Automatic Generation of Computational Meshes for the Efficient CFD Simulations of Wind Flows in Urban Environments in OpenFoam Using LIDAR Techniques

Gonzalo Veiga Piñeiro (PhD Student)
Elena B. Martin Ortega (Full Prof. and Supervisor)

Institute of Physics and Aerospace Sciences (IFCAE)
Universidade de Vigo
Email: gonzalo.veiga@uvigo.gal

Universidade Vigo
IFCAE Instituto de Física e Ciencias Aeroespaciais

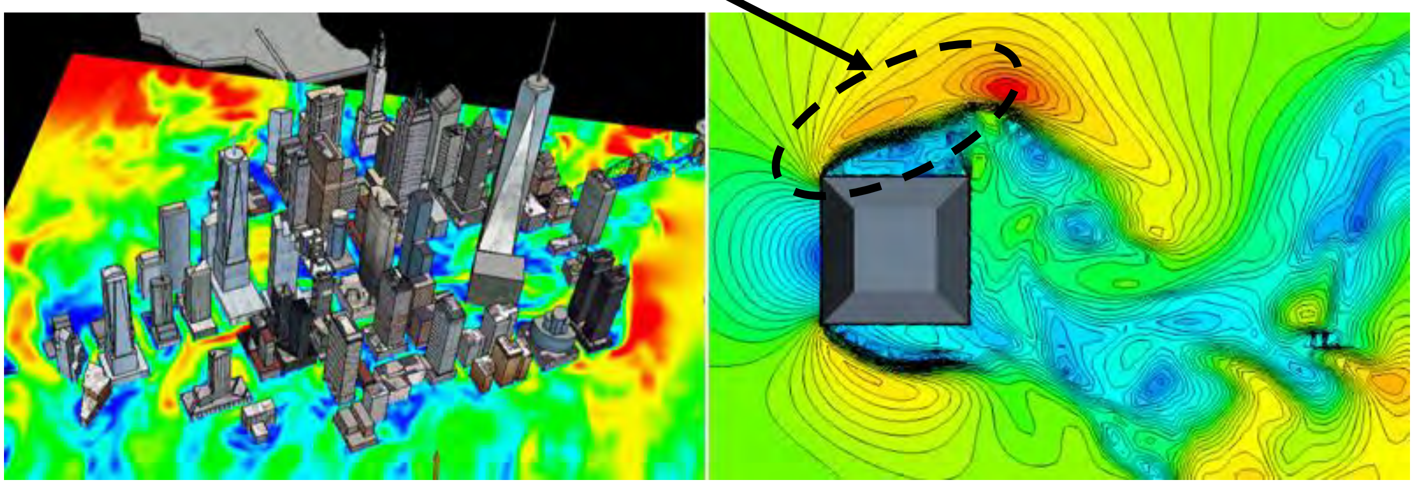
Introduction

- **SAFEVERTIPORT project (PID2021-125060OB-100)**
- On the way to **improve safety in Urban Air Mobility** (UAM)
- **Turbulence and wind gusts** present considerable **risks** to the **safety of UAVs**
- The **interaction** of flows with **buildings and terrain** generates **local flow effects** that can **destabilize** small aircraft
- To predict these phenomena, high-resolution **CFD models are necessary**, as well as **weather forecasting tools** that assist in the prediction.

Weather Conditions → **Generate ROM (Reduced Order Models)** → **Predict flow behaviour**

Necessary to **generate a CFD database** (for example, by parameterizing the boundary conditions of CFD)

Critical area for UAV



Example of CFD simulation over a city (image extracted from [1])

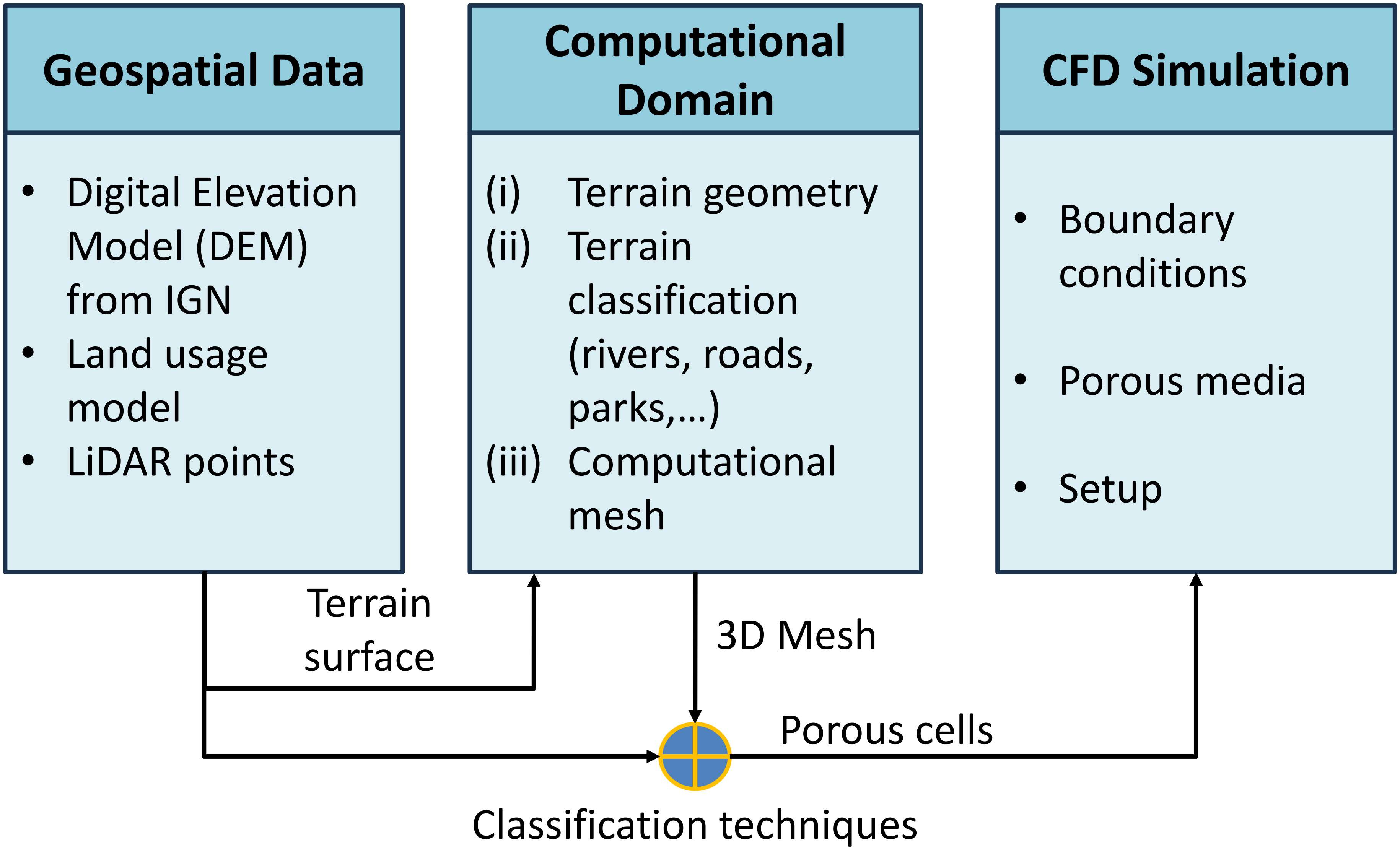
Objectives

- Automate CFD simulation for any environment

  (i) Generate a methodology to **automate the development of CFD simulations using geospatial data**.

  (ii) **Reduce computational costs** associated with the geometric modeling of city buildings by combining geospatial information and cells information using porous models.

Methodology

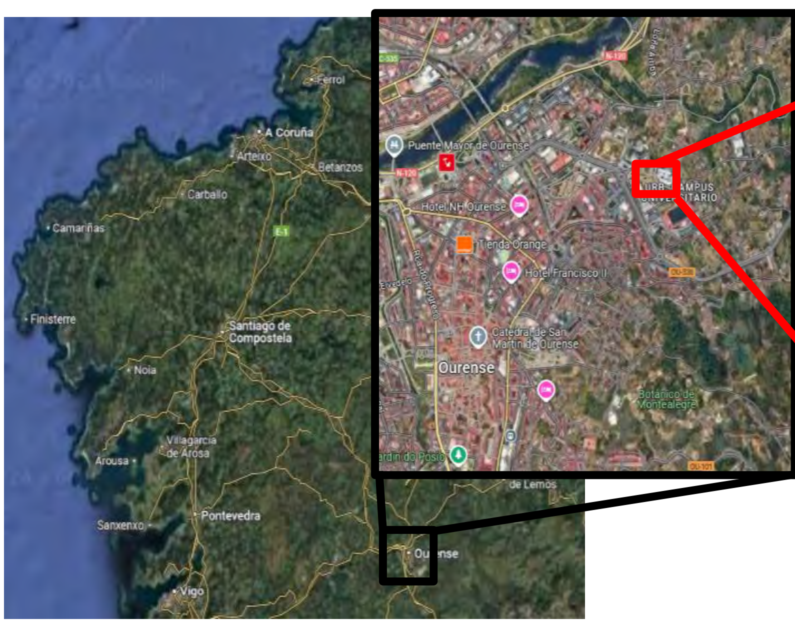


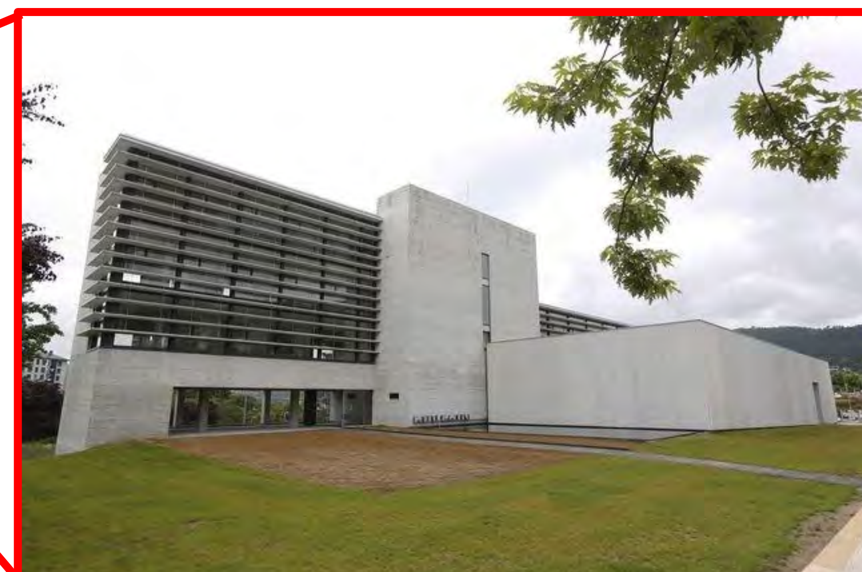
(I) Terrain surface model

- Campus de Ourense, was selected as a study case
- **DEM**: Spatial grid in UTM with
  - Horizontal resolution: 5m
  - Altimetric resolution: 25 cm

↳ Obtained from LiDAR cloud points

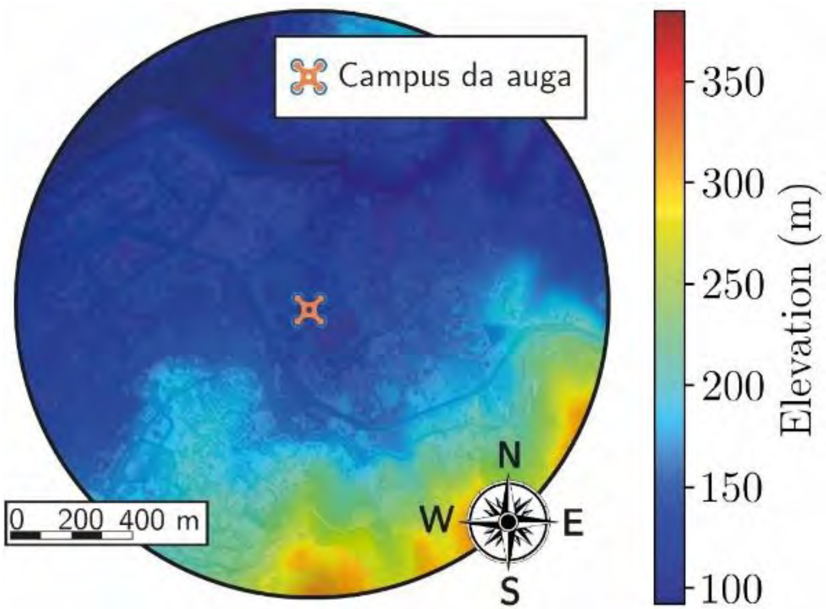
Spanish Geographic Institute (IGN) → **Digital Elevation Model (DEM) MDT05**





Campus da Auga, Ourense

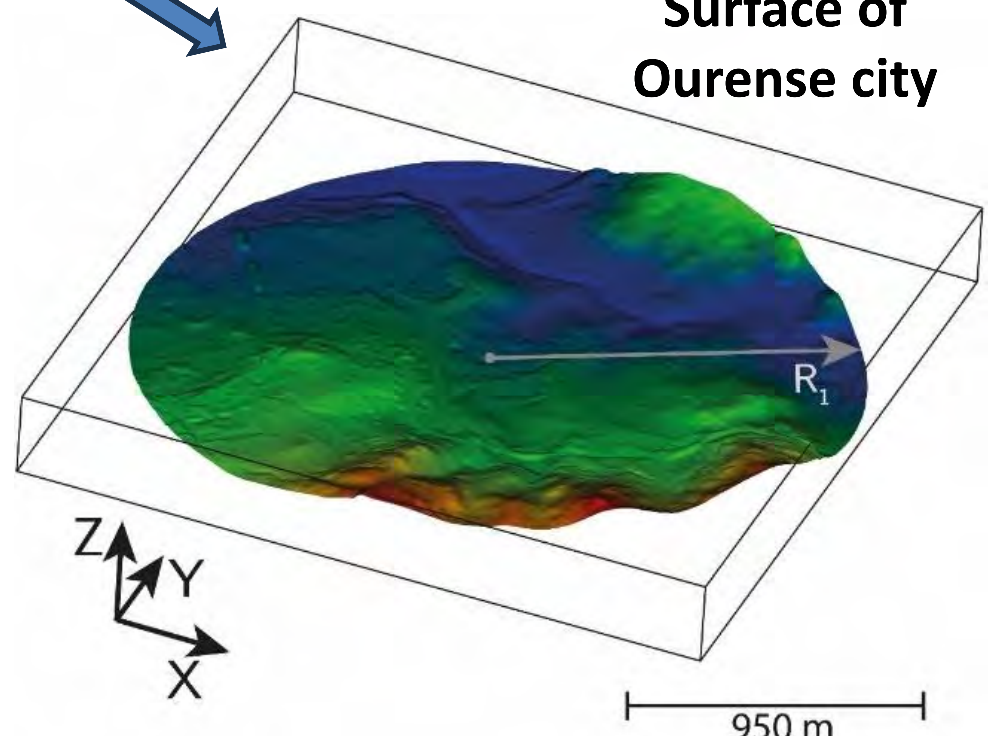
- Once the DEM is obtained, a surface is generated by applying a **Delaunay triangulation**



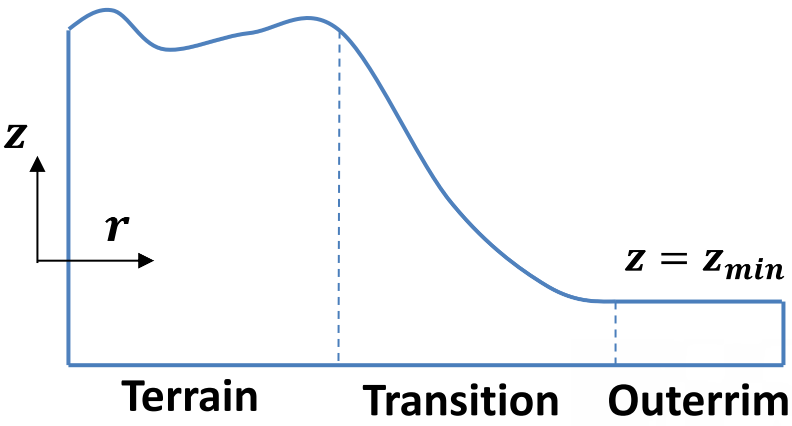
Digital Elevation Model of Ourense city

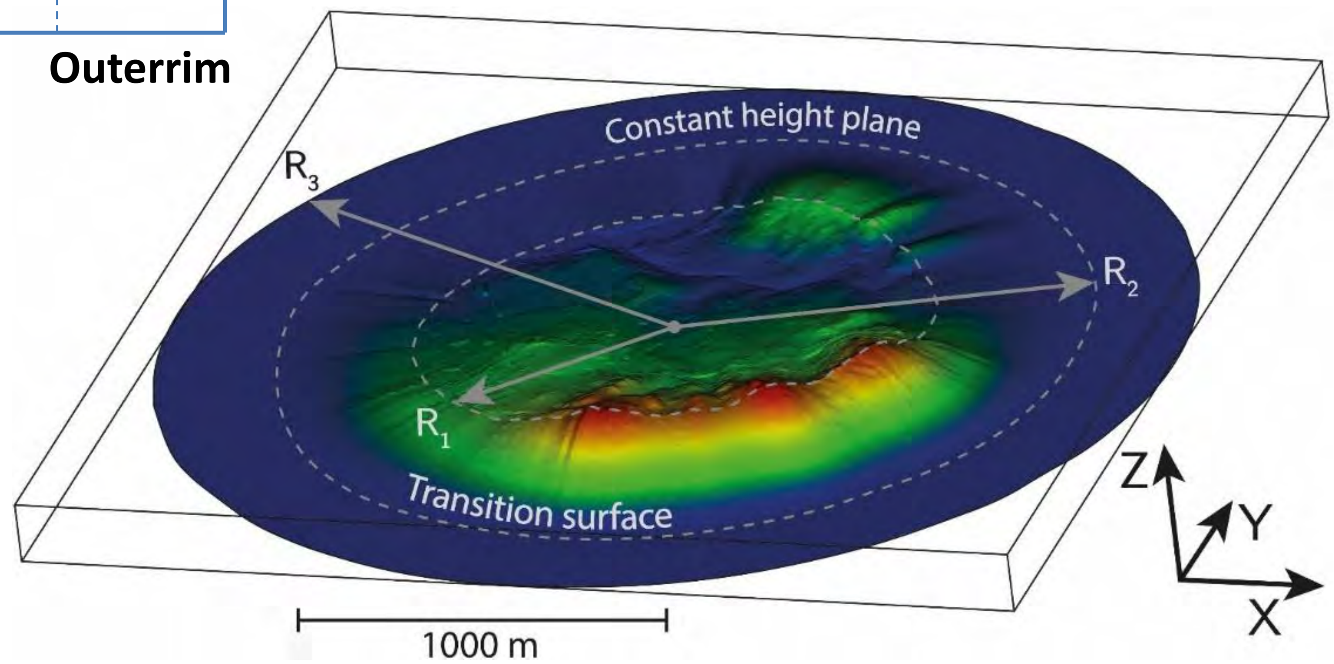
DELAUNAY TRIANGULATION

Surface of Ourense city

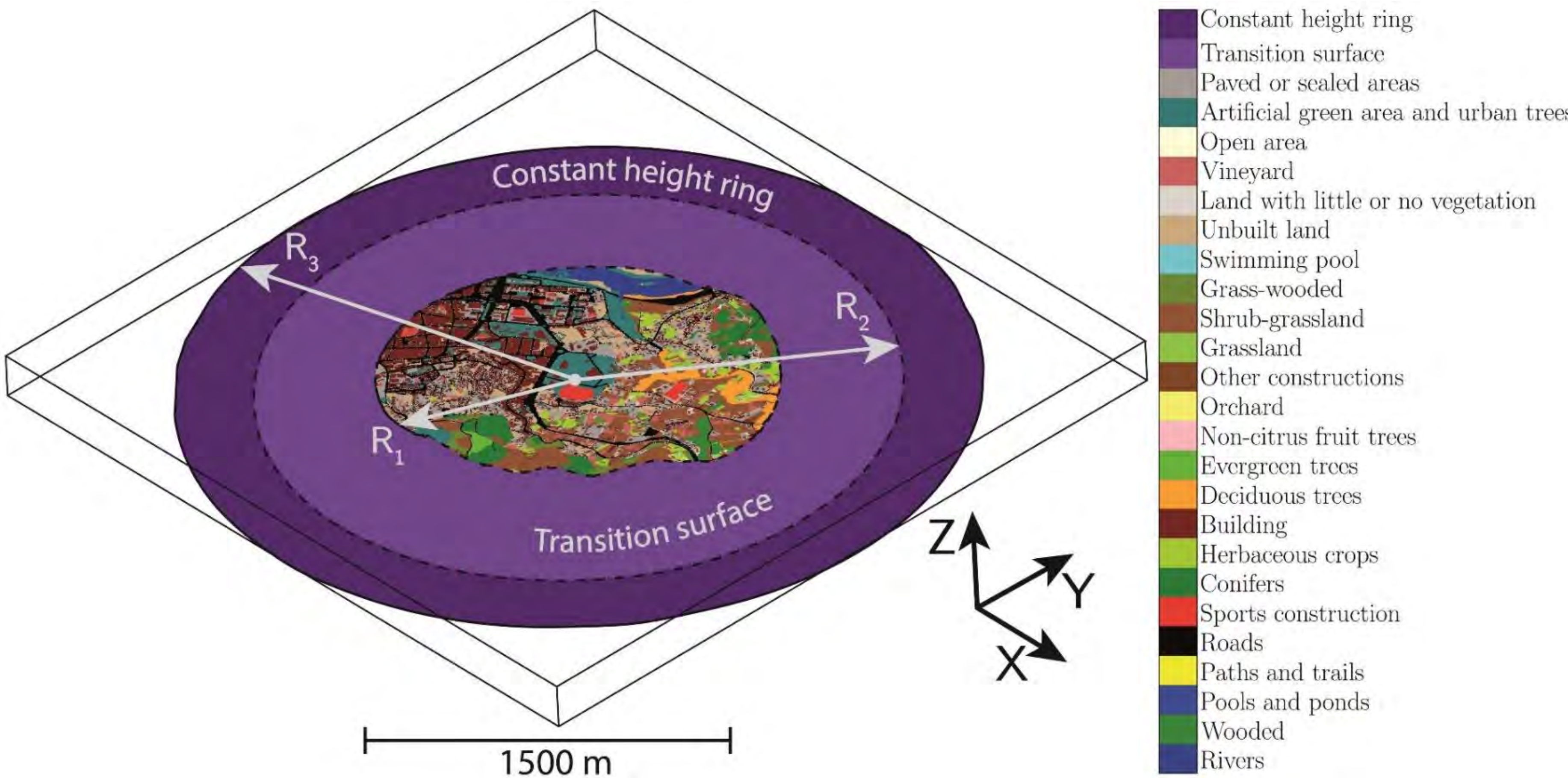


- The **surface boundary is irregular**, which could cause **future convergence issues** → Creation of **two additional surfaces**

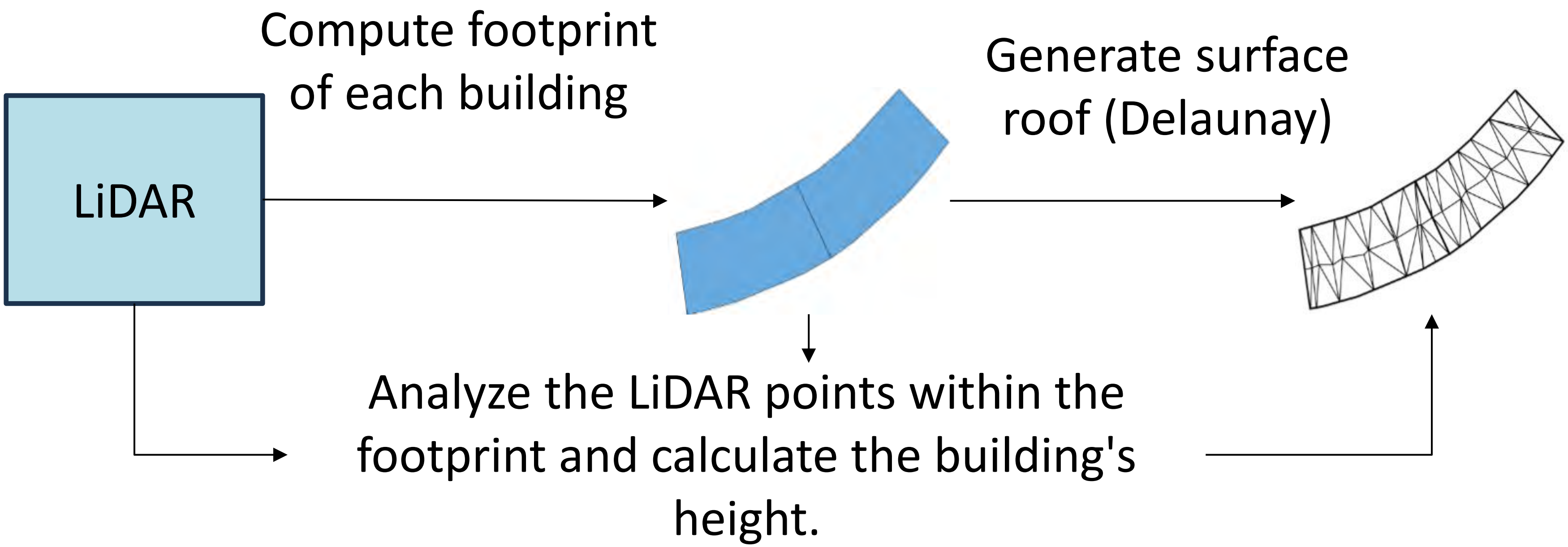




- **The terrain surface was categorized** to impose different roughness conditions in each category by **applying the SIOSE AR model** (from IGN)

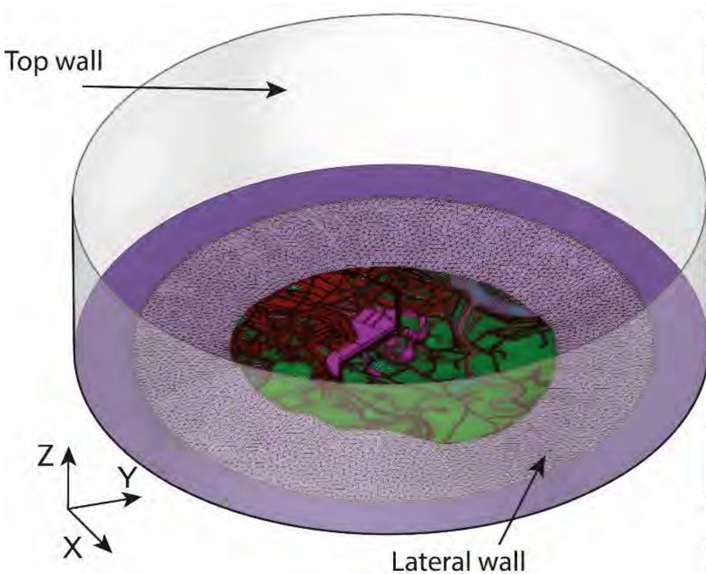


- After generating the classified surface, **the buildings were geometrically modeled** by combining LiDAR points and surface generation techniques.



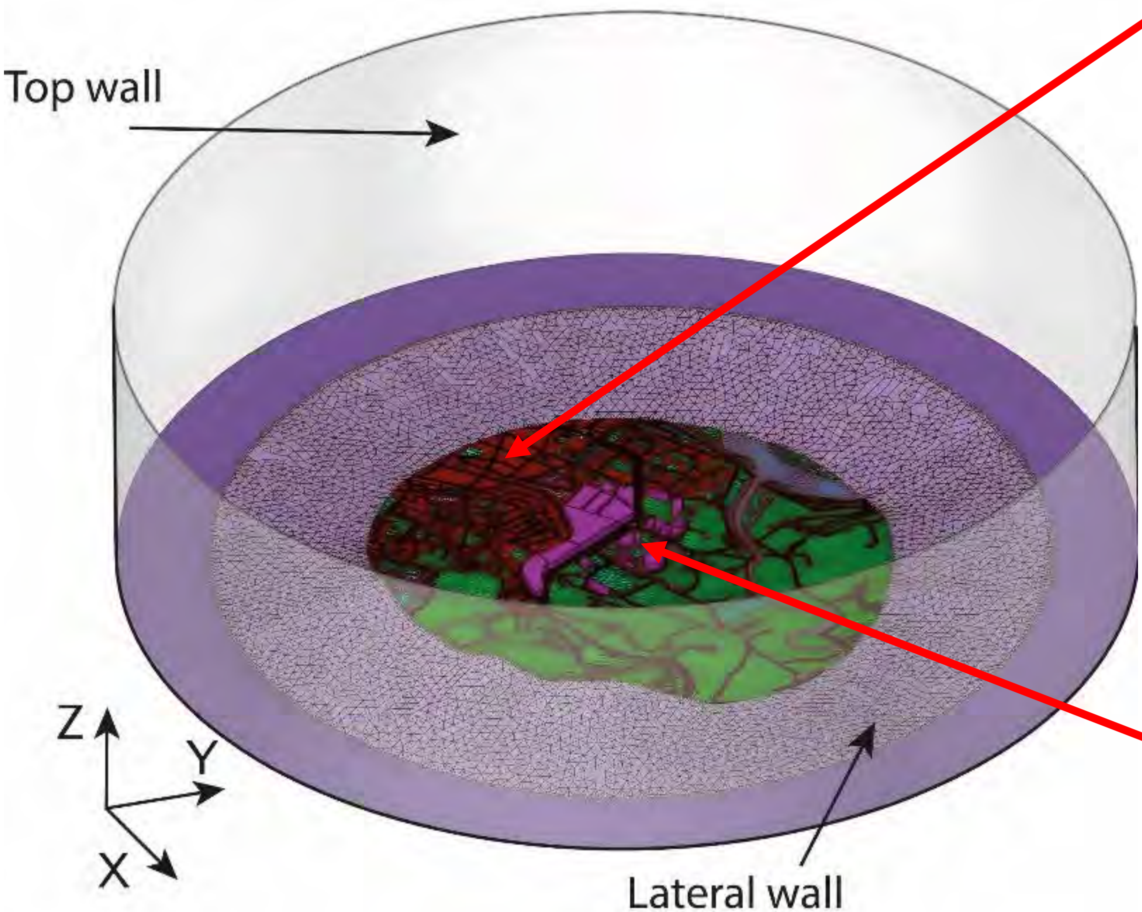
- **The roof edges are extruded down** to the surface terrain, thus generating the building surfaces.

- Once the surface was categorized, a **volumetric mesh was generated** (56M of cells) and used for the CFD simulation



	Surface categories	Boundary type	Roughness length (m)
	Water coverings	Wall function	0.05
	Transition area	Wall function	0.1
	Constant height ring	Wall function	0.1
	Paved or sealed areas, Roads, Paths and trails	Wall function	0.075
	Buildings, Sports constructions	Wall function	0.5
	Geometrically modelled buildings	Wall function	0.5
	Land with little or no vegetation, Unbuilt land, Grassland	Wall function	0.05
	Herbaceous crops, Vineyard, Shrub-grassland, Orchard, Artificial green area and urban trees	Wall function	0.1
	Wooded, Grass-wooded, Non-citrus fruit trees, Conifers, Evergreen trees, Deciduous trees	Wall function	0.7
	Lateral wall	ABL Conditions	
	Top wall	Symmetry	

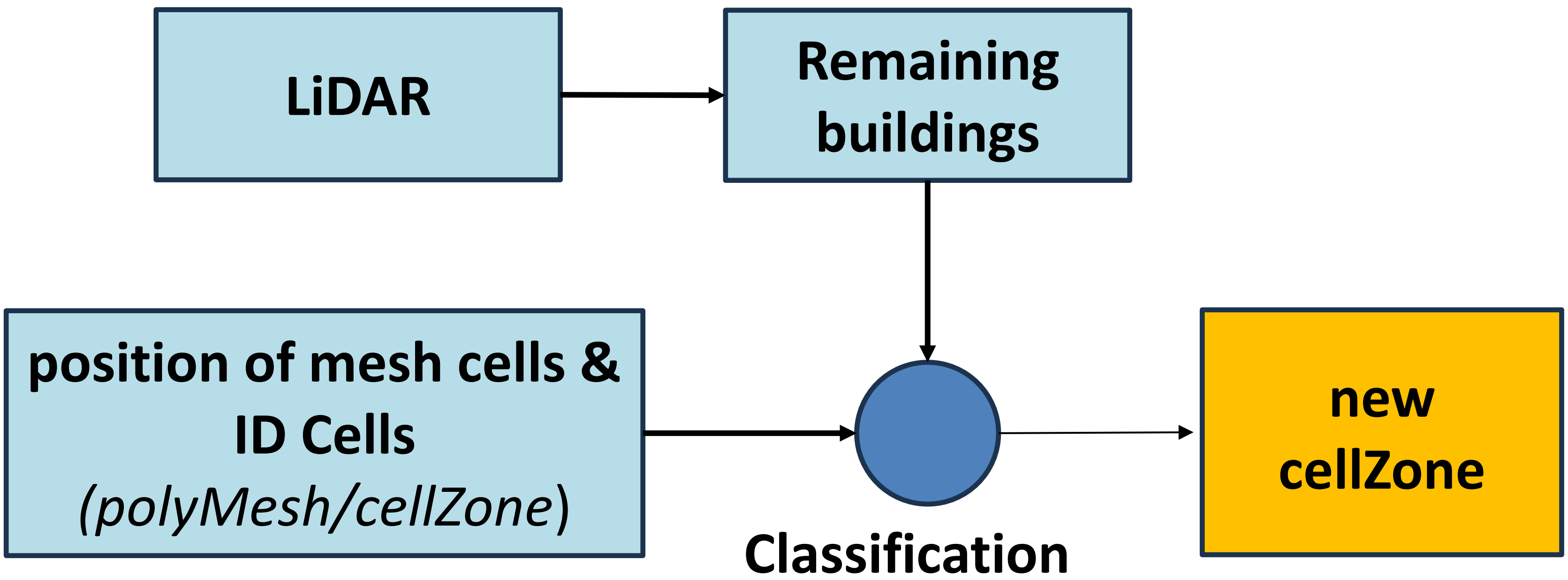
(II) Porous cell categorization



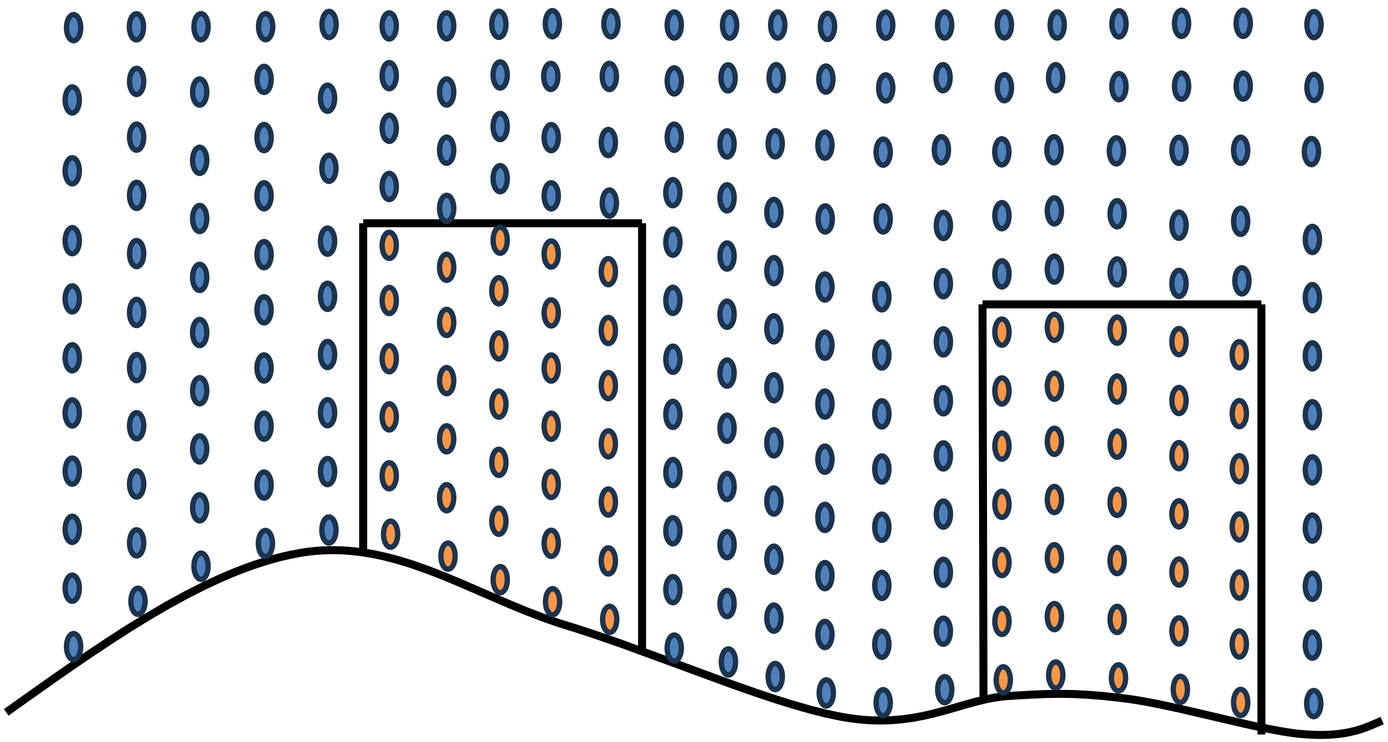
The **red surfaces are the footprints of the buildings that were not geometrically** modeled.

Only the **purple buildings** are **modeled geometrically.**

- **Objective**: Select the cells of the mesh that belong to the remaining buildings



- **LiDAR point cloud is voxelised**: to represent the area occupied on the ground by a building in 2D structured grid
- The **cells within the footprints are analyzed**: Those with a height lower than the roof are selected.



Graphical example of cells classification

- Since LiDAR points detect vegetation, the same **methodology** was **applied** to identify terrain cells with **vegetation**.

- After finding the mesh cells that corresponded to porous media, the **cellZone** file in the ‘polyMesh’ folder was modified to **including these new cellZones.**

- To **incorporate porous media** in OpenFOAM, the following steps must be taken:
  - *Solver:* ***porousSimpleFoam***
  - *Constant* (folder)> ***porosityProperties***

- Porosity model file:
  - ***Model: Darcy-Forchheimer***
  - ***CellZone: building/vegetation***
  - ***Parameters:*** **D, F**

```
..
porosity
{
    type            DarcyForchheimer;

    cellZone        vegetation;

    d   (0.00001 0.00001 0.0001);
    f   (2.076 2.076 2.076);

    coordinateSystem
    {
        type    cartesian;
        origin  (0 0 0);
        coordinateRotation
        {
            type    axesRotation;
            e1      (1 0 0);    //(0.7
            e2      (0 0 1);
        }
    }
}
```

- **Darcy-Forchheimer model** is used, which models a source term (S_m) in the momentum equation.

$$S_m = -\Bigg(\underbrace{\mu\mathbf{D}}_{\text{Viscous loss}} + \underbrace{\frac{1}{2}\rho\, tr(\mathbf{U}\cdot\mathbf{I})\,\mathbf{F}\Bigg)}_{\text{Inertial loss}}\mathbf{U}$$

- The parameters of the model:

$$\boldsymbol{D} = diag\left(\frac{1}{\alpha_x}, \frac{1}{\alpha_y}, \frac{1}{\alpha_z}\right) \qquad \boldsymbol{F} = diag\left(F_x, F_y, F_z\right)$$

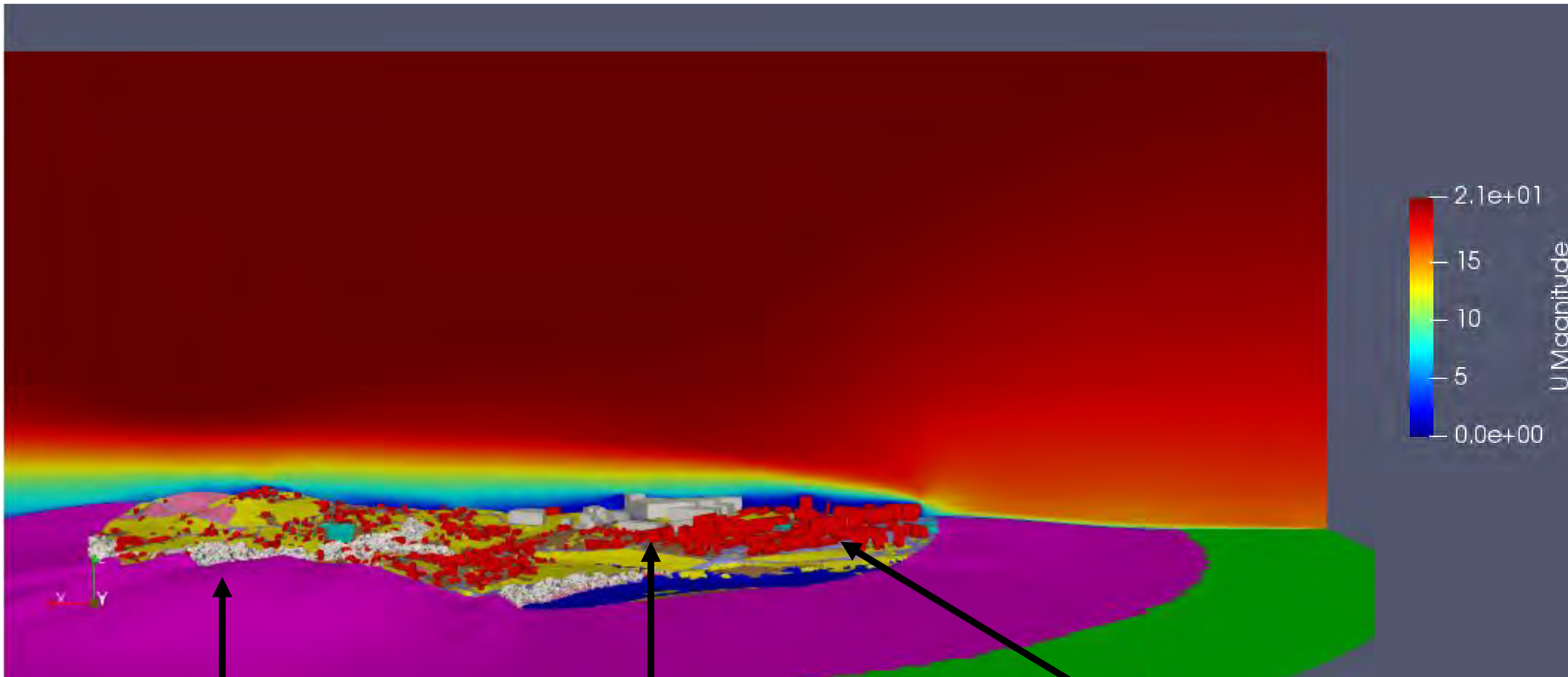
- **Buildings**: To model them as impermeable media, a high value was assigned to $\mathbf{D}$ and $\mathbf{F}$, specifically $\mathrm{D_i} = \mathrm{F_i} = 2000$).
- **Vegetation**: An expression was obtained to model $\mathbf{F}$ by combining vegetation model of Simscale [2] and DF.

$$\boldsymbol{F}_i = 2\, LAD\, C_D = 2{,}075$$

$LAD = 1{,}25\ [1/m]$ (BBDD [3])

$Cd = 0{,}83\ [-]$ (using [4-6])

Results

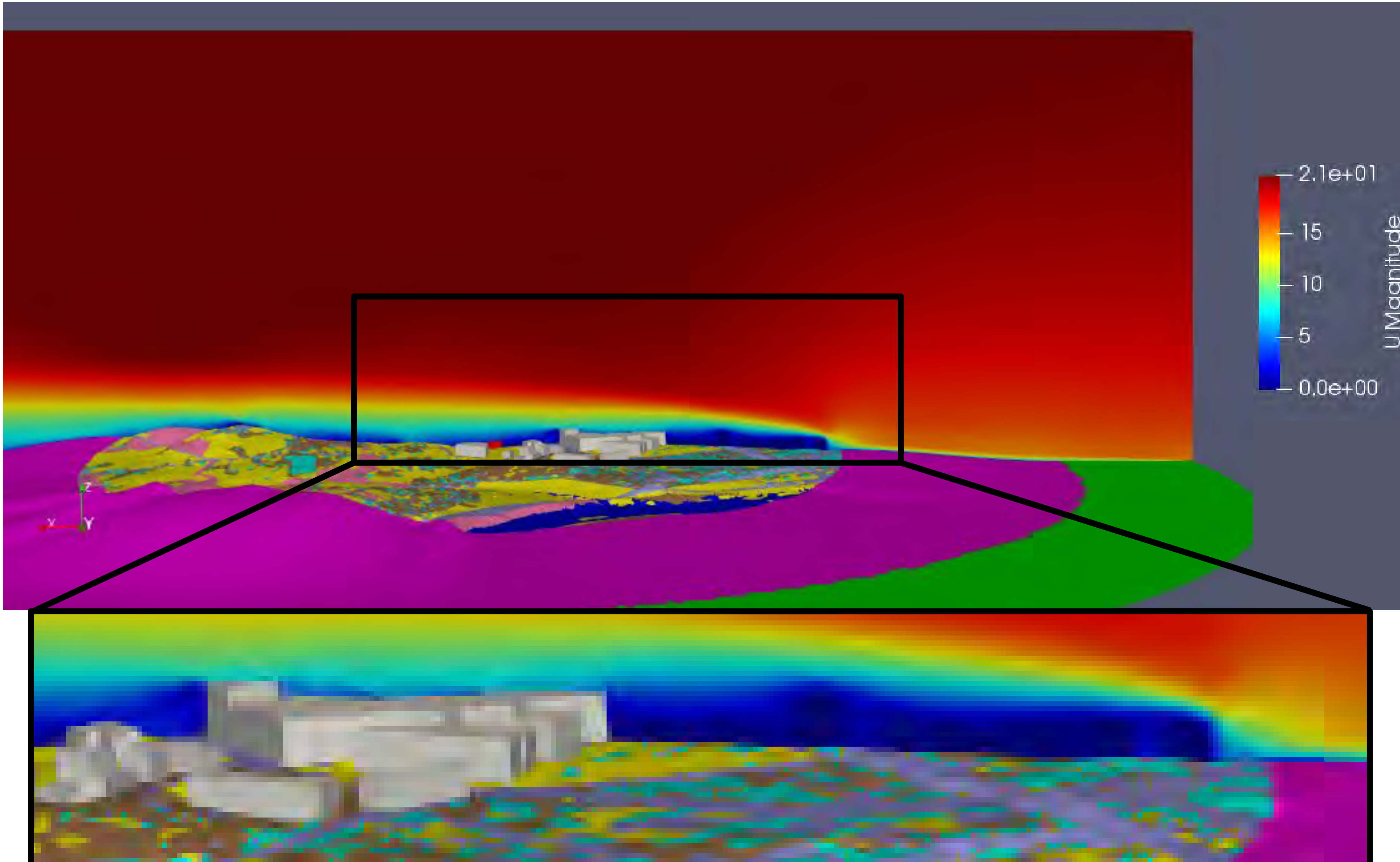


Vegetation (white)

Buildings geometrically modeled (Gray)

Buildings modeled as porous (Red)

- The porous cells are hidden



Conclusions

- A new methodology has been designed to automate the simulation of urban environments in CFD using geospatial data

- The cell classification tool is very useful for other CFD problems, such as coupling a combustion model and treating tree cells as flammable media.

- In combination with dimensionality reduction tools, wind prediction tools could be developed for urban environments to help improve UAV flights in these settings.

- Authors

1. Gonzalo Veiga Piñeiro (gonzalo.veiga@uvigo.gal)
2. Enrique Aldao Pensado
3. Pablo Dominguez Estevez
4. Gabriel Fontenla Carrera
5. Fernando Veiga Lopez
6. Higinio Gonzalez Jórge (Prof.) (higiniog@uvigo.gal)
7. Elena Martin Ortega (Prof.) (emortega@uvigo.gal)

References

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[2] https://www.simscale.com/docs/analysis-types/pedestrian-wind-comfort-analysis/advanced-modelling/*}*

[3] https://daac.ornl.gov/VEGETATION/guides/LAI_Woody_Plants.html

[4] [4] *C. C. Bekkers, N. Angelou, E. Dellwik, Drag coefficient and frontal area of a solitary mature tree, Journal of Wind Engineering and IndustrialAerodynamics 220 (2022) 104854. doi:10.1016/j.jweia.2021.104854.*

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[6] R. Gonc¸alves, C. Linhares, T. Yojo, Drag coefficient in urban trees, Trees 37 (1) (2023) 133–145. doi:10.1007/s00468-019-01951-1.

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