

# Automatization of mesh generation from point cloud 3D scans to model the surface atmospheric boundary layer

Mahitosh MEHTA<sup>1</sup> Martin FERRAND<sup>1,2</sup> Samuel GAUCHER<sup>2</sup>

<sup>1</sup>CEREA, École nationale des ponts et chaussées, EDF R&D, Île-de-France, France  
<sup>2</sup>EDF R&D



## Introduction

**Context:** Handling intricate geometries in industrial computational fluid dynamics (CFD) simulations present significant challenges. However, advancements in 3D scanning technologies now enable the detailed capture of highly complex structures for use in CFD models. The study presented in this article introduces the use of a new methodology for automatically reconstructing solid geometries from 3D scan data [2] integrating them into flow simulations.

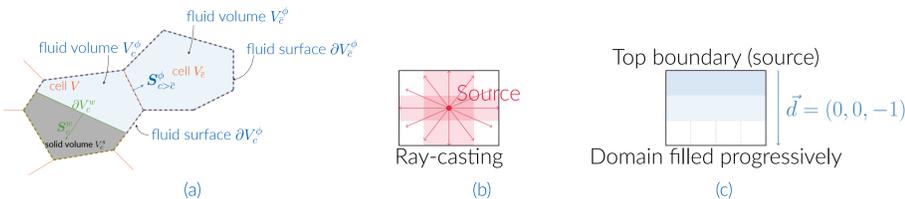
**Objectives:** The classic body-fitted mesh (BFM) paradigm consists in removing the solid domain from the mesh and imposing the boundary conditions directly on the mesh boundary, whereas in Immersed boundary method (IBM), the solid is embedded inside the fluid mesh and the boundary conditions are imposed at the fluid-solid interface inside the mesh within a co-located finite volume framework. This strategy eliminates the need for the traditionally labour-intensive and time-consuming body-fitted meshing process, while maintaining good accuracy and computational robustness. As the aim of this work is to develop an automatic framework to apply a point cloud to simulate fluid dynamics directly, it is a crossroad of multiple scientific domains, including immersed boundary computational fluid dynamics and geometry processing.

## HD LiDAR campaign description

An airborne laser scanning system allows distance measurements to be made between a point on an aircraft and points on the ground, whose frequency domains can be in the visible or infrared range. Coupled with a scanning system, a GPS (Global Positioning System) and an inertial unit, it makes it possible to obtain a georeferenced point cloud during an acquisition. Under the national HD LiDAR (High Density Light Detection And Ranging) programme, the IGN (Institut national de l'information géographique et forestière) produces and disseminates a 3D map of the entire soil and surface of France in LiDAR data[1]. Beyond the fundamental x, y, and z positional values, LiDAR data points are associated with a range of attributes that offer valuable insights into the characteristics of the scanned environment.

## Solid surface reconstruction and initial filling of a fluid domain

It should be noted that a specific finite volume control (cell)  $c$ , in which solid obstacles may be entirely or partially included (fig. 1a), then the new control volume is composed of fluid boundaries  $\partial V_c^f$  and solid boundaries  $\partial V_c^s$ . The volume occupied by the fluid within cell  $V$  is denoted by  $V_c^f$ , whose magnitude can be expressed as a function of the porosity  $\varepsilon$  by  $\varepsilon V$ .



**Figure 1.** fig. 1a, sketch of a cell  $V$  with a solid volume  $V_s^s$  and connected to the cell  $V_c$  through a fluid face  $S_{c \rightarrow s}^f$ . The solid wall  $\partial V_c^s$  separates the fluid volume  $V_c^f$  from the solid volume  $V_s^s$ . Illustration of radial fill in the fig. 1b. Top-down pure convection fill process in the fig. 1c. Filling condition ( $\psi = 1$ ) is injected at the top boundary and propagates in the direction  $\vec{d}$ .

- Surface reconstruction is a key process, transforming a set of points into a continuous surface. Generally surface reconstruction techniques can be divided into three categories: implicit, explicit, and hybrid.
- The algorithm used here to reconstruct the surface takes a hybrid approach by leveraging data points within a cell to form a plane that reduces the mean square error to its minimum.
- Two algorithms developed to extract the solid domain from the computational domain.
  - Radial filling** - an approach based on the gradient of porosity and the source of the scan.
  - Directional filling** - an approach based on pure convection which uses a direction vector.
- Radial filling** - numerically reproduces what a scanner does: from a point source where the scanner is located, numerical rays are traced in all directions (like the Discrete Ordinate Method to solve the radiative transfer equation).

$$\nabla \psi \cdot (\mathbf{x} - \mathbf{x}_o) = (1 - \psi) \delta_{\mathbf{x}_o}(\mathbf{x}) \quad (1)$$

$$\sum_{f \in \mathcal{F}_c} [\psi_f - \psi_c] (\mathbf{x}_f - \mathbf{x}_o) \cdot \mathbf{S}_{f_c}^{\psi,0} = (1 - \psi_c) \Omega_c \mathbf{1}_{\mathbf{x}_o \in c} \quad (2)$$

- Directional filling** - Unlike ray-casting-based formulations which trace fill from a point source outward, for "Directional fill" we model scalar transport as a directional flux propagating from a known inflow boundary (e.g., the top of the domain) downward as presented in fig. 1c.

$$\nabla \psi \cdot \mathbf{d} = 0 \quad (3)$$

$$\sum_{f \in \mathcal{F}_c} [\psi_f - \psi_c] \mathbf{d} \cdot \mathbf{S}_{f_c}^{\psi,0} = 0 \quad (4)$$

with  $\mathbf{x}_o$  being the source position,  $\mathbf{d}$  being the fixed convection direction and the indicator function  $\mathbf{1}_{\mathbf{x}_o \in c} = \int_c \delta_{\mathbf{x}_o}(\mathbf{x}) d\psi = 1$  if the cell contains the source, and zero otherwise. The scalar at the faces  $\psi_f$  is estimated by an upwind scheme. Cells with more than three scan points are penalised and stop the rays (i.e., are fully solid cells with  $\mathbf{S}_{f_c}^{\psi,0} = \mathbf{0}$ ). Thus,  $\psi$  fills the fluid domain ( $\psi = 1$  for fluid and  $\psi = 0$  for solid). As many loops as available scans are performed, storing the maximum of  $\psi$ . If  $\psi$  bigger than one-half, the cell is considered fluid. It means that  $\nabla_c \psi$  points towards the fluid region in solid cells in contact with the fluid.

This directional fill formulation enables efficient propagation of fill from the inflow boundary without requiring ray-tracing or distance computations. It is particularly well-suited for applications where the fill direction is uniform and known a priori, such as gravity-driven flooding or downward expansion in immersed boundary reconstruction.

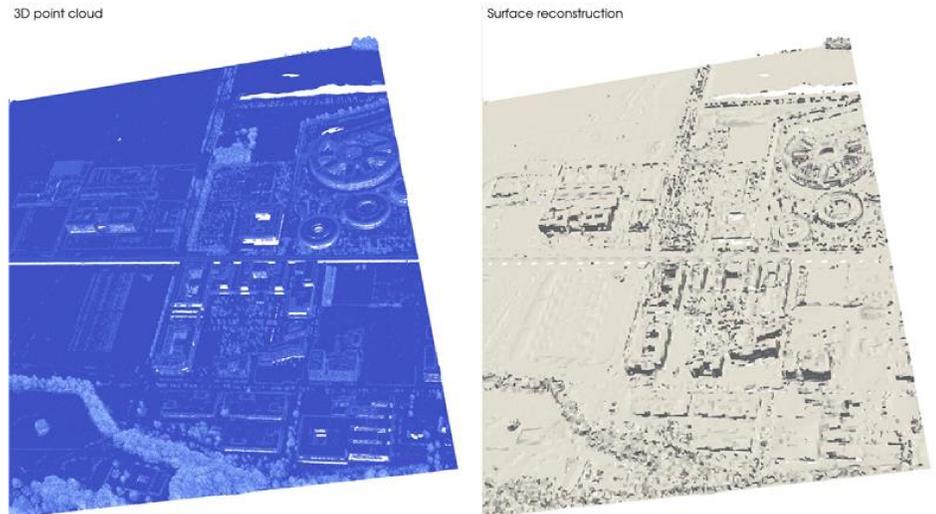
## Immersed plane orientation

- The plane's normal orientation is essential to identify between solid and fluid regions. The definition of the normal orientation is not an easy task.
- This step is critical for accurately representing the geometry and physical behaviour at the interface between fluid and solid regions, such as in simulations involving immersed boundaries or porous media.

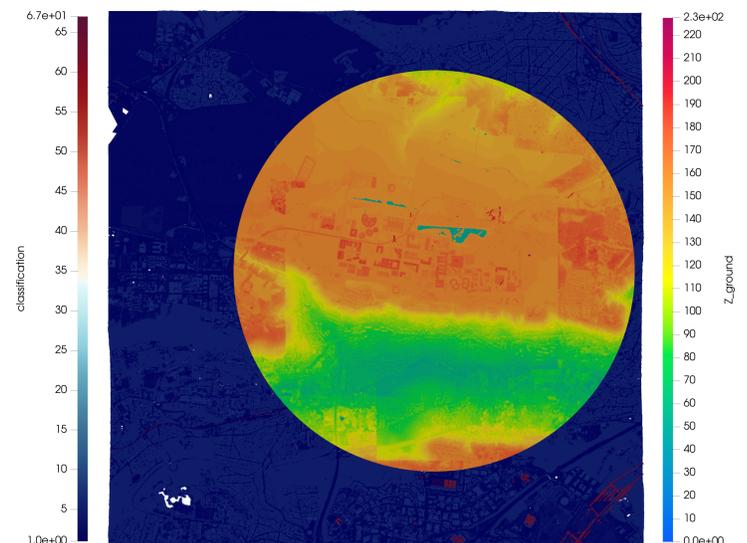
- Algorithm for the first approximation of the normal orientation:
  - temporarily enabling solid cells to compute the porosity gradient across the entire domain and determining the direction toward the solid region from that;
  - flipping face normal vectors if they are misaligned with the porosity gradient or a specified direction vector (for directional filling);
  - restoring the fluid-only computation mode by disabling solid cells.

## Results

- The high-resolution point cloud data obtained from LiDAR scans serves as input for surface reconstruction using code\_saturne (<https://www.code-saturne.org>), an open-source CFD software developed by EDF.
- This process enables detailed simulations of atmospheric flows over complex terrains, supporting a range of environmental and engineering applications.



**Figure 2.** representation of solid reconstruction from 3D scan point cloud of Sirta.



**Figure 3.** representation of the computed distance to the ground ( $z_{ground}$ ) in the computational domain (represented by the circular disk) with point clouds in the background for the site of Sirta.

- Figures 2 and 3 shows the successful reconstruction of the solid surface from the point clouds and successful computation of the distance to the ground for the atmospheric flows.

## Conclusion and Perspectives

- We have successfully managed to automatize the solid mesh formulation from the provided point clouds. This allows an automatic definition of the geometrical quantities to avoid the time-consuming mesh generation step of the body-fitted method.
- A detailed algorithm to fill the fluid domain and have the first approximation of the solid plane's orientation is implemented successfully, which gives us the solid-fluid interface.
- Simulations of atmospheric flow over complex terrains has been successfully carried out without the use of the turbulence models.
- Simulations of atmospheric flow with different turbulence models has to be carried out.
- Further development in order to fill the holes-which is one of the major defects of point clouds-has to be carried out.
- The LiDAR dataset includes multiple classification types such as building, bridges, vegetation, etc., each with a specific numerical value. An algorithm to apply automatic identification of materials to impose local properties has to be developed.
- Further developments to identify the physical and geometrical criteria for automatic local mesh refinement have to be done.

## References

- Institut national de l'information géographique et forestière (IGN). Documentation on lidar hd - version 1.0. Technical report, Institut national de l'information géographique et forestière (IGN), 2024. Accessed: 2024-11-08.
- Gabriel F Narváez, Martin Ferrand, Thomas Fonty, and Sofiane Benhamadouche. Automatic solid reconstruction from 3-d points set for flow simulation via an immersed boundary method. In *International Conference on Finite Volumes for Complex Applications*. Springer, 2023.