

Geometry preparation for air quality prediction in complex environments: The case of Venice airport

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SUMMARY

Air quality assessment in complex environments is highly sensitive to local wind conditions and pollutant dispersion mechanisms influenced by building aerodynamics. This may be the case of international airports, where emissions from aircraft operations and ground support equipment contribute to NO_x, CO, PM and ultrafine particle exposure risk for passengers and workers. Using *City4CFD*, we reconstruct an LoD1.2 geometry of Venice airport (Italy) from lidar point clouds and 2D polygons, and document key practical challenges that derive from input data. For lidar point clouds, these relate to incorrect coordinate reference system (CRS) information in metadata, low point cloud density and classification. For 2D polygons, they concern reconstruction inaccuracies for large polygons, and the inability to represent overhanging structures within the current framework. We discuss how targeted preprocessing of the data can mitigate these issues and highlight implications for pollutant source representation and future high resolution airport air quality modelling.

Keywords: *geometry reconstruction, air pollution, City4CFD, CFD, airport*

1. INTRODUCTION

Air quality in complex environments is significantly affected by geospatial conditions, vegetation, waterbodies as well as the geometry, composition, and arrangement of the buildings (Zhang et al., 2005). The complex interaction of atmospheric flow and flow regime around the building may hinder the dispersion of pollutant and affect the overall air quality in urban environments (Lee and Mak, 2021). Therefore, assessing the local wind flow and pollutant dispersion at airports is becoming important as passengers and ground workers are exposed to emissions and operations near the terminals (Bendtsen et al., 2021). This is a case study of Venice Marco Polo airport, one of the busiest airports in Italy, with 11.6 million passengers and almost 90,000 aircraft movements in 2024. The airport is located between the eastern edge of the Po Valley and the Adriatic Sea, a well-known European hotspot for air pollution (Finardi et al., 2014). Recent studies have revealed that airports are recognised sources of nitrogen oxides (NO_x), carbon monoxide (CO), particulate matter (PM) and ultrafine particles, arising from aircraft engines (especially in the landing–take-off cycle), ground support equipment, auxiliary power units and landside traffic (Innocente et al., 2020). In such environments, predictions from microscale computational fluid dynamics (CFD) simulations can strongly vary depending on the detailed 3D geometry. However, preparing geometry of complex environments remain a major challenge, especially where raw lidar data are not openly available.

2. GEOMETRY RECONSTRUCTION

When simulating air quality with CFD methods, it is important to pay attention to the small details of the geometry. Previous studies showed that balconies and chimneys, being relatively detailed

geometries, can strongly affect the wind flow field and pollutant dispersion near façade of buildings (Zheng et al., 2022). Following recent developments in automatic 3D city reconstruction, we used the open-source *City4CFD* software (Pađen et al., 2024) to automatically generate the 3D geometry of Marco Polo Venice airport and its surroundings.

2.1. Common challenges in the automatic urban reconstruction process

City4CFD software generally needs two types of input data: 2D polygons (building footprints, semantic surfaces such as vegetation/water) and elevation information (from values stored in the 2D polygon fields or from aerial point clouds). In our case, we used 2D polygons from OpenStreetMap (Bennett, J., 2010), and the point clouds were provided by the *Ministry of Environment and Energy Security* of Italy. The point clouds provided integrated metadata information with latitude and longitude of area of interest (AoI), and the associated Coordinate Reference System (CRS).

2.1.1. CRS inconsistencies in lidar point clouds

A first critical issue concerns the CRS information embedded in the lidar data. In our case, for example, within the raw point-cloud dataset provided, the LAS header was projected using as CRS EPSG:2030, which corresponds to a common CRS in Canada. However, our footprints were expressed using the local CRS EPSG:25833, leading to inconsistent coordinates from the two-input data and to the consequent misalignment when the data were loaded together as it can be seen in Figure 1.

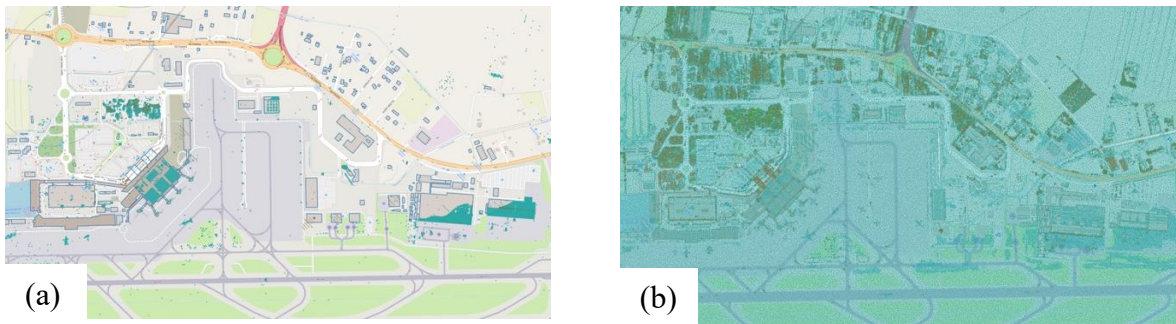


Figure 1: Unclassified point cloud over Venice airport: (a) wrong EPSG (2030); (b) reprojected in EPSG (25833). Basemap obtained from OSM, blue dots represent the point cloud.

2.1.2. Point cloud density

The targeted Level of Detail (LoD), which represent how much details in roofs are reconstructed (Biljecki et al., 2016) is fundamentally constrained by the density and quality of the input lidar data. *City4CFD* requires enough points per square metre on roofs and ground surfaces to reliably estimate building heights and terrain shape (Pađen et al., 2024). In the Venice airport dataset, point densities over hard surfaces are generally adequate for LoD1.2, which is the lowest level of detail that *City4CFD* reconstructs. However, coverage is not uniformly dense enough to reconstruct higher LoDs (1.3, 2.2), which may include tilted roofs and small architectural details across the entire influence region (Figure 2).

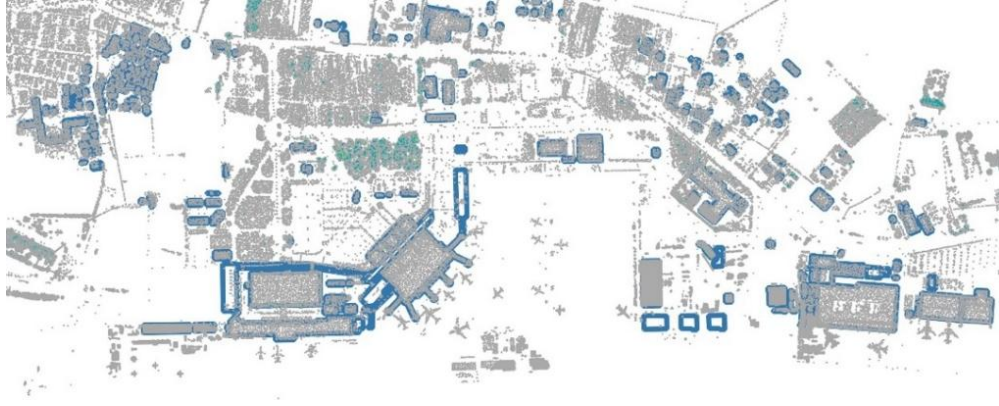


Figure 2: Unclassified off-ground point cloud data over building polygons of Venice airport and surrounding.

2.2.2. Reconstruction with large polygons

The Venice airport is embedded in an extensive lagoon (water surface), and the corresponding water polygons cover large, continuous areas. In the reconstruction pipeline, these polygons must be intersected with the terrain and integrated as surface layers. We observed that providing a single, very large water polygon to *City4CFD* could lead to incomplete generation of the water OBJ layer as shown in Figure 3 (a), due to the handling of extended polygons. To address this, the lagoon water surfaces were partitioned into smaller, logically coherent tiles aligned with the influence and city regions. After this subdivision, the reconstruction successfully produced water surfaces that were correctly imprinted into the terrain (Figure 3b). Given the strong dynamical role of the lagoon in modulating wind speed and stability around the airport, robust representation of water surfaces is essential for credible air-quality simulations.

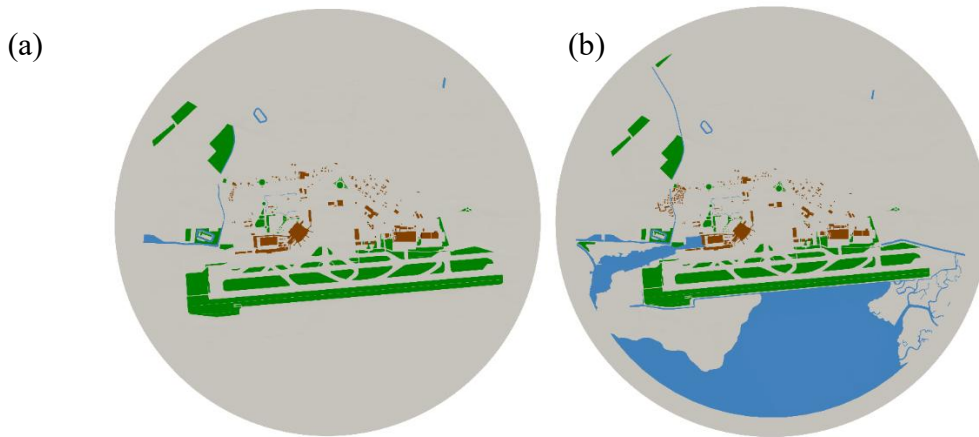


Figure 3: Final reconstruction of geometry with: (a) incomplete water obj.; (b) complete water obj.

2.2. Missing features

City4CFD reconstructs building geometries with 2D polygons and point cloud data or heights, reconstructing with a top view approach. Consequently, overhanging elements and undercut geometries – such as hanging bridge or airport fingers, cannot yet be explicitly represented. Figure 4 shows such effect for the Venice airport.

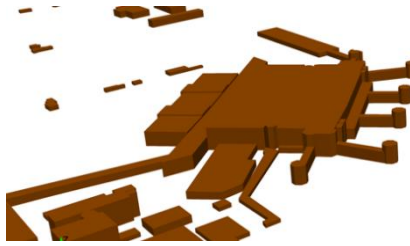


Figure 4: Airport terminal detail where the fingers are reconstructed until the floor.

3. POLLUTION SOURCES IN CFD SIMULATIONS

Beyond geometric fidelity, an additional modelling choice that can affect CFD based air quality assessments is the representation of pollutant emissions. Several wind tunnel and numerical studies have shown that pollutant emissions are idealised as line, point or volume sources. However, Qin et al., 2024 by comparing idealised line sources with multiple realistic vehicle sources has shown that such idealisations may be inadequate to reproduce the concentration fields generated by discrete emitters, especially in the near source region and close to façades.

4. FUTURE WORK

Future work will focus in performing CFD analysis that first compares our current geometry with a more detailed one where the airport fingers and the traffic line underneath are represented. Considering the available measurement data at Venice airport for this study, we will evaluate multiple source apportionment and set-up and compare the results with the measurements available. In addition, we will perform multiple wind direction evaluations based on the local wind conditions and pollutant dispersion modelling over the airport and nearby residential areas. This study will support exposure assessment and contribute to the design of mitigation and climate adaptation strategies for a complex environment such as an international airport.

REFERENCES

- Bennett, J. (2010). *OpenStreetMap*. Packt Publishing Ltd.
- Biljecki, F., Ledoux, H. and Stoter, J., 2016. An improved LOD specification for 3D building models. *Computers, environment and urban systems*, 59, pp.25-37.
- Bendtsen, K. M., Bengtson, E., Saber, A. T., & Vogel, U. (2021). A review of health effects associated with exposure to jet engine emissions in and around airports. *Environmental Health*, 20(1), 10.
- Finardi, S., Silibello, C., D'Allura, A., & Radice, P. (2014). Analysis of pollutants exchange between the Po Valley and the surrounding European region. *Urban Climate*, 10, 682-702.
- Innocente, E., Pecorari, E., Zannoni, D. and Rampazzo, G., 2020. Methodology choice could affect air quality interpretation? A case study for an international airport, Marco Polo, Venice. *Science of the Total Environment*, 707, p.135326.
- Lee, K.Y. and Mak, C.M., 2021. Effects of wind direction and building array arrangement on airflow and contaminant distributions in the central space of buildings. *Building and Environment*, 205, p.108234.
- Pađen, I., Peters, R., García-Sánchez, C., & Ledoux, H. (2024). Automatic high-detailed building reconstruction workflow for urban microscale simulations. *Building and Environment*, 265, 111978.
- Qin, P., Ricci, A. and Blocken, B., 2024. On the accuracy of idealized sources in CFD simulations of pollutant dispersion in an urban street canyon. *Building and Environment*, 265, p.111950.
- Zhang, A., Gao, C. and Zhang, L., 2005. Numerical simulation of the wind field around different building arrangements. *Journal of wind engineering and industrial aerodynamics*, 93(12), pp.891-904.
- Zheng, X., Montazeri, H. and Blocken, B., 2022. Impact of building façade geometrical details on pollutant dispersion in street canyons. *Building and Environment*, 212, p.108746.