ValUr: A High-Fidelity Dataset for Validation of Urban Pollution Dispersion Models – Project Overview and Geometry Preparation

Citation for the original published paper (version of record):
Pantusheva, M., Mitkov, R., Hristov, P. et al (2025). ValUr: A High-Fidelity Dataset for Validation of Urban Pollution Dispersion Models – Project
Overview and Geometry Preparation. Lecture Notes in Civil Engineering, 718 LNCE: 83-94.
http://dx.doi.org/10.1007/978-3-031-98893-6_9

ValUr: A High-Fidelity Dataset for Validation of Urban Pollution Dispersion Models – Project Overview and Geometry Preparation

Mariya Pantusheva[1](✉), Radostin Mitkov[1], Petar O. Hristov[1], Evgeny Shirinyan[1], Vasilis Naserentin[2], A. K. R. Jayakumari[3], Stefanie Gillmeier[3], and Anders Logg[2]

[1] GATE Institute, Sofia University "St. Kliment Ohridski", Sofia 1164, Bulgaria
mariya.pantusheva@gate-ai.eu

[2] Department of Mathematical Sciences, Chalmers University of Technology, 412 969 Gothenburg, Sweden

[3] Building Physics and Services, Department of the Built Environment, Eindhoven University of Technology, P.O. Box 513, 5600 MB Eindhoven, The Netherlands

Abstract. Computational fluid dynamics (CFD) models, used independently or integrated into city digital twins, can predict air pollution dispersion and support informed decision-making in urban planning. While modelling complexity and capabilities have increased, systematic validation and uncertainty quantification remain crucial, yet are among the least understood and applied aspects of the analysis process.

To address this issue, the ValUr project, supported by the ERIES programme, aims to establish a best-practice protocol for urban CFD validation and to generate a high-quality, open-access pollution dispersion dataset.

This work introduces the project scope, motivation, and goals, detailing early project activities, including the identification of the study area - part of the city centre of Sofia, Bulgaria, where air quality is a pressing concern, and the creation of a scaled geometry suitable for physical model-making, wind tunnel testing, and CFD simulations. The geometry goes beyond the basic level of detail (LoD) 1, typically used in validation databases and reaches LoD 2.2, capturing the complex building morphologies and realistic urban conditions of the area.

By sharing protocols and data openly, ValUr seeks to promote the importance of model reliability and to encourage validation consistency within the computational wind engineering community.

Keywords: Model validation · Urban pollution dispersion modelling · Wind tunnel testing · Geometry preparation

G. O'Reilly and G. M. Calvi (Eds.): ERIES-IW 2025, LNCE 718, pp. 83–94, 2025.
https://doi.org/10.1007/978-3-031-98893-6_9

1 Introduction

1.1 Project Motivation

Urban areas today face serious challenges related to air pollution, a problem that directly affects public health and quality of life. In many cities, including Sofia, measured levels of particulate matter and gaseous pollutants frequently exceed the thresholds recommended by health organizations.

Despite advances in computational fluid dynamics (CFD) models, reliably predicting how pollutants spread through complex urban environments remains challenging. The issue of reliability is made even more significant in the paradigm of digital twin creation, which sees multiple models and data streams being connected in a system to provide real time insights into the operation of a physical asset. Contrary to the popular technocratic opinion, digital twins and massive volumes of data do not automatically provide a reliable representation of the investigated system. The core tenet of model reliability, instead, is bringing trust in the model not by its complexity or resolution, but by careful uncertainty quantification and validation, tailored to the intended application of the model.

The ValUr project aims to establish this perspective through the design and execution of an experimental wind tunnel campaign, judicial uncertainty quantification and validation, and objective predictive capability estimation for urban pollution dispersion CFD models.

1.2 Overview of ValUr Work

To achieve the goals described in Sect. 1, the project is split into four general stages – model making, wind tunnel testing, data analysis and validation.

Model making includes the selection of a suitable region in Sofia, the creation of the geometry and the manufacturing of the test article to be used during the experimental campaign. The rest of the paper is dedicated to this process.

The experimental campaign will be carried out in the atmospheric boundary layer wind tunnel of Eindhoven University of Technology (TU/e). To ensure good quality data is collected during the experimental campaign, the tests will focus on one flow direction and the detailed concentration measurements of a passive scalar gas, released from two point sources in turn. Measurements will be done at locations flagged as important to the area and by preparatory CFD simulations.

The raw data of pollutant concentrations, approach flow conditions, and release rates, among others, will be analysed and cast into a format suitable for validation work. Particular focus is placed on quantifying uncertainty from different sources to ensure the effect of potential errors and various unknowns is accounted for.

Reynolds-averaged Navier-Stokes (RANS) solvers will be used for some of the preliminary screening tests, but for the core of the validation work, the modelling paradigm will be large-eddy simulation (LES). The computational and validation aspects of the work will be covered in a future work.

1.3 State of the Art of Geometry Preparation for Wind Tunnel Testing

Scale modelling for urban wind tunnel testing for pollution dispersion has progressed considerably since the early work of Castro and Robins [1] and Stathopoulos and Baskaran [2], who used handcrafted wooden blocks to represent simplified environments with limited geometric fidelity. The advent of CAD-based approaches [3] and parametric modelling [4] allowed more systematic geometry variations, while 3D printing methods outlined in [5] pushed physical models toward unprecedented amount of detail, including entire and GIS-based workflows in the process [6, 7].

However, this has given rise to another area of research, namely, the identification of the level of geometric detail to be included in the model. To this end, Hertwig et al. [8] proposed methods for selecting essential features when refining models. Carpentieri and Robins [9] built on their work by assessing how different abstraction levels affect flow predictions. A notable example of such an abstraction level is the inclusion of roof profiles, which Yassin [10] demonstrated can significantly alter dispersion behaviour. Despite the significant amount of work done over the years, some challenges, such as representing urban structures at multiple scales [11] and adapting geometric detail to target areas [12], remain open issues.

Manufacturing techniques have also seen significant advancement, integrating precision stereolithography [13], multi-material 3D printing [14], among others. These developments allow the focus of physical modelling to shift to high utilisation and sustainability using modular designs [3] and standardized connections [15].

1.4 Objectives and Outcomes

This paper focuses on creating a scaled model for the ValUr project wind tunnel tests, which preserves critical features that affect the flow, while addressing practical fabrication constraints. It is meant to document the process of geometry creation for wind tunnel testing and CFD modelling, so that it can be used and improved on by the computational and experimental wind engineering communities. The practical implementation of the workflow is illustrated on the ERIES ValUr project geometry. The remainder of the paper is structured as follows and is shown in Fig. 1. Section 2 describes the requirements and selection process for the test area and some scaling considerations. The main body of the work on preparing the geometry for validation tests is presented in Sect. 3. Section 4 summarises the main conclusions of the work and outlines the next steps in ValUr.

2 Study Area and Model Setup

Given that the overall goal of ValUr is to promote the importance of validation in computational wind engineering, the region of the city to use and the most appropriate scale of the wind tunnel model had to be carefully determined.

2.1 Region Selection

The main driver behind the choice of region was the level of air pollution it experiences and a somewhat inhibited ventilation. In an urban context, elevated levels of air pollution

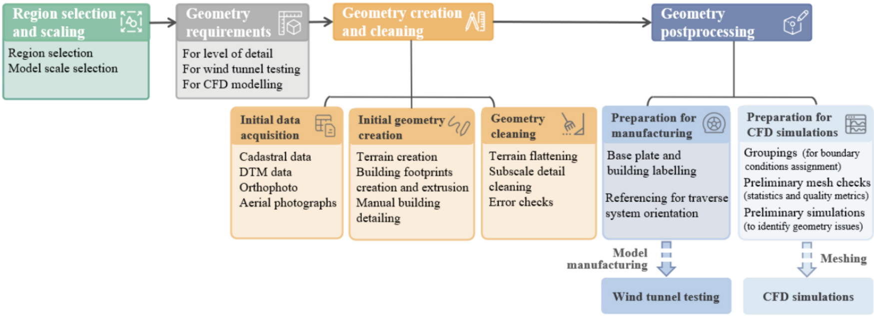


Fig. 1. Graphical representation of the geometry preparation workflow.

is associated with proximity to a pollution source in the direction opposing the prevailing winds for the region. The principal pollution source in Sofia is road traffic, which means that built-up areas with roads, running perpendicular to the wind, are candidates for elevated pollution levels. To identify suitable test model locations, major roads in the city were listed, with those roads that frequently experience congested traffic chosen for the next stage of the selection process. Sofia has five official meteorological and air quality stations in the city, which do measure wind velocity, but these measurements are not reliable because they are strongly affected by the presence of buildings and local terrain. Instead of using this data to determine the prevailing wind direction over the city, annual data from the airport for several years was obtained and aggregated [16]. The resultant directional wind rose is shown in Fig. 2, which clearly indicates west-northwesterly, east-southeasterly and easterly winds dominating the landscape. Thus, a region with a busy road running north-northeast to south-southwest is a good filter for locations to conduct the validation experiments.

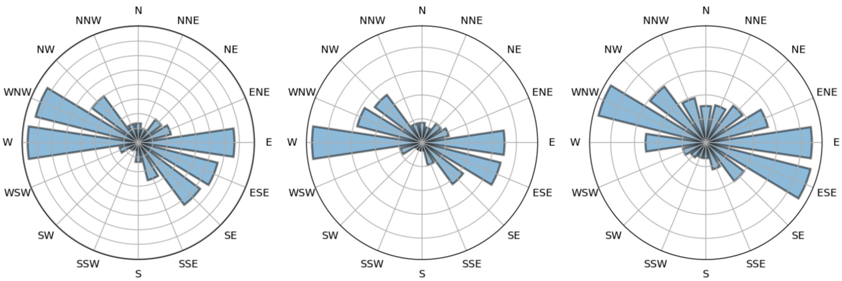


Fig. 2. Directional wind roses for Sofia airport for 2007, 2010, and 2018 (left to right).

Several sites around the city fit this requirement. A subset of these is shown in Fig. 3. The next major selection criteria were that the area around the road be heterogeneous in terms of building heights and layouts close to where the measurements are to be taken (referred to hereafter as the *inner region*) to promote flow.

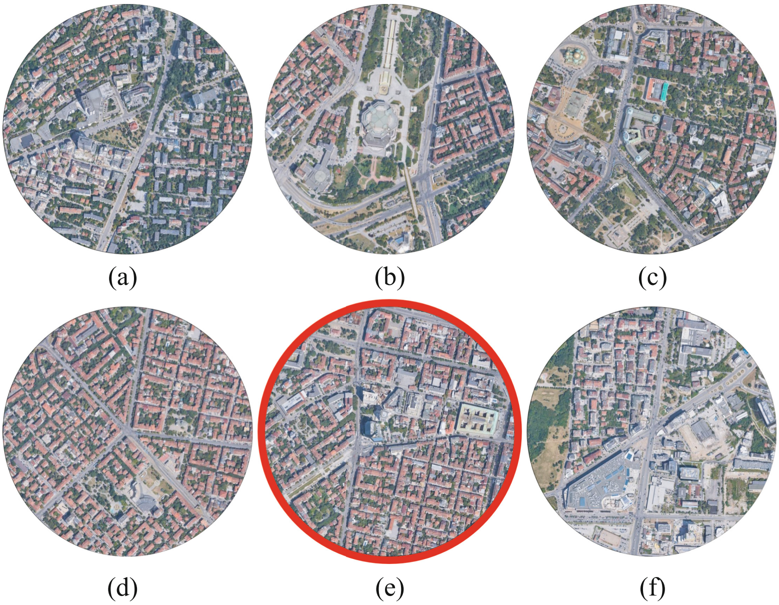


Fig. 3. Shortlisted locations in Sofia (selected region marked in red), images source: Google Maps

mixing, but at the same time exhibit a degree of homogeneity in the *outer region* to ensure the flow reaches a steady state more quickly. It can be seen that the regions depicted on Fig. 3(b)-(e) all fit this criterion relatively well. Another criterion that was enforced concerning the test area is that regions with large green spaces and dense vegetation were avoided, to minimise the extent of uncertain and unidentifiable phenomena in the test campaign and, ultimately, maximise the quality of validation [17, 18]. This rules out the regions in Fig. 3(b) and (c). Finally, regions with large roads aligned with the wind direction, or other means of quick ventilation were also discarded to focus on challenging setups commonly avoided in validation. Thus, the region around Sofia Courthouse, shown in Fig. 3(e) was chosen, as it exhibits all desirable features outlined above. It is worth noting that even though none of the areas shown in Fig. 3 would have made a better candidate by small relocations of the circular perimeter, there are, naturally, many other regions in Sofia that could have been considered. Some additional factors that weighed in on the decision were the presence of many pedestrian streets and points of interest, cultural buildings, and the overall interesting architectural landscape, featuring what will be Sofia's fourth-largest building upon its completion.

2.2 Model Scale

Urban wind tunnel model scales used in literature vary from 1:225 to 1:350 or smaller[1]. There are several constraints in choosing the model scale for the ValUr experimental campaign. Perhaps the most important of these is the *blockage ratio*, computed as the

[1] Models used in the CEDVAL database.

ratio of the sum of the projected frontal areas of the model and of any test equipment to the overall area of the test section of the wind tunnel. The overall blockage ratio should be below 5% for closed section wind tunnels, such as the one at TU/e, unless appropriate correction for edge effects are applied [19, 20]. Since the goal of this project is to produce a high-quality dataset, all effort is made to keep such empirical corrections to a minimum. For the 6 m^2 test section of the tunnel, this translates to a maximum overall frontal area of 0.3 m^2. Another important constraint for the scale is the minimum manufacturable detail size, which in this case was determined at 1 mm. Considering these two constraints and considering points of interest in the region, the scale was chosen to be 1:350. For the 2.6 m diameter turntable at the wind tunnel, this resulted in a 910 m region, with a scaled, projected, windward area of 0.254 m^2 (approx. 4.2%), enough to accommodate the test equipment within the allowable 5% blockage ratio.

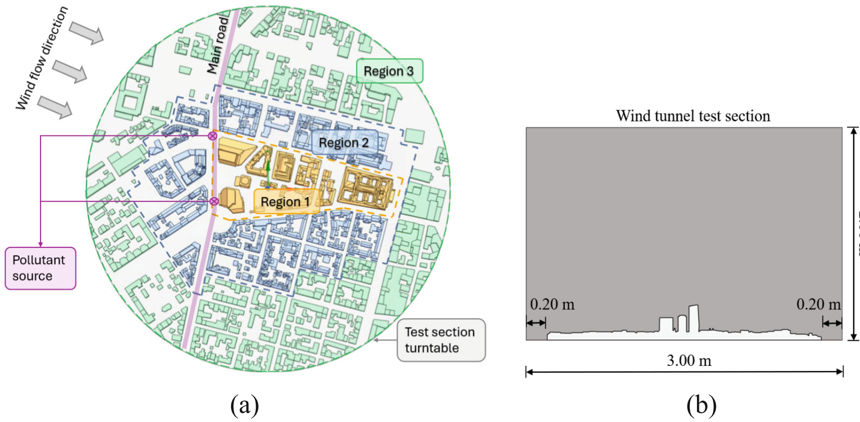


Fig. 4. Scaled model. (a) Zoning; (b) Cross-section.

3 Geometry Preparation

In the next step, creation of the urban geometry representation, it was important that it can be effectively utilized for both experimental and computational modelling. Having such a geometry can facilitate the compatibility and consistency between the two analysis types, reduce uncertainties, and improve the quality of the validation dataset on urban pollution dispersion that will be produced under the ValUr project.

This section describes the procedure how the selected target region, identified in Sect. 2, was transformed into a 3D-printed wind-tunnel model that captures relevant urban features with an adequate level of detail. For this purpose, a framework of requirements was formulated based on the best practices outlined in wind-engineering standards and existing guideline documents, further denoted as best-practice guidelines (BPGs) [17–27]. These requirements were followed in all stages of geometry preparation - from data acquisition, geometry creation and processing steps, through the final stage of physical model making.

3.1 Requirements and Best Practices (RBP)

RBPs related to the **level of detail** (LoD) of urban representation must balance capturing sufficient geometric features to reproduce realistic flow patterns and maintaining correct similarity scales, against the practical requirements of manufacturing, physical testing, and the computational efficiency needed for subsequent CFD simulations. In this work, that balance was achieved by applying the highest fidelity to a selected target region and progressively simplifying the outer areas, as recommended also by the BPGs [17, 18, 22]. In addition, the wind-tunnel model manufacturing technique imposed a minimum feature size of 1 mm in reduced scale (0.35 m at full scale). To respect these constraints, the domain described in Sect. 3 was subdivided into three zones of decreasing geometric complexity, depicted in Fig. 4(a). **Region 1** (inner zone) encompasses the city area with the highest community significance (urban landmarks, pedestrian zones, and main roads, including the pollutant source). The measurement points that require highest quality and densest grid are located here. The buildings in this area are modelled to LoD 2.2, according to the classification presented in [28], considering architectural features larger than or equal to 1 m at full scale (approximately 2.8 mm in model scale). Smaller features, if present, are simplified. **Region 2** (middle zone) extends outward by at least one city block from, retains the same LoD as Region 1, but has a comparatively sparser measurement grid. Finally, **Region 3** (outer zone) covers the remainder of the turntable without having any measurement points in this area. Here the captured LoD is reduced to 1.3 as per [28], preserving only protrusions or gaps exceeding 2 m at full scale (about 5.7 mm in model scale).

RBPs related to **wind tunnel testing** mandate an adequate offset between the test-section obstructions (walls, ceiling, or equipment) and the scaled model to prevent boundary-layer mismatch and artificial flow acceleration. The same principle applies for CFD simulations, where the obstructions are the computational domain boundaries. In this work, these considerations were applied as discussed in Sect. 2. A common practice in wind tunnel testing is using a flat surface for the ground representation in the scaled model. This assumption is acceptable given the terrain does not exhibit major elevation changes across the modelled area, and can facilitate the manufacturing process and reduce measurement uncertainties. A practical standpoint requirement is ensuring adequate referencing and labelling for a precise alignment between the base plate, the buildings, and the instrumentation.

Although the focus of the collaboration activities under ValUr is on a wind tunnel testing campaign, the ultimate goal is generating a high-quality dataset that can be used for validation of urban pollution dispersion models. For this reason, any requirements related to **CFD simulations** must also be considered at the early stages of geometry preparation. Along with the topics discussed so far, additional CFD-specific considerations include:

- Geometry cleaning and simplification: Along with simplifying the geometry to the selected level of detail, features with very sharp angles (e.g., below 30°) should also be simplified or smoothed during geometry preparation, as they can produce highly skewed or distorted elements in the computational mesh and decrease numerical accuracy and solver stability.
- Mesh resolution and Courant–Friedrichs–Lewy (CFL) considerations: the BPGs for CFD simulations [17, 18, 21–23] recommend a certain resolution of urban features

in the computational mesh. For instance, AIJ suggests using approximately 10 cells per cube root of the building volume and applying finer grids near building corners to effectively capture flow separation zones [22]; VDI 3783 Part 9:2017 guidelines recommend having at least 3 grid points per spatial direction, and at least 5 grid points in areas with relevant flow phenomena [17], etc.

On the other hand, in transient simulations such as LES or Unsteady Reynolds-Averaged Navier–Stokes (URANS), the CFL condition links the mesh resolution, the flow velocity, and the time-step size [29]. Hence, preliminary calculations on the CFL criterion can be a good practice to define a threshold for capturing small geometric features and maintain a practical balance between accuracy, stability, and computational resource demand.

- Analysis Considerations: once the geometry is error-free and ready for simulation, it is essential to assess its suitability for the specific modelled phenomena and analysis type. Initial grid tests statistics, mesh quality metrics, and preliminary CFD simulations, that weren't detected in previous steps, can help avoid major changes at later design stages.

The general requirements established in this section, including the level of geometric detail and considerations specific to wind tunnel testing and CFD modelling, should ensure that the geometry preparation phase provides consistency and a sound foundation for all subsequent project activities.

3.2 Initial Data Acquisition

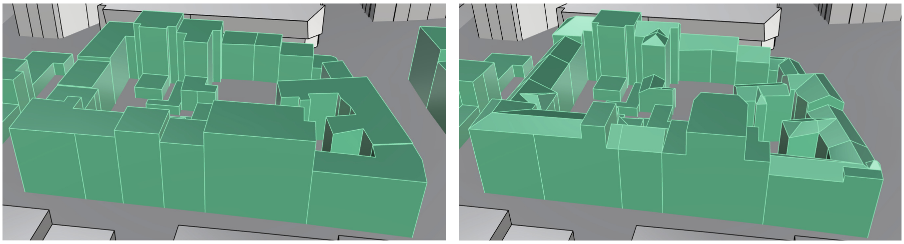
Key datasets for geometry creation were acquired from open sources of spatial data. The building footprints were obtained from the cadastral map of Sofia as 2D contours with attributes in. shp format. The terrain dataset was downloaded from a portal of a municipal enterprise Sofiaplan as the Digital Terrain Model (DTM) in .geotiff format. The resolution of the raster files was 1 m/px. In the absence of a drone survey, rooftop heights of buildings with flat roofs in Regions 1 and 2 and the buildings in Region 3, were derived from publicly available aerial photographs and pedestrian-level images using photogrammetric methods of geometry reconstruction. An aerial orthophoto of the study area with a resolution of 10 cm/px was also utilized.

3.3 Initial Geometry Creation

Terrain raster datasets were imported as meshes in Rhino® Grasshopper® using a plugin Heron dedicated for the integration with geospatial data. Then the terrain meshes were regularized with Quadremesh and converted to a patch surface. The resulting NURBS surface was clipped with the boundaries of the study area; thus, the solid body of the terrain was generated.

Building footprints of Region 1 from the cadastral map were draped onto the terrain and extruded. The rest of the modelling process was manual. The heights of the roofs and building details were taken from the orthophoto and site surveys. The building footprints of Region 2 were optimized beforehand using FME Form®. This step included the removal of small polygons, aggregation of groups of touching buildings, generalization of contours, the removal of spike vertices, and manual refinements. Then the optimized 2D footprints were extruded to a rooftop level with Heron.

Once the footprints were extruded, roofs and additional details on in Regions 1 and 2 were created manually in Rhino 7. Roof and facade features were added according to the requirements related to the level of geometric detail - details larger than 1 m in full scale were added. Figure 5 shows the initial extrusion of the building footprints and the outcome of the manual construction of the roofs on a set of buildings in Region 2. Sets of buildings, touching each other as in Fig. 5, were then combined into a single object to facilitate geometry management.



(a) (b)

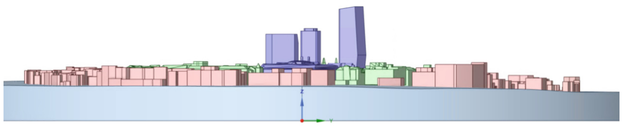
Fig. 5. Example set of buildings in Region 2 (a) before and (b) after roof creation

3.4 Geometry Cleaning

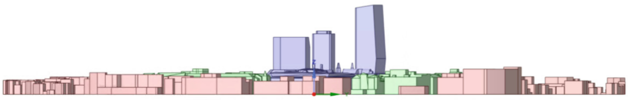
Once the initial geometry creation was completed, the .step file was exported to Ansys® SpaceClaim®, Release 2024 R2 for further cleaning and processing.

To fulfil the requirement of a flat ground surface in the scaled geometry model, the urban terrain had to be flattened, while preserving the true building elevations above ground. For this purpose, first, the footprints of all buildings extracted from Rhino were used to cut each structure at the midpoint between its highest and lowest intersection points with the terrain. This resulted in objects with horizontal bases which were then aligned on a horizontal plane at $z = 0$ m (see Fig. 6).

Next, architectural features below 1 m for Regions 1 and 2, and 2 m for Region 3, where still present, were removed. These included facade protrusions which resulted from the extrusion of footprints obtained from the cadastral map, as well as roof details in Regions 1 and 2. Additionally, small gaps less than 1 m between buildings were removed by connecting the corresponding buildings. Such modifications were made in Regions 2 and 3 where they are not expected to greatly influence the measurements in the area of interest. Finally, the geometry was checked for non-manifold vertices, extra edges, duplicate, small or non-planar faces, among other defects which may have resulted from inaccuracies in the input data, its processing, or the integration between the different tools used for geometry preparation. These checks were performed to ensure smooth and easy manufacturing and meshing processes.



(a)



(b)

Fig. 6. Complete geometry with (a) real-world terrain and (b) idealized horizontal base.

3.5 Geometry Post-processing

The geometry preparation process concluded with post-processing related to the intended use of the model. Preliminary discretisation tests assessing the grid statistics and quality metrics were performed, as well as initial RANS simulations. Based on their results, minor geometry changes (fixing misaligned nodes at two roofs) were applied. Geometry post-processing activities, related to physical model-making, included base plate and building labelling. The final geometry was exported into a .step file as requested by the manufacturer.

3.6 Model Making

The base plate, with a diameter of 2.6 m, was made of plexiglass (PMMA). The outlines of the buildings were scored onto the base plate, along with their corresponding labels, to ensure accurate positioning and alignment. The 3D models of the buildings were printed using a Bambu Lab X1 Carbon 3D printer, featuring a high-speed CoreXY motion system and a 7 µm LIDAR-assisted first-layer inspection for precision and detail. PLA filament was used as the primary printing material, allowing for details to be printed with a resolution of up to 1 mm. The building models were then glued onto the base plate and positioned in the test section.

4 Conclusions and Next Steps

This paper presented geometry preparation for ValUr, a project which aims to establish a high-quality validation and predictive capability estimation protocols for computational wind engineering. The main purpose of reporting the geometry preparation procedure in detail is to promote consistency and reliability in future urban CFD validation efforts by enabling other researchers to replicate, adapt, and enhance the current workflow. The reasoning behind the test region selection, scaling, geometric modelling and preparation were all discussed in detail, providing the foundation for the experimental and modelling work to follow in ValUr.

Subsequent effort will concentrate on details of the experimental campaign setup and testing, the analyses of measurement data, and the validation process itself.

Acknowledgements. This work is part of the transnational access project "ERIES-ValUr", supported by the Engineering Research Infrastructures for European Synergies (ERIES) project (www.eries.eu), which has received funding from the European Union's Horizon Europe Framework Programme under Grant Agreement No. 101058684. This is ERIES publication number C61. The research was also supported by the GATE project funded by the Horizon 2020 WIDESPREAD-2018-2020 TEAMING Phase 2 programme under grant agreement no. 857155, the programme "Research, Innovation and Digitalization for Smart Transformation" 2021–2027 (PRIDST) under grant agreement no. BG16RFPR002-1.014-0010-C01, and the Sweden's Innovation Agency Vinnova under Grant No. 2024-03904. The research team would like to express their sincere gratitude to Geert-Jan Maas and the rest of TU/e wind tunnel technical team, TU/e Innovation Space, and all the students who helped with the 3D printing of the scaled model of Sofia.

References

1. Castro, I., Robins, A.: The flow around a surface-mounted cube in uniform and turbulent streams. J. Fluid Mech. **79**, 307–335 (1977)
2. Stathopoulos, T., Baskaran, A.: Computer simulation of wind environmental conditions around buildings. Eng. Struct. **18**, 876–885 (1996)
3. Kubota, T., Miura, M., Tominaga, Y., Mochida, A.: Wind tunnel tests on the relationship between building density and pedestrian-level wind velocity: Development of guidelines for realizing acceptable wind environment in residential neighborhoods. Build. Environ. **43**, 1699–1708 (2008)
4. Bruno, L., Salvetti, M.V., Ricciardelli, F.: Benchmark on the aerodynamics of a rectangular 5:1 cylinder: an overview after the first four years of activity. J. Wind Eng. Ind. Aerodyn. **126**, 87–106 (2014)
5. Tominaga, Y., Stathopoulos, T.: CFD simulation of near-field pollutant dispersion in the urban environment: a review of current modeling techniques. Atmos. Environ. **79**, 716–730 (2013)
6. Amorim, J.H., et al.: Pedestrian exposure to air pollution in cities: modeling the effect of roadside trees. Adv. Meteorol. **2013**, 1–7 (2013)
7. Buccolieri, R., Sandberg, M., Di Sabatino, S.: City breathability and its link to pollutant concentration distribution within urban-like geometries. Atmos. Environ. **107**, 1–38 (2015)
8. Hertwig, D., Efthimiou, G.C., Bartzis, J.G., Leitl, B.: CFD-RANS model validation of turbulent flow in a semi-idealized urban canopy. J. Wind Eng. Ind. Aerodyn. **111**, 61–72 (2012)
9. Carpentieri, M., Robins, A.G.: Influence of urban morphology on air flow over building arrays. J. Wind Eng. Ind. Aerodyn. **145**, 61–74 (2015)
10. Yassin, M.F.: Impact of height and shape of building roof on air quality in urban street canyons. Atmos. Environ. **45**, 5220–5229 (2011)
11. Blocken, B.: Computational Fluid Dynamics for Urban Physics: Importance, scales, possibilities, limitations and ten tips and tricks towards accurate and reliable simulations. Build. Environ. **91**, 219–245 (2015)
12. Tominaga, Y., Stathopoulos, T.: Ten questions concerning modeling of near-field pollutant dispersion in the built environment. Build. Environ. **105**, 390–402 (2016)
13. Toparlar, Y., Blocken, B., Maiheu, B., van Heijst, G.: A review on the CFD analysis of urban microclimate. Renew. Sustain. Energy Rev. **80**, 1613–1640 (2017)
14. Aliabadi, A.A., et al.: Effects of roof-edge roughness on air temperature and pollutant concentration in urban canyons. Bound.-Layer Meteorol. **164**, 249–279 (2018)

15. Yazid, A.W.M., Sidik, N.A.C., Salim, S.M., Saqr, K.M.: A review on the flow structure and pollutant dispersion in urban street canyons for urban planning strategies. Simulation **90**(8), 892–916 (2014)
16. Sofia Municipality Report: A comprehensive programme for the improvement of the quality of atmospheric air in Sofia Municipality for the period 2021–2026 (2020). (in Bulgarian)
17. VDI 3783: Part 9, Environmental meteorology - Prognostic microscale wind field models - Evaluation for flow around buildings and obstacles, Berlin, Germany, 2017
18. Franke, J., Hellsten, A., Schlünzen, H., Carissimo, B.: Best practice guideline for the CFD simulation of flows in the urban environment: COST action 732 quality assurance and improvement of microscale meteorological models (2007)
19. ASCE 49-21: Wind tunnel testing for buildings and other structures (2021)
20. VDI 3783 Part 12: Physical modelling of flow and dispersion processes in the atmospheric boundary layer – application of wind tunnels, Berlin, Germany (2000)
21. Franke, J., et al.: Recommendations on the use of CFD in wind engineering. In: Proceedings of the International Conference on Urban Wind Engineering and Building Aerodynamics (2004)
22. Tominaga, Y., et al.: AIJ guidelines for practical applications of CFD to pedestrian wind environment around buildings. J. Wind Eng. and Ind. Aerodyn. **96**, 1749–1761 (2008)
23. Casey, M., Wintergerste, T.: ERCOFTAC Special Interest Group on "Quality and Trust in Industrial CFD": Best Practice Guidelines, ERCOFTAC (2000)
24. Bartzis, J.G., Vlachogiannis, D., Sfetsos, T.: Thematic area 5: Best practice advice for environmental flows. QNET-CFD Netw. Newsl. **2**, 34–39 (2004)
25. Eurocode 1: Actions on structures - Part 1–4: General actions - Wind actions
26. Blocken, B., Stathopoulos, T., Carmeliet, J.: CFD simulation of the atmospheric boundary layer: wall function problems. Atm. Environ. **41**, 238–252 (2007)
27. Pantusheva, M., Mitkov, R., Hristov, P.O., Petrova-Antonova, D.: Air pollution dispersion modelling in urban environment using CFD - a systematic review. Atmosphere (2022)
28. Biljecki, F., Ledoux, H., Stoter, J.: An improved LOD specification for 3D building models. Comput. Environ. Urban Syst. **59**, 25–37 (2016)
29. Courant, R., Friedrichs, K., Lewy, H.: Über die partiellen Differenzengleichungen der mathematischen Physik. Math. Ann. **100**, 32–74 (1928)