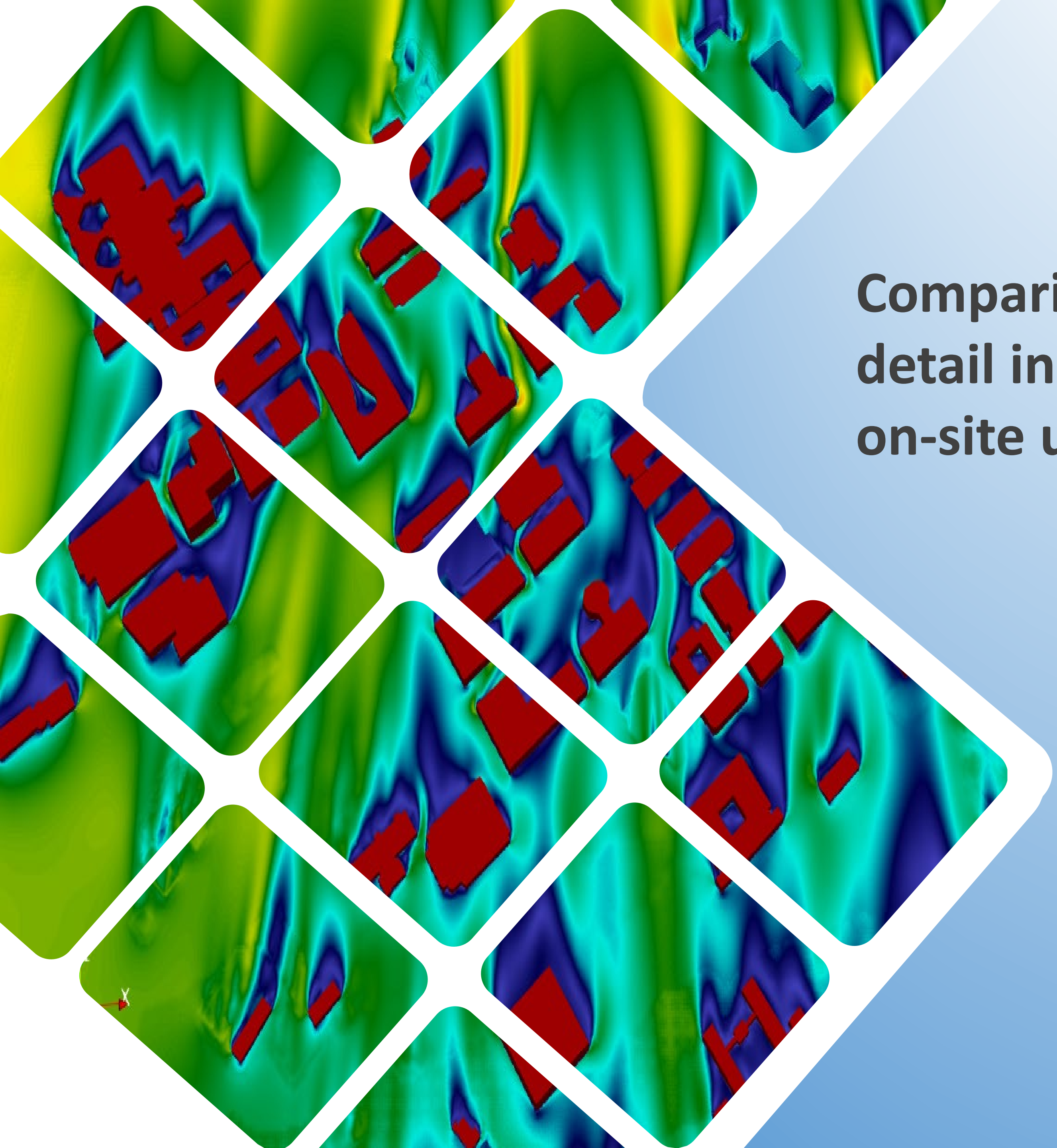

Comparing the impacts of geometry level of detail in computational wind engineering with on-site urban measurements

Pinelopi-Eirini Kountouri

Supervisor 1: Clara García-Sánchez
Supervisor 2: Ivan Pađen
Co-reader: Nadine Hobeika

External advisor : Nijso Beishuizen, Bosch

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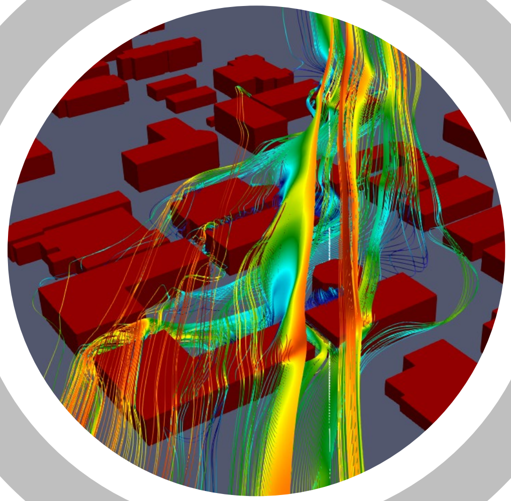


1 Motivation & Research Questions

2 Related Work

3 Methodology

4 Case study

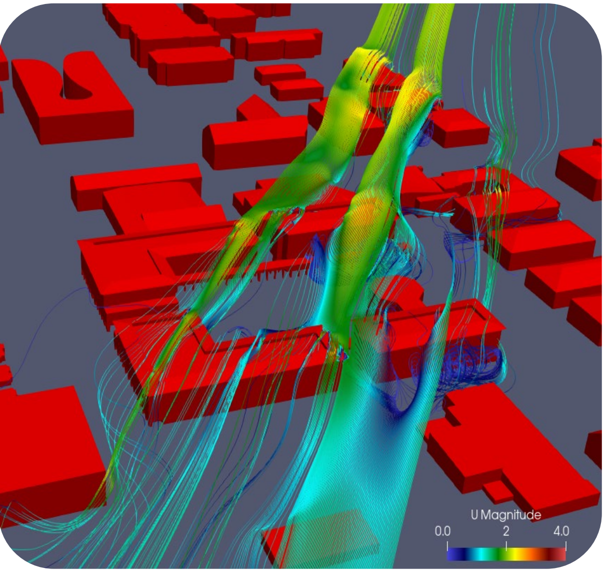
5 Results & Analysis

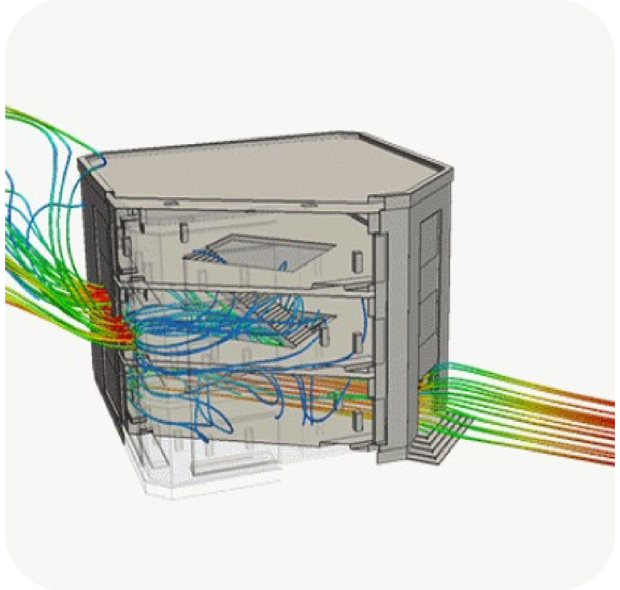
6 Conclusions

7 Future Work

TU Delft Delft University of Technology

Why ‘modeling wind in urban environments’ ?





Densely build-up areas

- Varying speeds
- Multiple directions

Benefits

- Wind power generation
- natural ventilation

Improvements

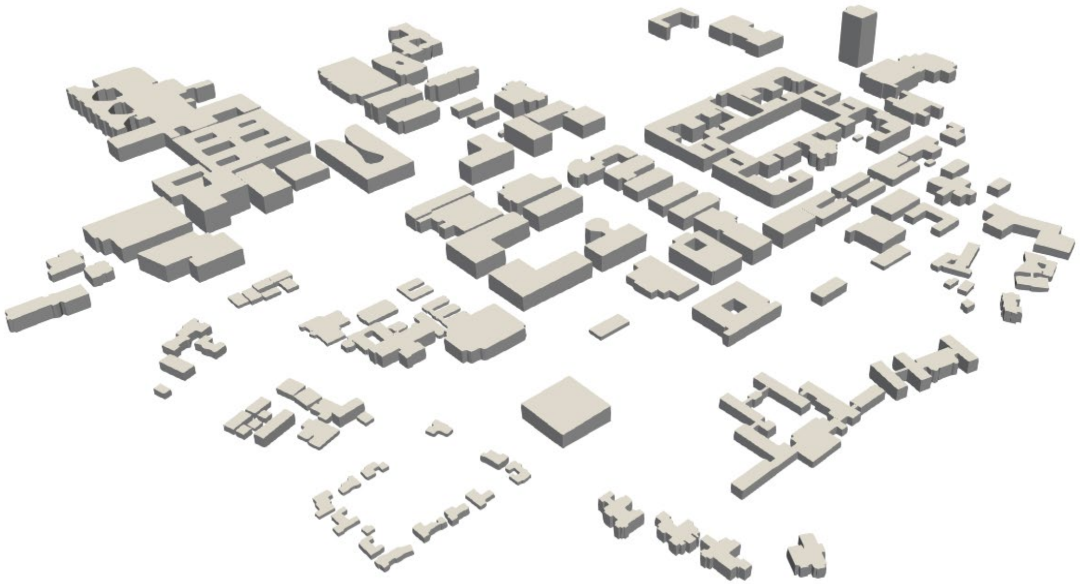
- Air quality
- Pedestrian comfort

Design more **sustainable** and **resilient** cities

Scope of research

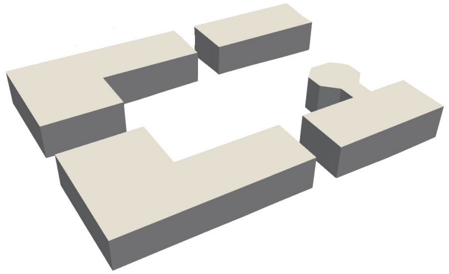
- Create **automatically** a **3D model** of Stanford University at LoD1.2
- Use the open source **City4CFD**
- Use **LoD1.2** model and manually reconstructed model at **LoD2.1** as input in CFD simulations
- Compare results with **on-site measurements**
- Determine which model is more **appropriate**
- **Execution time** and **results** closer to measurements

✓ **Applicable** to other similar scenarios



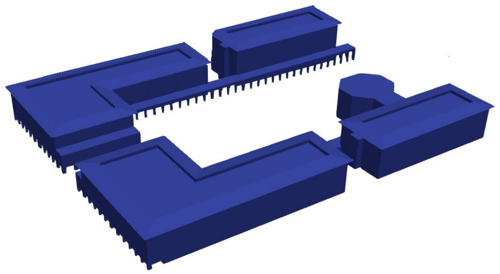
Main research question:

- What is the **impact** of **different geometry LoDs** for the wind around an urban environment?



Sub-questions:

- What are the **needed steps** to automatically reconstruct a 3D city model?
- How large can be the **differences** introduced by geometry discrepancies?
- Is it possible a **higher LoD** geometry **better predict** real-world measurements?



Level of Detail

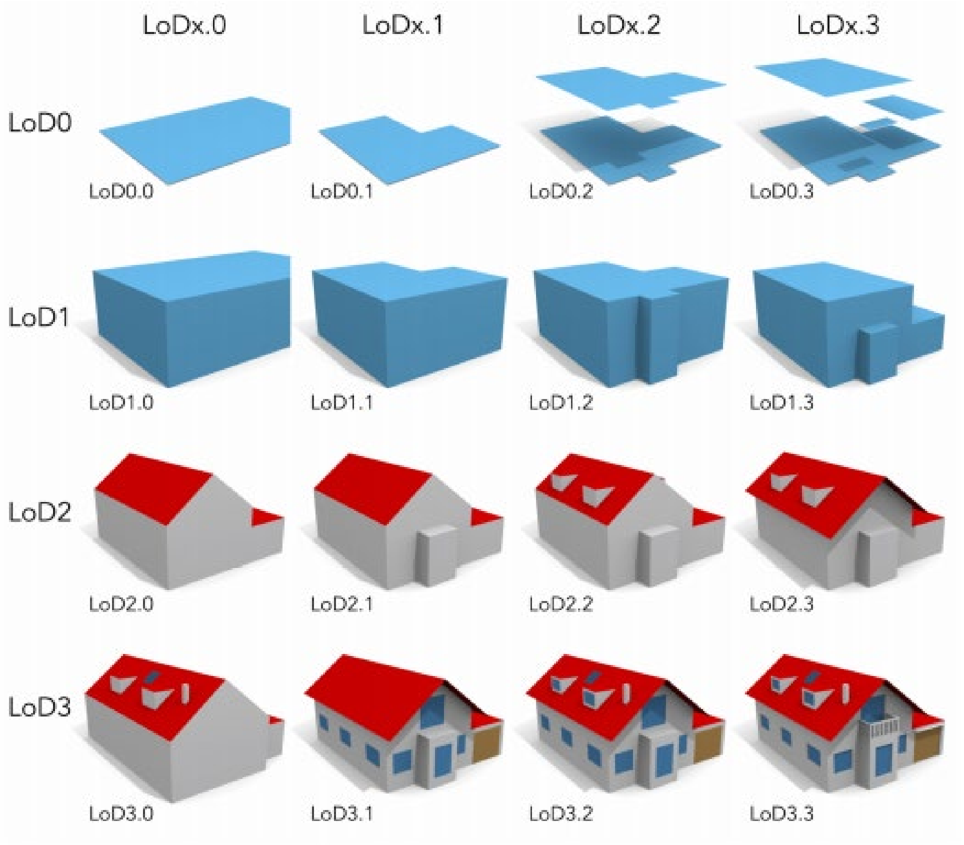
LoDO : Depiction of footprints, and potentially roof edge polygons

LoD1 : Horizontal flat roof surfaces

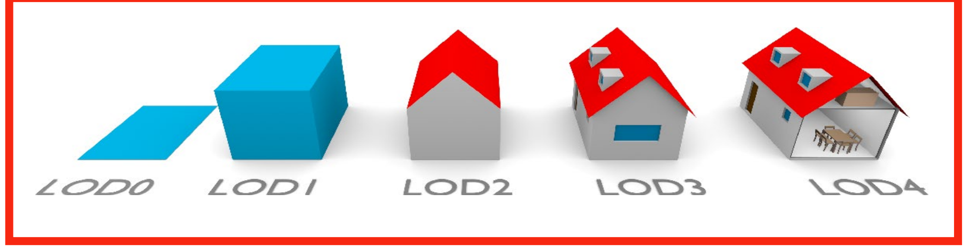
LoD2 : More detailed multi-pitched roof shape

LoD3 : Highly detailed building model with windows and doors

LoD4 : Complete model with indoor elements



OGC standard: CityGML 2.0



Source: *An improved LOD specification for 3D building models*
https://www.sciencedirect.com/science/article/pii/S0198971516300436

Level of Detail

LoDO : Depiction of footprints, and potentially roof edge polygons

LoD1 : Horizontal flat roof surfaces

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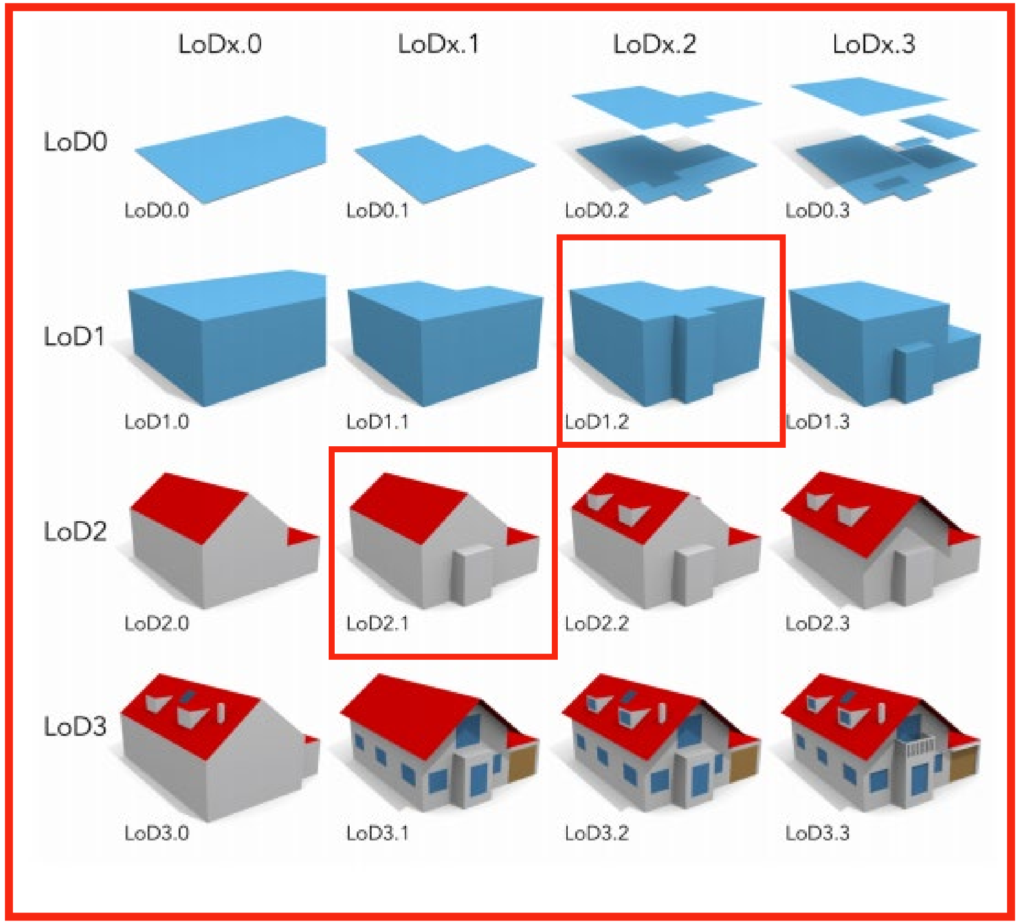
LoD4 : Complete model with indoor elements

✓ **"TUDelft LoDs"** more beneficial for wind analysis

TUDelft LoDs



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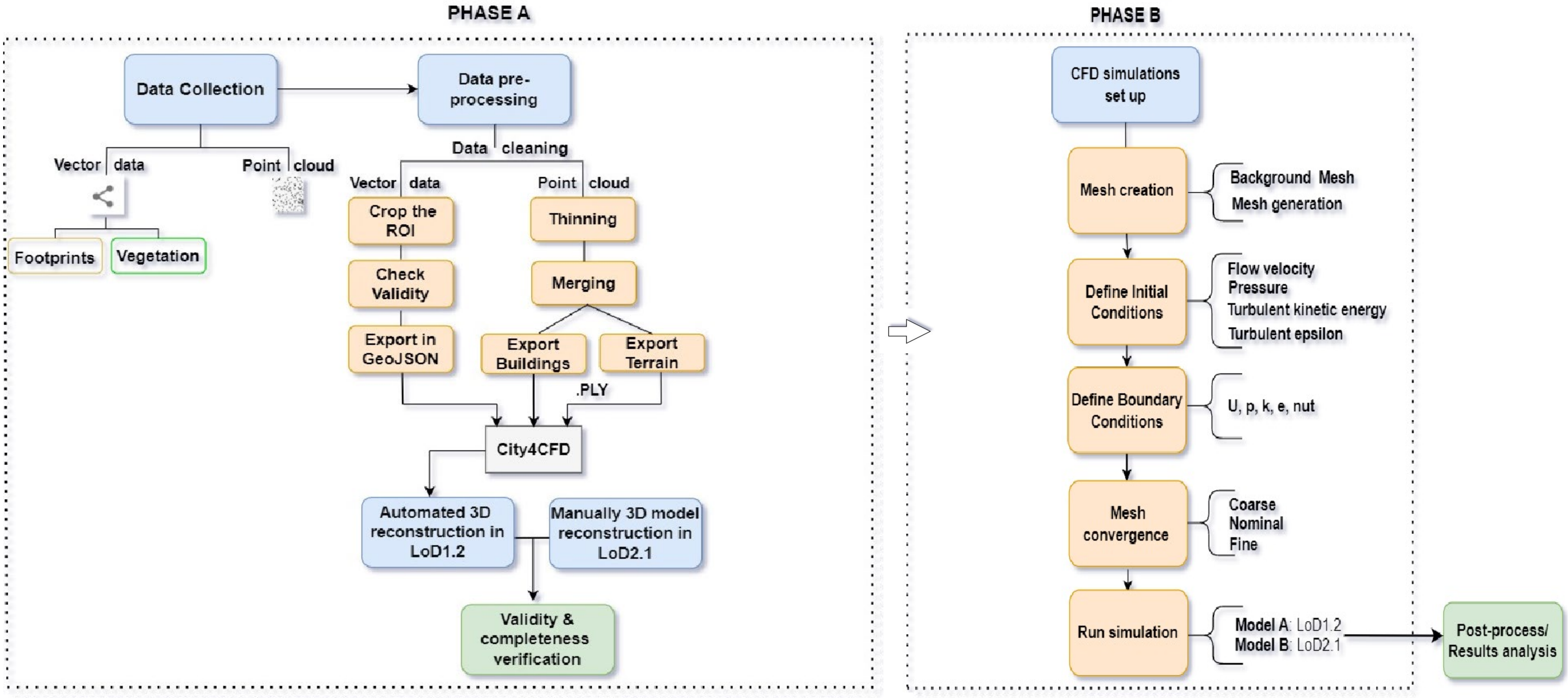
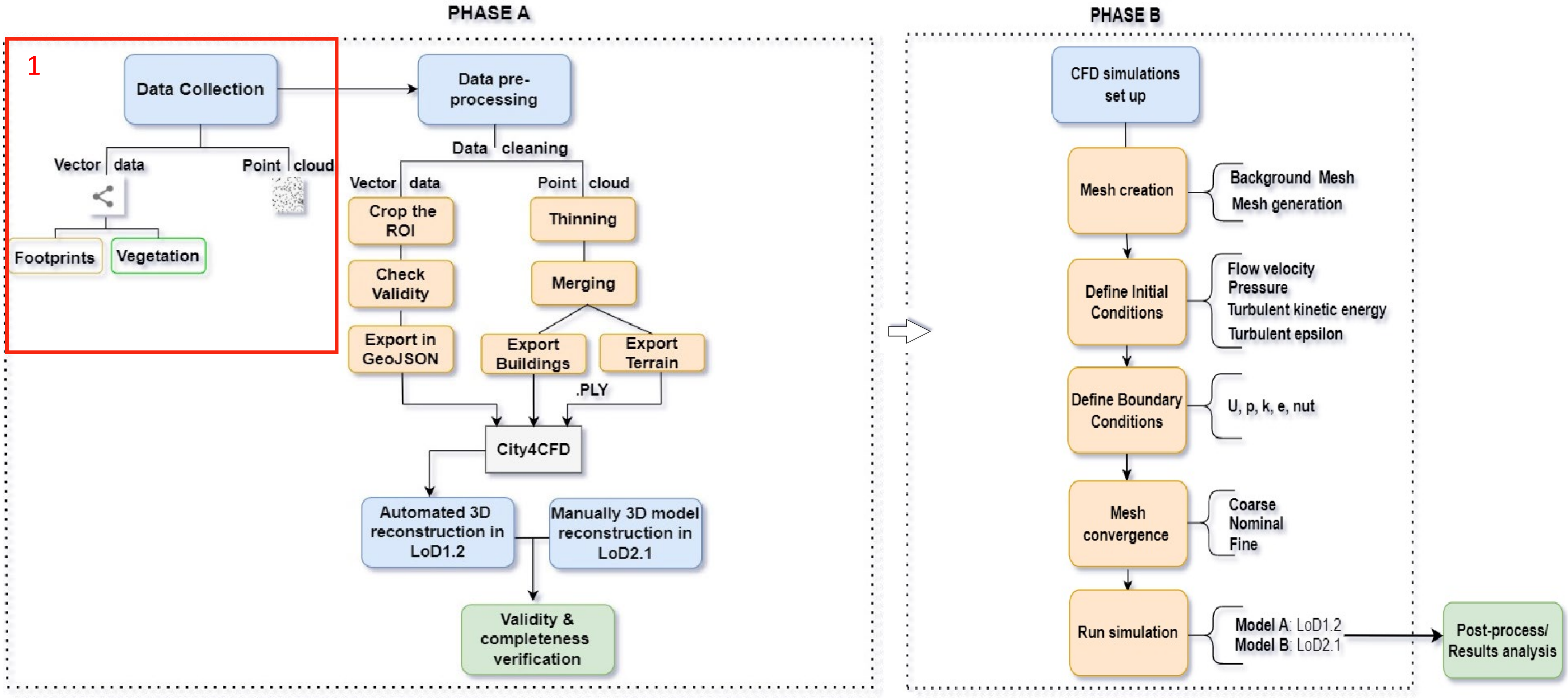


Methodology



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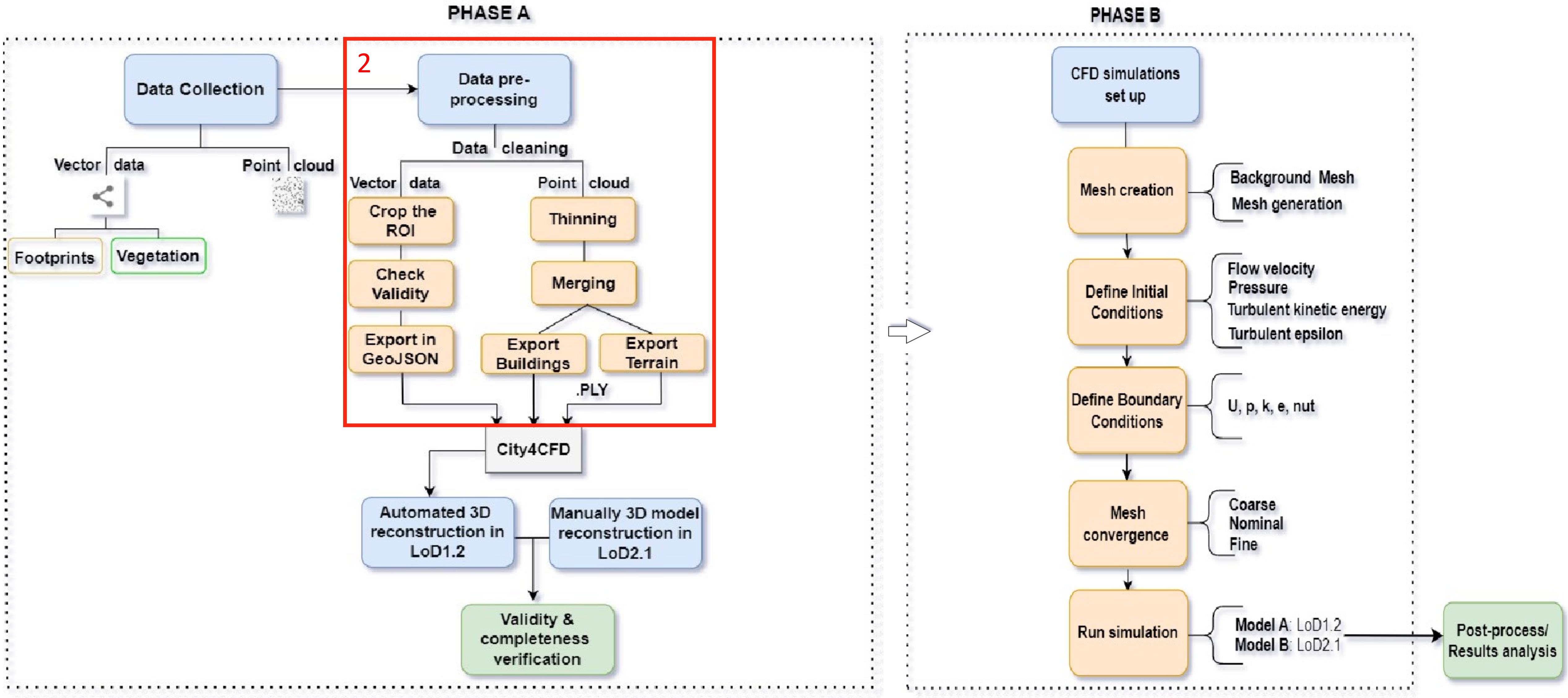
PHASE A
2
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Data pre-processing
Data cleaning
Vector data
Point cloud
Footprints
Vegetation
Crop the ROI
Check Validity
Export in GeoJSON
Thinning
Merging
Export Buildings
Export Terrain
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Manually 3D model reconstruction in LoD2.1
Validity & completeness verification
PHASE B
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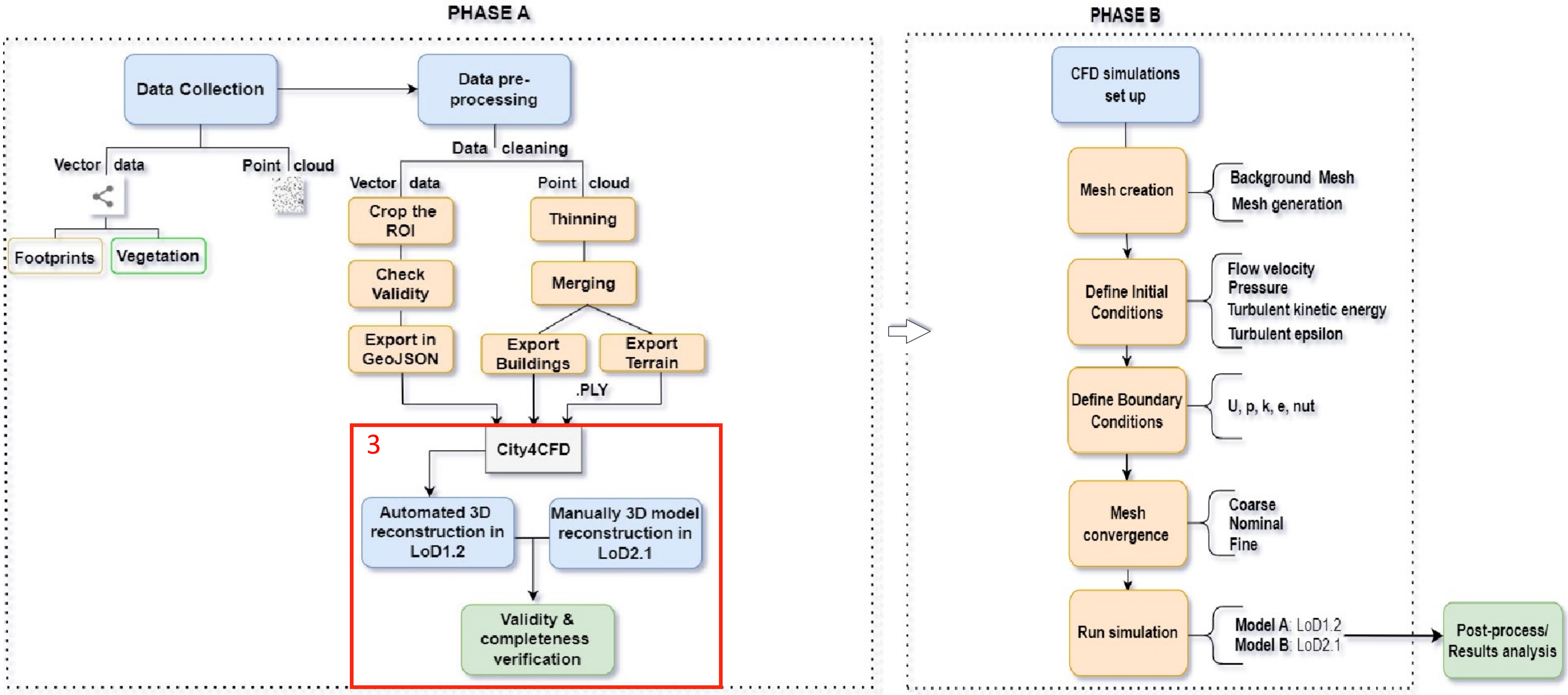
Mesh generation
Define Initial Conditions
Flow velocity
Pressure
Turbulent kinetic energy
Turbulent epsilon
Define Boundary Conditions
U, p, k, e, nut
Mesh convergence
Coarse
Nominal
Fine
Run simulation
Model A: LoD1.2
Model B: LoD2.1
Post-process/ Results analysis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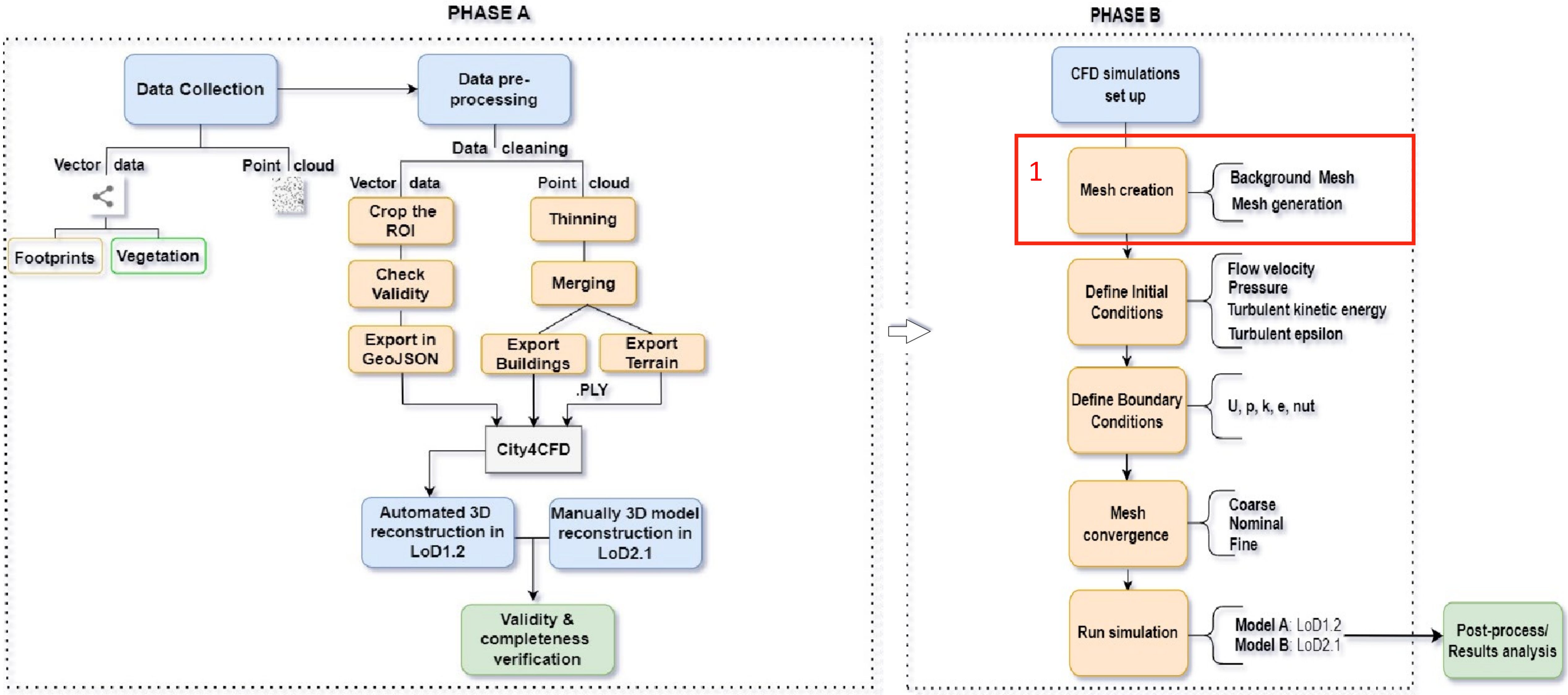

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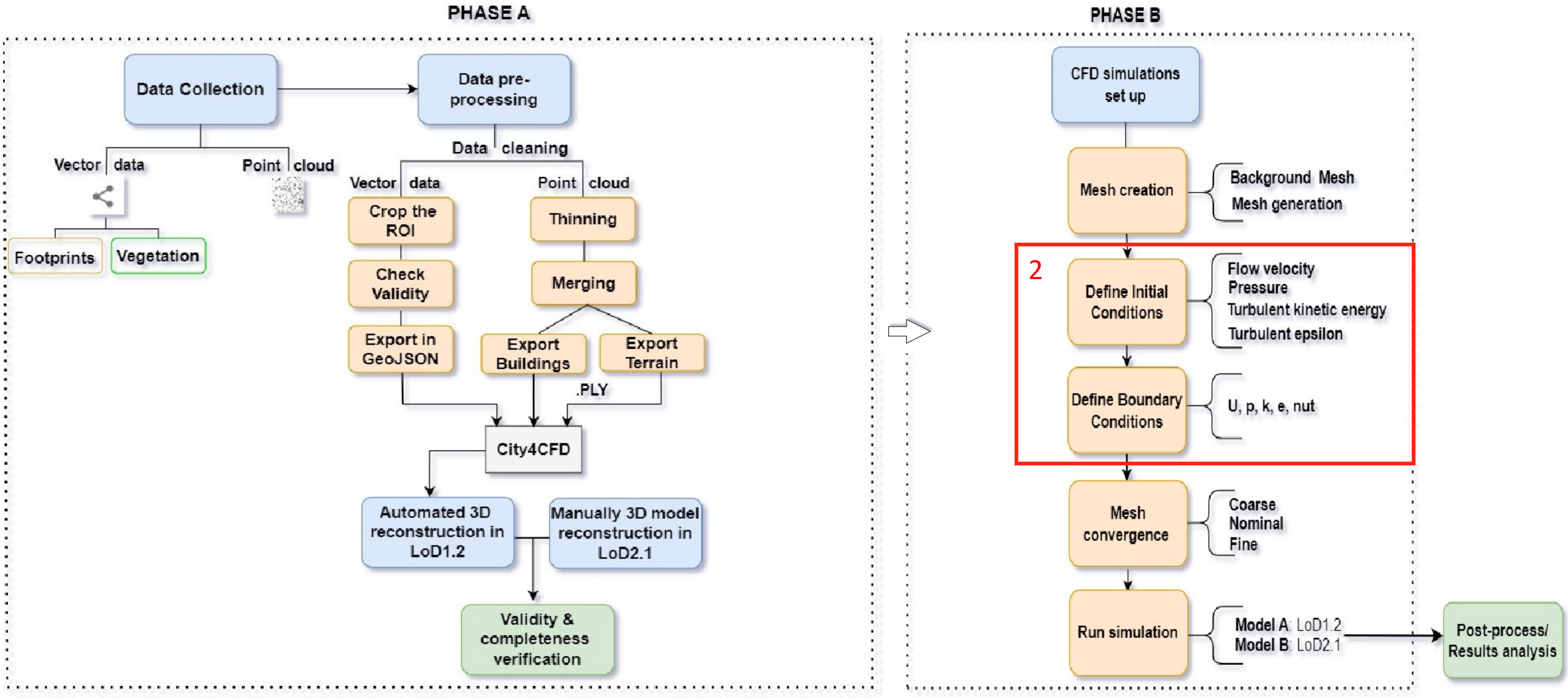
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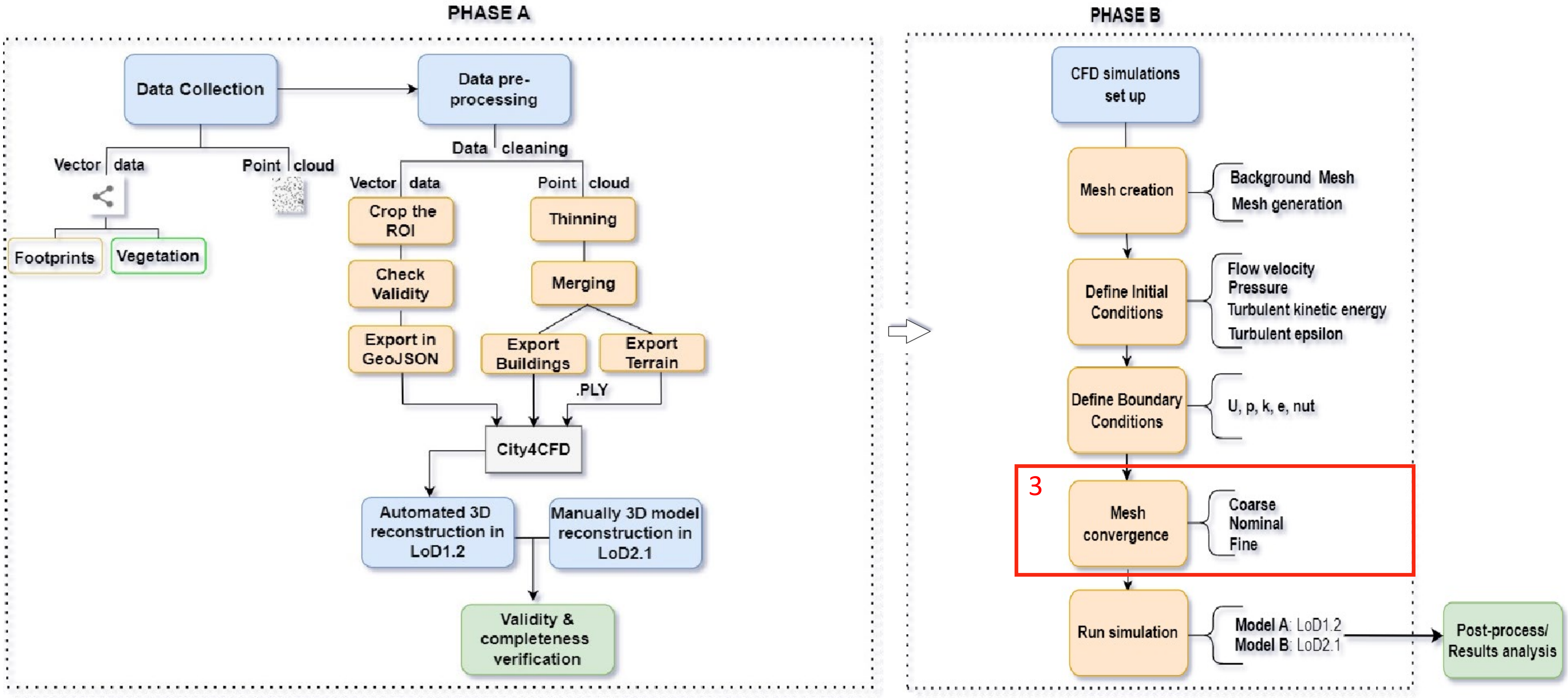
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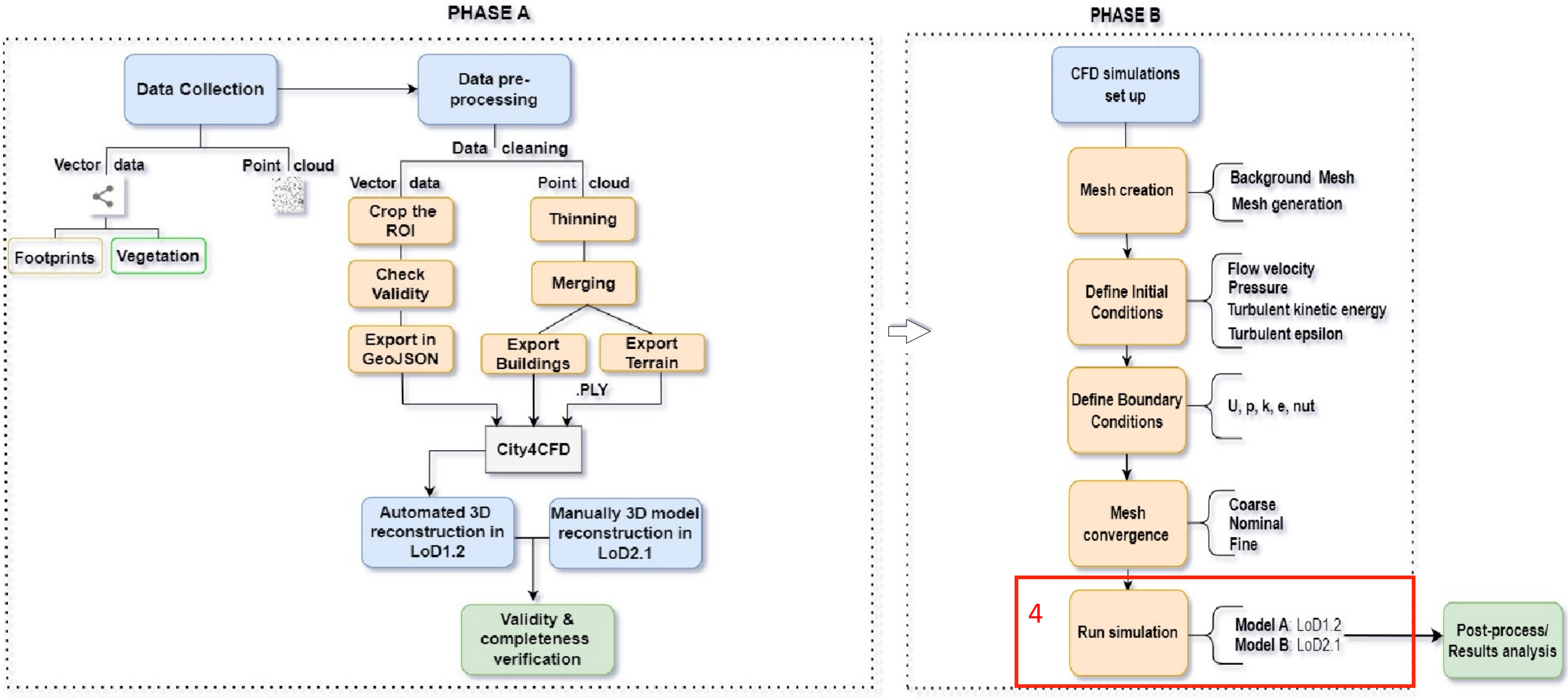
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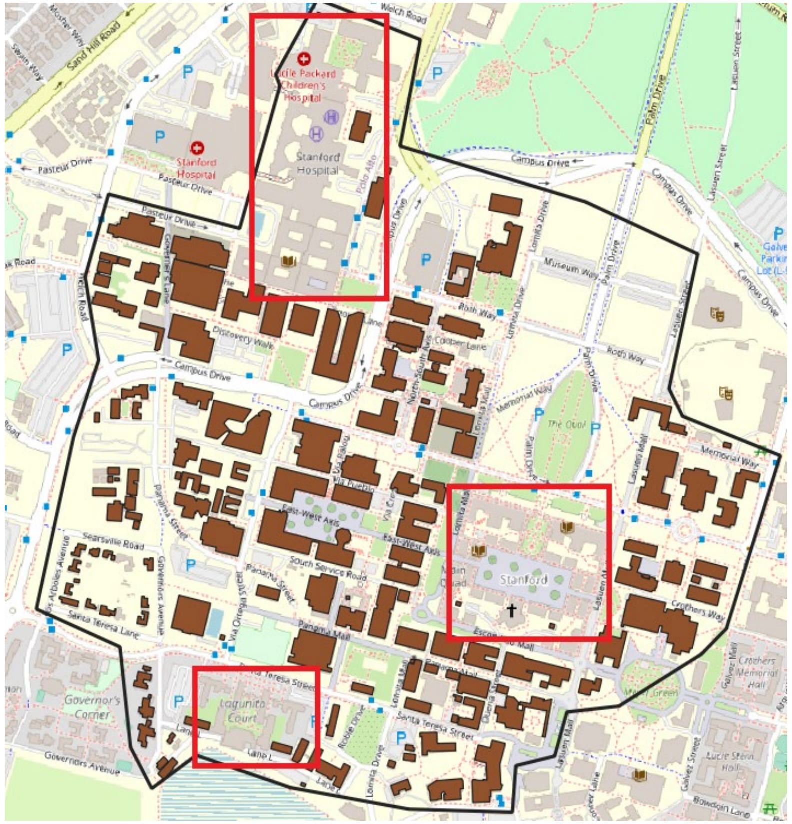
Datasets - Footprints (1/5)

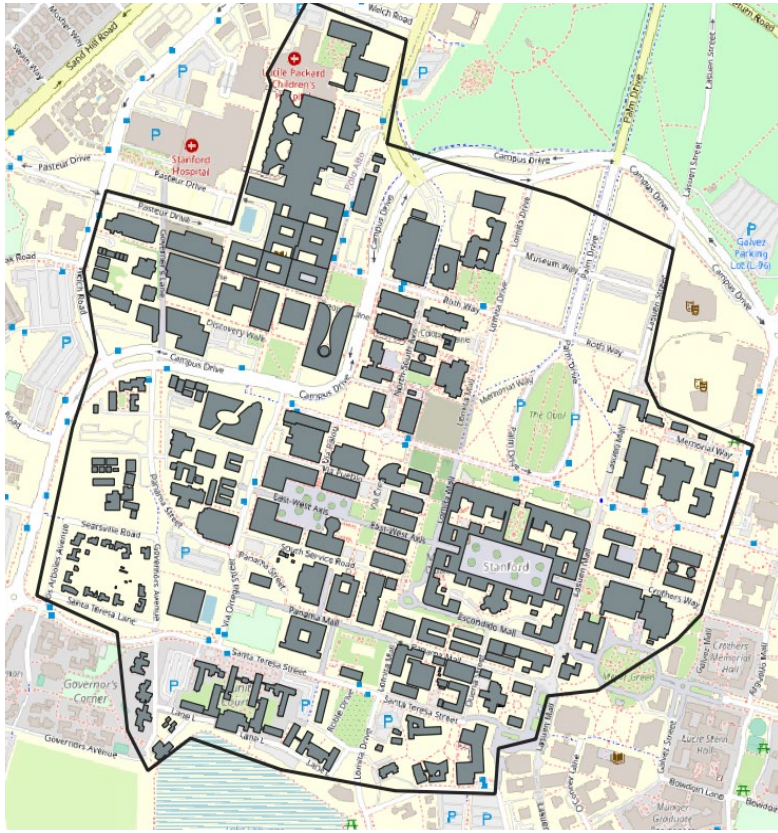
Microsoft Maps:

- 11,542,912 footprints for California (EPSG: 4326)
- Crop ROI
- Footprints are missing

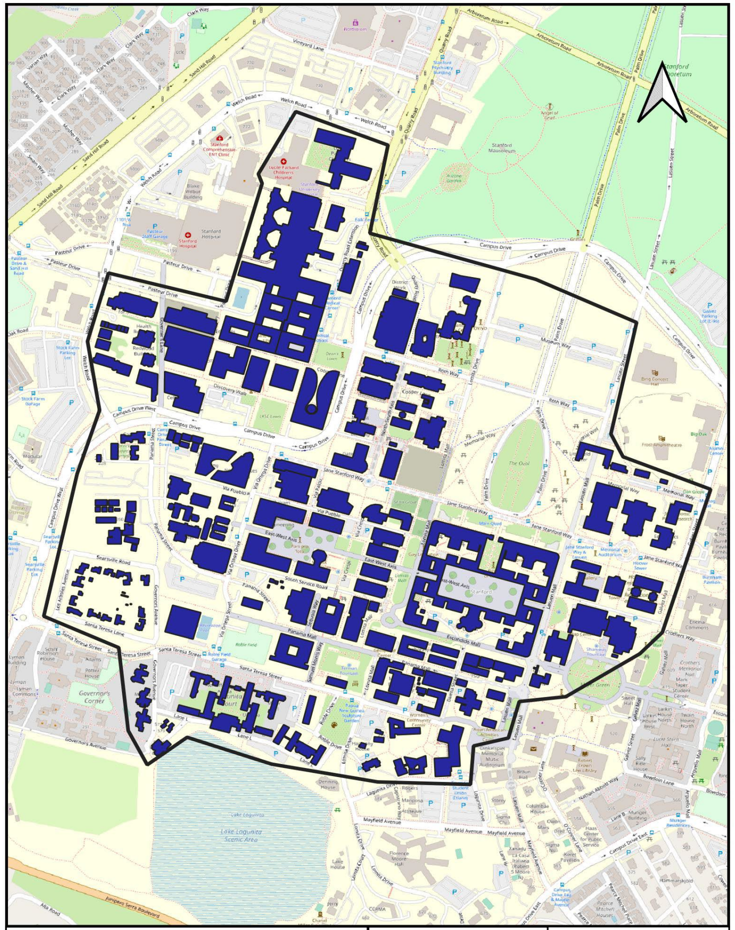


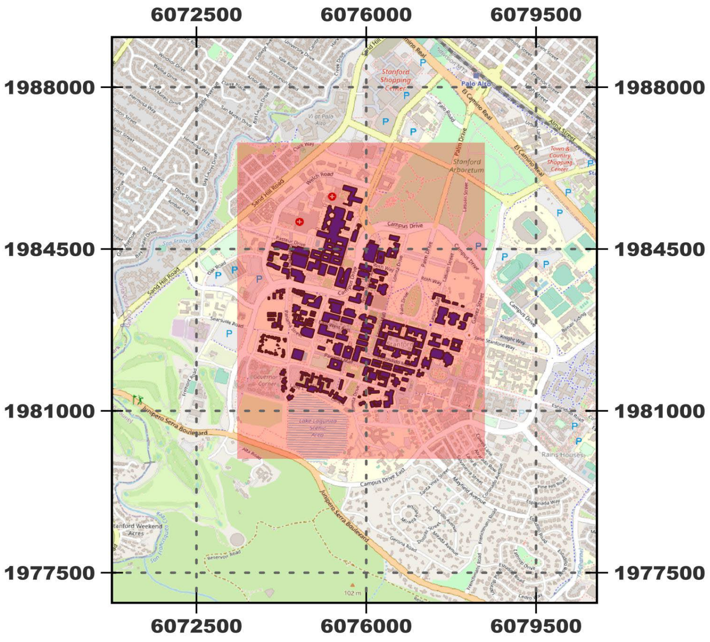
Open Street Map:

- Plugin QuickOSM
- Extract 206 footprints
- Export to EPSG 6419



Datasets - Footprints (2/5)





Scale:
0 300 600 m
1:12,000

Source:
Open Steet Map

Lagend:
Footprints
ROI

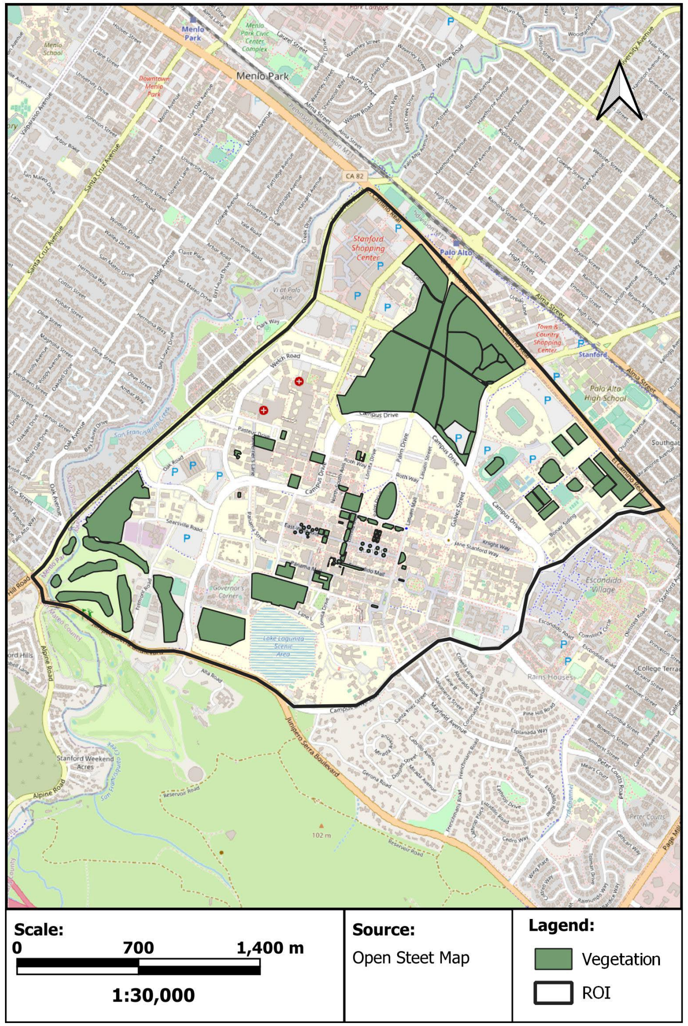
Scale:
0 800 1,600 m
1:35,000

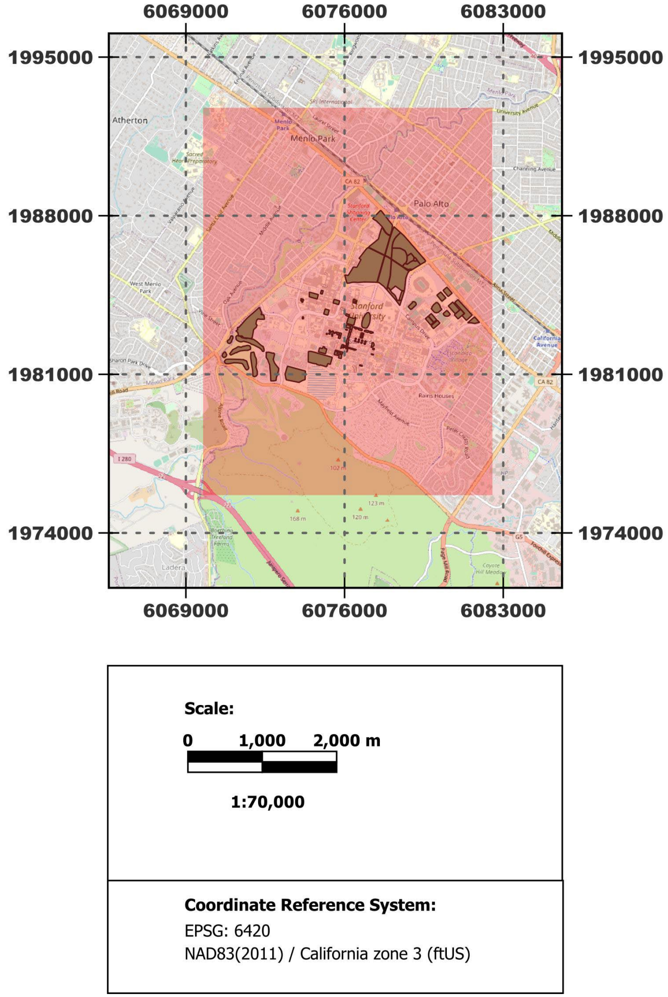
Coordinate Reference System:
EPSG: 6420
NAD83(2011) / California zone 3 (ftUS)

Datasets - Vegetation (3/5)

Open Street Map:

- Plugin QuickOSM
- Extract Vegetation
- Manual digitization
- Export to EPSG 6419

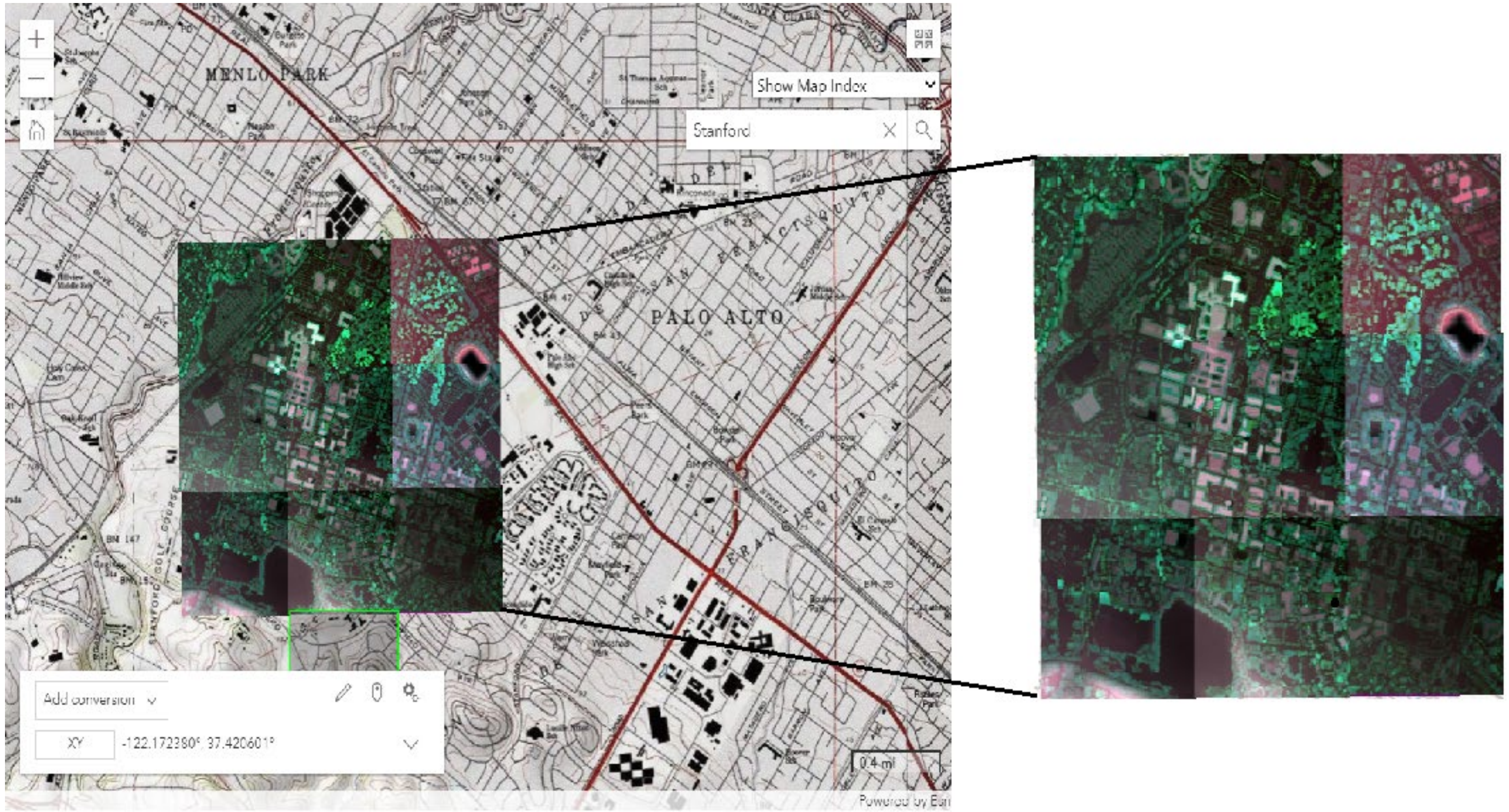




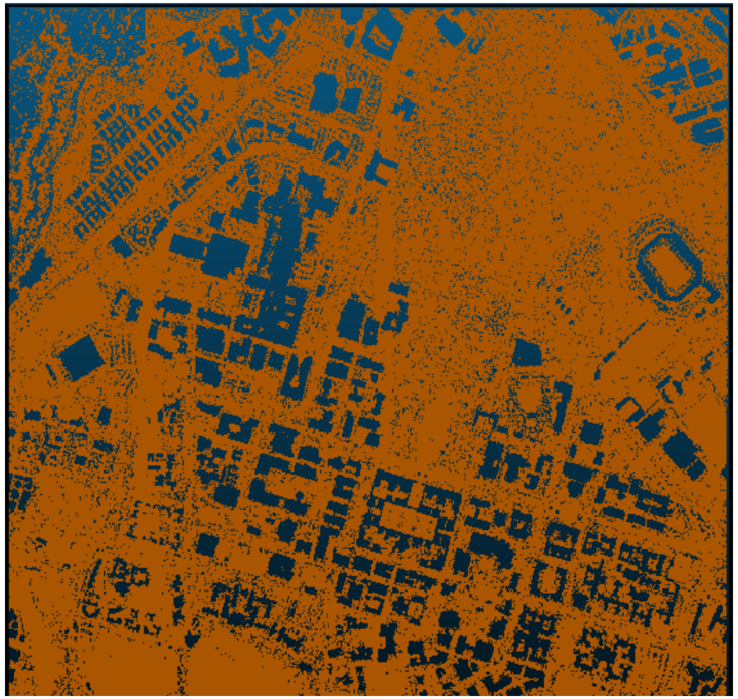
Datasets - Point Clouds (4/5)

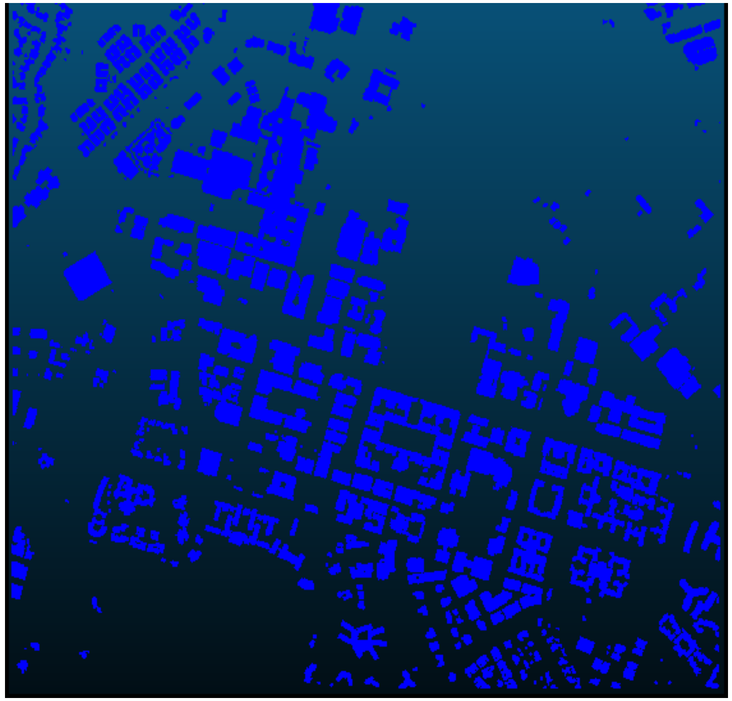
U.S Geological Survey:

- Nine point cloud tiles published in 2021
- Thinning
- Merge into 1 point cloud
- Extract buildings and terrain



Datasets - Point clouds (5/5)





Classified point cloud:

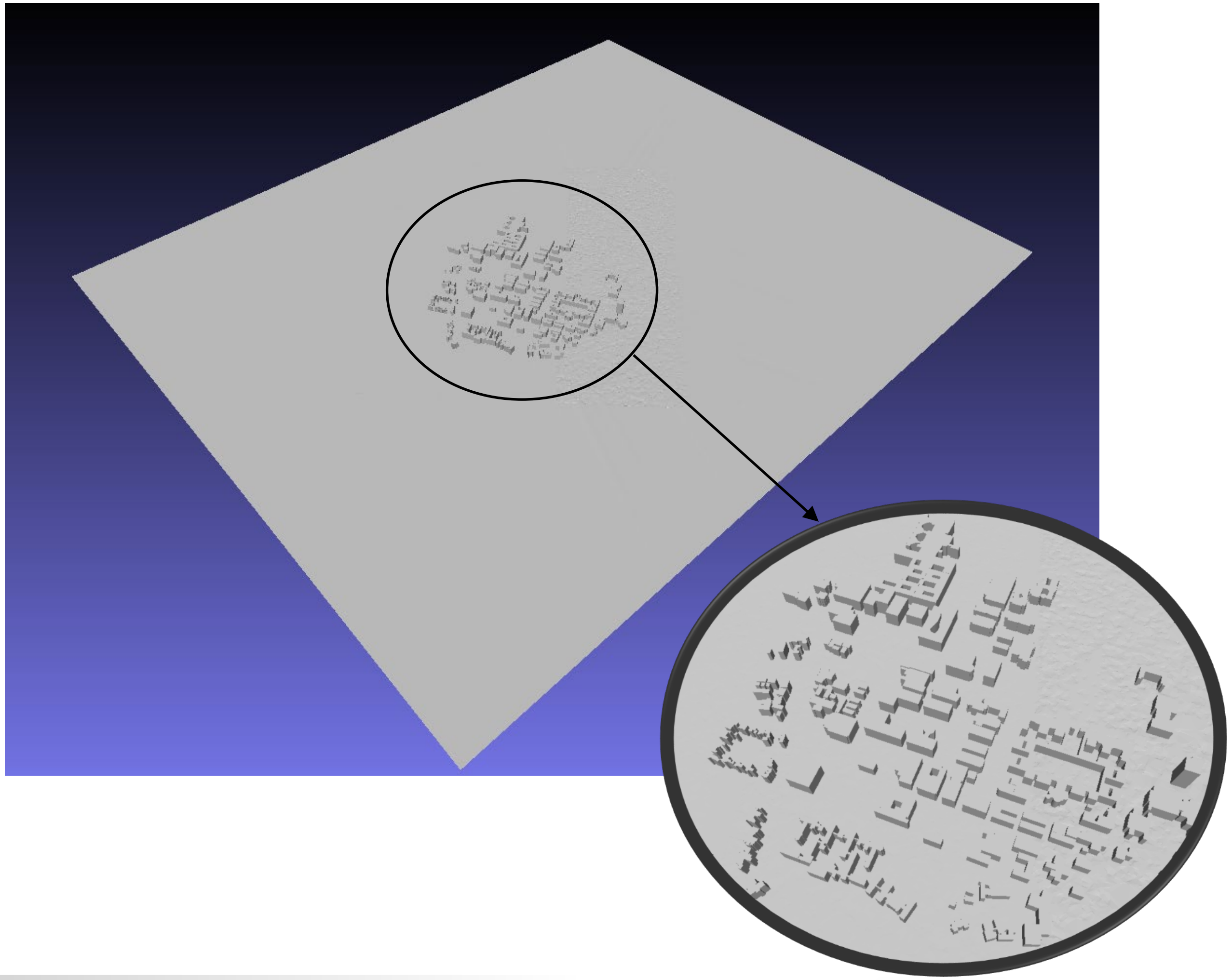
- Class 2: Ground
- Class 6: Buildings

Point Cloud ID	Initial size	Subsample (3m)	Subsample (4m)	Subsample (5m)
A20_07259800	14,213,805	960,593	568,101	372,101
A20_07259825	13,750,364	902,819	533,533	350,182
A20_07259850	15,043,391	1,192,588	712,670	468,317
A20_07509800	13,644,984	953,914	564,937	370,333
A20_07509825	13,245,837	922,218	546,703	359,418
A20_07509850	13,281,408	935,342	551,961	363,194
A20_07759800	14,458,018	1,012,626	593,315	389,121
A20_07759825	14,299,969	1,010,662	597,720	393,796
A20_07759850	14,570,931	1,084,323	645,617	427,786
Merged Point Cloud	-	**8,975,085**	**5,314,557**	**3,494,248**

City4CFD **Output** - LoD1.2 model

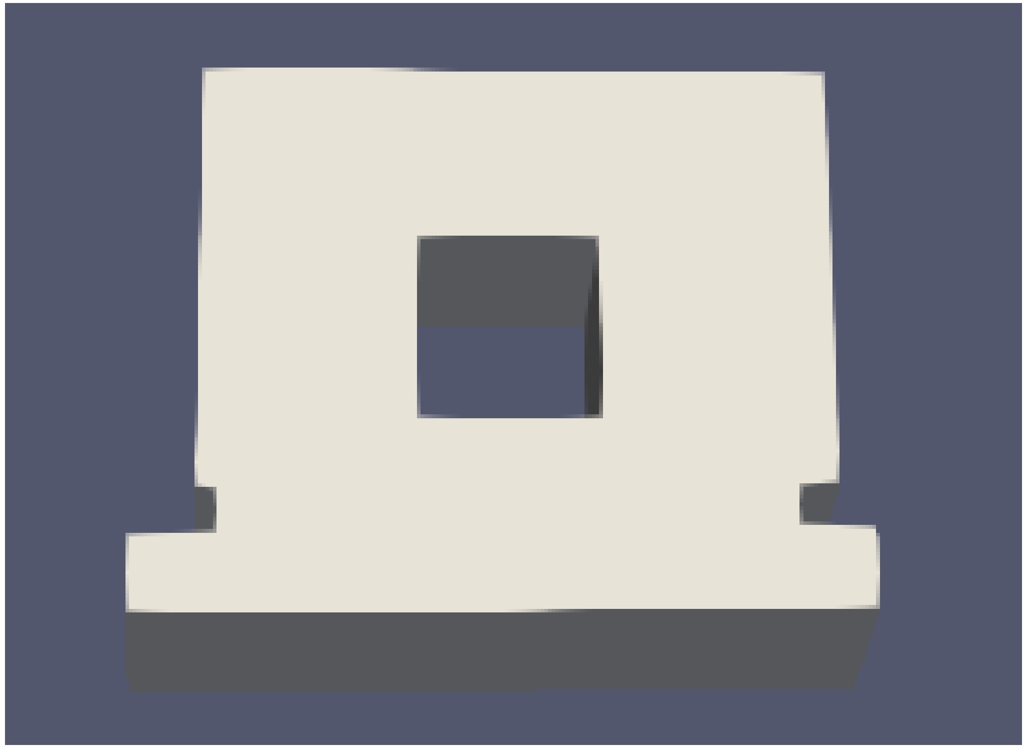
LoD1.2 Model:

- Vegetation and buildings are seamlessly integrated into the terrain
- 142 buildings
- Execution time: 0.95 min.
- 100% success

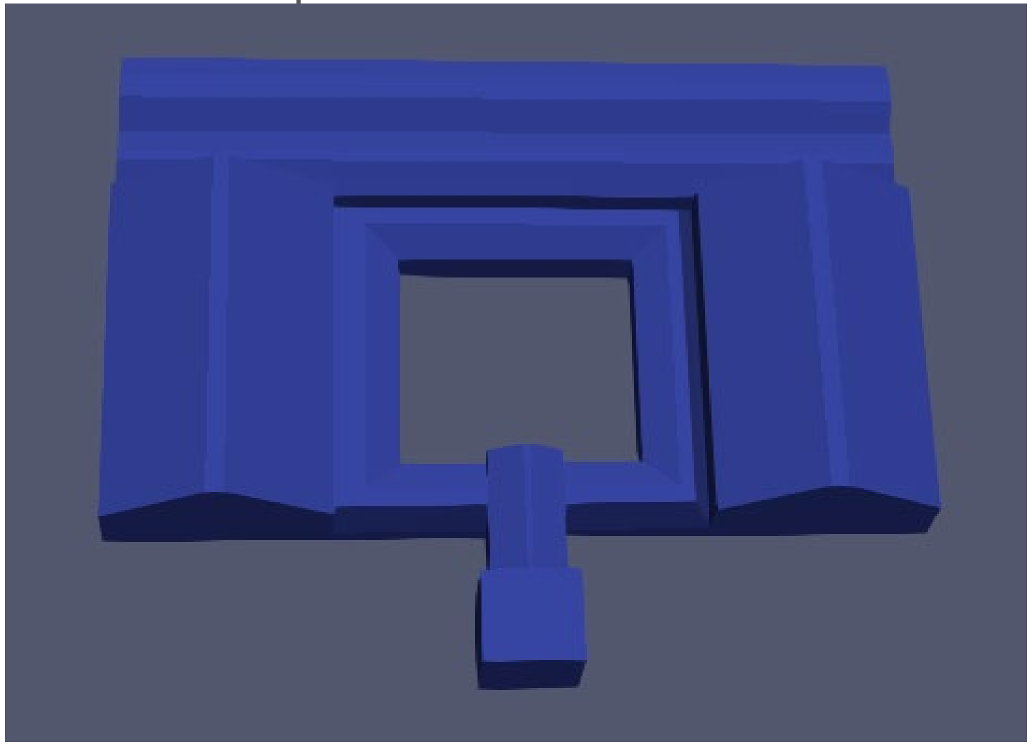


Comparison between models: Level of detail (1/3)

LoD1.2: Horizontal flat roof surface

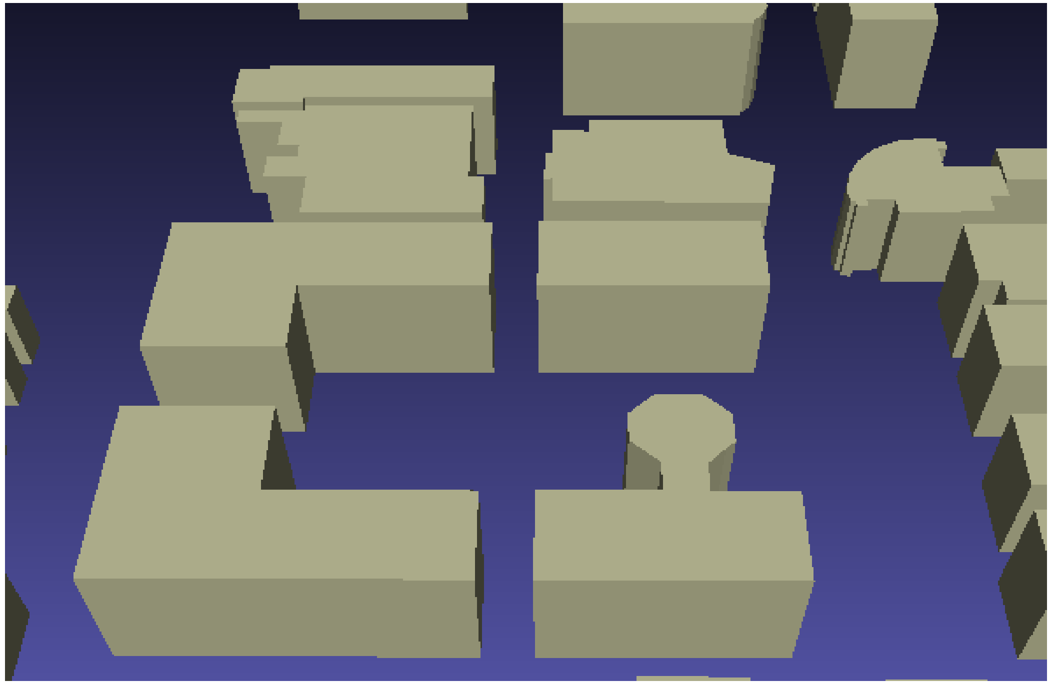


LoD2.1: More detailed multi-pitched roof shape

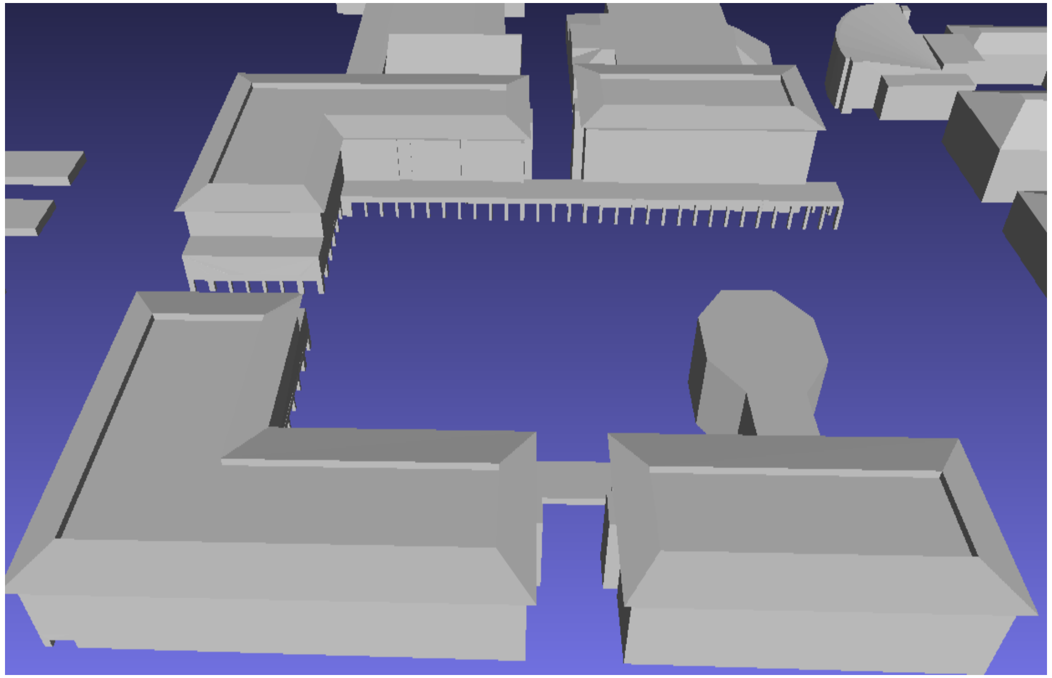


Comparison between models: Level of detail (2/3)

LoD1.2 captures details up to 2.5D

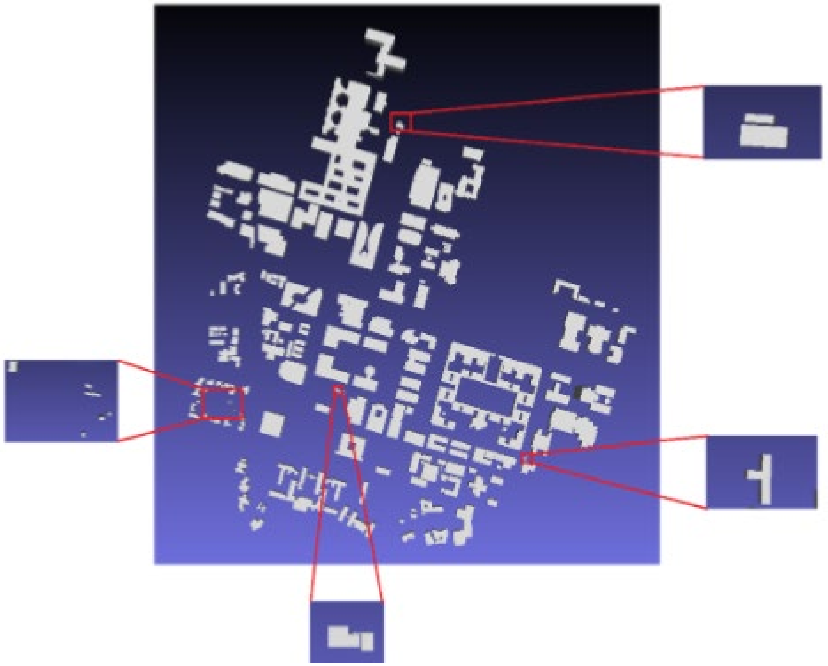


LoD2.1 full 3D geometry (open passages, columns)



Comparison between models: Different time period of input data (3/3)

LoD1.2: Buildings that not exist in LoD2.1



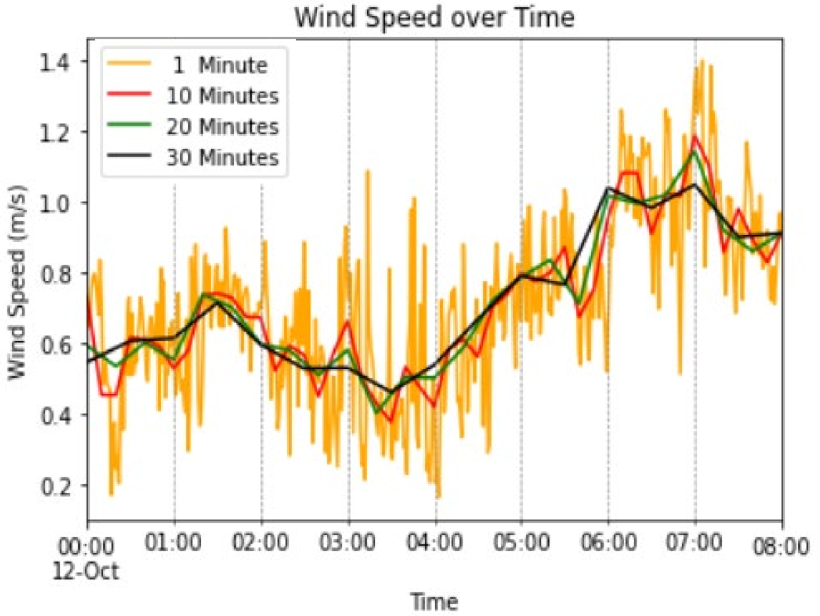
LoD2.1: Two buildings are missing in Lod1.2

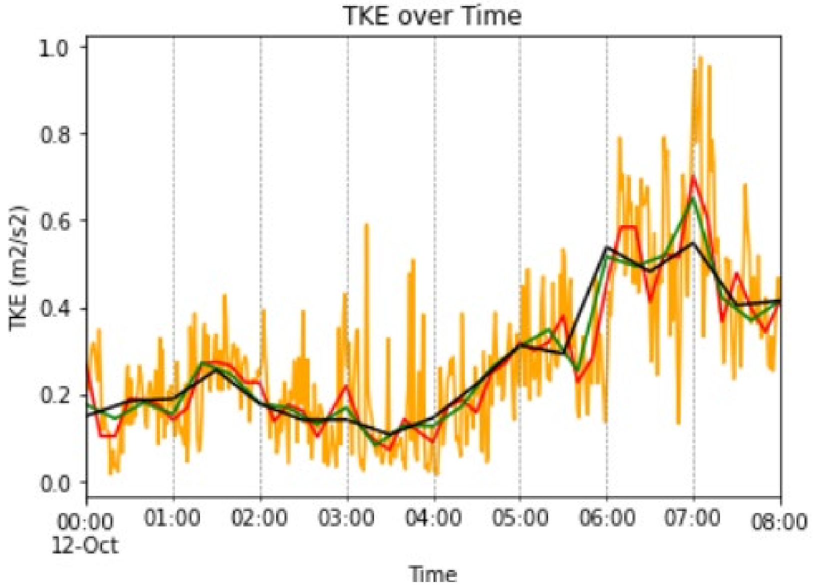
CFD simulation set up: Define initial wind direction and wind speed

- Analysis of wind speed and TKE over a period of three days (10-12 October)
- Identify an hour with stable wind speed and TKE
- Assume steady flow
- Less fluctuations during night

⇩

Most **steady hour** : October 12th between 3-4 a.m.



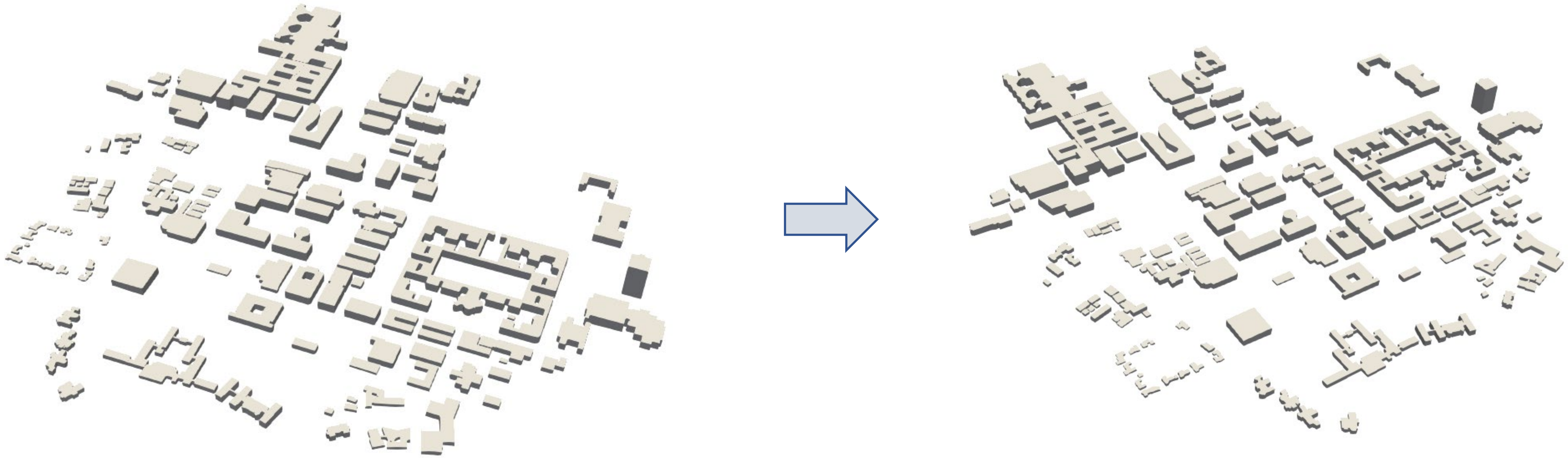


CFD simulation set up: Initial Conditions

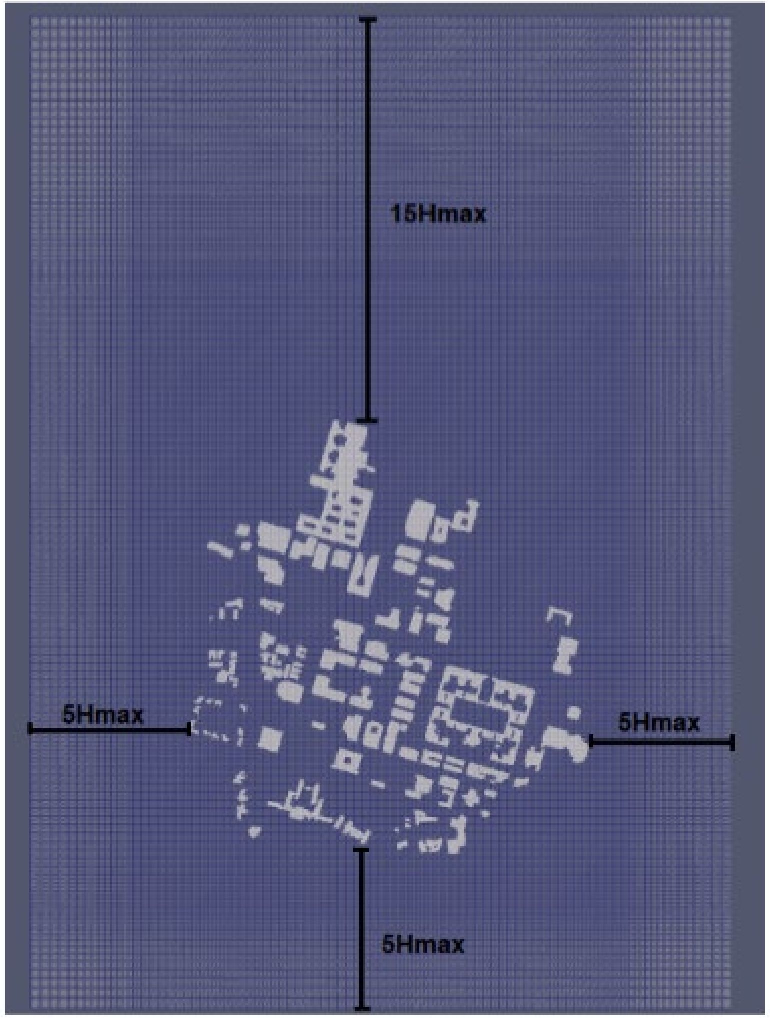
Weather station

Day	Time	Wind Direction (degrees)	Wind Speed (m/s)
2017-10-12	03:00:00	220.3	3.03978542691104
2017-10-12	04:00:00	214.8	3.08448815377738
	Mean	217.55	3.06

U inltet	U*	k [m2s−2]	e [m2s−3]
3.06	0.297679940741515	0.29538	0.00316934



Computational model set up: Computational domain (1/2)



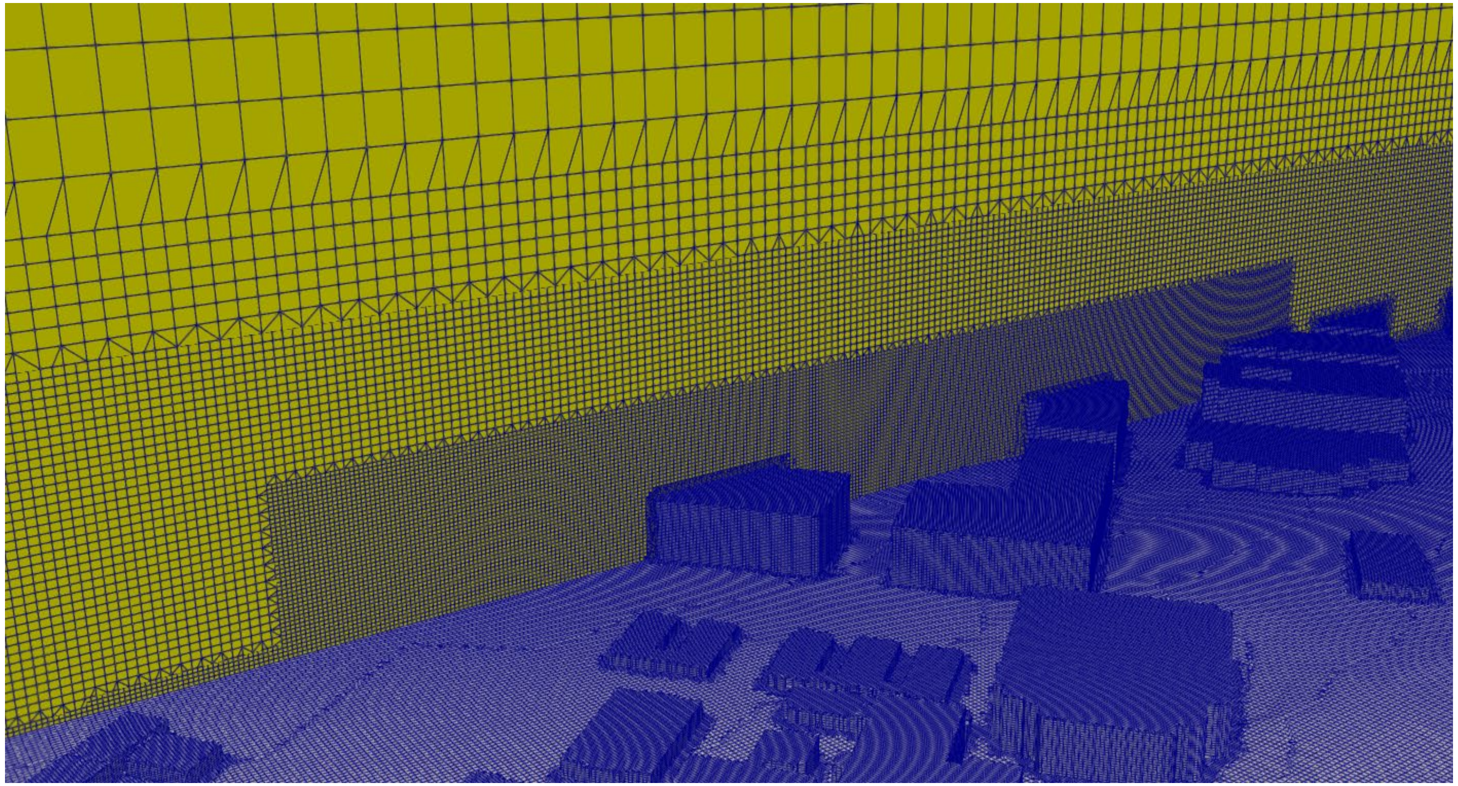
✓ **Best practices guidelines by Blocken [2015]**

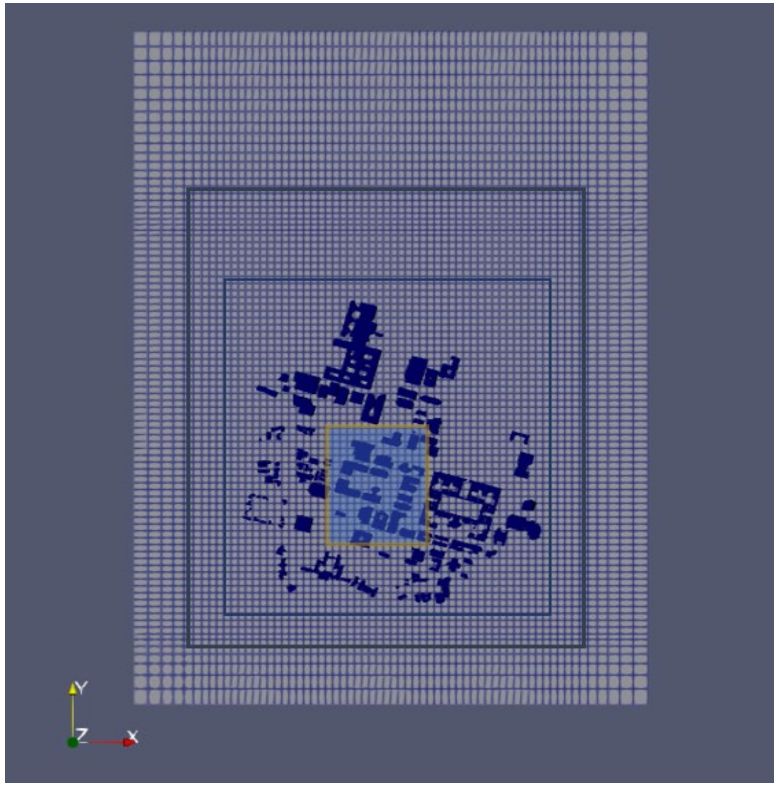
- Set Inlet, lateral and top boundaries
- Set outflow boundary
- Hoover Tower: 75m
- Domain size:

  2 x 3 km2 in the horizontal direction

  530m in the vertical direction

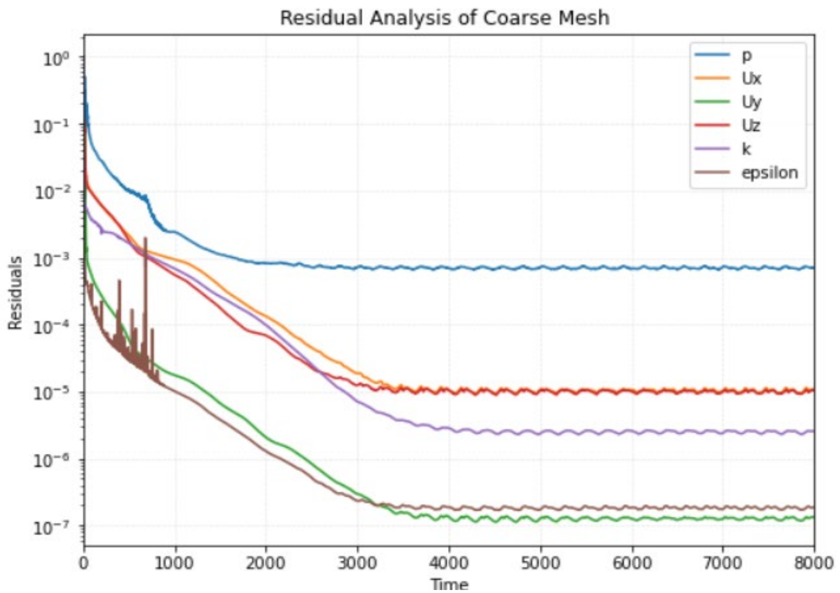
Computational model set up: Computational mesh (2/2)

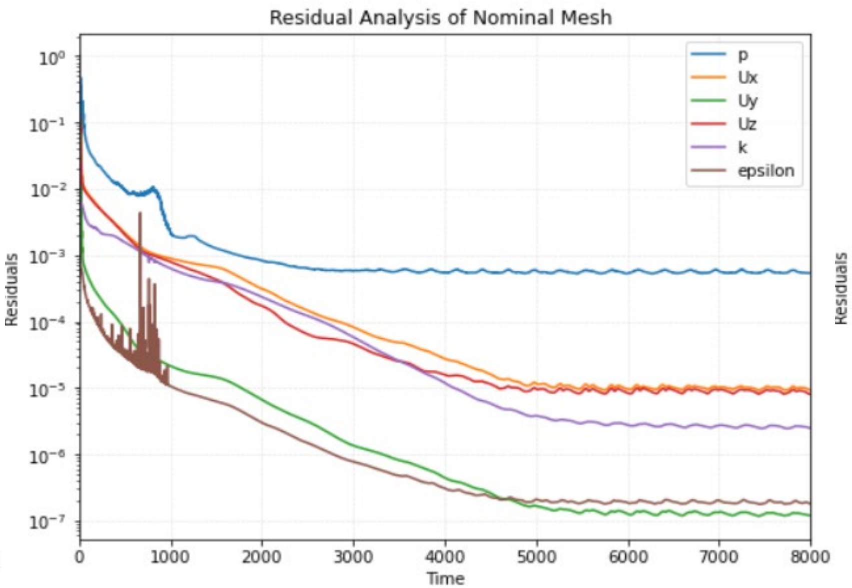


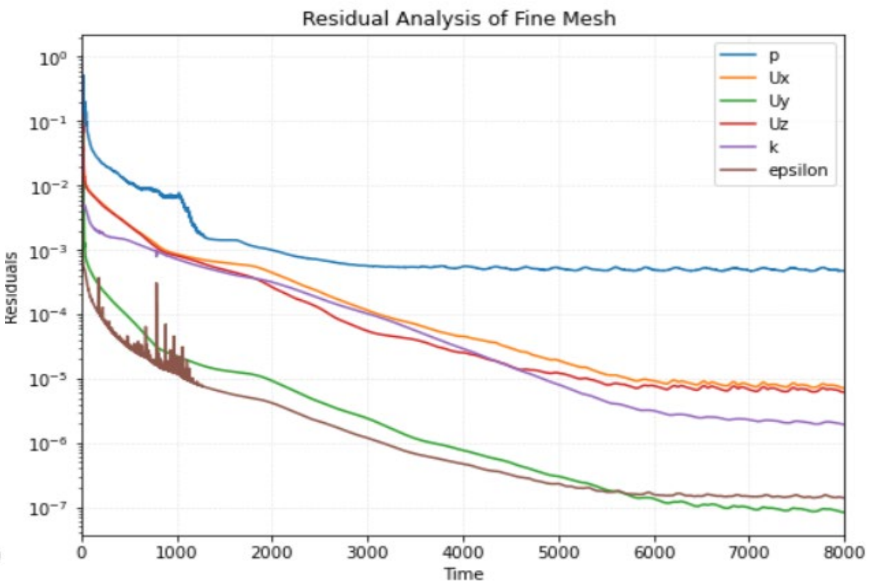


	Background Mesh (cells)	Mesh (million cells)	Resolution x and y direction (m)	Resolution z direcction (m)	Time
Coarse	512.000	12	14	14	15min
Nominal	772.000	23	12	9	40min
Fine	1.400.000	34	10	9	1 hour

Mesh convergence (1/4)

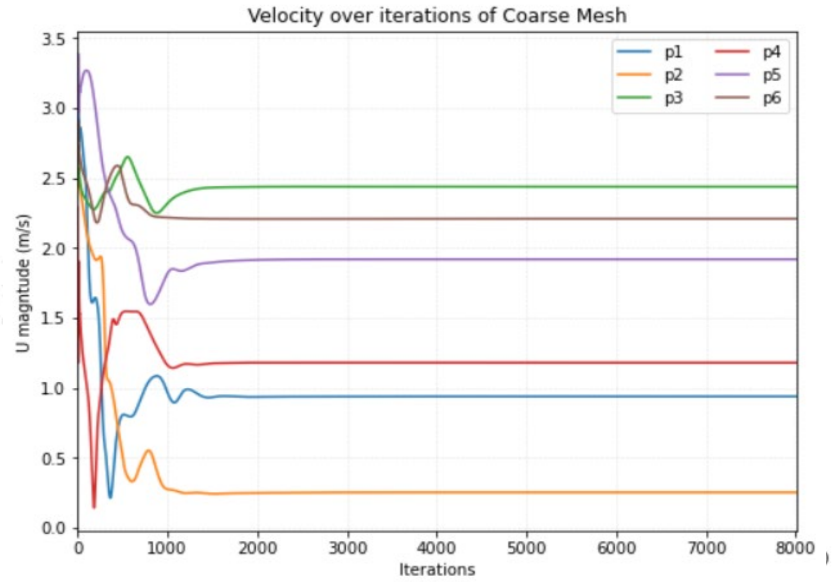


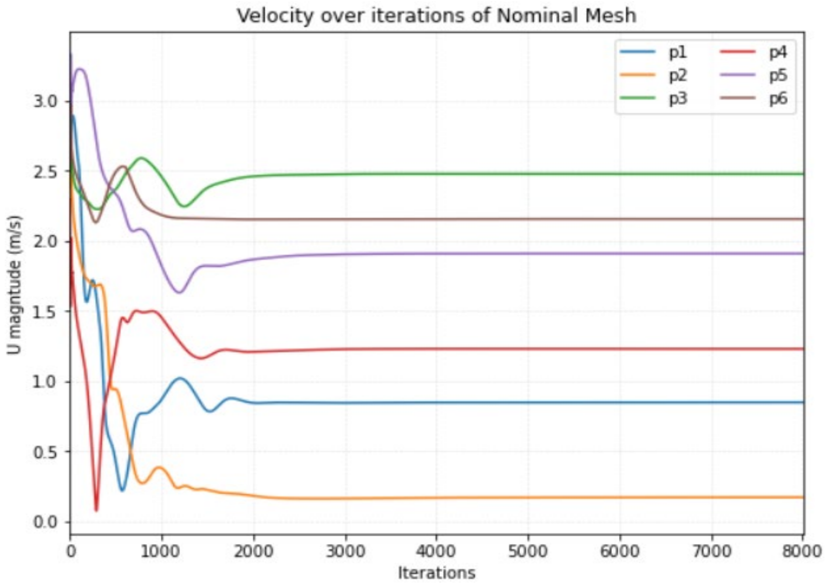


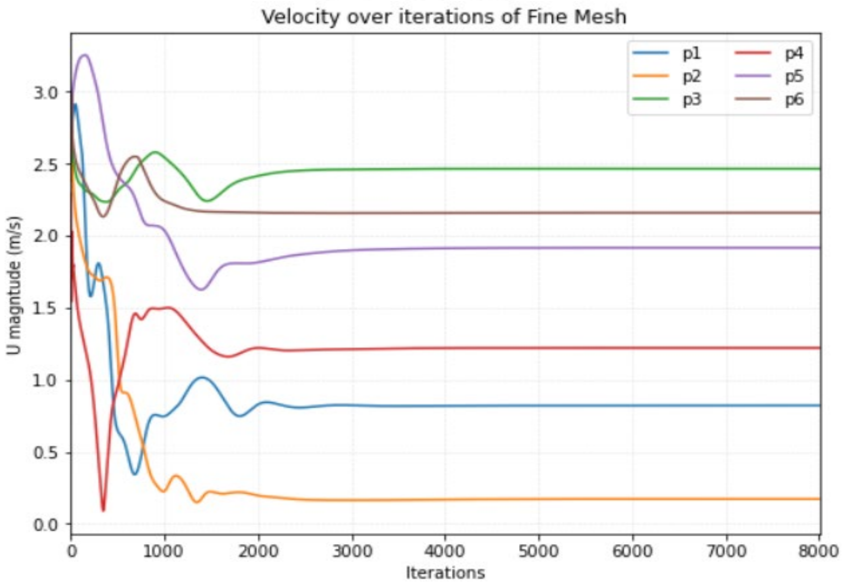


Excecution time			
Itterations	**coarse**	**nominal**	**fine**
5002	5h	8h	13h
8002	10h	14h	23h

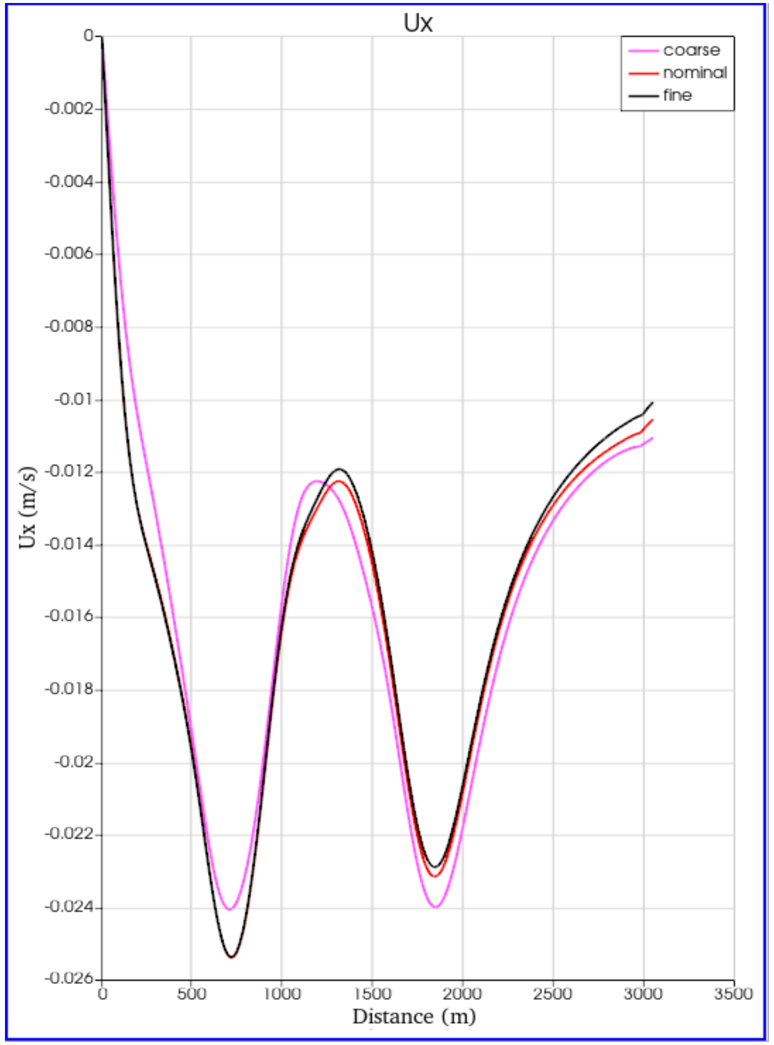
Mesh convergence (2/4)

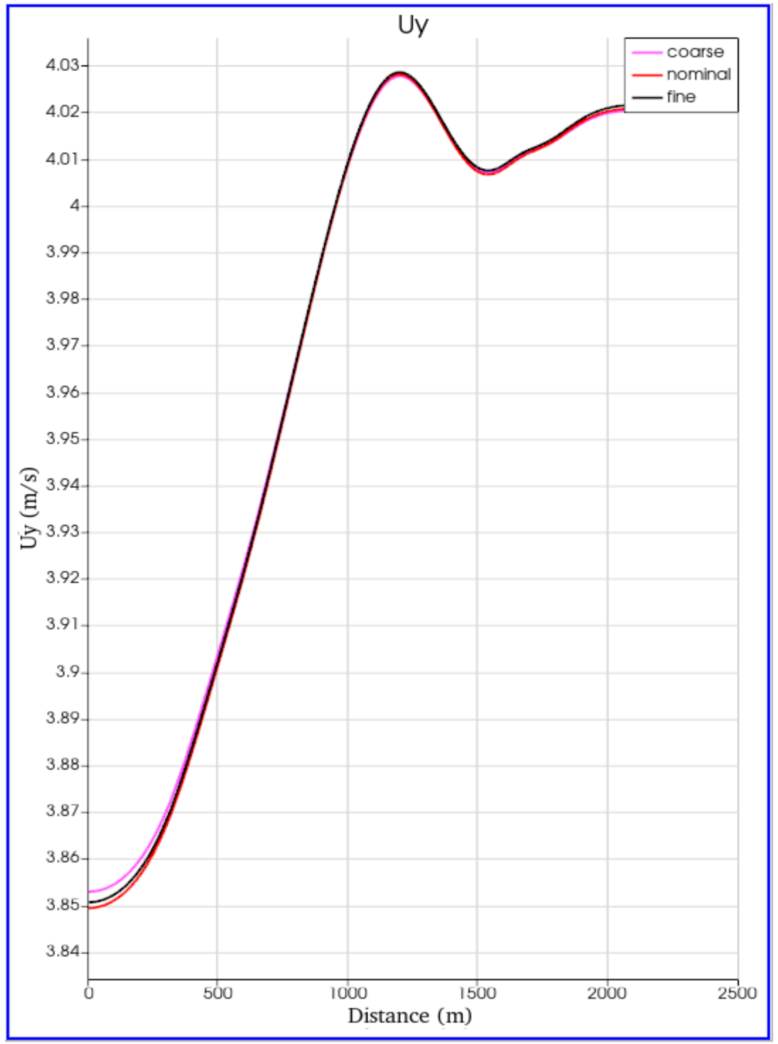


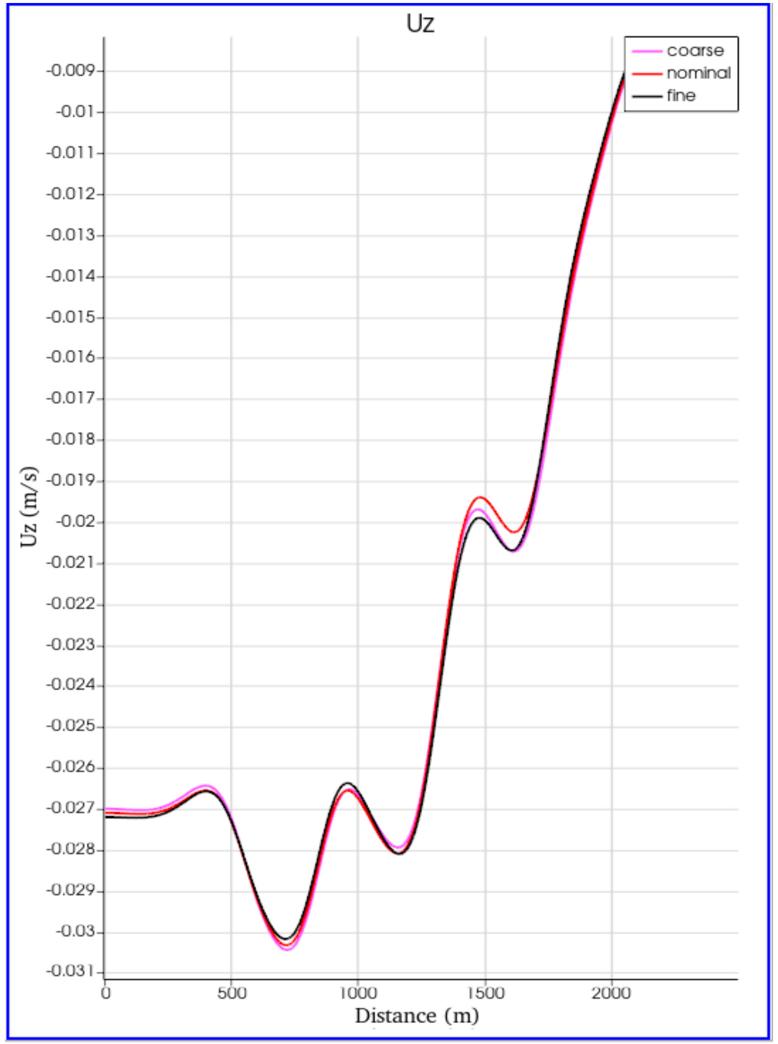




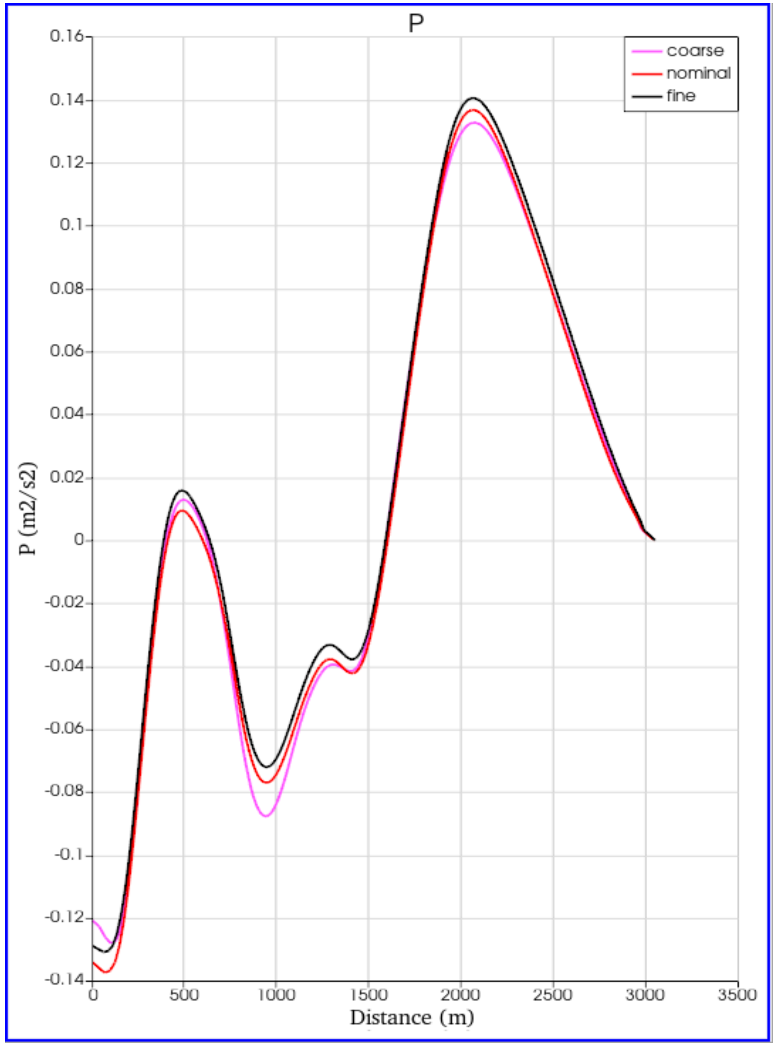
Mesh convergence (3/4)

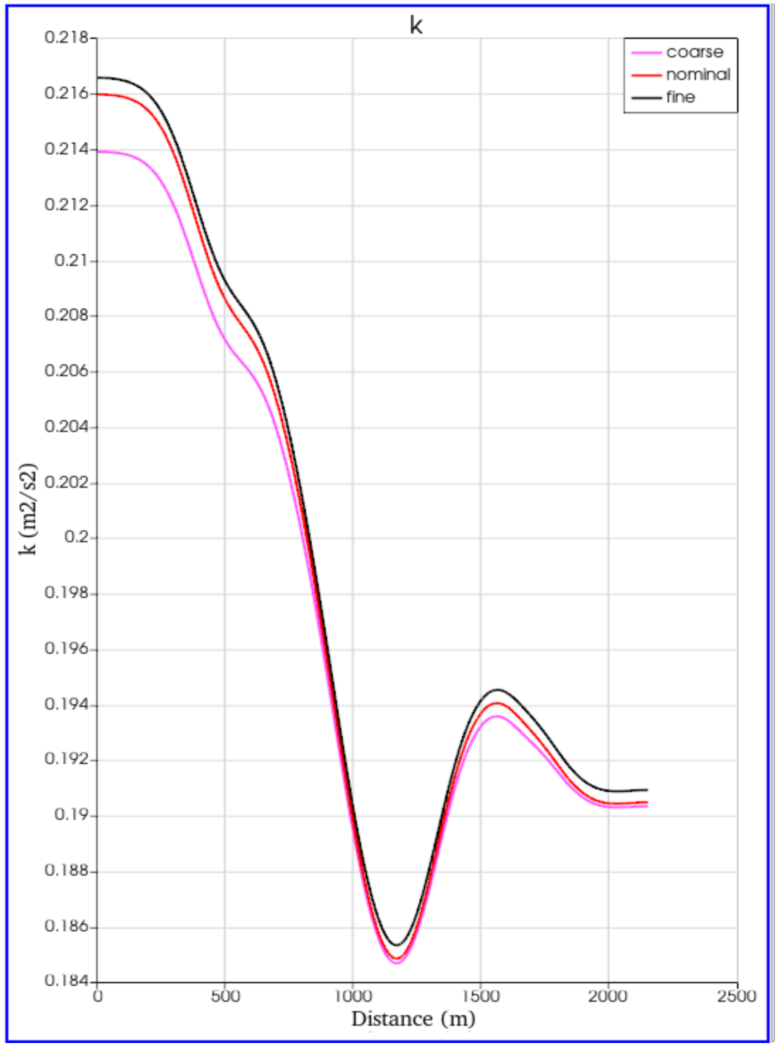


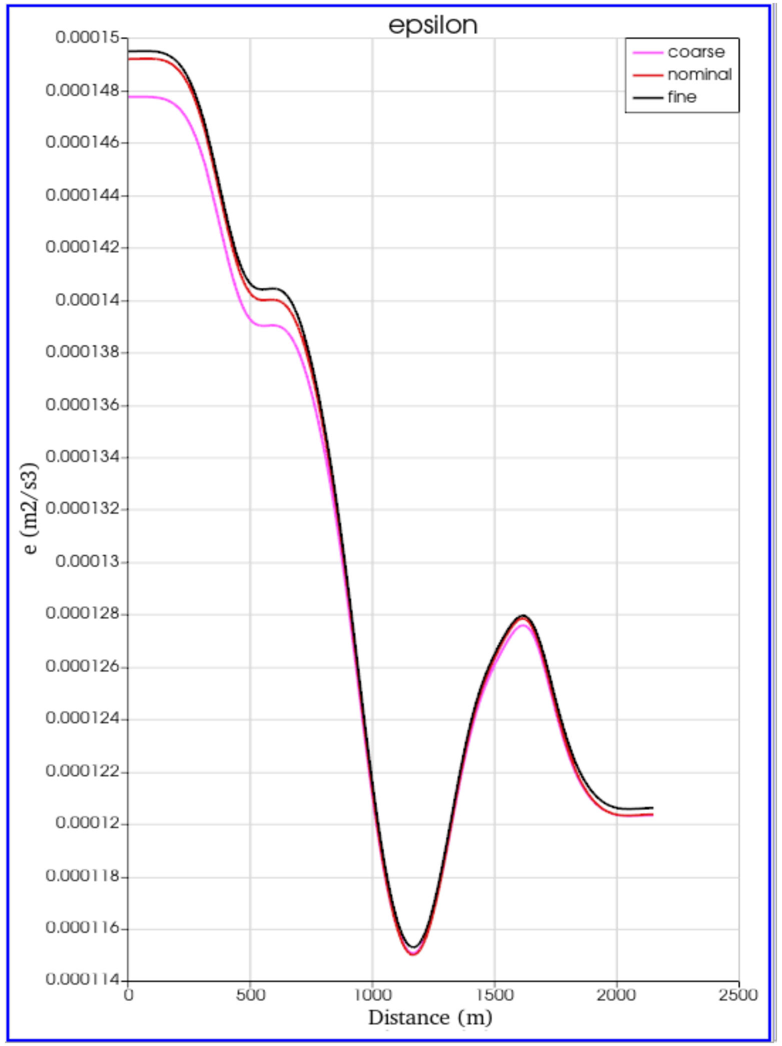




Mesh convergence (4/4)

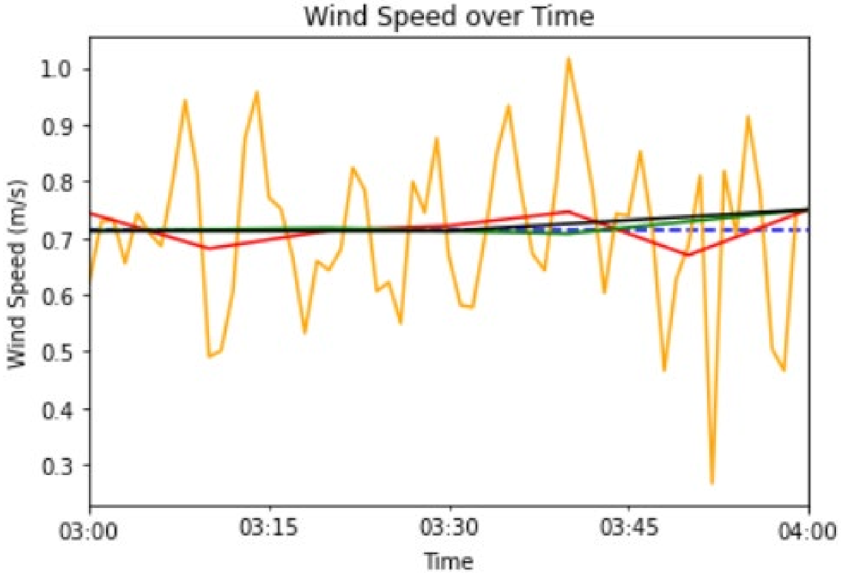




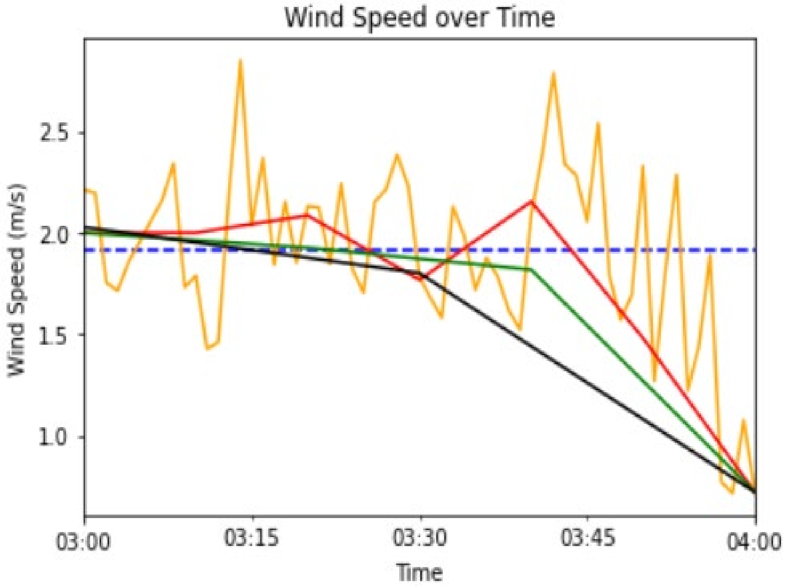


Measurements

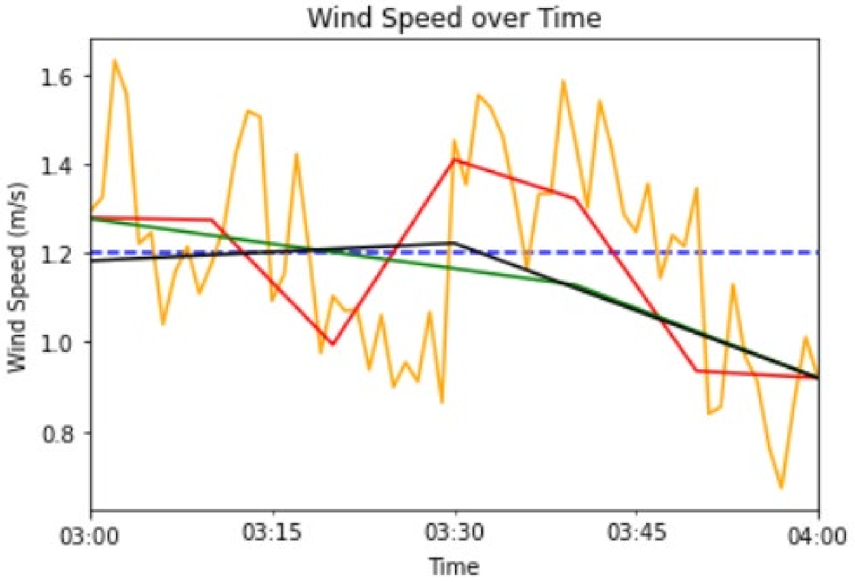
Station 2



Station 3



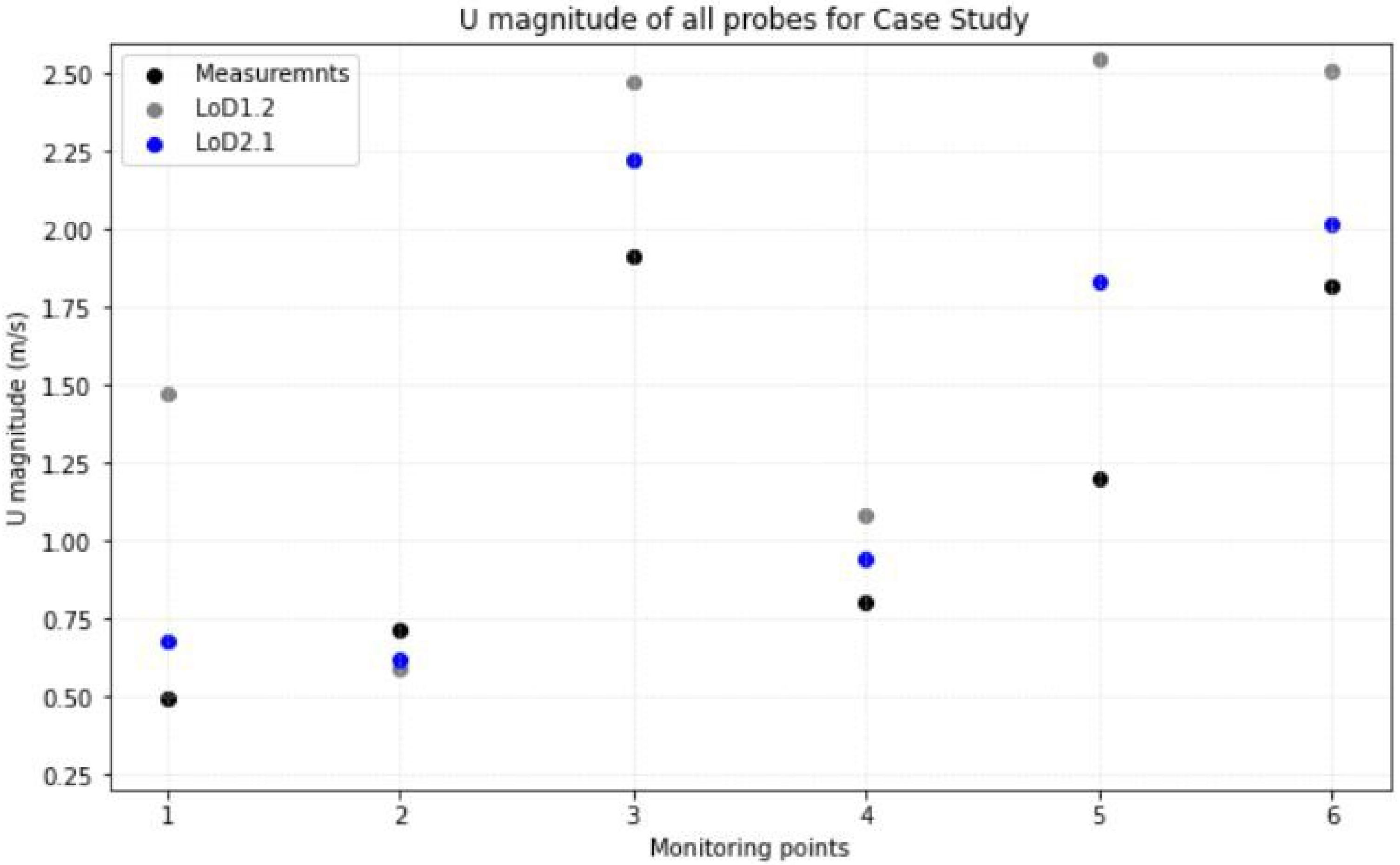
Station 5

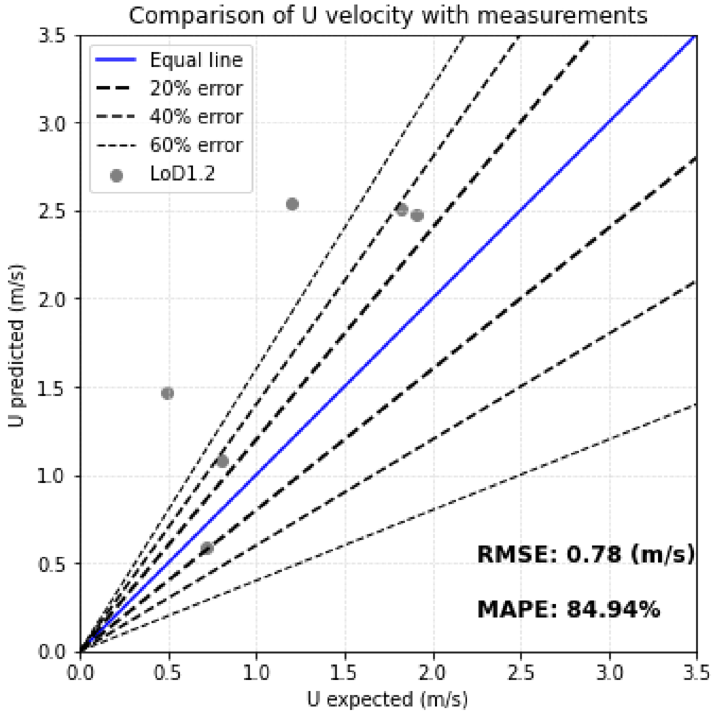


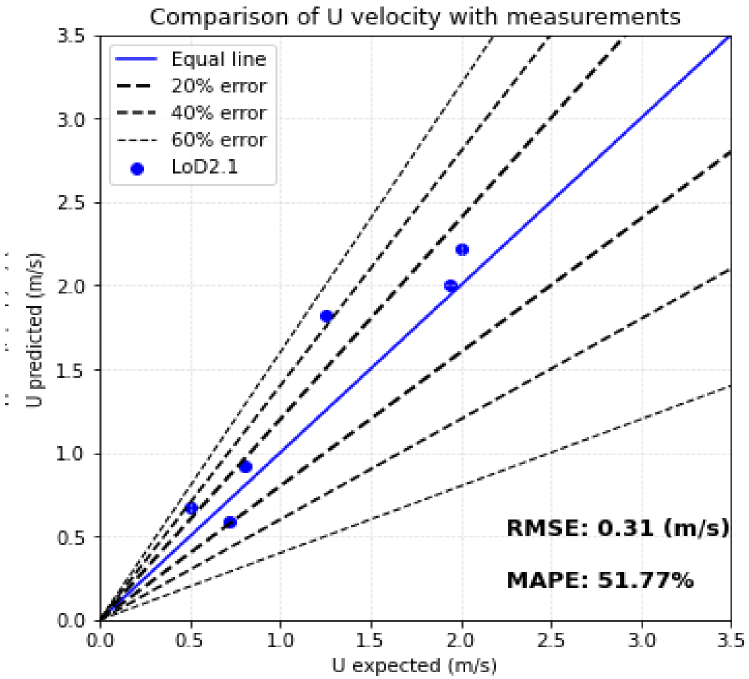
	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6
Umean 1hour [m/s]	0.49	0.71	1.91	0.80	1.20	1.82
Umean 45min [m/s]	0.50	0.72	2.01	0.80	1.25	1.94

Comparison between models and measurements:

1-Hour Average Measurements

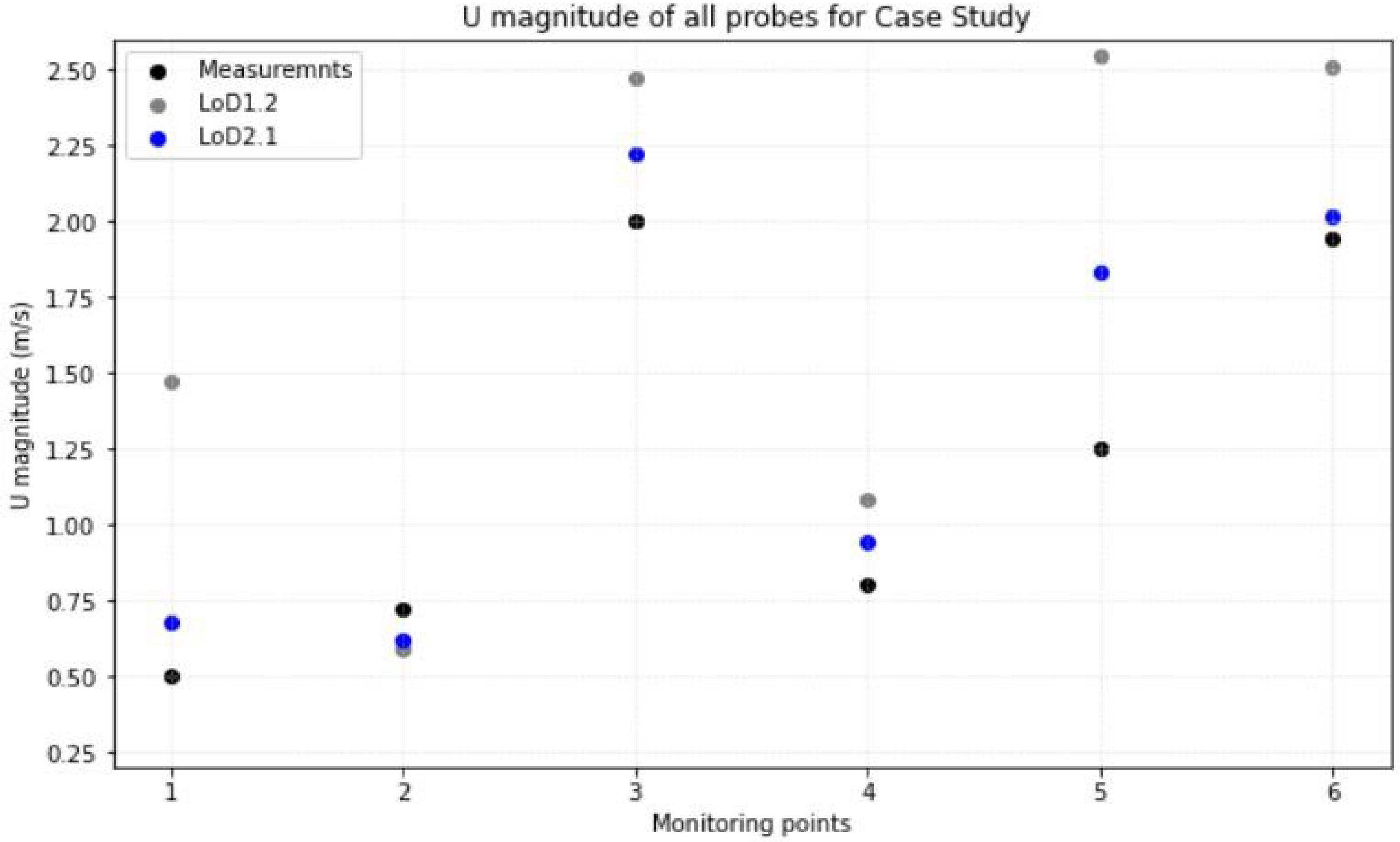


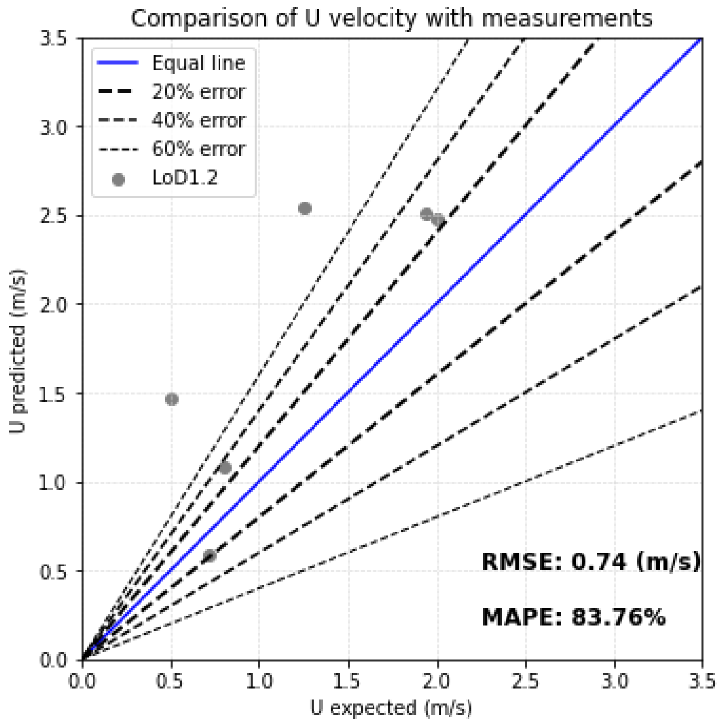


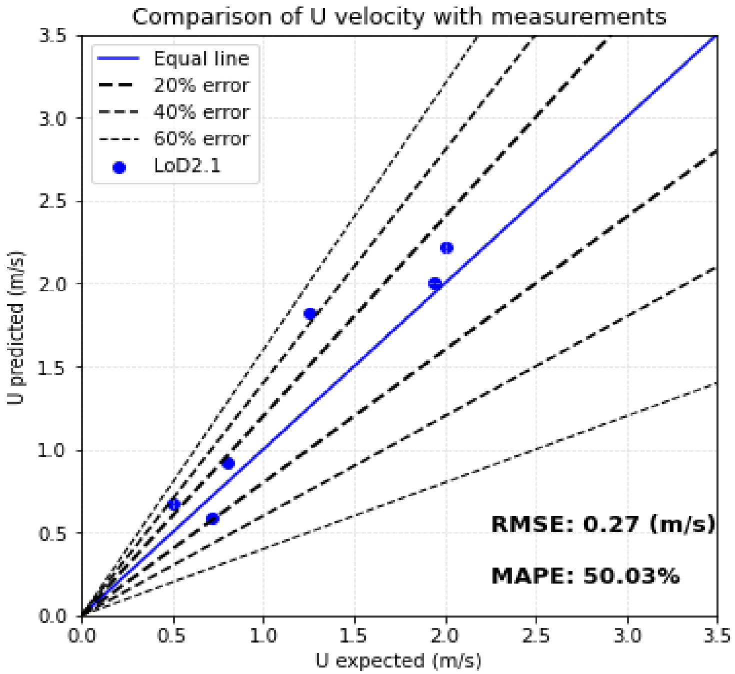


Comparison between models and measurements:

45min Average Measurements

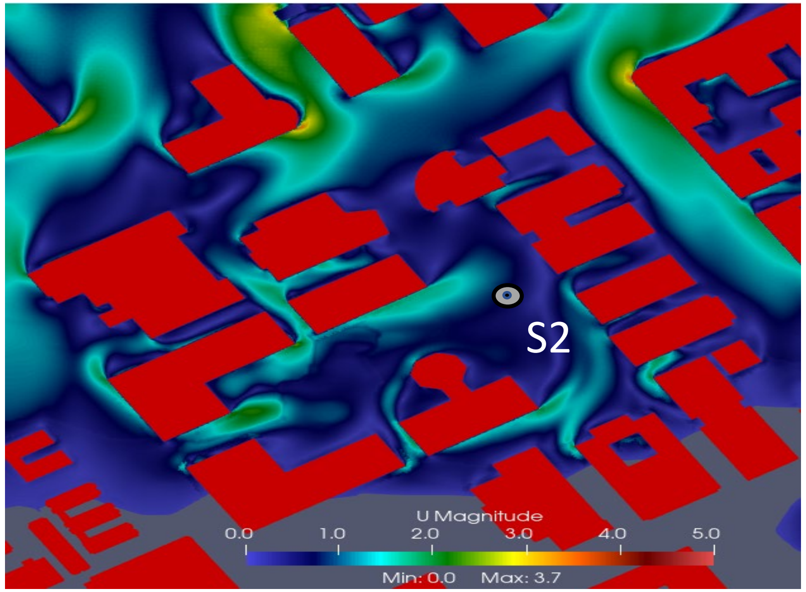




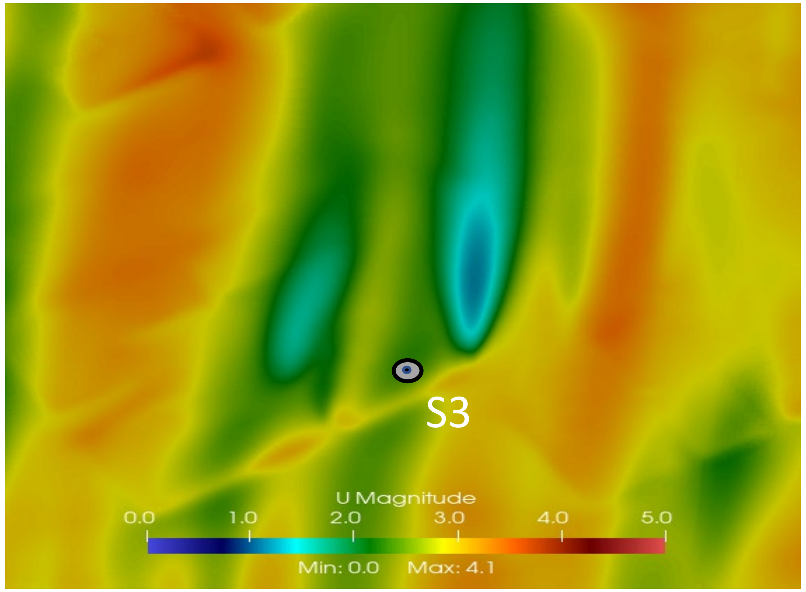


Contour plots of wind velocity

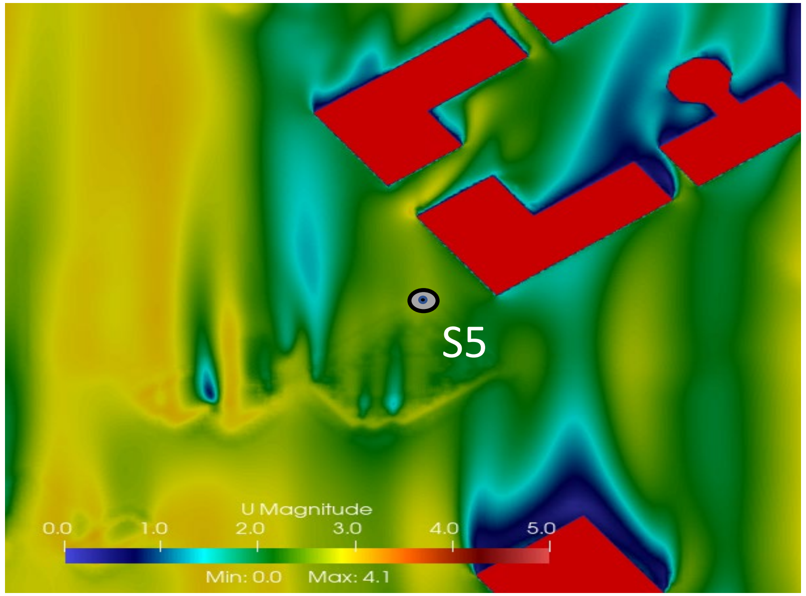
Station 2: LoD1.2



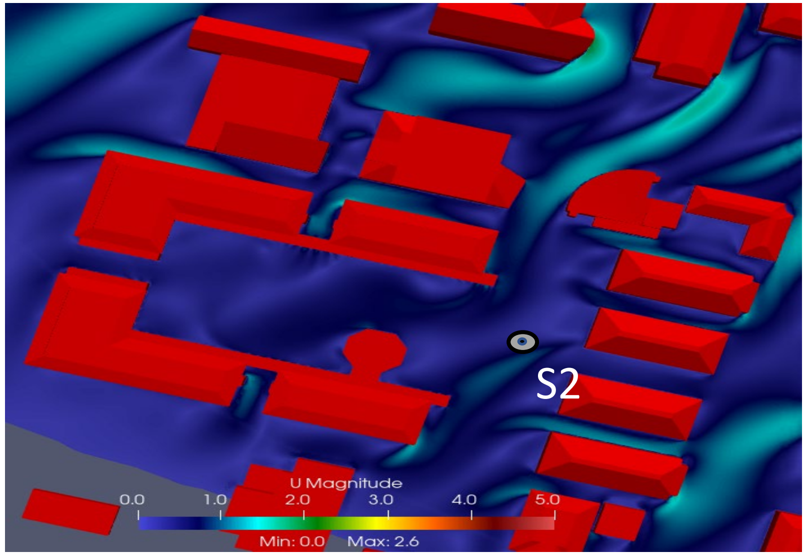
Station 3 : LoD1.2



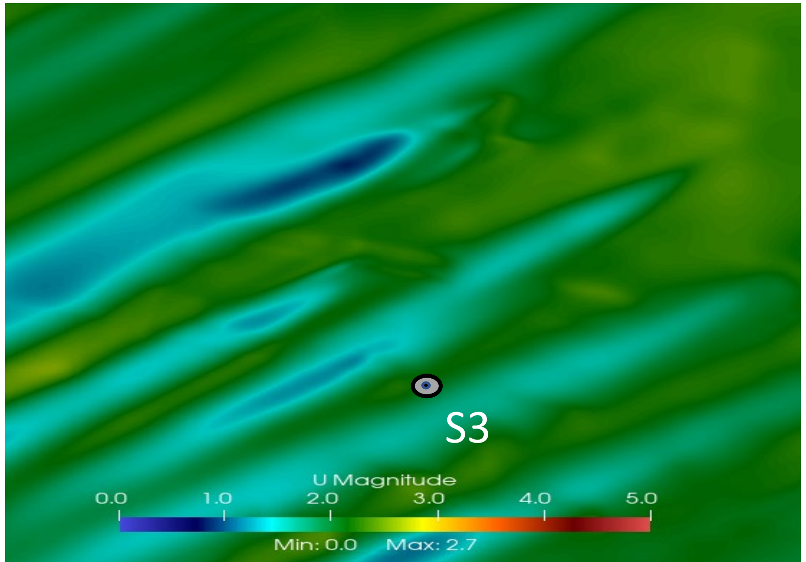
Station 5: : LoD1.2



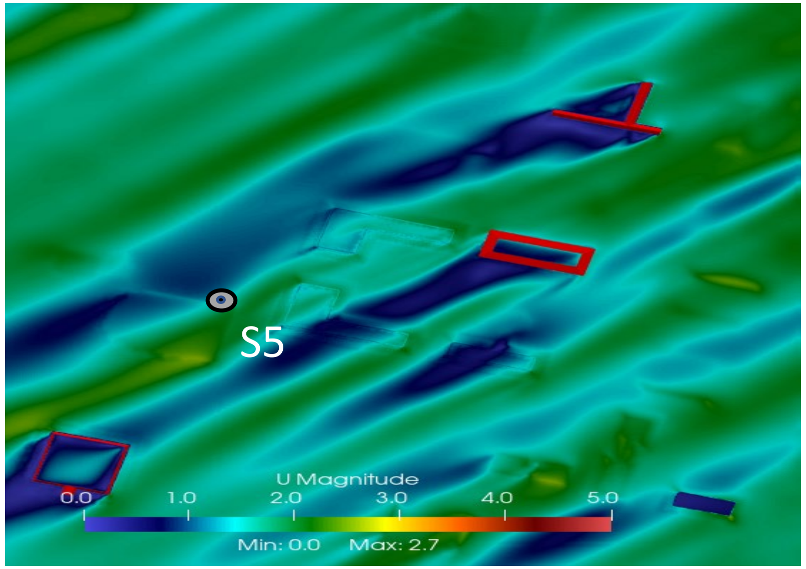
Station 2: LoD2.1



Station 3 : LoD2.1

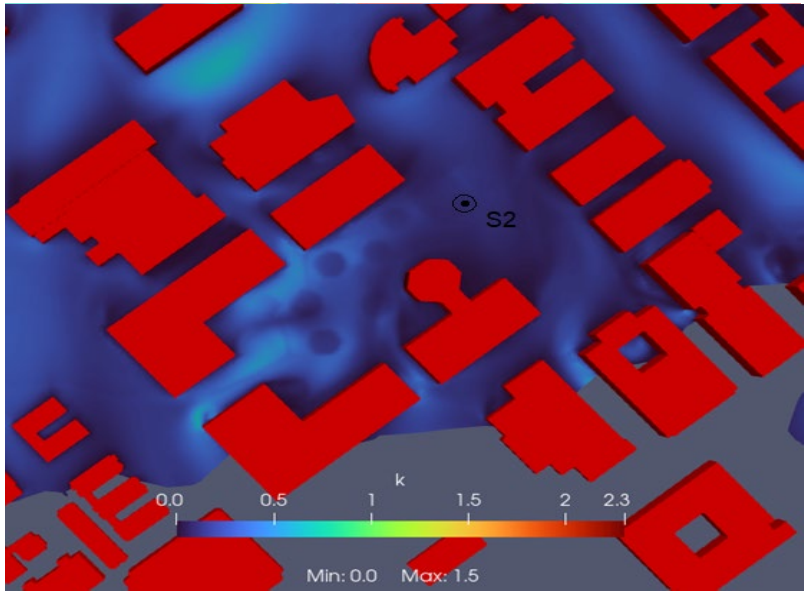


Station 5 : LoD2.1



Contour plots of TKE

Station 2: LoD1.2



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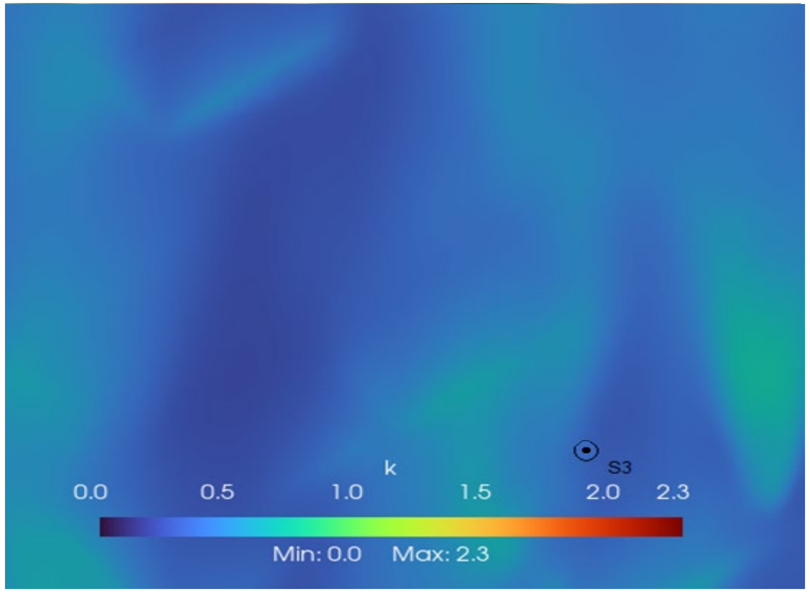
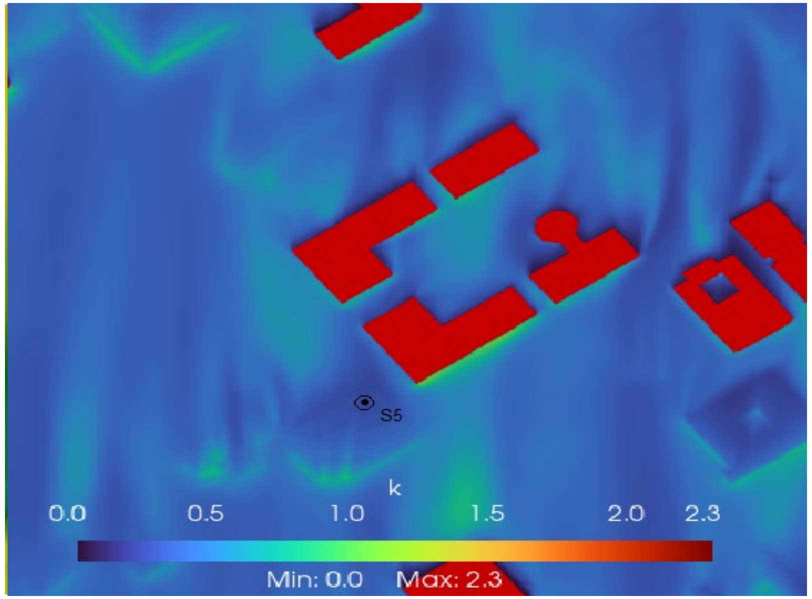
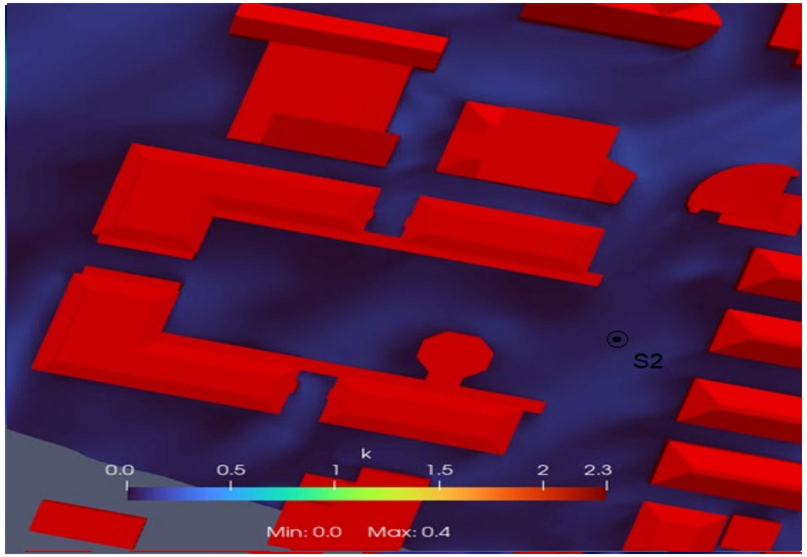


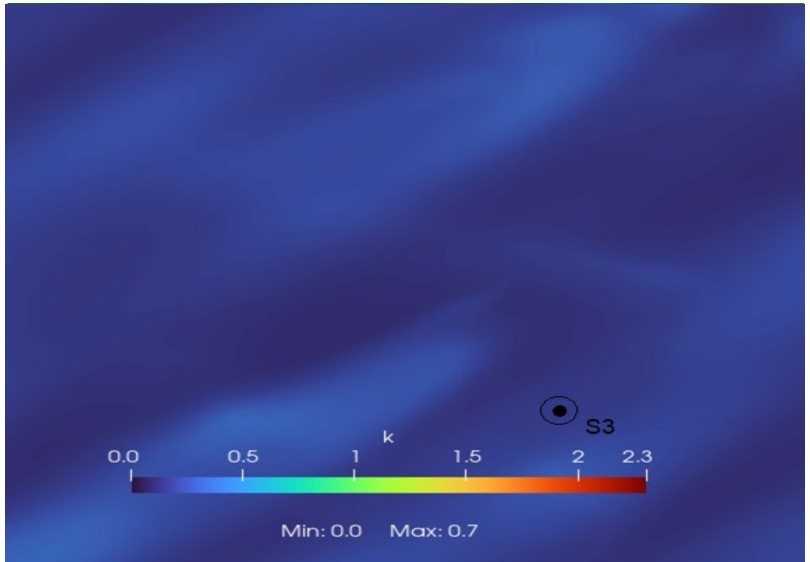
Station 5: : LoD1.2



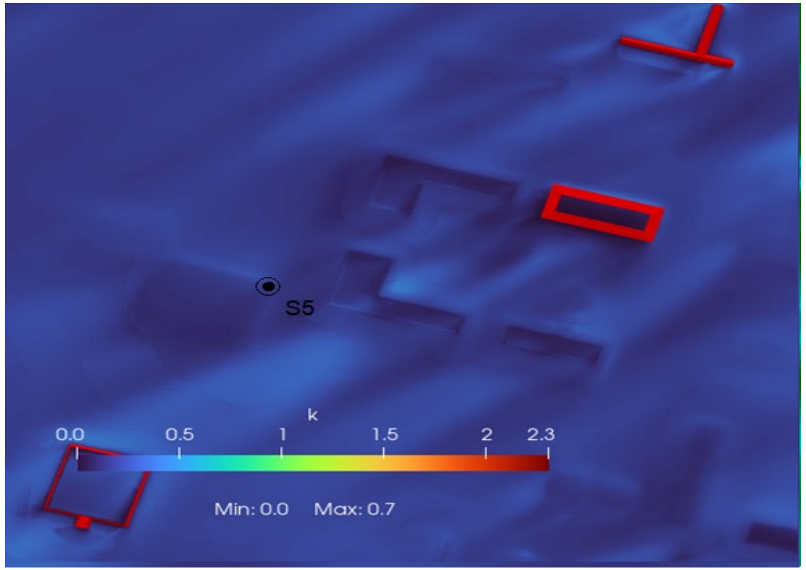
Station 2: LoD2.1



Station 3 : LoD2.1



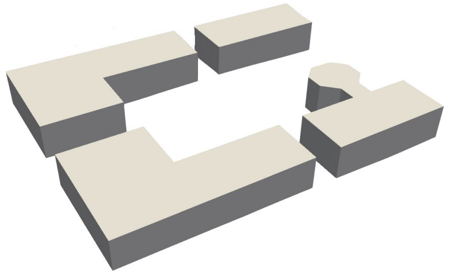
Station 5 : LoD2.1



Research Questions

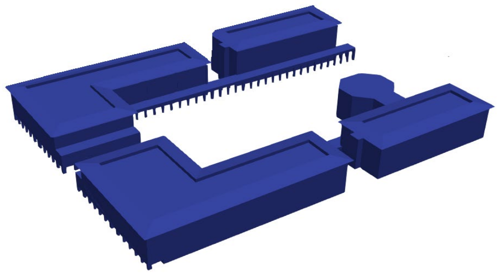
Main research question:

- What is the **impact** of **different geometry LoDs** for the wind around an urban environment?



Sub-questions:

- What are the **needed steps** to automatically reconstruct a 3D city model?
- How large can be the **differences** introduced by geometry discrepancies?
- Is it possible a **higher LoD** geometry **better predict** real-world measurements?



Addressing research questions

Sub-questions:

- **What are the needed steps to automatically reconstruct a 3D city model**?
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1.Geometry preparation:

- Data collection
  - -Footprints
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  - -Point cloud
- Data pre-processing
  - -Cleaning of data
  - -Crop to ROI
  - -Extract Buildings & Terrain
- City4CFD
  - -automated reconstruction

2.Impact of LoDs

- LoD2.1 better performance
  - -20% error
- LoD1.2 less accurate
  - -40% error
  - - Over 60% error
- 30% difference

3.More accurate predictions

- Higher LoD geometry
  - -better predictions
- Less detailed LoD1.2 model
  - - higher error
- Increased simulation time with Lod2.1 approximately 2 hours
- Geometry preparation time
  - - one day LoD1.2
  - - appr. 1-2 months LoD2.1

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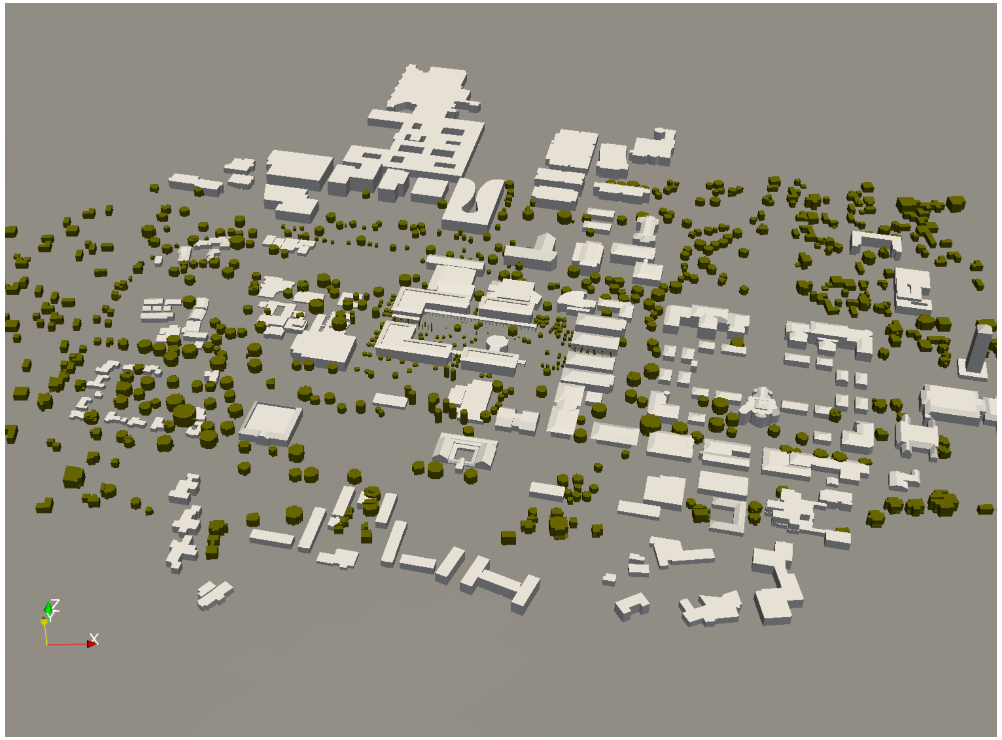
What is the impact of different geometry LoDs for the wind around an urban environment?

LoD2.1 Model Vs LoD1.2 Model

- ✓ Enhance accuracy with the use of more complex geometry
- ✓ LoD2.1 model, which includes more complex and detailed features showed better performance in simulating wind velocities
- ✓ Validate the results in other time periods

Future work



Create a more **realistic** model

THANK YOU FOR YOUR ATTENTION