Research Practicum

Simulating wind around the Flatiron building using RANS CFD simulations

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Abstract

Contents

1 Introduction

The Flatiron building, as seen in figure 1, is the iconic Manhattan skyscraper shaped like a right triangle. Clasped between 5th Avenue and Broadway, with Madison Square Park just north-east of him, there is a lot of open space around this building. If the wind comes from the north, it will be forced through an “alley”, creating a windtunnel effect around the Flatiron building. Legend has it that men would hang out out at the corner to watch the wind blowing women’s dresses up so that they could see their ankles [2]. This is also shown on a postcard from the early 20th century (figure 2), showing a man being blown away by the wind and a woman’s skirt being blown up by the wind.

The main goal of this research is to see if it was actually the geometry of the building creating the updraft. This will be done by simulating the building and surrounding buildings in an in-house built CFD program made for CFD analysis for urban areas.

This report will first discuss the theory and numerical models of the CFD simulation, after which it describes the cases and their results, and furthermore these results will be discussed and a conclusion about the billowing of the skirts will be made.

Figure 1: A picture of the famous Flatiron building

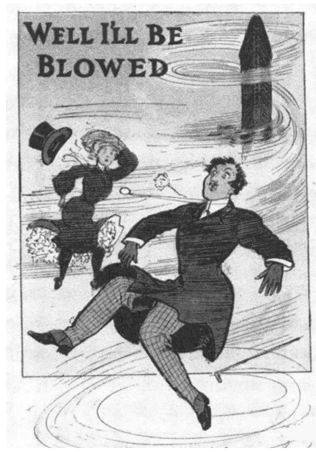

Figure 2: A postcard by an unknown artist displaying the unpredictable winds and billowing skirts around the Flatiron building [1].

2 Theory

2.1 Navier Stokes

2.2 Reynolds Averaged Navier Stokes

2.2.1 Turbulence

2.2.2 k-ϵ model

3 Case and Results

In this section the setup of the CFD analysis will be discussed. This includes the generation of the obstacles for the CFD analysis, a discussion on the Reynolds number associated with this geometry and the fluid properties used during the simulation. Our goal is to see if there is any updraft around 1 meter height, because if there is, that would mean skirts will be blown away in the wind.

3.1 Obstacle creation

To be as true to reality as possible (within the scope of the research practicum), not only the Flatiron building was simulated, but also 4 of the surrounding buildings, creating the "alley" of wind talked about in the introduction and [2]. The dimensions of the Flatiron building itself were found in Bradford and Condit's book "Rise of the New York Skyscraper 1865-1913" [3], while the other dimensions were roughly estimated from Google Maps (see appendix A for a clarification of the method and a complete list of dimensions used).

The program used makes use of an "obstacle generator", in which you specify the start and end of the obstacle in the x, y and z direction, creating rectengular cuboids as obstacles. By combining multiple obstacles together, more complex shapes can be created. By discretizing a right angled triangle, the Flatiron building has been built up of 58 blocks of 1 metre wide, all varying in length to build up the triangle. The height of the building is uniform. The other buildings were 58 metres long and 25 metres wide.

3.2 Mesh

While the mesh is automatically created by the program used in this experiment, there are some parameters that influence the amount of control volumes. To avoid long computation times and the inability of the computer to post-process the results, it was recommended that the total amount of control volumes should not exceed 2 million.

In order for the ground effect to not affect our results, it has been decided that the minimum height of the control volumes at walls should be 0.1 meter. To keep the amount of control volumes around 2 million, the cell width and length of the cells at the walls were set at 0.5 meters. Due to the linear nature of the buildings in question, the cell expansion factor has been set at 1.25.

The last parameter that was set was the parameter that determines the space in front and after buildings. This has been set at 50 meters for both x, y and z directions. This was done in order to give enough space for the wind to develop and ensure as close to reality results as possible.

This way of obstacle creation and parameters for the mesh results in the following wind tunnel model. Notice the high density of control volumes around the Flatiron building in the x direction, this is to ensure that the effects of the shape of the building are well taken into account. At the base and top of the buildings (both surrounding and the Flatiron) there is also a high density of cells in the z direction, this is caused by the 0.1 meter cell height that was imposed on the mesh generator.

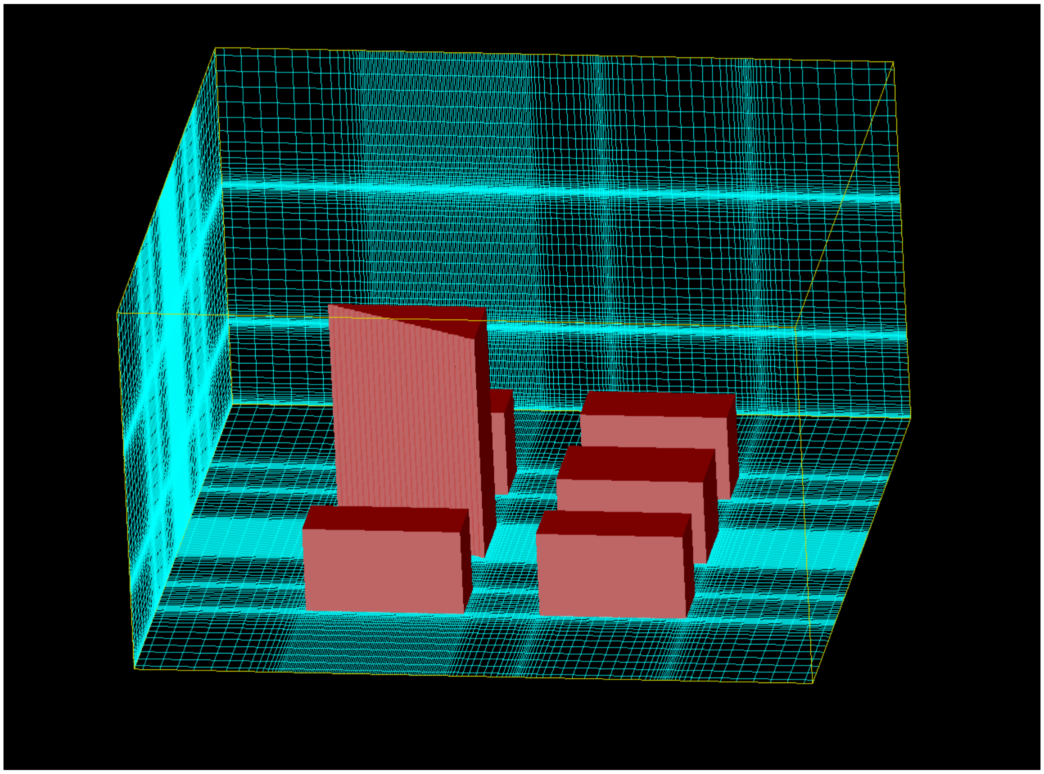

Figure 3: The obstacles and mesh used in the analysis

3.3 Reynolds Number

3.4 Fluid properties

4 Results

Because the men would hang around the corner on windy days [2], a windy day was simulated with a wind speed of 9 ms^{-1}. To get a relatively accurate simulation, a iteration convergence of $1 \cdot 10^{-4}$ was recommended to us.

In order to adequately judge the wind around the building, an overview is created by plotting the streamlines at 3 different heights. These are shown at the bottom(figure 8), around the middle(figure 9) and at the top(figure 10) of the Flatiron building and can be found in appendix B

To check if women's ankles would really show, a plot of the velocity in the z-direction, the pressure and the turbulent kinetic energy were made at a height of 1.37 meter (this was the lowest the program could go). These a shown, respectively, in figures 4, 5 and 6.

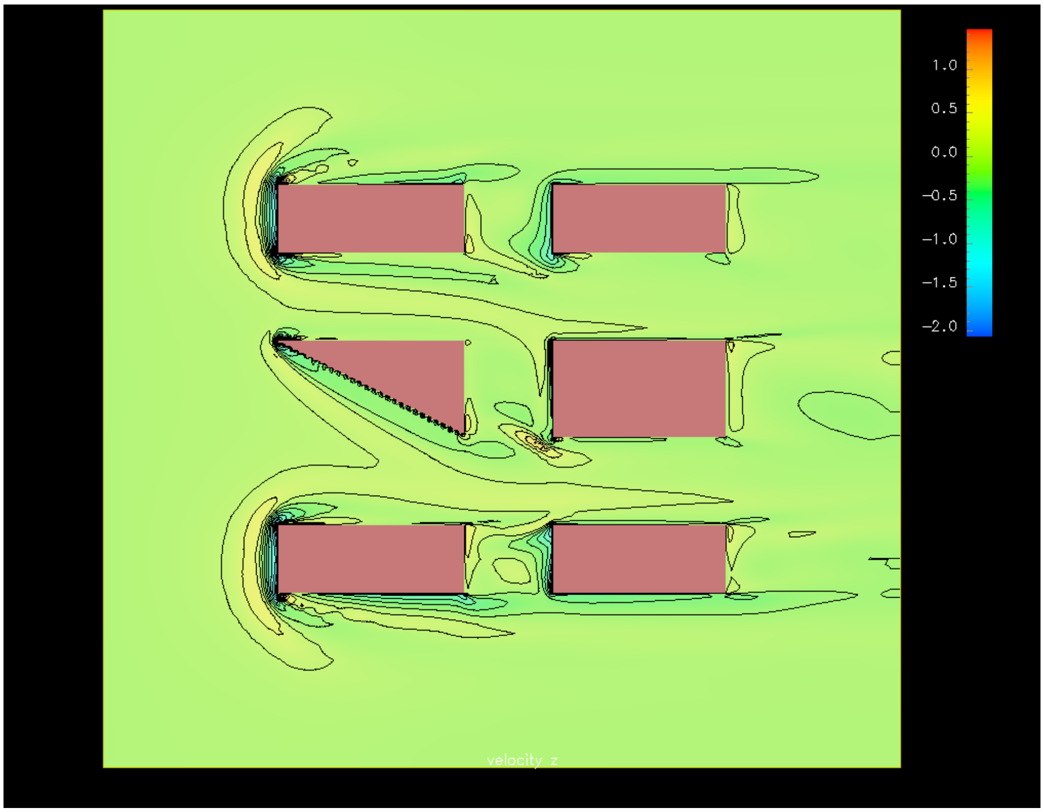

Figure 4: Velocity in the z-direction around the Flatiron building at z=1.37 m

What is most interesting about the Flatiron building is the way it diverges the air. As seen in figure 6, there is barely any turbulence at the tip of the Flatiron building (a maximum of 2 m^2s^{-2}) while at the other most upfront buildings, around the corners there is up to 7 m^2s^{-2}. At the widest point of the Flatiron building, there is a lot of turbulent kinetic energy, most likely due to the wind hitting the edge of the building just behind that. This is also shown in figure 5, where the pressure builds up at that same corner. This rise in pressure and turbulent energy creates a small updraft, seen in 4.

Figure 5: Pressure distribution(in Pa) around the Flatiron building at z=1.37 m

Another remarkable thing is that the turbulent kinetic energy at the short side of the Flatiron building is lower than at the long side. It is suspected that this is because of the flow of air that goes into the street behind the Flatiron building. That this flow from the short side into the street and not from the long side can be seen in figure 8, where you see one streamline duck behind the building. This effect is more visible in figures 9 and 10 where it is seen that at different heights, the wind from the shorter side of the Flatiron building ducks behind building, while the wind that comes from the longer side doesnt́.

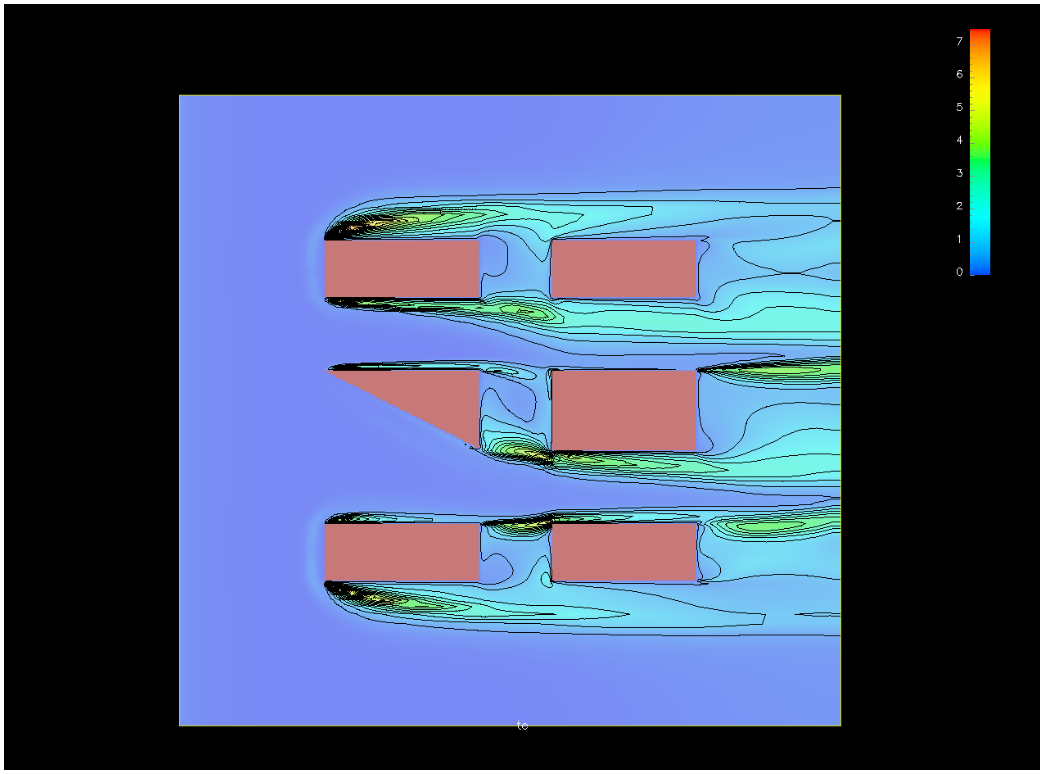

Figure 6: Turbulent kinetic energy(in m^2s^{-2}) around the Flatiron building at z=1.37 m

5 Conclusion and Discussion

5.1 Grid convergence

5.2 Uncertainty

References

[1] Alice Sparberg Alexiou. *The Flatiron*. St. Martin's Griffin, 2010.

[2] Andrew S. Dolkart. *The Architecture and Development of New York City*. Columbia University, 2014.

[3] Carl W. Condit Sarah Bradford Landau. *Rise of the New York Skyscraper 1865-1913*. 1999.

A Dimensions of the obstacles

As discussed in section 3.1, the obstacles used in the CFD analysis were estimated using Google Maps. In figure 7 it is shown how these distances were estimated. From this figure and the measurement tool on the Google Maps

Figure 7: A snapshot of the method used to estimate the dimensions using Google Maps. The red lines indicated the measured distances.

program, we found the following dimensions for the Flatiron building and surroundings. The numbers correspond with the building numbers in table 1.

Table 1: Parameters used in the generation of the obstacles that are not the Flatiron building, in meters

Building No.	x-length	y-length
1	30	140
2	30	60
3	30	140
Space between	25	25

B Streamlines

In this section the streamlines to get a general overview.

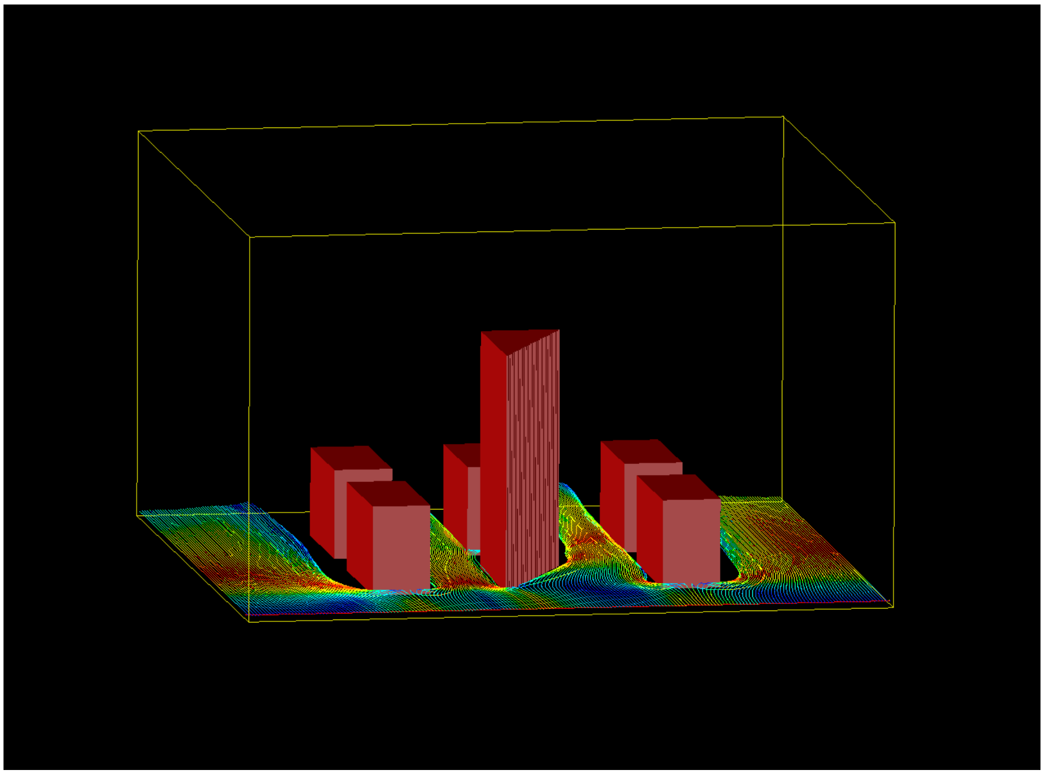

Figure 8: Streamlines around the Flatiron and surrounding buildings just above ground level

C configuration.yml

```
title: Urban simulation

properties:
  velocity: 9
```

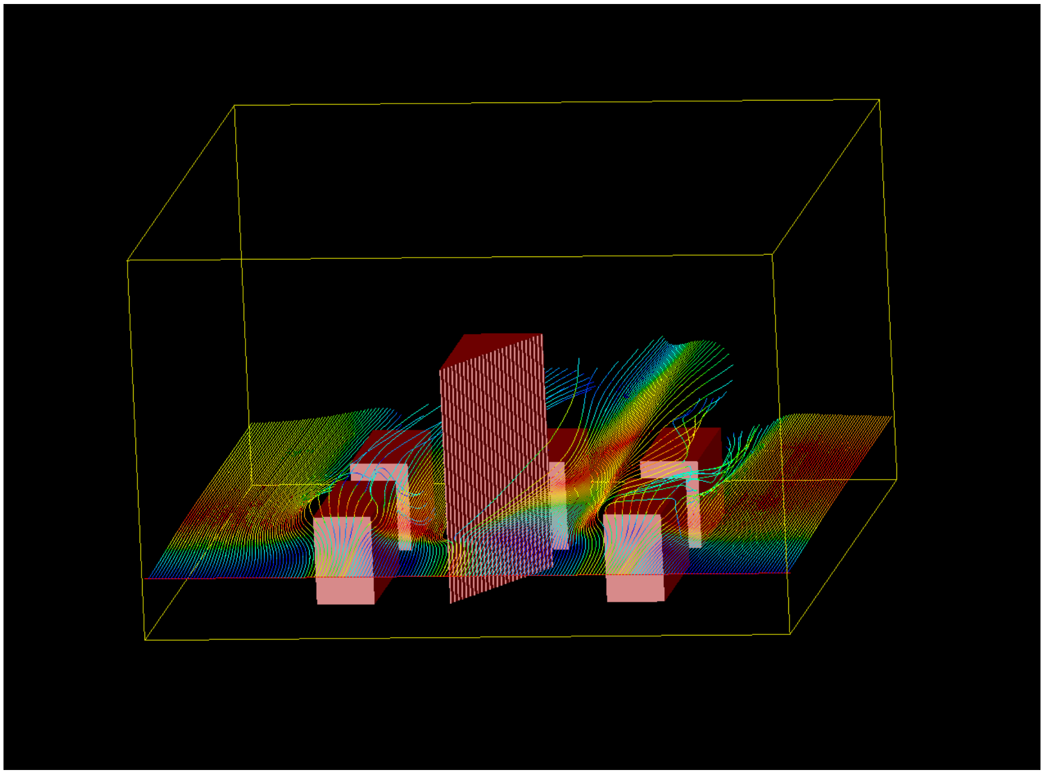

Figure 9: Streamlines around the Flatiron and surrounding buildings just below the top of the surrounding buildings

```
  angle: 0
  density: 1.205
  viscosity: 1.82e-5
  pressure: 0
  temperature: 20

  #initial turbulence properties
  turbulence intensity: 5
  viscosity fraction: 500

simulation:
  number of presimulations: 0
  do final simulation: [uds]
  simulation status: begin

  number of iterations: 10000
```

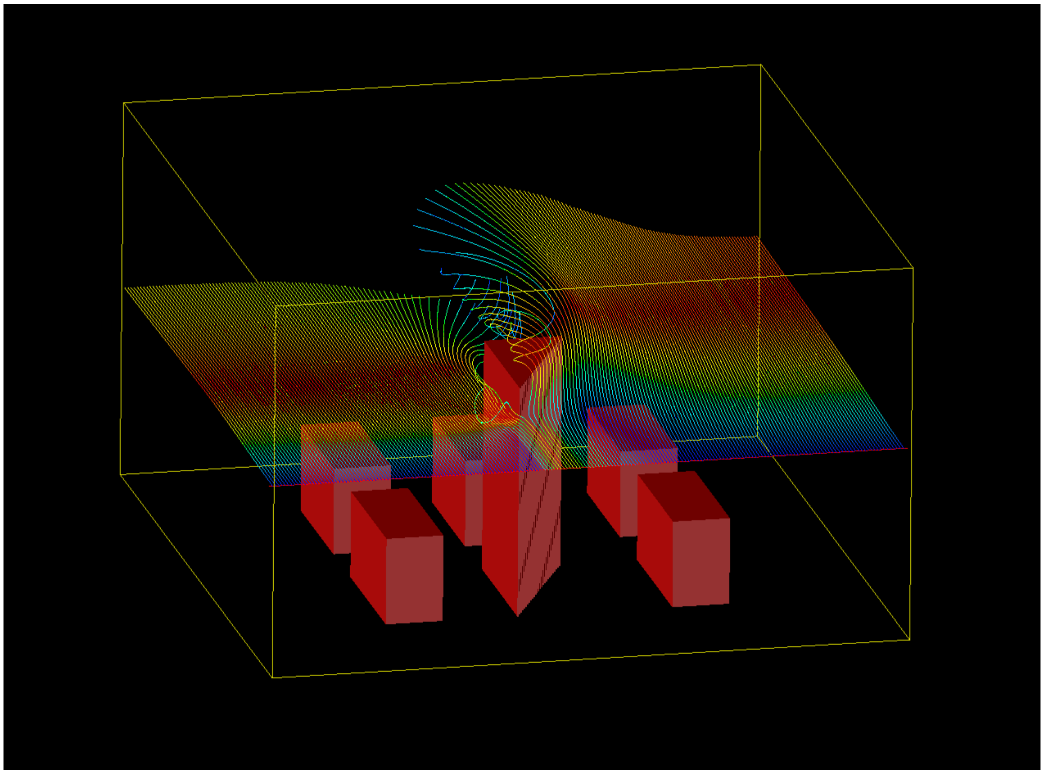

Figure 10: Streamlines around the Flatiron and surrounding buildings just below the top of the Flatiron building

```
iterations convergence: 1.0e-4
iterations written every: 500

# Reynolds stress model. Options: standard (eddy viscosity), non-linear eddy viscosity model,
reynolds stress model: standard

use generalized gradient diffusion hypothesis: false

constants:
  Cmu: 0.09
  E smooth wall: 8.432
  E rough wall: 30
  C1: 1.44
  C2: 1.92
  von Karman constant: 0.41
  # Cphi for concentration GGDH or AFM
```

```
    Cphi: 0.15
    # Ctheta for concentration AFM (SKSI in simulation definition is 1.0-Ctheta)
    Ctheta: 0.4

  #now the numerical properties
  relaxation:
    velocity: 0.6
    pressure: 0.1
    turbulent kinetic energy: 0.6
    energy dissipation: 0.6
    viscosity: 0.8
    concentration: 0.8
    concentration variance: 0.7
    temperature: 0.8
    temperature variance: 0.7

  time dependent:
    time step: 1.0e10
    number of timesteps: 1
    time iterations: 102
    monitoring points:
      - {x: 0.5 , y: 1, z: 1}
#      - {x: 10, y: 49, z: 11}

  algebraic stress model:
    constant1: 1.8
    constant2: 0.6
    constant3: 0.6

  cells before end for outlet plane: 3

mesh:
  # Dimensions, setting these to dynamic will make these dynamic based on obstacles
  # if value is given, space after obstacles is ignored
  width: dynamic
  length: dynamic
  height: dynamic

  x space before obstacles: 50
  x space after obstacles: 50

  y space before obstacles: 50
  y space after obstacles: 50

  z space before obstacles: 0
```

```
  z space after obstacles: 50

  # Set this to 0 to use the full refined mesh without making it more coarse in pre-simulations
  number of cells in the flow direction: 0

  cell expansion factor: 1.25
  max deviation from cell expansion factor: 0.15
  allow obstacle shifting: true
  required number of cells between obstacles: 0

  scale height to: 1.0

  cell width at walls: 0.5
  cell length at walls: 0.5
  cell height at walls: 0.1

  #if there is no wall or obstacles present, these values will become the cell sizes
  max cell width: 10
  max cell length: 10
  max cell height: 10

  refined boundary types: [wall]

obstacles:
  default roughness: 1.0e-6

  operations:
    - toZero
    #- flipX
    - flipY

trees:
  constants:
    # Svenson
    drag coefficient: 0.1
    beta p: 0.0
    beta d: 0.0
    C4 epsilon: 0.0
    C5 epsilon: 0.0

walls:
  #give here the wall names and assign a roughness of the wall in meters
  bottom:
    roughness: 1.0e-6
#    inlets:
```

```
#      - xs: 45
#        xe: 48
#        ys: 54
#        ye: 57
#        velocity_x: 0
#        velocity_y: 0
#        velocity_z: 0.02
#        turbulence intensity: 0
#        viscosity fraction: 500
#        concentration: 1.0

solar:
  year: 2011
  month: 9
  day: 8
  hour: 14
  minute: 48
  seconds: 0
  latitude: 52.22
  longitude: 4.53
  accuracy: 0.1
  inlet type: 41
  Value: 30

system:
  f77 compiler: gfortran -w -O
  editor: gedit
  timezone: Europe/Amsterdam
```