HELYX®

Open-source CFD for Enterprise

RAPID PEDESTRIAN WIND COMFORT ASSESSMENT

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About ENGYS

- Global providers of CFD products and services
- Founded in the UK (2009)
- Main focus on leveraging open-source software
  - FOAM/OpenFOAM developers since 1999
  - ~20 software developers
- Worldwide offices
  - UK, Germany, Italy, Greece, USA, Australia, RSA, Brazil
- Well established resellers network
  - Japan, South Korea, China, USA, Germany, France, Spain

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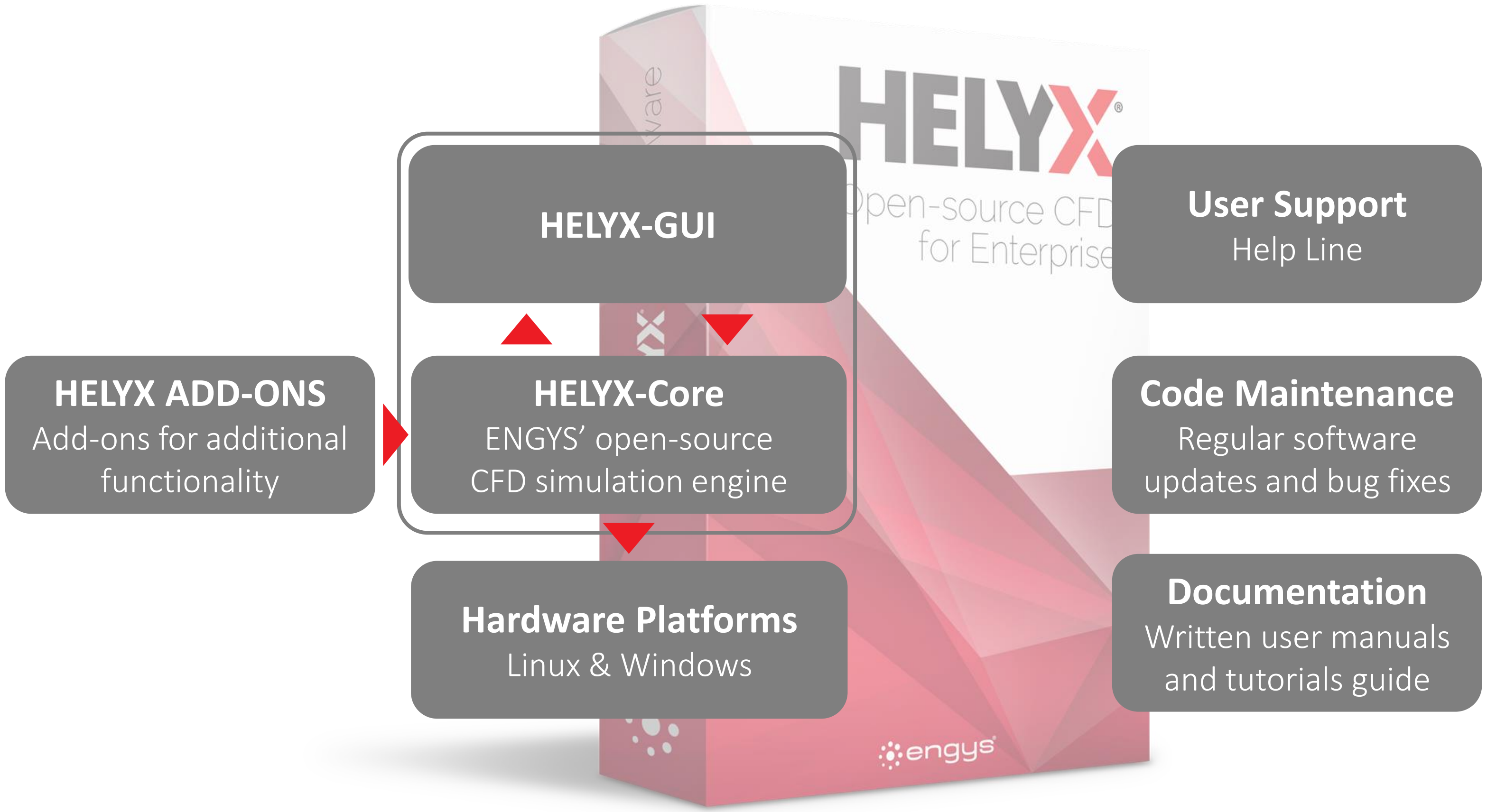
What is HELYX?

- CFD software suite
- General purpose
- Enterprise product
- Highly scalable
- Cost effective
- Cloud ready
- Multi-platform
- Extendable
- In production since 2010



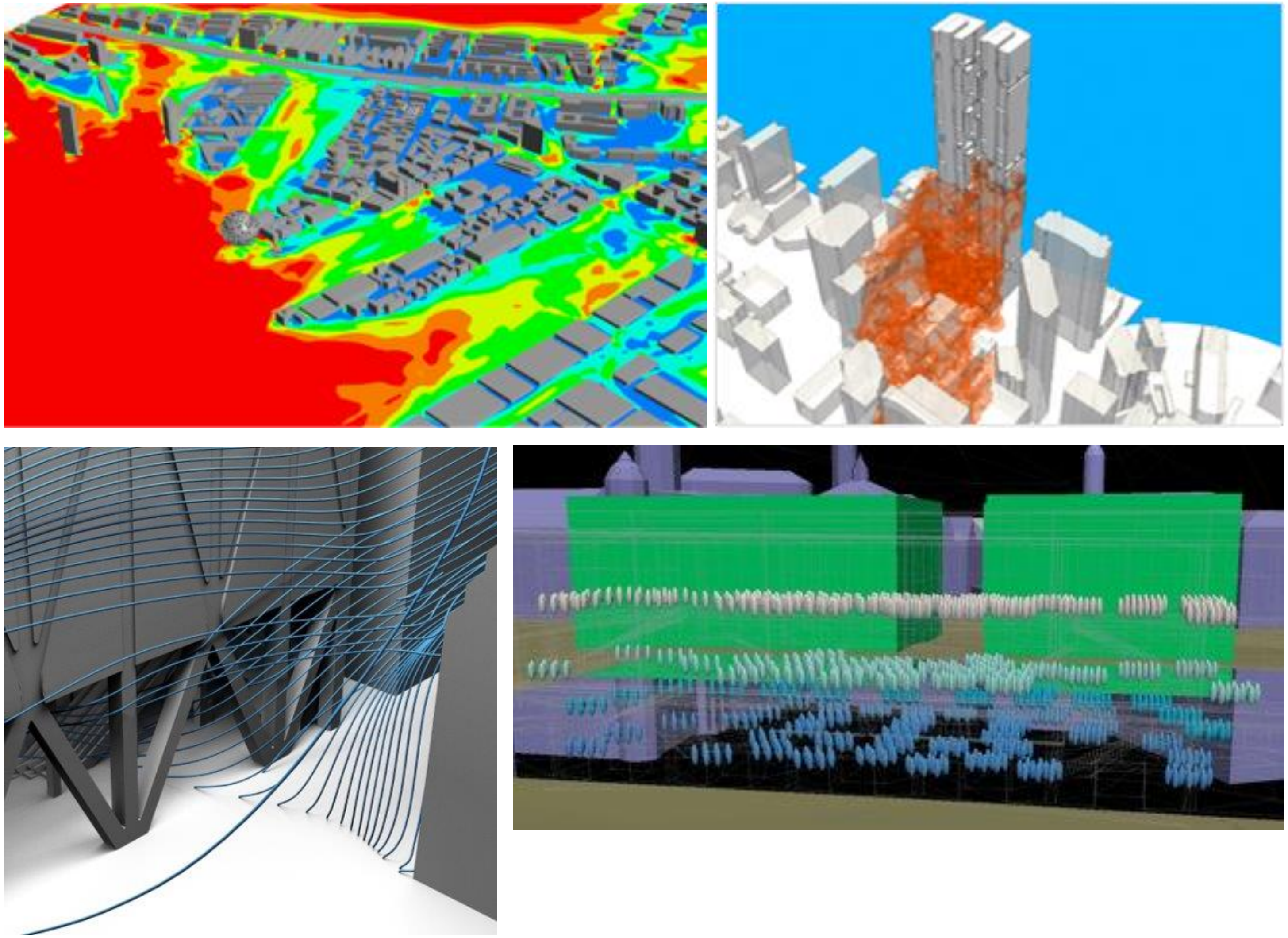
"HELYX combines the best of two worlds: the proven capabilities, support and reliability of commercial tools with the inherent advantages of cost-effective, scalable open-source software."

OUTLINE

1. Motivations
2. Block-Coupled Solver
3. Multi-Instance Solver
4. Wind Comfort Assessment
5. Conclusions

Motivations | CFD in AEC (Architecture, Engineering, Construction)

- Pedestrian level wind
- Wind driven rain
- Wind loading
- Outdoor thermal comfort
- Pollutant dispersion
- Indoor thermal comfort
- Fire analysis
- HVAC design
- …



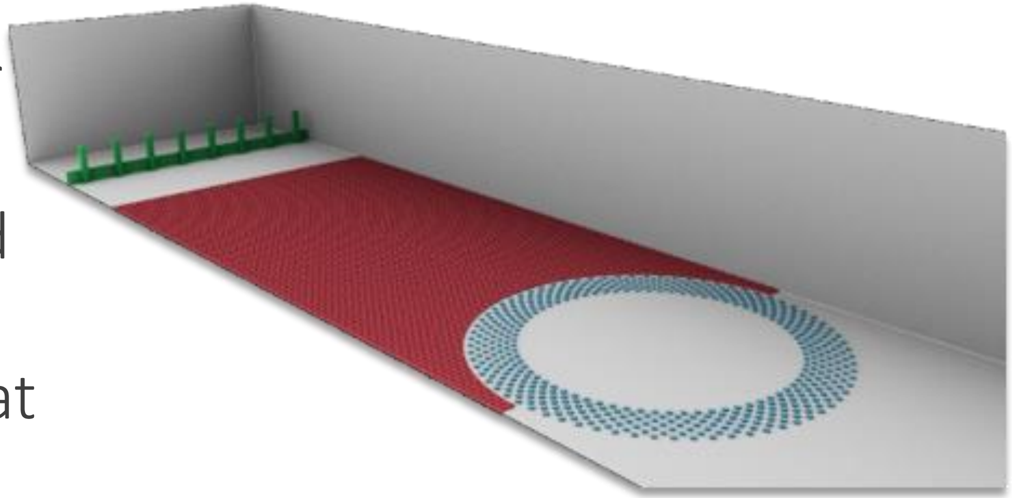
Motivations | Pedestrian Comfort

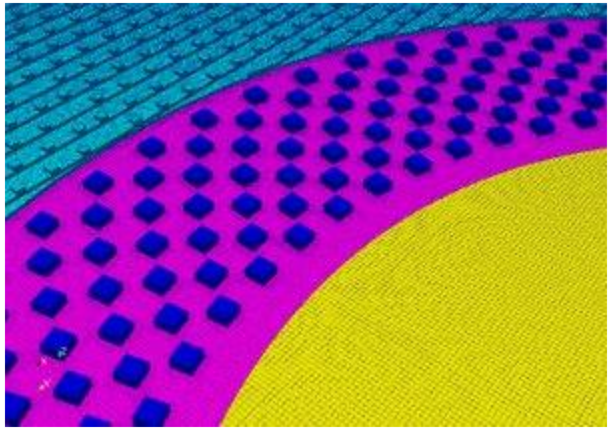
- High rise buildings increase winds at pedestrian level
- Impact on human activities to be assessed to grant planning permission
- Flow velocities (from CFD/WT) combined with climate data to evaluate pedestrian comfort at chest height
- In 2019, City of London and RWDI published standard methodology based on 36 wind directions analysis and modified Lawson Criteria*

* **”Wind Microclimate Guidelines for Developments in City of London”**, City of London/RWDI 2019

Motivations | Pedestrian Comfort

- Analysis of different scenarios (with and without target, mitigation barriers) results in large number of runs/experiments
- Wind consultants develop their own workflow and methodology (bash/python scripting)
- Some cloud solutions offer "*black-box*" approach at expense of wind engineers expertise
- ENGYS mission is to provide streamlined, cost effective, open-source solutions to complex engineering problems
- Our key ingredients:
  - Accelerate solution → Block Coupled Solver
  - Simplify the process → Multi-instance





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Block-Coupled Solver

- Features
  - New pressure-velocity block symbolic and solution infrastructure
  - Algebraic Multi-Grid
  - Steady/transient, dynamic mesh
- Leverage existing code structures
- fvOptions compatible (MRF, ERF, porosity etc)
  - Boundary conditions
  - Interfaces (AMI etc)
- Backward compatible with segregated system and I/O
  - Enables rapid workflow transition
- Speed-up
  - from 2 to 5 times faster than segregated

Case Study

Description

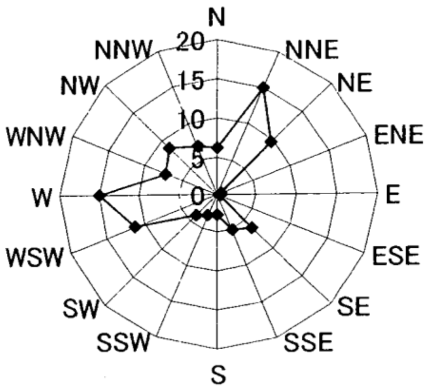
- Flow around buildings in Niigata City*
- Urban area with dense concentration of low-rise buildings
- 60 m high rise building and two mid-rise 18 m buildings to be constructed
- Impact of new buildings on the surrounding wind environment
- Wind data from local measurement station at h_{ref} = 15.9 m

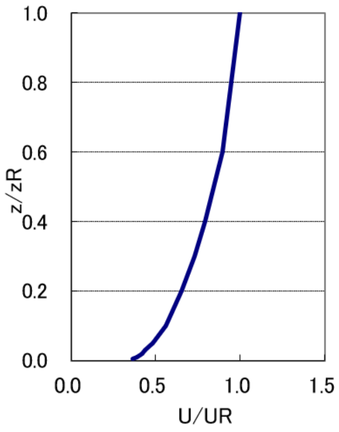
* **"AIJ Benchmarks for Validation of CFD Simulations Applied to Pedestrian Wind Environment around Buildings"**, Architectural Institute of Japan 2016

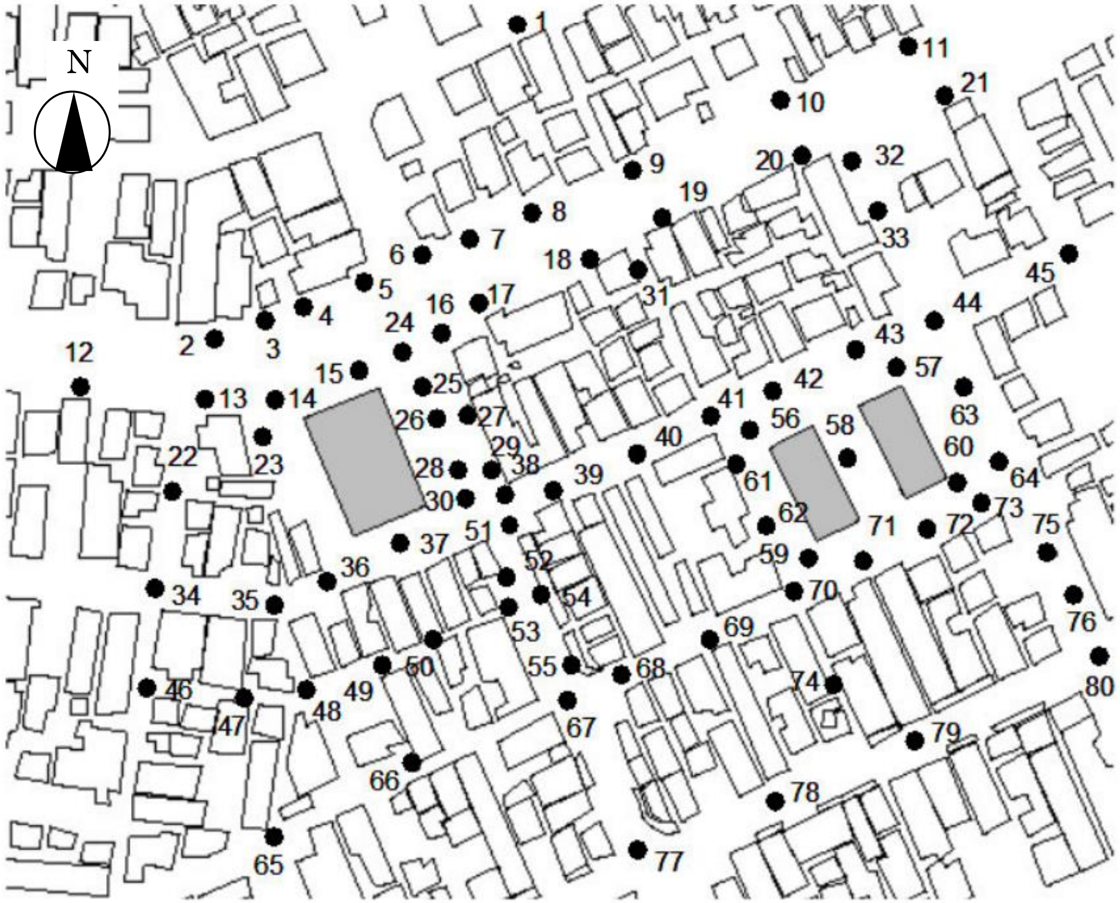
Case Study

Description

- Wind rose → 16 directions
- Prevailing winds → NNE and W
- Measurements carried out in wind tunnel (scale model 1:250) → 80 probes @ 2 m height



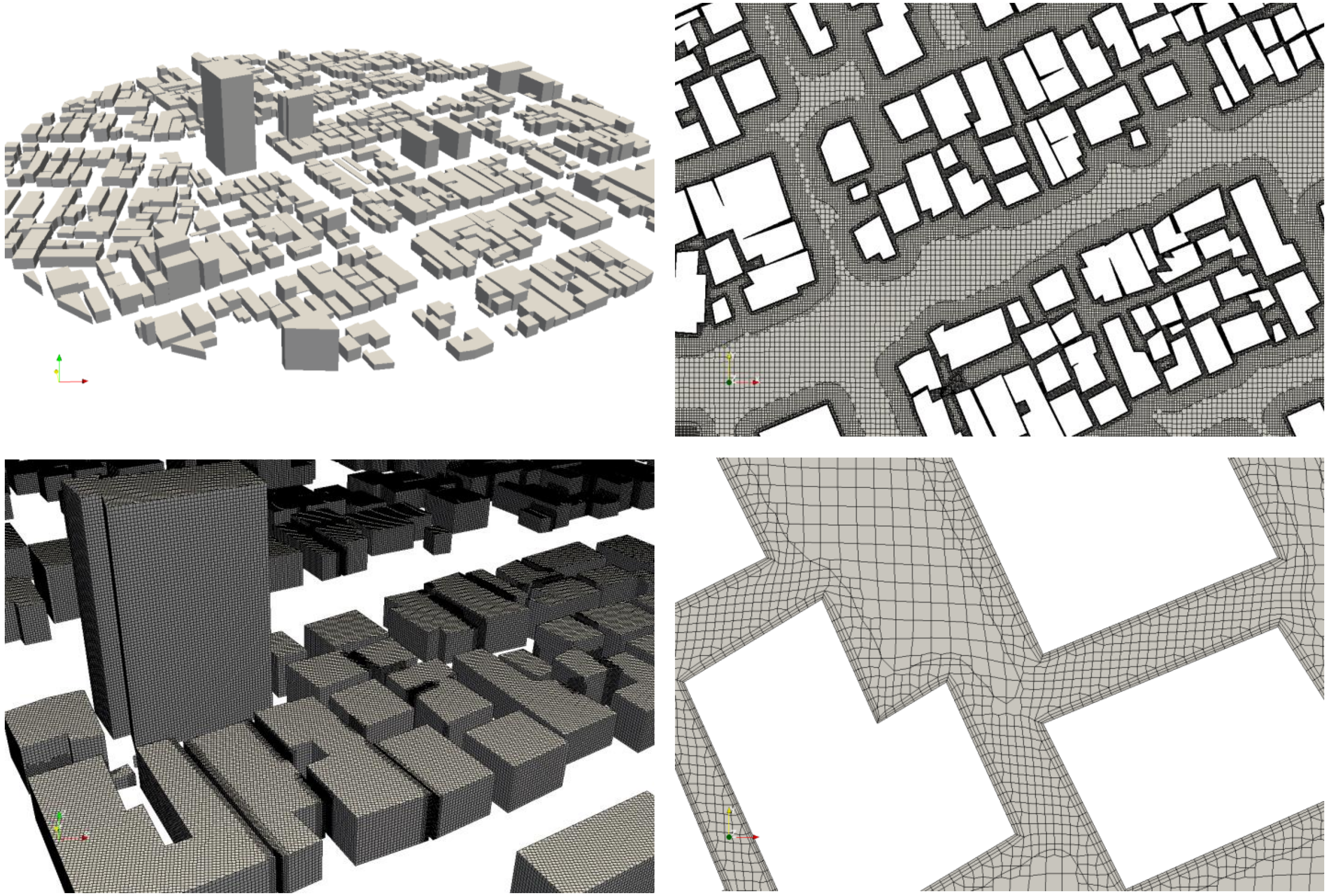




Case Study | Modelling

Mesh

- Max. cell size → 22 m
- Min. cell size → 0.085 m
- No. near-wall layers → 3
- Total mesh size → 26.5 M cells
- Layers coverage → 99.5 %
- Meshing Time → 0.22 hrs.
- HPC Cluster → 4 Nodes - 2 x 16 Cores EPYC 7351 @ 2.4 GHz - 4GB per core

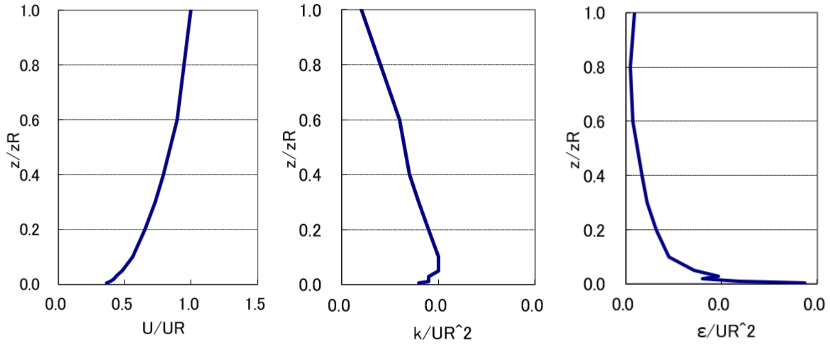


Case Study | Modelling

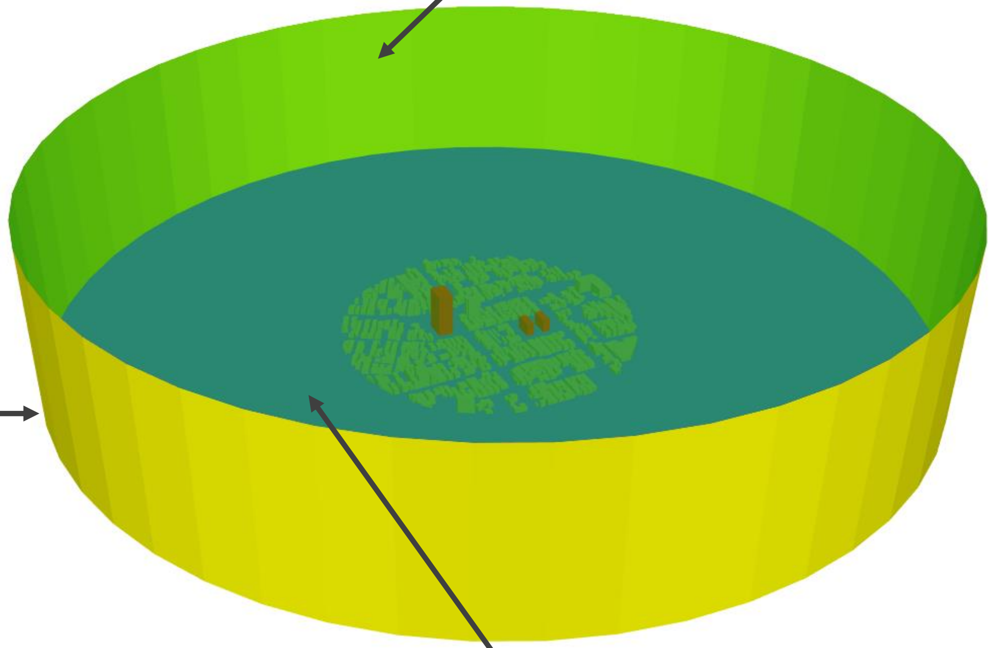
Case Setup

- Incompressible steady-state RANS solution
- Turbulence → realizable k-ε model
- *helyx (simpleFoam)* vs *helyxCoupled*
- SIMPLEC settings for segregated solver

Ambient Sides
Velocity and turbulence wind profiles



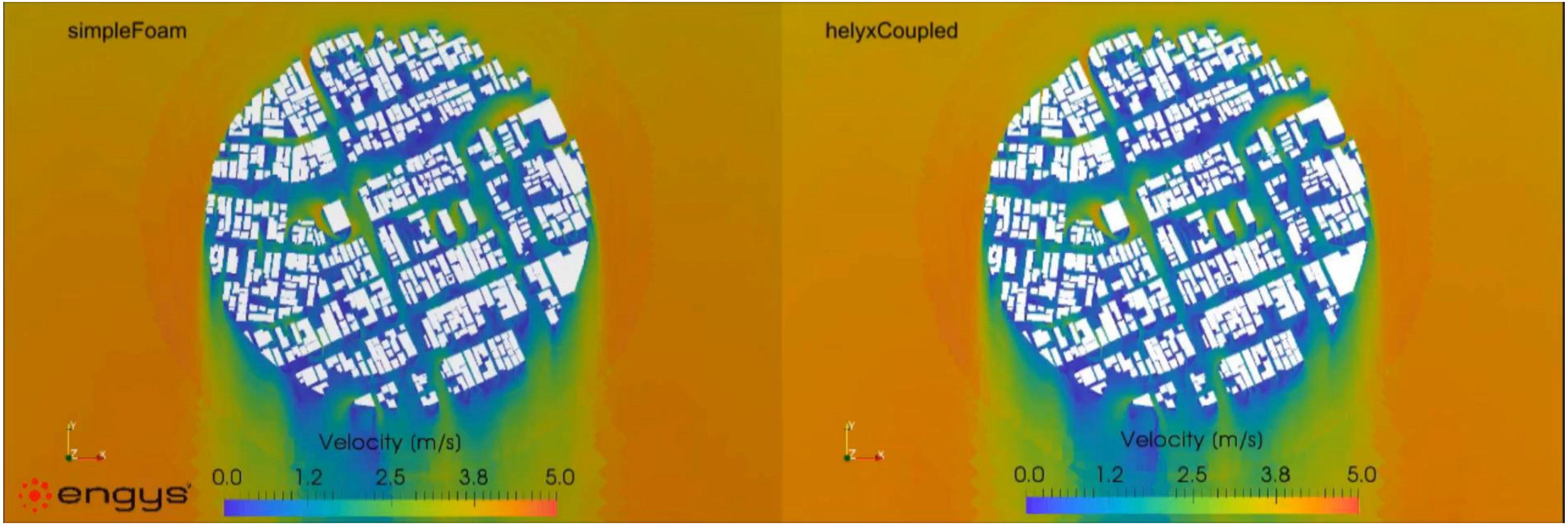
Ambient Top
Fixed Mean Pressure



Ground and Buildings
No slip wall

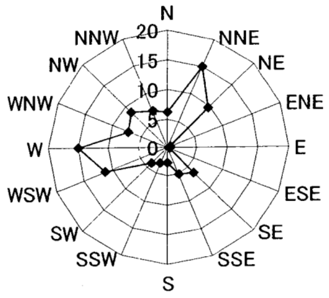
Case Study | Accuracy

Velocity Contours 2 m above the ground

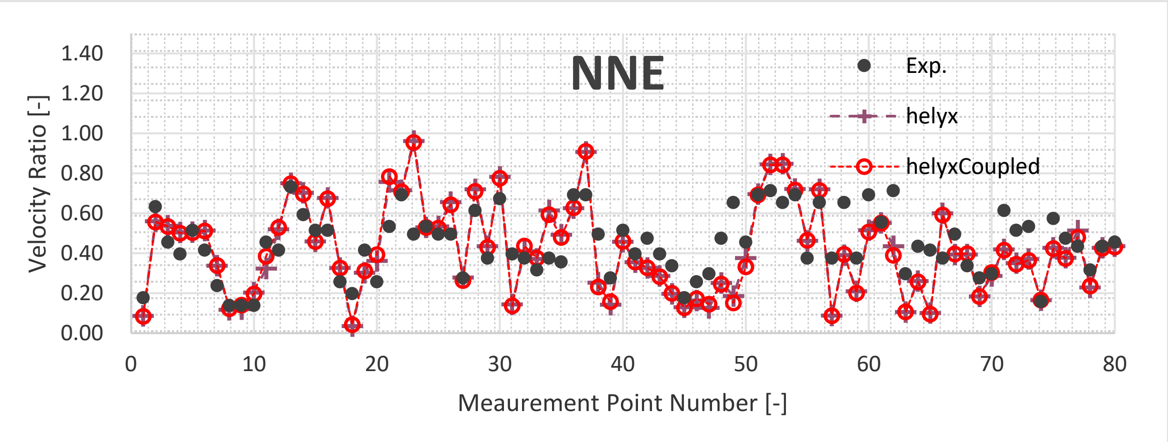


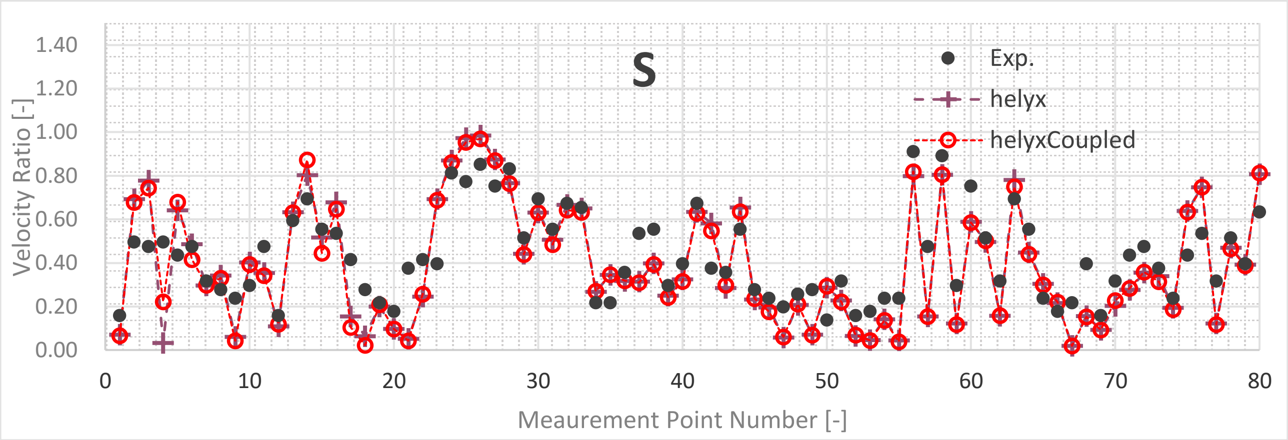
Segregated and coupled solver solutions compare very well for the various wind directions

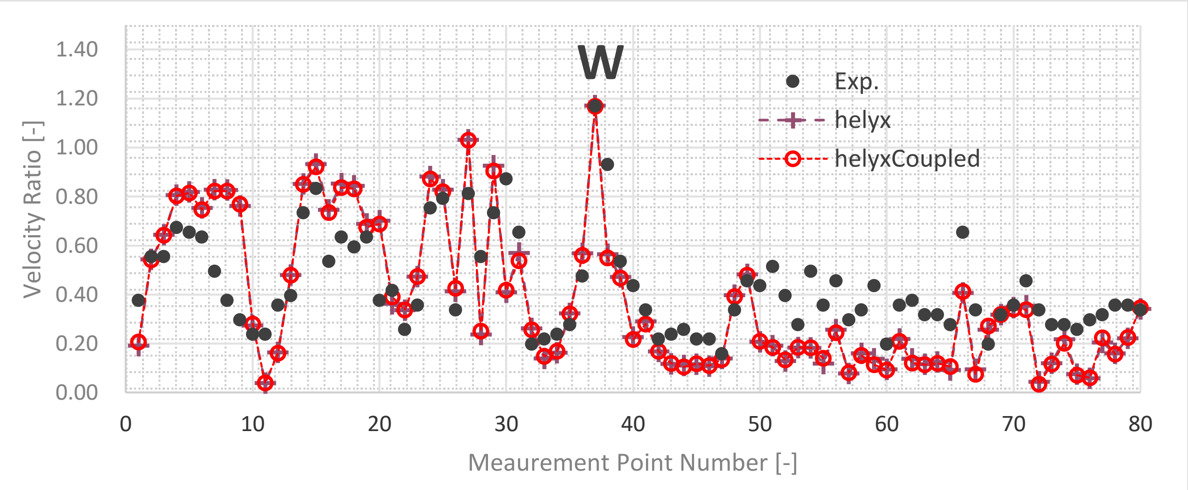
Case Study | Accuracy

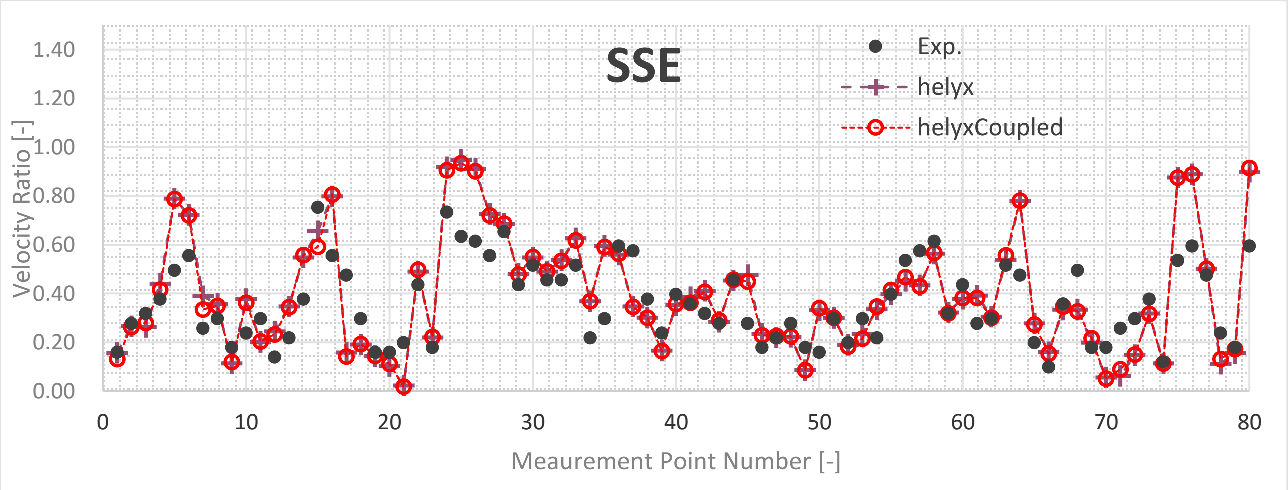


Comparison of Wind Speed Ratios at Measurement Points









Case Study | Convergence

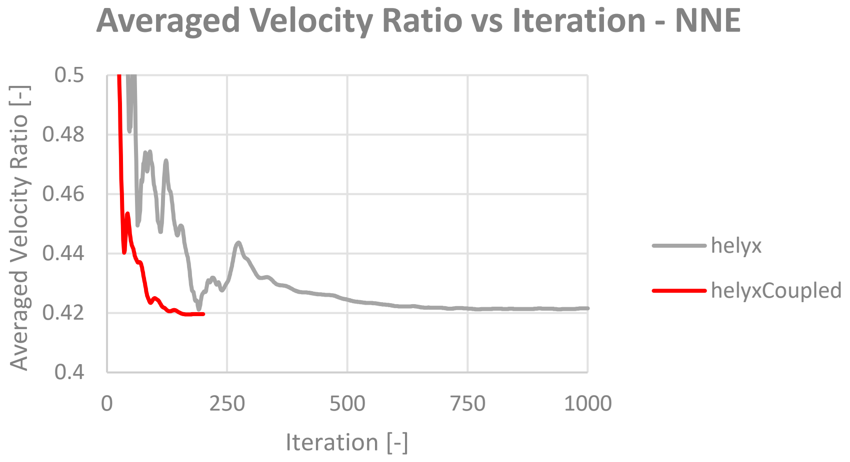
Summary

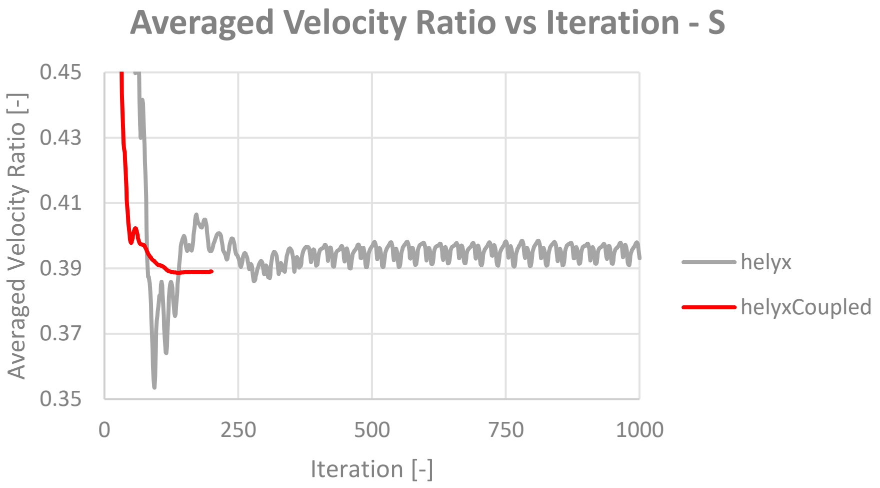
- HPC Cluster → 128 cores - 4 Nodes - 2 x 16 Cores EPYC 7351 @ 2.4 GHz - 4GB memory per core
- Objective convergence assessment
  - *a-posteriori* incremental trend analysis in trailing signal of aggregated data from the 80 velocity probes
  - the largest consistent averaging box from the end of the signal with no underlying trend
- Total CPU Time for 16 wind directions
  - Segregated → 4.12 hrs.
  - Coupled → 2.13 hrs.
- Performances
  - Total speed-up → 1.93
  - Total saving on CPU time → 47.4 %

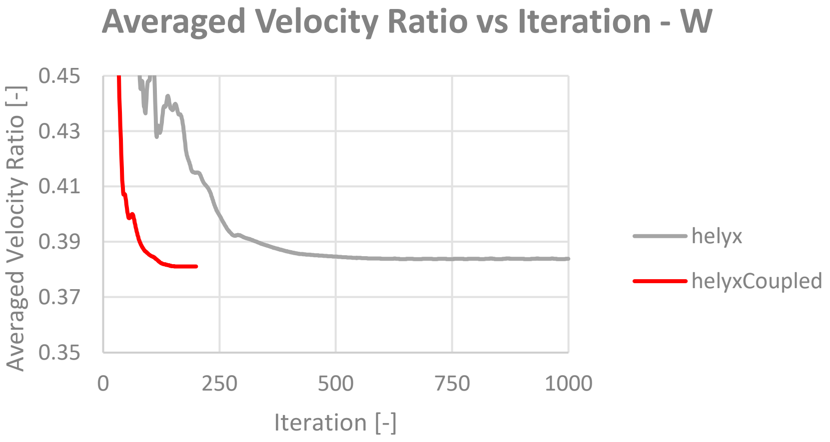
	Segregated		Coupled	
Direction	Iterations [-]	CPU [s]	Iterations [-]	CPU [s]
N	422	722	153	604
NNE	753	1327	159	627
NE	445	791	66	246
ENE	637	1140	81	343
E	735	1295	105	422
ESE	397	702	134	557
SE	736	1284	191	730
SSE	348	612	125	502
S	369	635	158	634
SSW	577	983	135	514
SW	471	811	98	415
WSW	477	837	126	496
W	599	1045	155	607
WNW	637	1110	105	438
NW	441	740	101	360
NNW	466	809	81	307
		14842		7800

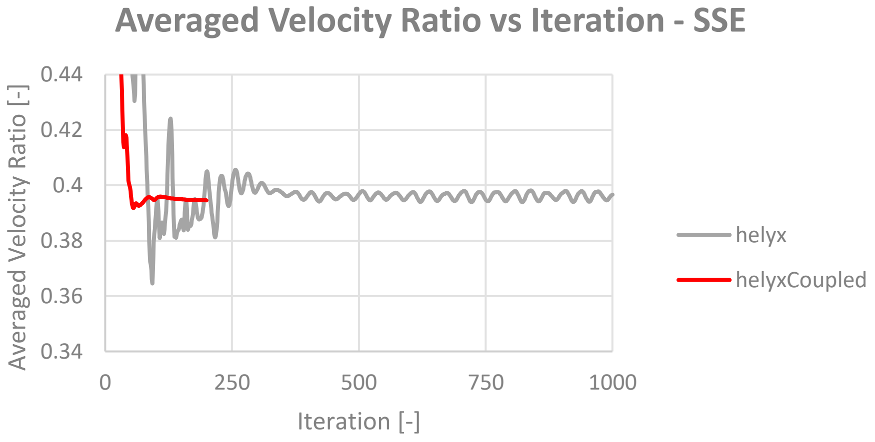
Case Study | Convergence

Ave. Velocity Ratio vs Iteration



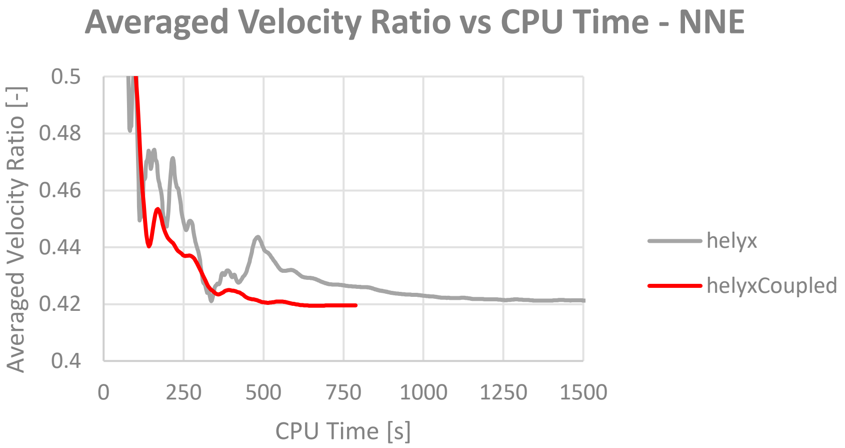


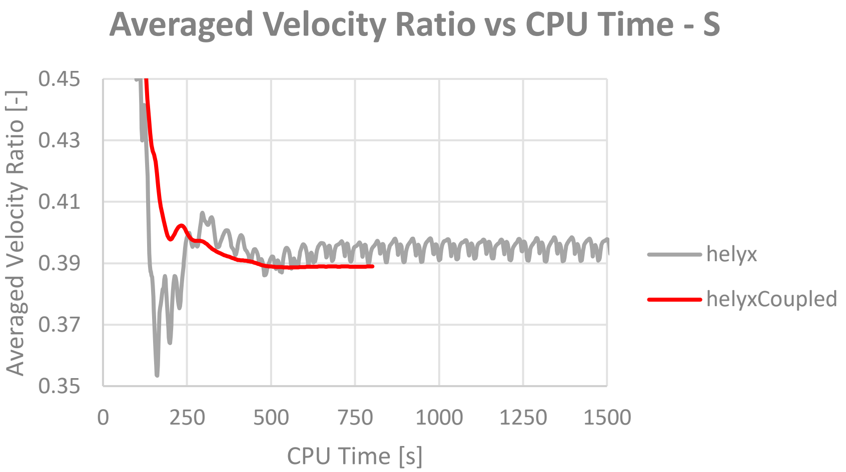


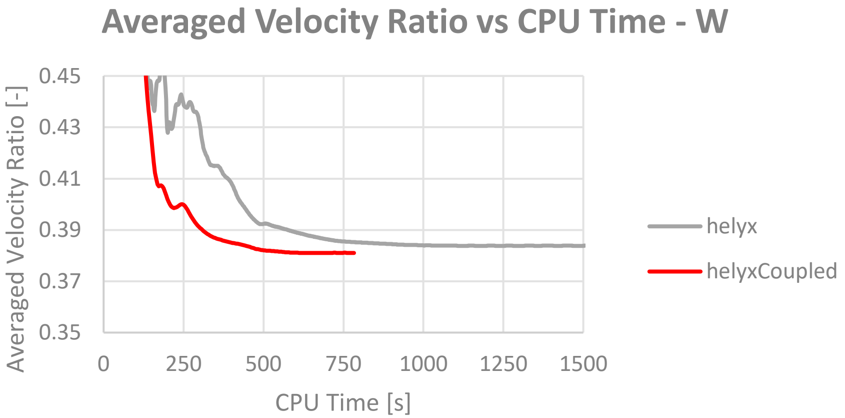


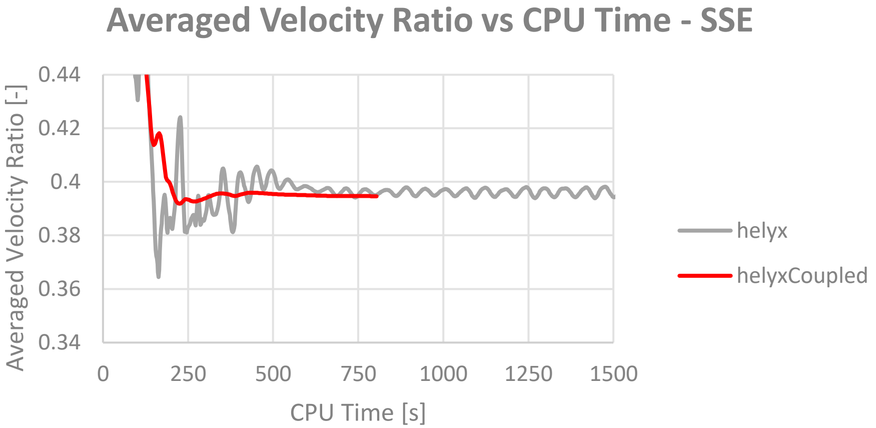
Case Study | Convergence

Ave. Velocity Ratio vs CPU Time









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Multi-Instance Solver

Implementation

- Uses multi-region structure to solve multiple design points (instances) sequentially in a single run
  - Single-mesh multi-region
  - Multiple-mesh multi-region

```
solutionSchedule
{
    instance1 {mesh1 (fluid1); mesh2 (solid1);} // helyxCHT example
    instance22 {mesh1 (fluid1); mesh2 (solid1); radMesh (fluidRad); radMesh (solidRad);}
    instanceMP {mesh1 (fluid1 fluid2 fluid3 fluid4);} // Adjoint Multipoint Example
    instance2 {mesh1 (region1);} // Single Mesh Multi Region
    instance3 {mesh1 (region2);} //          .
    instance4 {mesh1 (region3);} //          .
    instance5 {mesh1 (region4);} //          .
    ……
}
```

- Multi-instance aware function object for automatic evaluation of pedestrian comfort

Multi-Instance Solver

Folders Structure

- Single-mesh multi-region
  - Mesh→ *constant/polyMesh*
  - Dictionaries → *constant/dir*/ & system/dir*/*
  - Fields → *time/ & time/dir**

- Multiple-mesh multi-region
  - Mesh→ *constant/mesh*/polyMesh*
  - Dictionaries → *constant/mesh*/dir*/ & system/mesh*/dir*/*
  - Fields → *time/mesh* & time/mesh*/dir**

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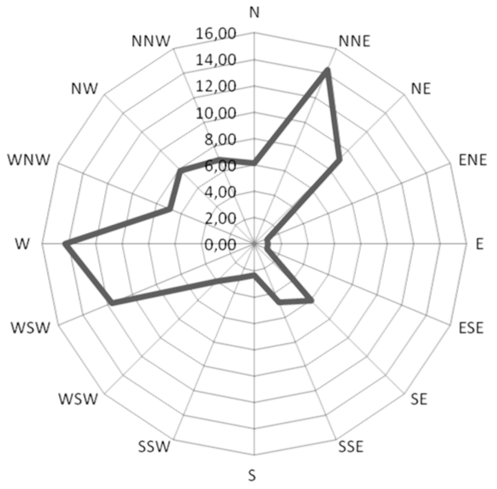
Wind Comfort Assessment

Methodology



Wind rose frequency Distribution (Weibull distribution)

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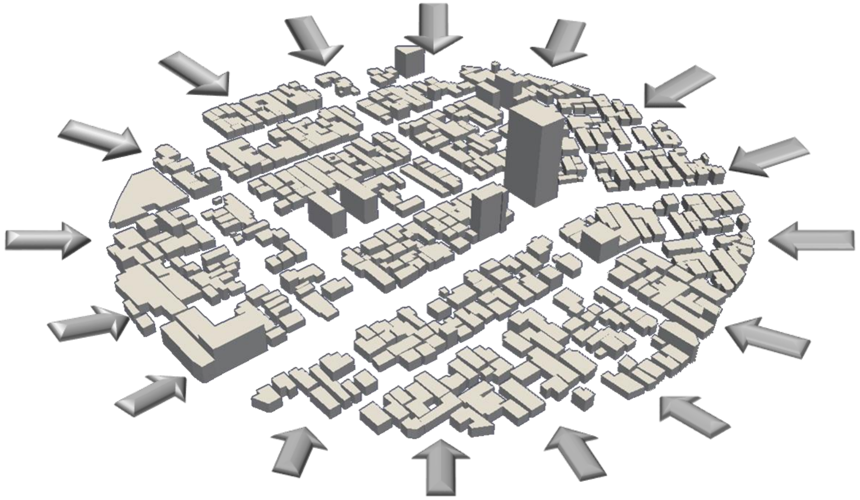
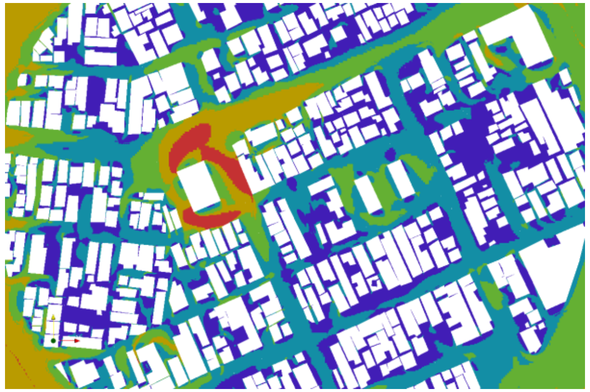


Specific Exceedance probability map from Weibull and CFD for multiple wind directions

=



Exceedance Probability per velocity threshold and Comfort Levels

Category	Color	Wind Speed (5% exceedance)
Frequent sitting	1	2.5 m/s
Occasional sitting	2	4.0 m/s
Standing	3	6.0 m/s
Walking	4	8.0 m/s
Uncomfortable	5	>8.0 m/s

City of London Lawson LDDC Criteria
"Wind Microclimate Guidelines for Developments in City of London", City of London/RWDI 2019

Wind Comfort Assessment

Function Object

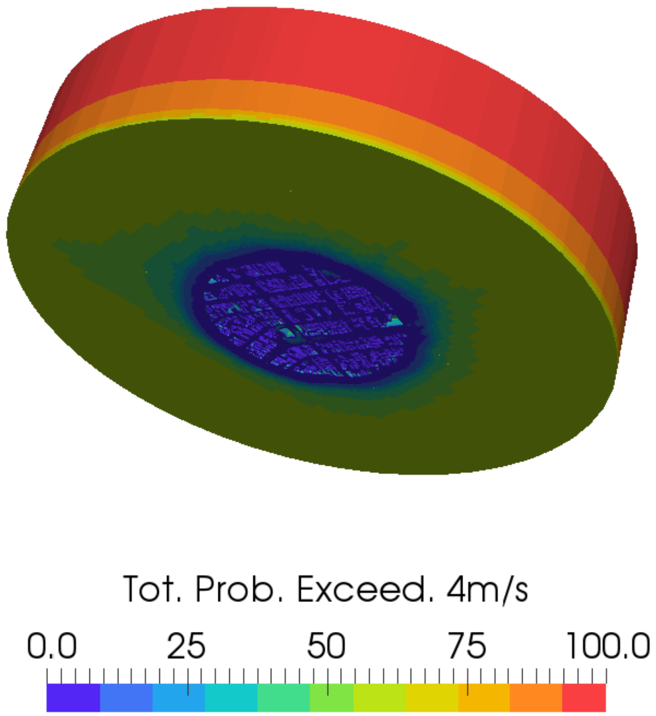
- Calculate total probability of exceedance for each threshold U_{lim} in the criteria, using seasonal or annual parameters:

$$P(> U_{lim}, cell) = \sum_{\theta} p(\theta) \cdot \exp\left\{-\left(\frac{U_{lim}}{R(cell,\theta)c(\theta)}\right)^{k(\theta)}\right\}$$

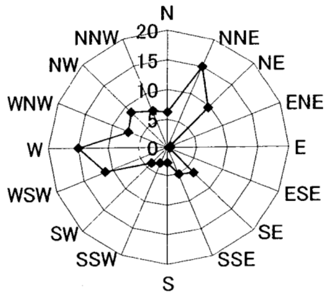
with:

  - θ wind direction
  - $p(\theta), c(\theta), k(\theta)$ Weibull parameters
  - $R(cell,\theta) = \frac{\bar{U}(cell)+\sigma\cdot\left(\frac{2}{3}tke(cell)\right)^{0.5}}{U_{ref}(\theta)} \cdot SF$ velocity ratio
  - U_{ref} reference velocity and
  - SF scaling factor

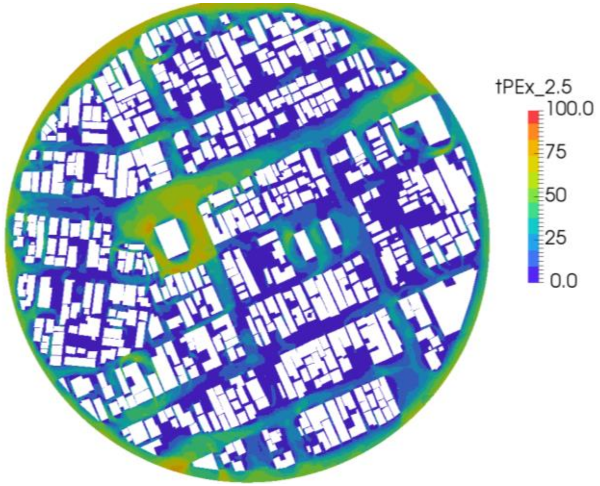
- Assess comfort based on specific criteria and total probabilities of exceedance
- Velocity thresholds and exceedances set by user. Different criteria such as Lawson, Davenport, NEN8100 and Safety Conditions can be defined
- Volumetric fields generated for total probability of exceedance and comfort
- Support in multi-instance solver



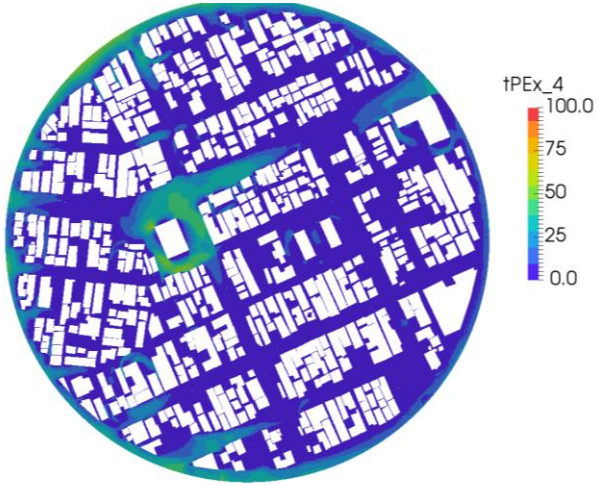
Case Study | Pedestrian Comfort



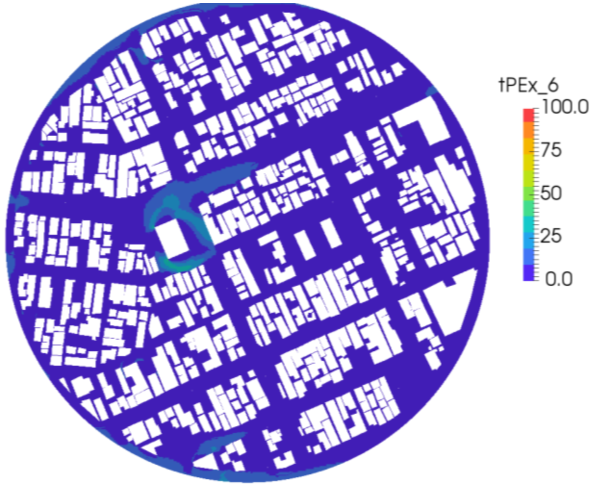
Total Probability of Exceedance



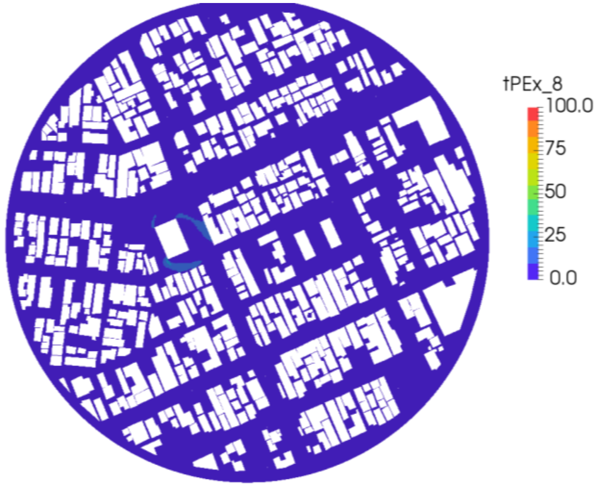
Tot. Prob. Exceed.
for V>2.5 [m/s]



Tot. Prob. Exceed.
for V>4.0 [m/s]



Tot. Prob. Exceed.
for V>6.0 [m/s]



Tot. Prob. Exceed.
for V>8.0 [m/s]

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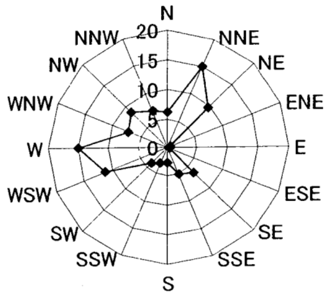
Case Study | Pedestrian Comfort



CoL Lawson Criteria @ 1.5 m above the ground

Category	Color	Wind Speed (5% exceedance)
Frequent sitting	1	2.5 m/s
Occasional sitting	2	4.0 m/s
Standing	3	6.0 m/s
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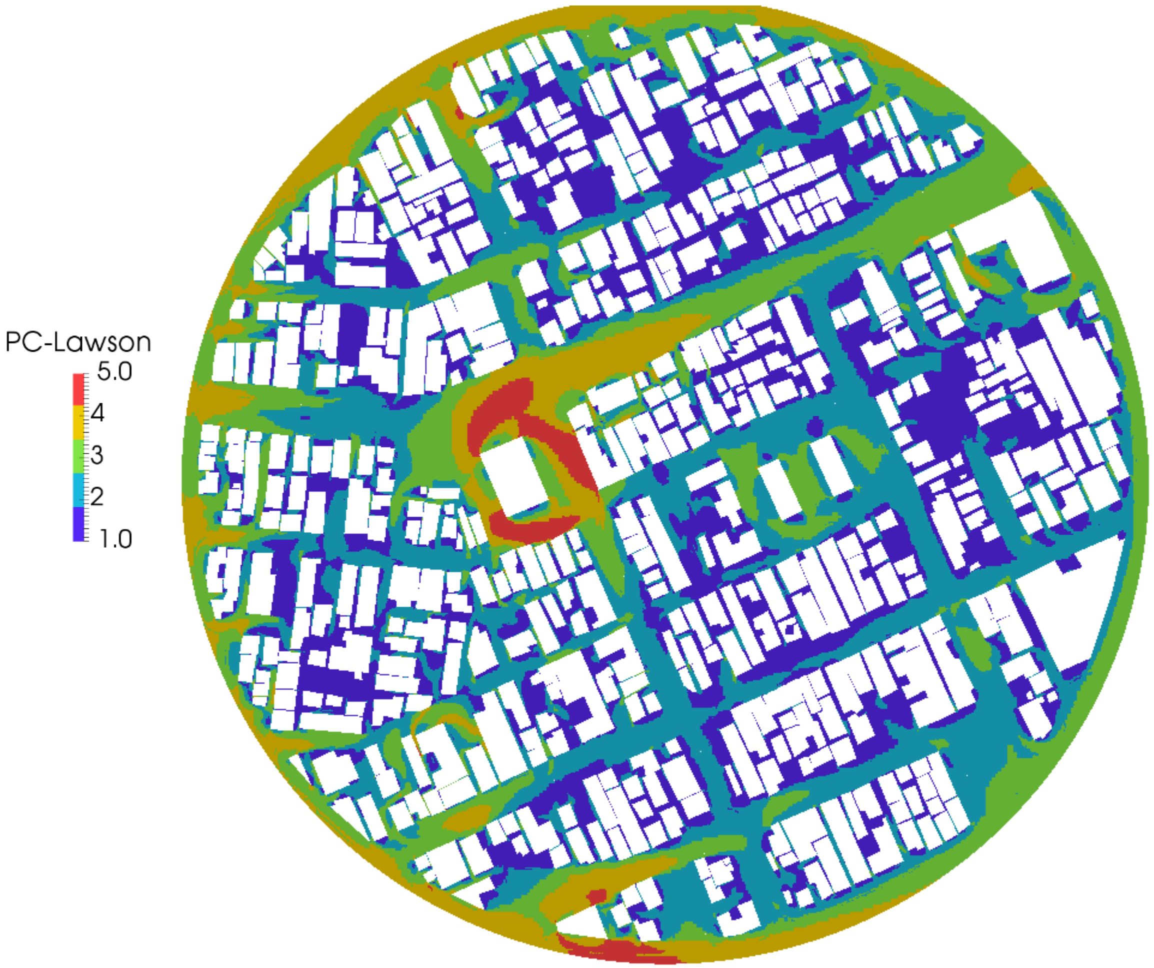

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Conclusions (1)

- The pressure-velocity block-coupled solver was shown to be 2x faster to reach convergence than the segregated solver, whilst the accuracy of the solution is preserved.
- The coupled solver is still a new product, with large potential for performance improvement.

Conclusions (2)

- The multi-instance solver is ideal for types of analysis taking advantage of an automatic workflow, e.g., DoE and similar.
- It removes the need for external scripting (e.g., bash and python).
- Combined with Runtime Post-processing, it enables automatic execution and reporting for wind comfort and safety studies.
- It will be fully integrated inside the HELYX framework.

Thank you for your attention!

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