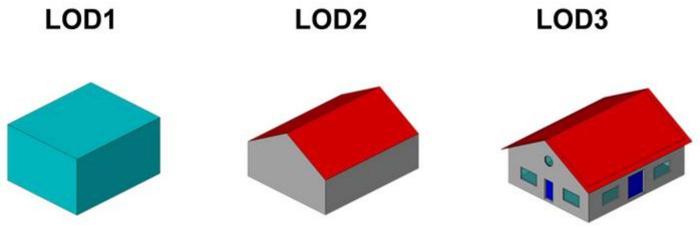
Motivation

- Reducing the meshing times
- Immersed boundary method
- Geometry abstraction (LoD)





(Verzicco, 2023)



(Heazel, 2021)

Research Question

- Keeping geometric detail while reducing mesh complexity

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- Keeping geometric detail while reducing mesh complexity

How does the voxel resolution within building voxelized models influence the accuracy and computational efficiency of wind flow simulations using Computational Fluid Dynamics (CFD)?

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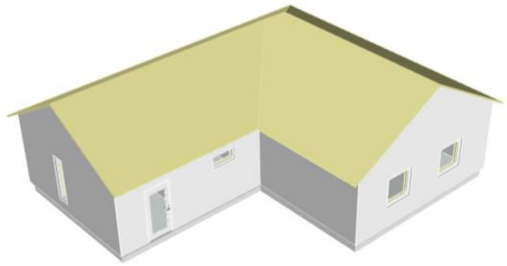
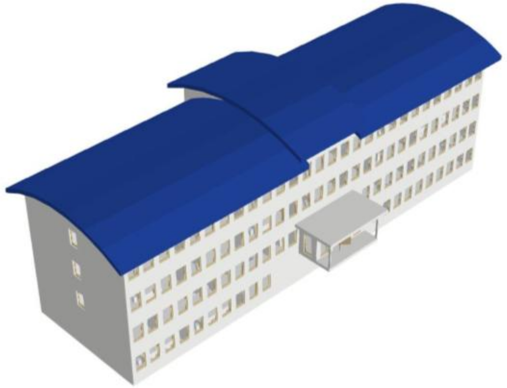
Model voxelization

- Three models



A-40

FZK-Haus (IAI and KIT, a)

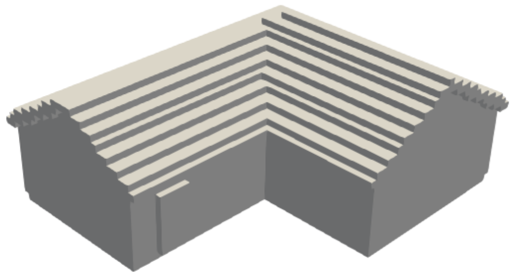


Institute (IAI and KIT, b)

Model voxelization

- Three models
- IFCEnvelopeExtractor (Vaart, 2025)

A-40	FZK-Haus	Institute
LoD 3.2	LoD 3.2	LoD 3.2
1 m.	1 m.	1 m.
0.5 m.	0.5 m.	0.5 m.
0.25 m.	0.25 m.	0.25 m.
0.1 m.	0.1 m.	0.1 m.
0.05 m.	0.05 m.	0.05 m.
0.025 m.	0.025 m.	0.025 m.



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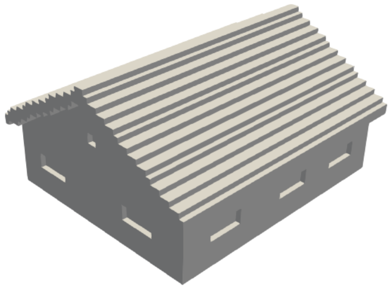
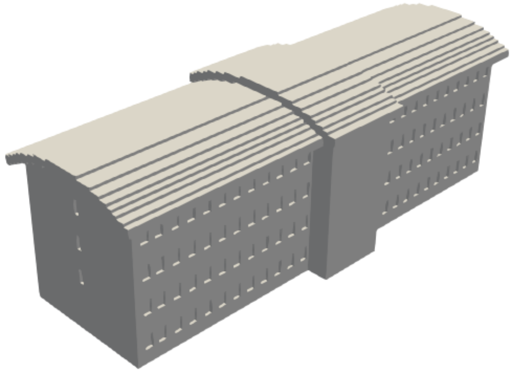


FZK-Haus



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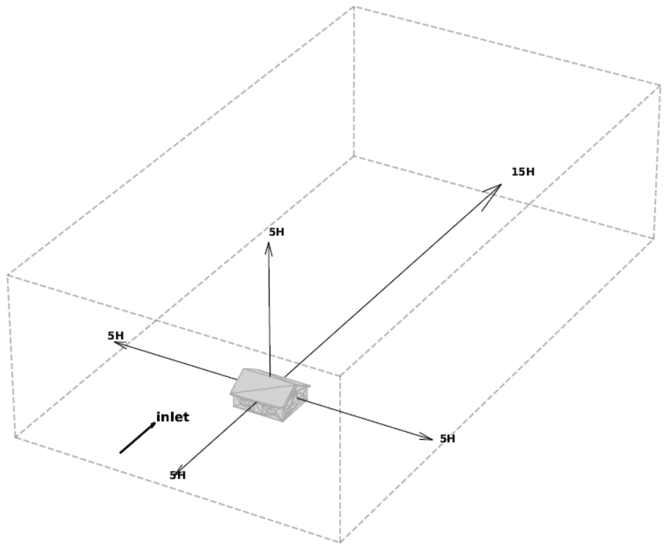
CFD Domain

- Guidelines on domain size (Blocken, 2015)
- Directional domain



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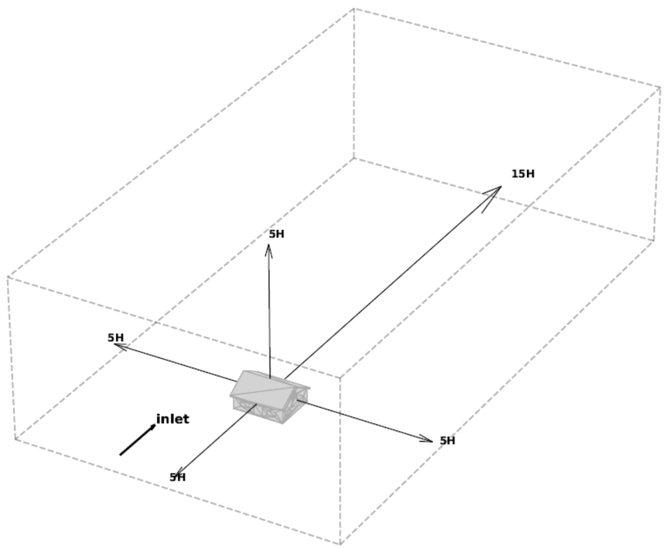
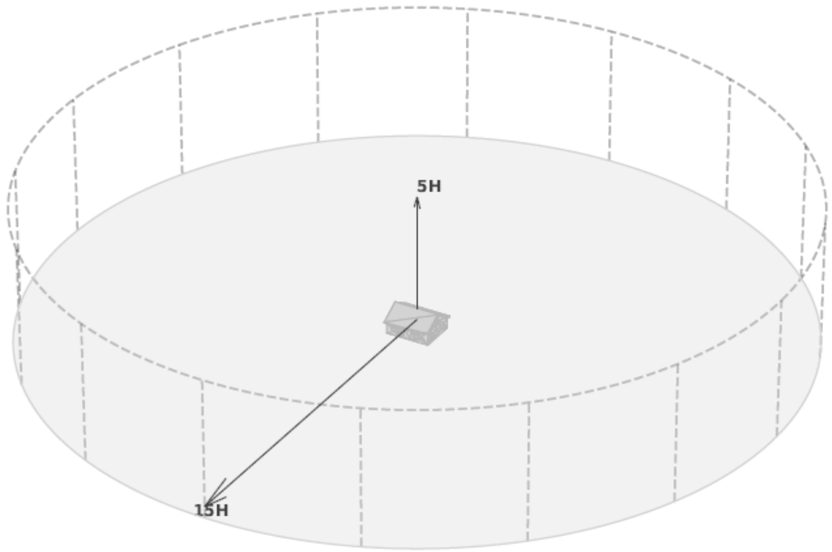
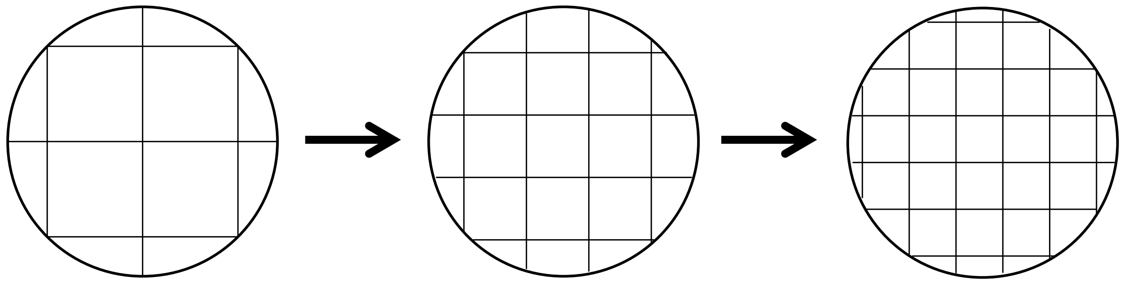


- Omnidirectional domain



Grid independence & Solver setup

- Prevents the mesh from impacting the results
- Grid Convergence Index (GCI)



- RANS solver
- k-ε turbulence model

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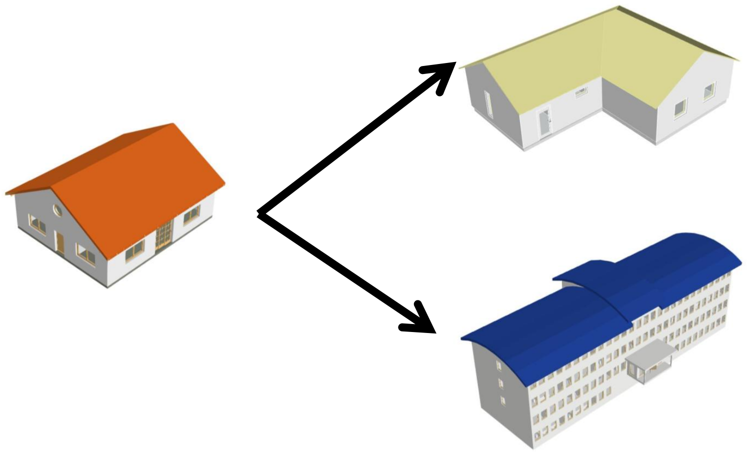
Grid Convergence Index

- Overall good convergence

- One GCI test for three models

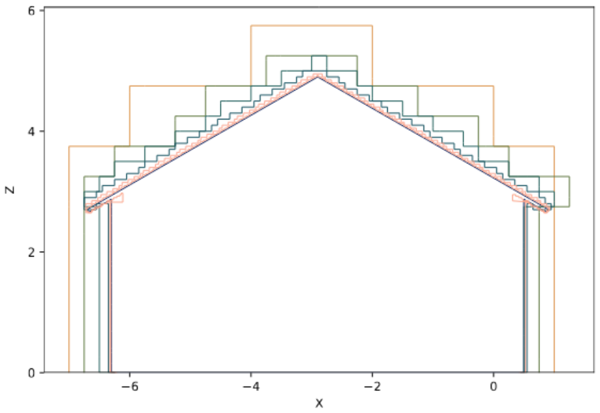


Grid Level	Total Cells (x10^6)	Mesh Volume (x$10^6 m^3$)	Av. Cell Length Δh_r (m)
Coarse	6.136	1.638	0.64
Medium	17.148	1.642	0.46
Fine	44.444	1.644	0.33

Metric	ε	k	p	U_x	U_y	U_z
Apparent order p	2.80	2.87	3.62	6.63	3.01	4.63
Relative Approx. Error (%)	3.26	0.24	8.13	12.21	0.44	15.51
Extrapolated Relative Error (%)	1.87	0.15	4.18	1.67	0.21	5.81
GCI (%)	2.29	0.19	5.12	2.08	0.27	7.34

Geometric differences

- Increased footprint and height
- Small features disappear



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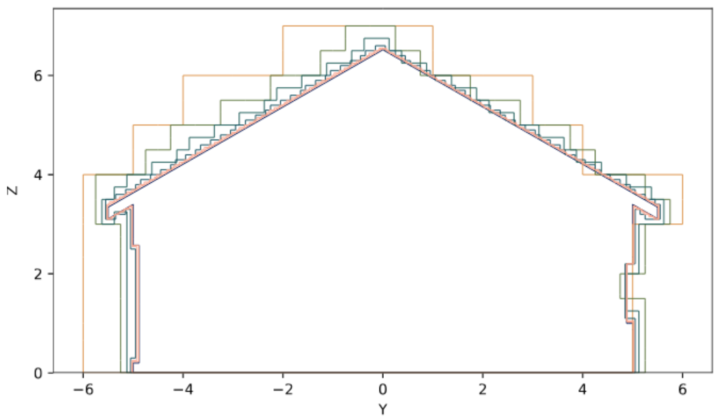

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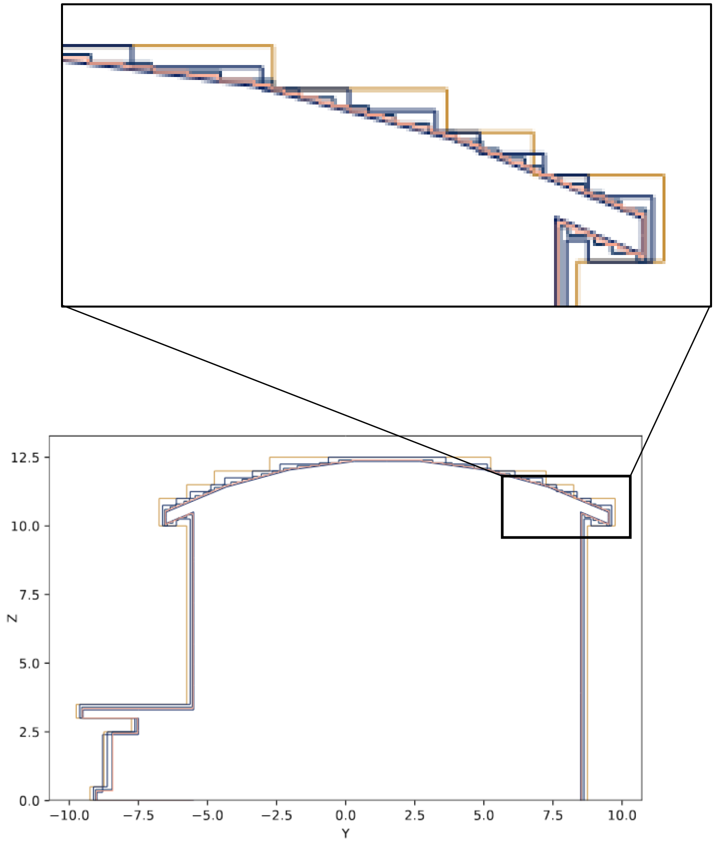

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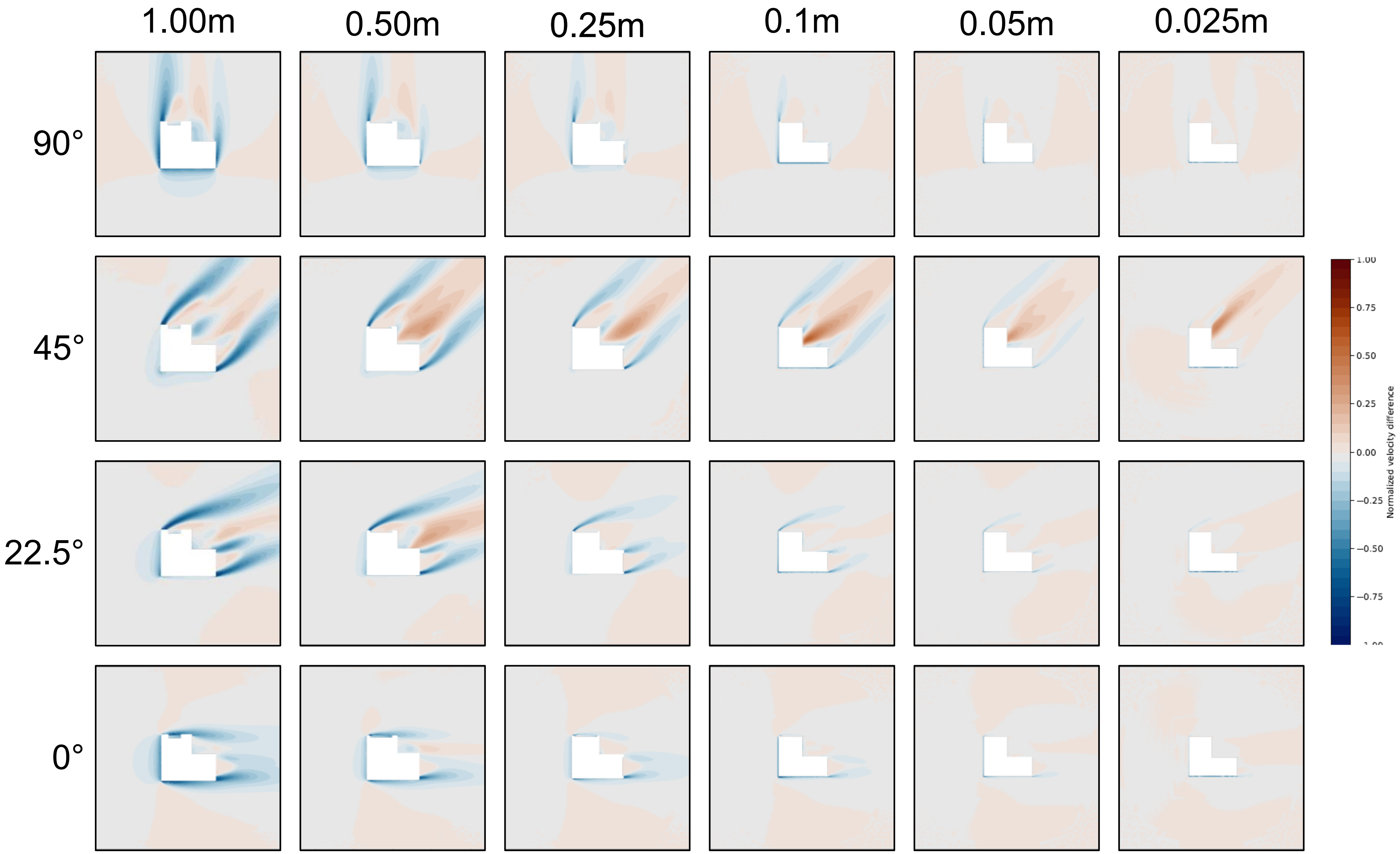
Wind velocity differences

A-40

- Coarse voxels underpredict
- Differences reduce with resolution
- Reduction stagnates after 0.25m
- 45° shows persistent deviation



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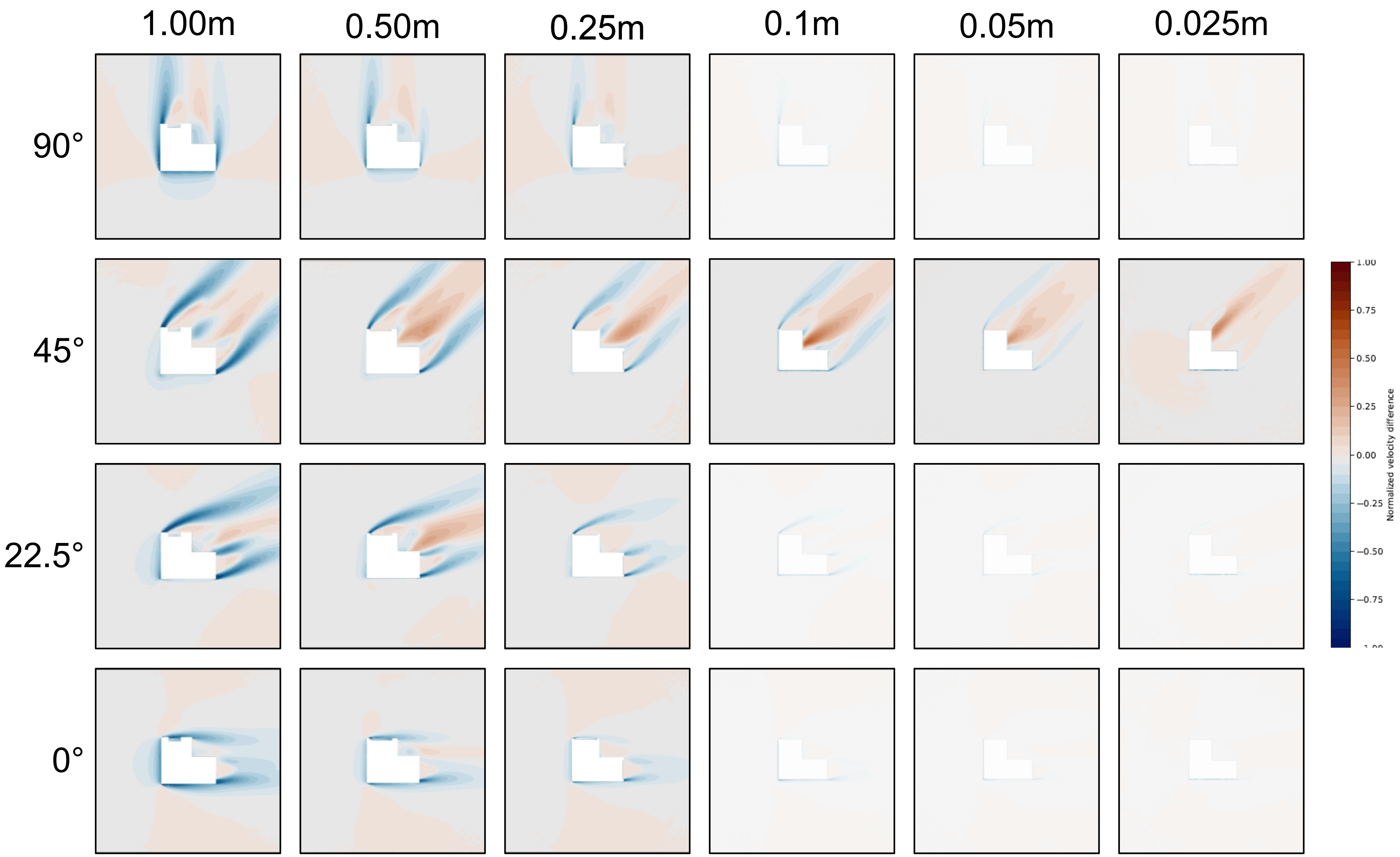

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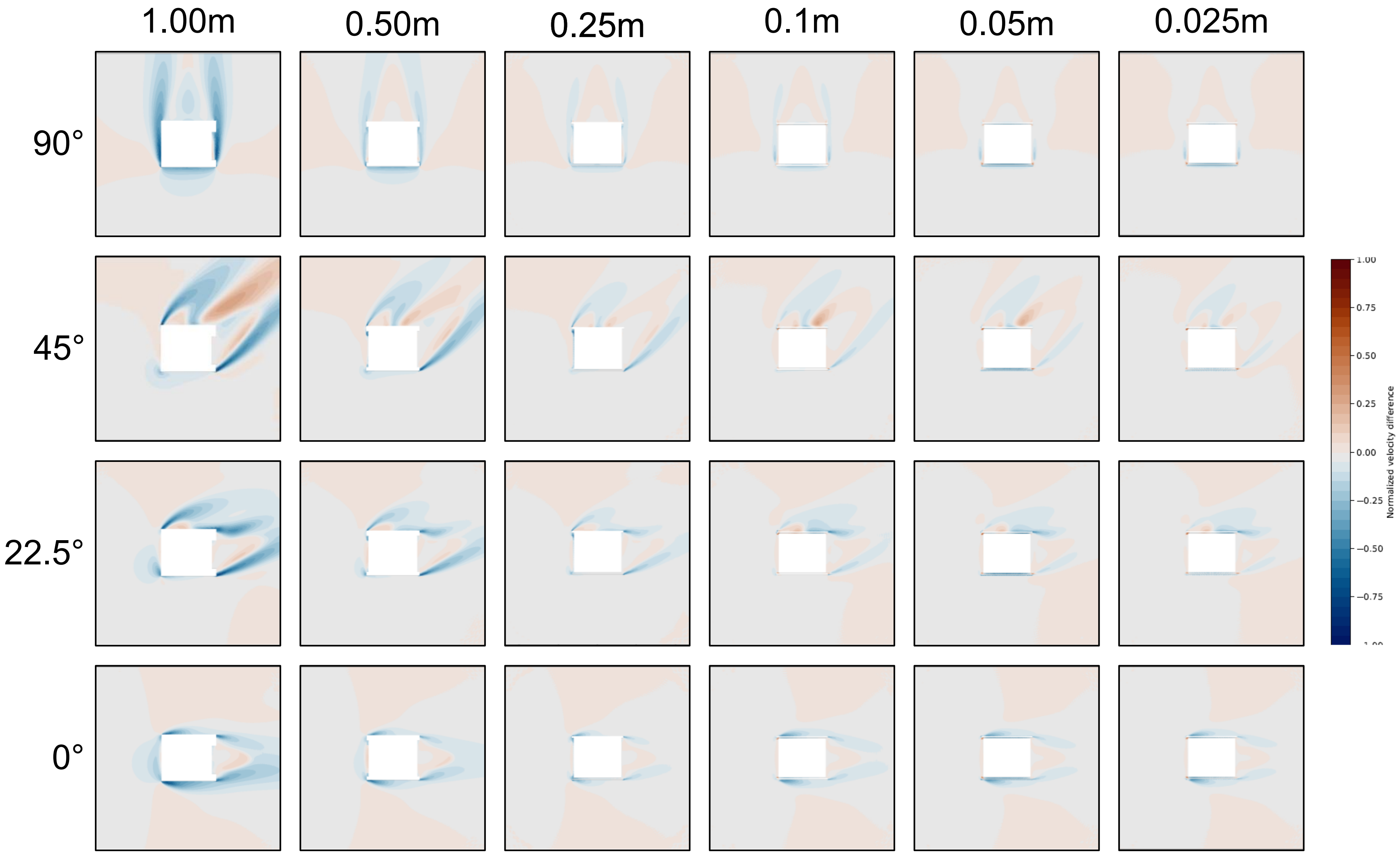
Wind velocity differences

FZK-Haus

- Coarse voxels underpredict
- Smaller differences compared to A-40
- Less improvement for smaller voxel sizes
- 45° shows persistent deviation



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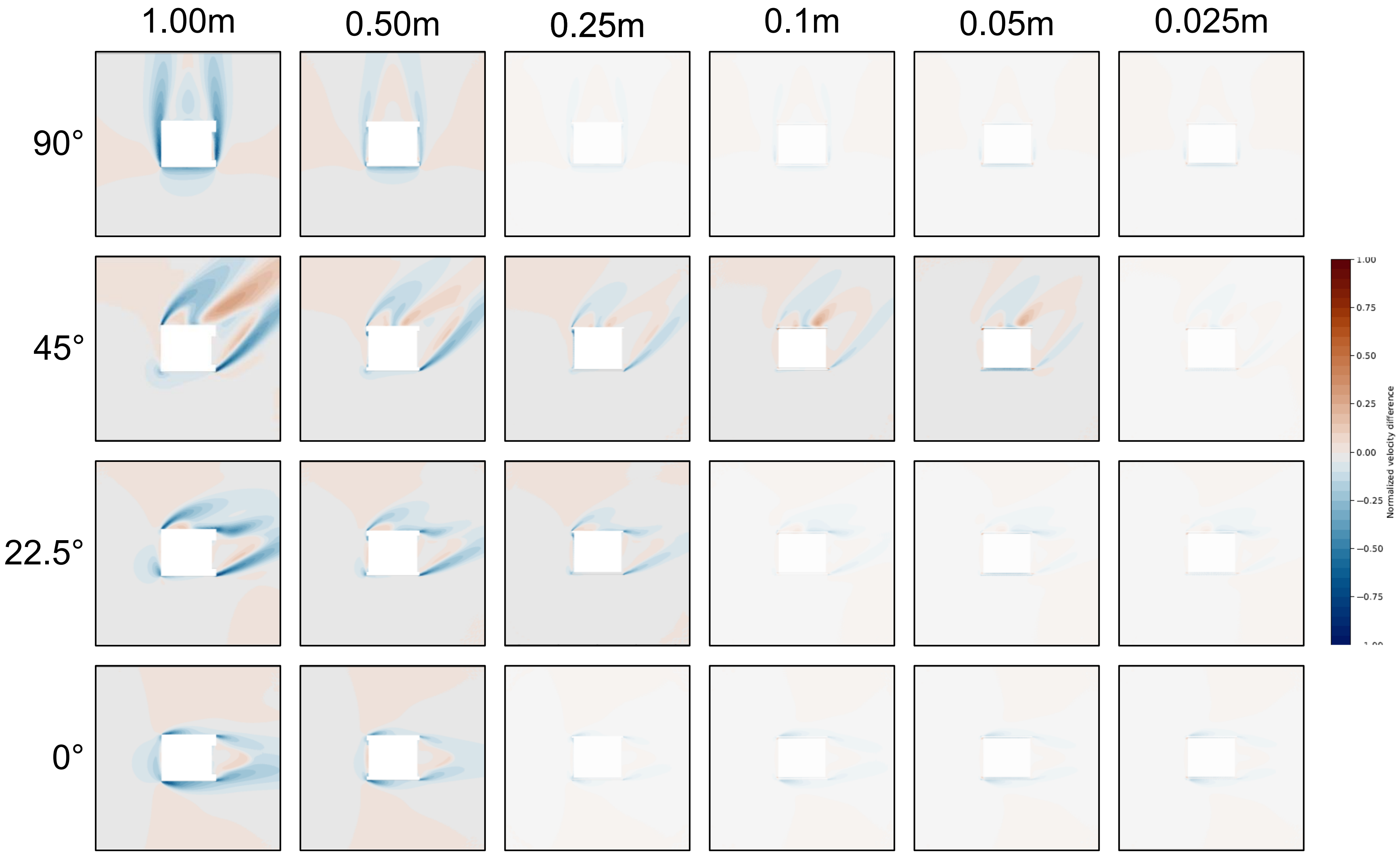
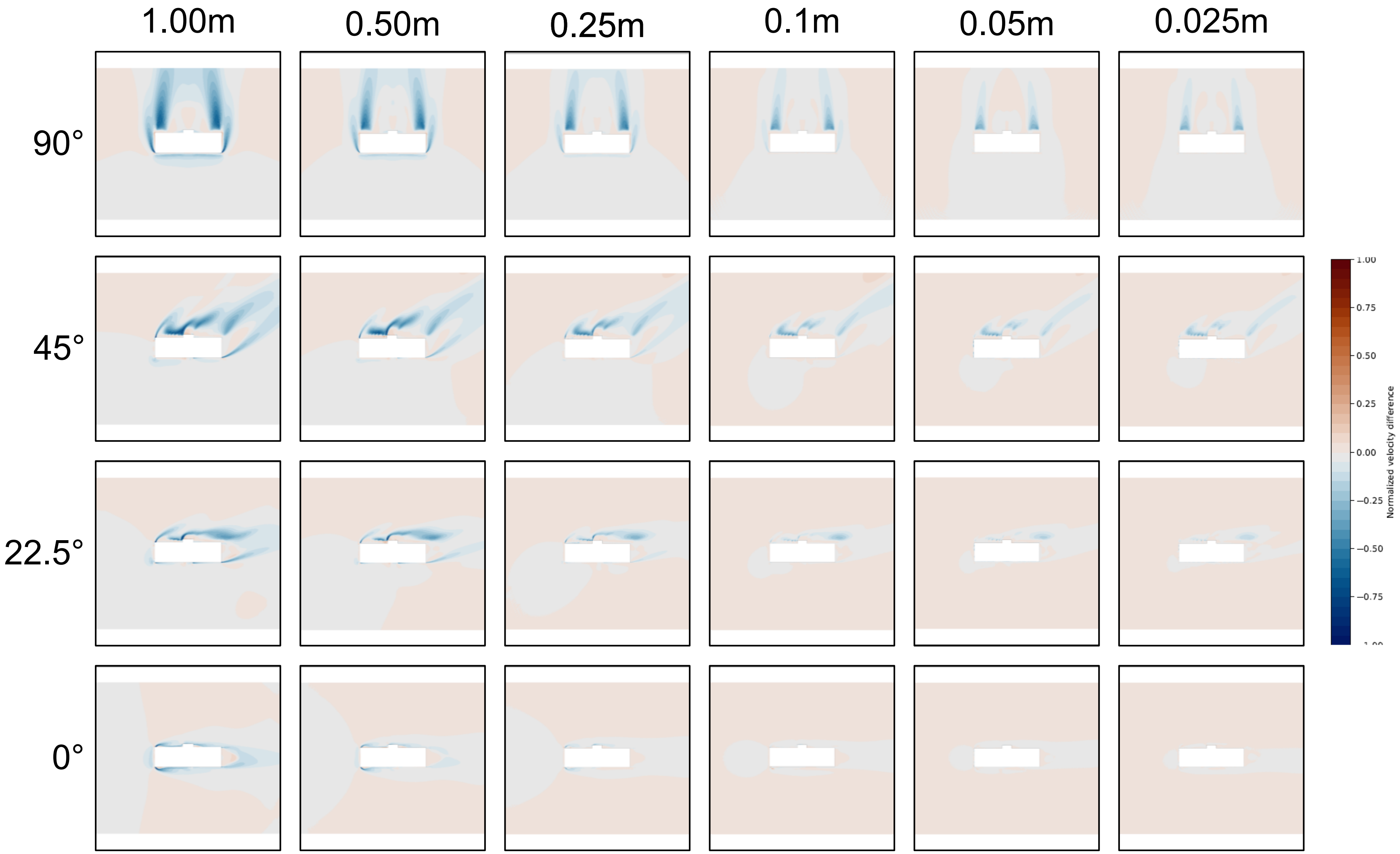


Wind velocity differences

Institute

- Coarse voxels underpredict
- Smallest differences even at coarse voxels
- 90° shows most persistent deviation



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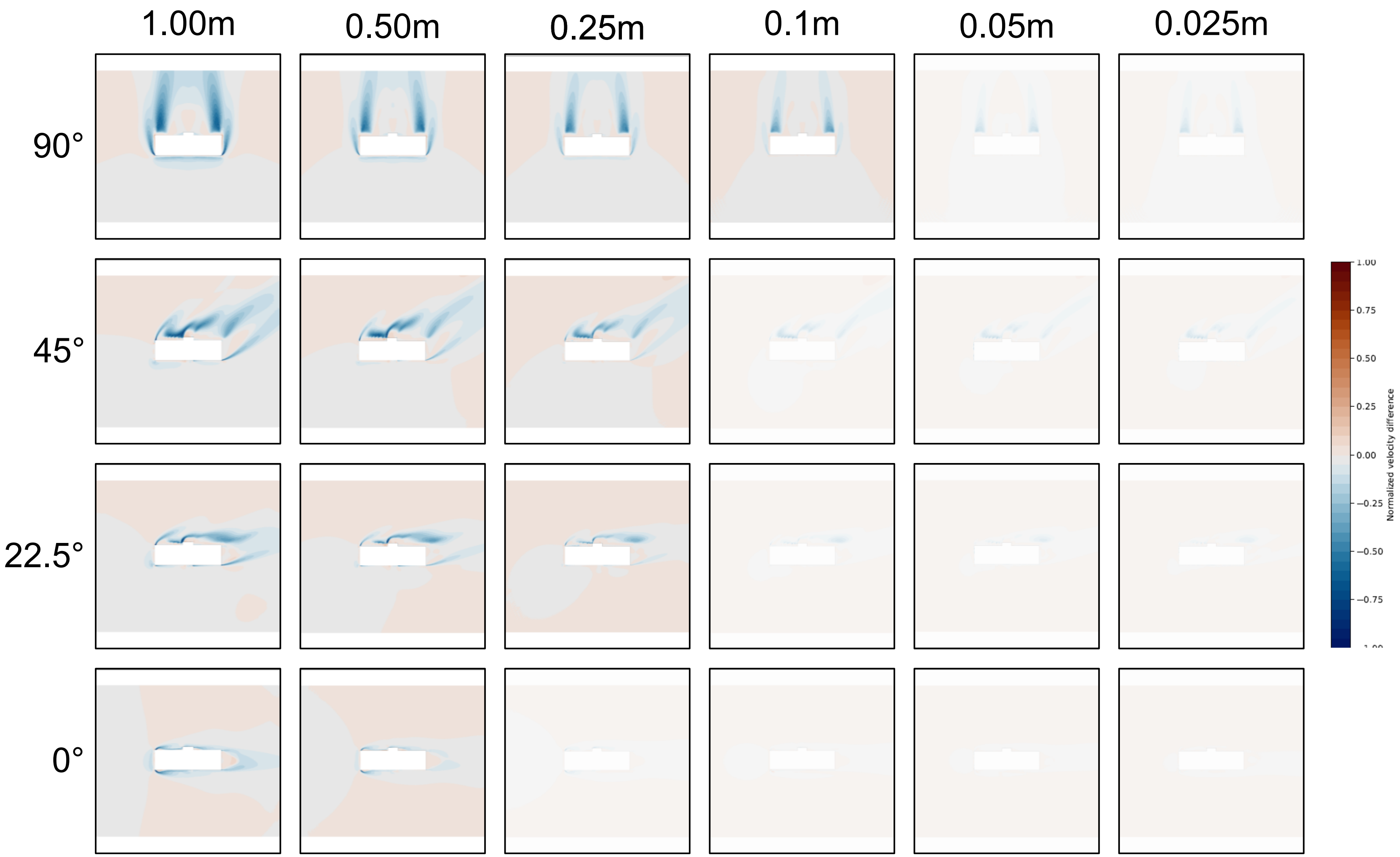


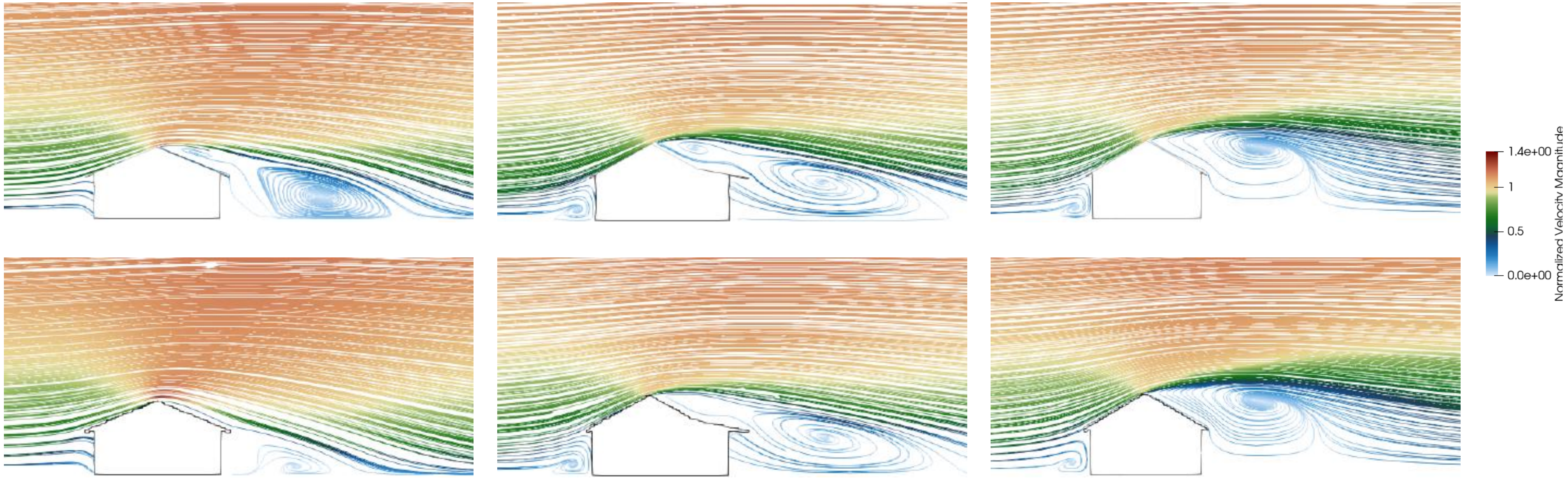
Wake Structure Differences

- Altered ridge structure
- Change in effective roof angle

- Change in effective voxel with

Truth model

0.1m voxel model



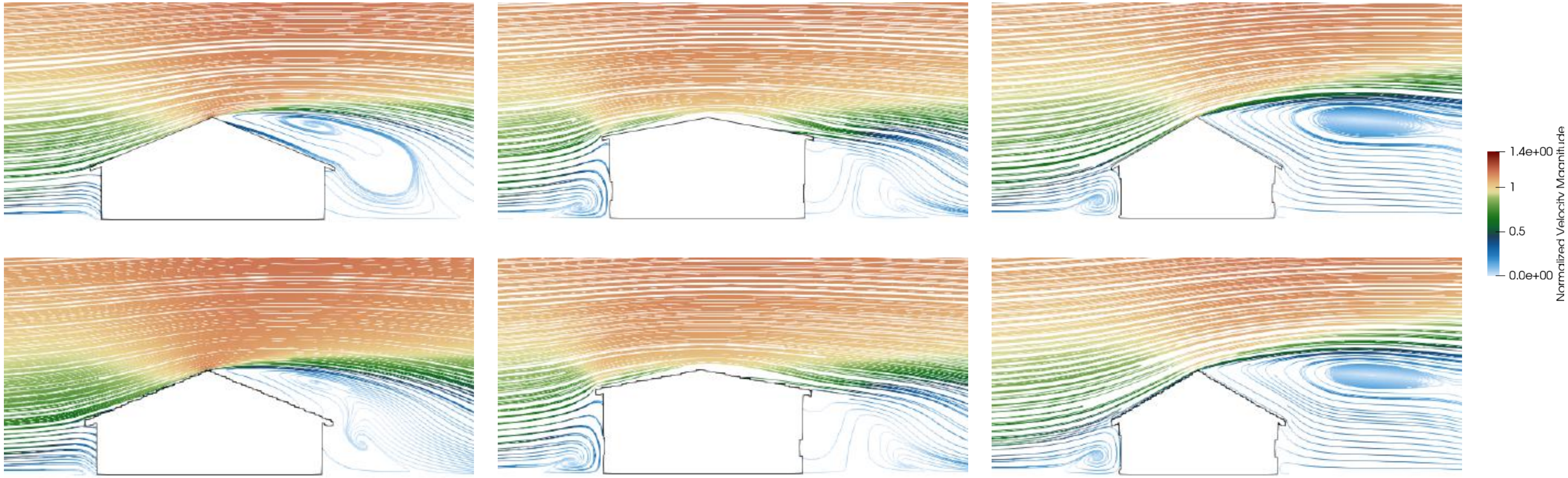
45° 22.5° 0°

Wake Structure Differences

- Significant change in effective roof angle
- Change in effective voxel with
- Interrupted recirculation zone

Truth model

0.1m voxel model



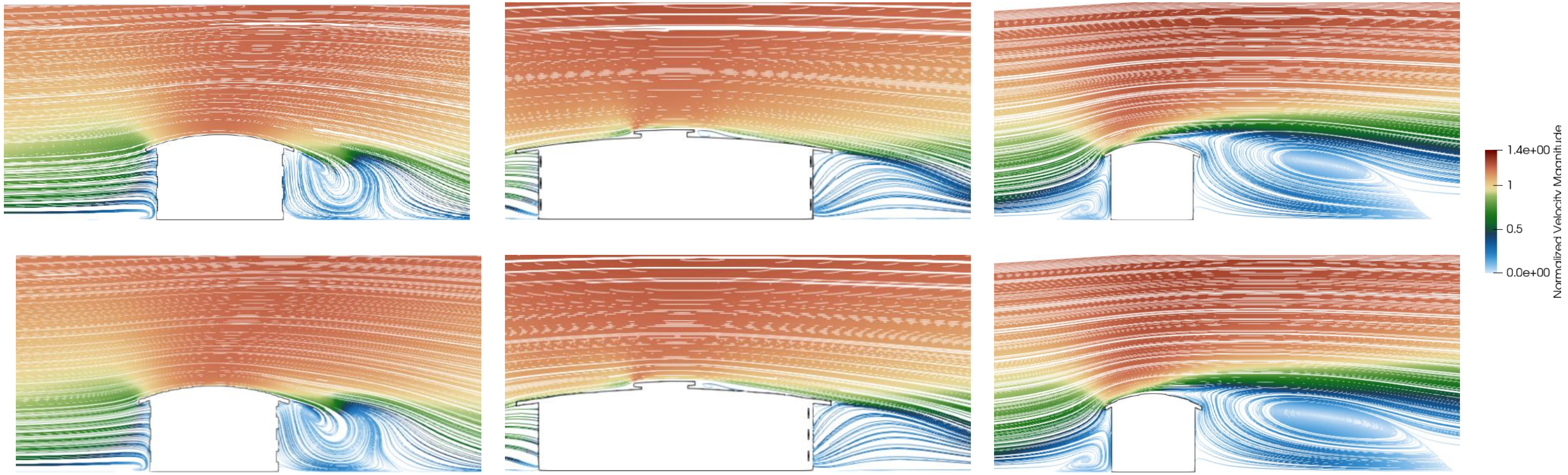
45° 22.5° 90°

Wake Structure Differences

- Roof shape stays similar to the truth
- 45° has shallower curve than 90 °

Truth model

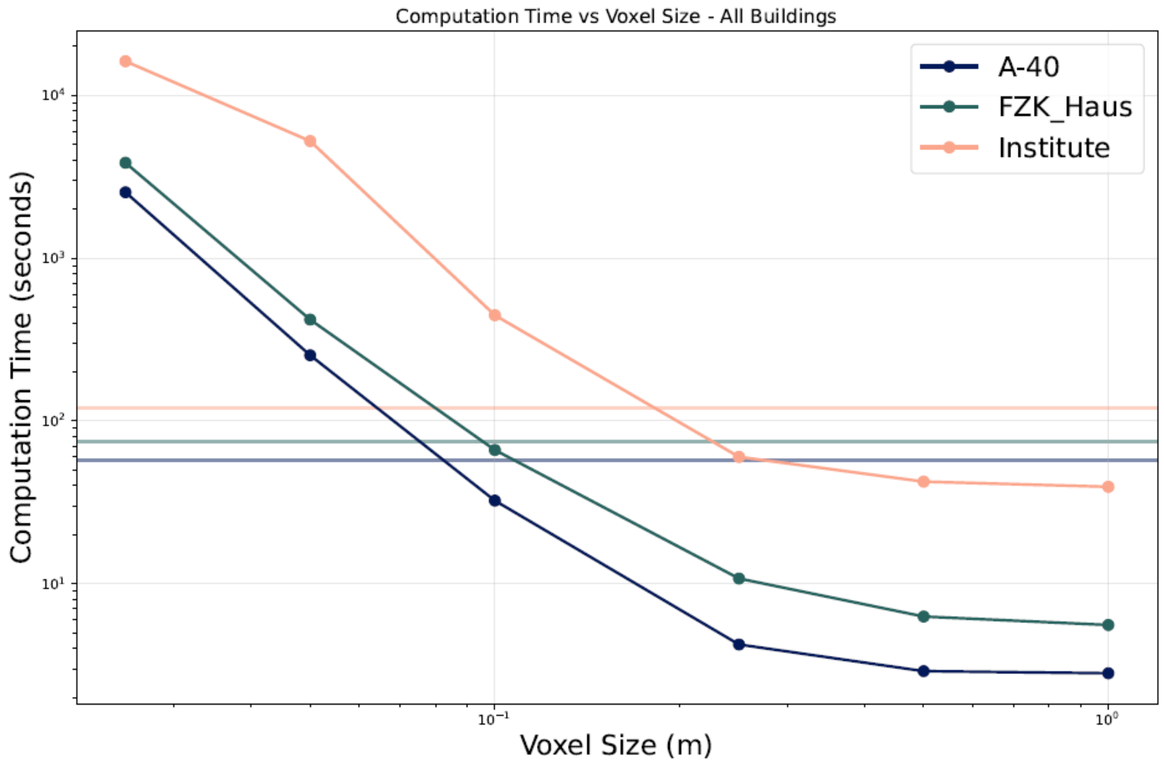
0.1m voxel model



45° 22.5° 90°

Computational performance

- Only voxelization times
- Sharp increase after 0.25m
- Software specific



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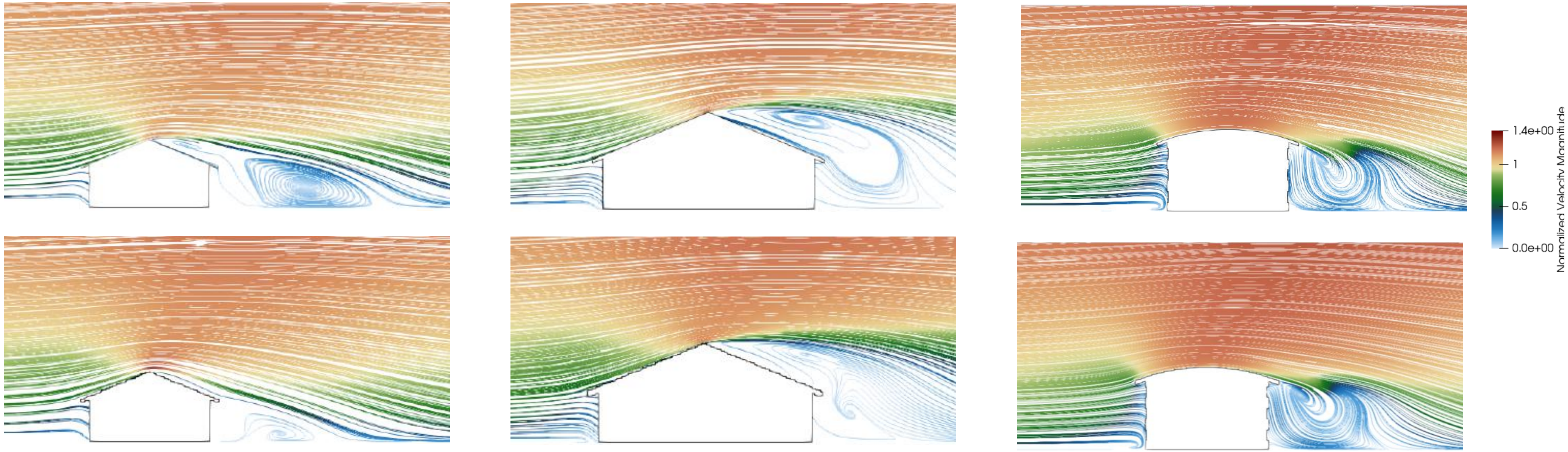
Conclusion

- Sloped roofs most affected
- 45° remains sensitive across voxel sizes

- Big increase in computation time with small decrease of velocity differences

Truth model

0.1m voxel model



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Future Work

- LES instead of RANS
- Influence of obstacles
- More wind directions
- Coarser meshes for voxel models
- Unaligned voxelized buildings
- Increased complexity in models

Thank you for your attention!

Bart Manden

28-10-2025

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