Geo-visualisation of Air-Pollutant Dispersion in Complex Urban Environments using 3D City Models: Insights from High-Resolution Street Canyon Simulation - Concept and First Results

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Abstract

Urban air quality poses a significant public health challenge, particularly in complex urban areas like street canyons, where traffic emissions intensify the issue. The limitations of traditional monitoring methods, marked by a narrow scope and poor visualisation, hinder our understanding of pollutant dispersion dynamics, impeding effective air quality management. Consequently, this study explores the synergy of 3D city models and Computational Fluid Dynamics (CFD) simulation to analyse air pollutant dispersion in complex urban settings. To enhance geo-visualisation, the research employs the next generation of Open Geospatial Consortium (OGC) APIs for data delivery. The integration of 3D city models with CFD simulations and geo-visualisation techniques aims to develop an urban digital twin. This digital twin is envisioned to offer valuable insights into the dynamics of air pollutant dispersion within street canyons, thereby informing more effective air quality management strategies.

1. Introduction

Urban air quality poses a significant challenge, particularly in densely populated areas characterised by high traffic volumes. Streets and squares are generally the main zones of urban areas where human activities take place but also where air pollutants are present in high concentrations. Air pollutants tend to accumulate in these urban hotspots, where the architectural landscape constrains natural airflow, exacerbating the accumulation of pollutants. This phenomenon not only impacts outdoor air quality but also infiltrates indoor environments, presenting substantial health risks to the residents. Despite efforts to monitor outdoor air quality, traditional methods often fall short of providing a comprehensive understanding of air pollutant dispersion in urban settings. Conventional monitoring stations, while offering direct measurements of pollutants and wind conditions, frequently lack the spatial resolution needed to capture the intricate dynamics of air pollutant distribution. Additionally, ground-based stations face limitations in coverage, resulting in gaps in data collection, especially in areas with diverse sources of air pollution. Remote sensing technologies, on the other hand, provide a broader perspective, enabling the monitoring of air pollution over large geographical areas and facilitating the tracking of pollution plumes. However, it's important to acknowledge that remote sensing may overlook smaller-scale variations critical for targeted interventions in specific urban micro-environments.For target-based interventions at a granular scale, the integration of 3D city models with Computational Fluid Dynamics (CFD) simulation forms an interesting synergy.

CFD is a powerful numerical model for predicting fluid (including air) behaviour around buildings, bridges, vehicles, and other structures in cities, enabling more effective interventions to combat air pollution. Therefore, by using 3D city models as an input to CFD simulation, there is an opportunity to advance our knowledge of the intricate airflow patterns within street canyons and other urban micro-environments, thereby gaining a more detailed understanding of how air pollutants disperse and accumulate. Such an approach enables the identification of air pollution hotspots, the assessment of building layouts, and other morphological factors influencing air pollutant dispersion dynamics, along with the more precise evaluation of potential mitigation strategies.

In addition to accurate predictions, it is also crucial to have advance visualisation tools for the interpretation and extraction of detailed information from the obtained simulation results. Traditional data visualisation of outdoor air quality data has often relied on static charts, graphs and numbers, which can be cumbersome and time-consuming to interpret for larger datasets and non-experts. Interactive visualisation tools and dynamic maps, particularly those integrated with Geographic Information System (GIS) capabilities, provide a powerful means of visualising spatial data. They allow for the overlay of air quality data onto geographical representations, such as street maps or 3D city models. This integration enables stakeholders to visualise air quality variations across different times and locations. 3D city models are increasingly becoming indispensable for urban planning and environmental analysis (Schrotter and Hürzeler, 2020). They can help city officials to identify and focus on urban opportunities and challenges more effectively. Integrating air quality data into these models enhances their utility by providing a holistic view of how air pollution levels vary within urban environments.

With this context, the current research aims to explore the potential of integrating 3D city models with CFD simulations to analyse air pollutant dispersion in complex urban environments. For geo-visualisation, the next generation of OGC APIs is used for data delivery to a web client. The web client is developed using the open-source CesiumJS library. By combining 3D city models with CFD simulation and geo-visualisation techniques, the objective is to develop an urban digital twin that offers valuable insights into the dynamics of air pollutant dispersion within street canyons. This paper provides a detailed explanation of the concept and shows the first geo-visualisation result on web.

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2. State of Art

2.1 Use of 3D City Models in CFD Simulation

It is well established that the dispersion of air pollutants in street canyons is directly affected by urban morphology, such as building geometries (Miao et al., 2020). Within the geoinformation field, 3D city models, in particular the OGC CityGML data model, is commonly used to store and exchange geometries and semantics of the built environment, including buildings, roads, terrain, vegetation, and other objects. Presently, CityGML datasets commonly incorporate buildings at Level of Detail (LoD)1, which represents volumetric shapes with flat roofs approximating the actual building height, or LoD2, which extends LoD1 by including basic roof shapes. The possibility to model CityGML datasets in higher LoD also exists, but such datasets are rarely available. However, a key challenge in using CityGML for CFD simulation lies in the requirement that the input geometric data must adhere to a CAD (Computer-Aided Design) format such as STEP (Standard for the Exchange of Product Model Data) or STL (Standard Triangulation Language). This necessitates a data conversion from CityGML to one of the mentioned CAD formats. However, the benefits of using a CityGML dataset as a starting point (before conversion to CAD) are two-fold. First, as mentioned before, 3D city models based on the CityGML data model are widely available globally[1], and second, quality check tools such as CityDoctor [2] and Val3dity [3] are freely available for validating the geometry of CityGML datasets. Nevertheless, following the conversion from CityGML to CAD formats, it remains imperative to ensure that the derived CAD model possesses solid geometry with an appropriate level of detail suitable for the specific problem at hand, facilitating proper meshing. The generation of meshes for CFD simulation typically occurs within dedicated CFD software packages. Numerous open-source and commercial desktop software packages are accessible for conducting CFD simulations (Toparlar et al., 2017). (Blocken, 2015) highlighted that a high-quality computational mesh plays a pivotal role in ensuring the success of CFD simulation, impacting both computational efficiency and the reliability of results. Researchers and practitioners worldwide acknowledge that within the CFD simulation workflow, geometry preparation is frequently perceived as a laborious and time-intensive task. Many practitioners identify it as a primary bottleneck in the simulation process. Therefore, various approaches are being actively investigated for validating (Saeedrashed and Benim, 2019) and automating the reconstruction of 3D city models specifically tailored for CFD simulations (Deininger et al., 2020), (Pađen et al., 2022). Post geometry processing, researchers have showcased the use of CityGML datasets for CFD simulations. For example, (García-Sánchez et al., 2021) used validated CFD libraries from OpenFOAM to predict wind flows and study pedestrian wind comfort within a troublesome section of the TUDelft campus. In doing so, they also explored what are the effects of oversimplifying geometries by comparing wind simulations of different levels of detail building geometries. (Brennenstuhl et al., 2021) used Ansys Fluent software for CFD simulation to study wind flow in a proposed re-development neighbourhood called "Neuer Stöckach" in the city of Stuttgart, Germany. Subsequently, the CFD simulation results were integrated into another simulation model, INSEL, to estimate the energy yield of photovoltaic systems and small wind turbines at the site.

2.2 Geo-visualisation of CFD Simulation Results

The Kalasatama Digital Twins Project [4] is a notable example of the visualisation of CFD simulation results. The project employed the CityGML dataset in ANSYS Discovery, allowing real-time simulation and iterative urban design enhancements across various disciplines, including wind flow analysis. However, this tool does not support the export of simulation results for external visualisation purposes. A fundamental aspect of the smart city concept involves integrating data, including simulation results, from diverse sources into a unified platform. This platform is usually a web-based application that enables interactive exploration, showcasing outcomes within the framework of a 3D city model. This approach offers a comprehensive view of various integrated datasets, facilitating informed decision-making and urban management (Cepero et al., 2022). With the progress of web technologies, simulation results can now be transformed into graphical information for visualisation on web browsers using digital web globes like Google Earth, Cesium, Mapbox, and ArcGIS Earth. While the majority of studies showcase wind visualisation on a national[5] or global scale[6], very few examples can be found in the context of a neighbourhood or a street canyon scale. (Liu and Kenjeres, 2017) visualised their CFD simulation results of wind flows and pollutant dispersion using Google Earth. This was achieved by developing code in the Java language to convert simulation results into the Keyhole Markup Language (KML) format. However, this approach requires additional installation of Google Earth software. Moreover, KML files are typically static and not optimised for streaming large datasets. With the advent of HTML5 technology, it has now become easier to implement immersive and high-performance 3D geospatial applications directly in web browsers without the need for additional installations. Additionally, with the development of web streaming standards, such as the OGC community standards of 3D Tiles and i3S, delivering large and heterogeneous 2D or 3D geospatial content on the web has become more efficient and scalable. These standards enable the streaming and rendering of complex geospatial data, including terrain models, buildings, and other features, in a dynamic and interactive manner within web-based applications. (Schneider et al., 2020) converted their CFD simulation results on wind pressure (scalar) and wind direction (vector) to 3D Tiles and consumed it in a web 3D application built using CesiumJS to showcase different visualisation methods of urban wind fields. Besides 3D Tiles, authors also investigated other data formats like GeoJSON and point clouds to deliver and visualise simulation results on the web. Due to the availability of many such data formats and to simplify and standardise how developers interact with geospatial information, in 2019, OGC released a new generation of OGC APIs[7] to make it simple for anyone to provide and access geospatial data on the web, also ensuring seamless data exchange between different systems and platforms. (Santhanavanich et al., 2023) illustrated an example implementation of utilising different OGC APIs within the urban building energy domain.

In this study, we explore the utilisation of CityGML datasets with CFD simulation to analyse air-pollutant dispersion within a street canyon. Additionally, we present the initial implementation of web-based geo-visualisation of simulation results, optimised for data delivery through OGC APIs.

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[1] https://github.com/OloOcki/awesome-citygml

[2] https://transfer.hft-stuttgart.de/pages/citydoctor/citydoctorhomepage/en/

[3] https://github.com/tudelft3d/val3dity

[4] https://shorturl.at/apsV2

[5] http://hint.fm/wind/

[6] https://cesium.com/blog/2019/04/29/gpu-powered-wind/

[7] https://ogcapi.ogc.org/

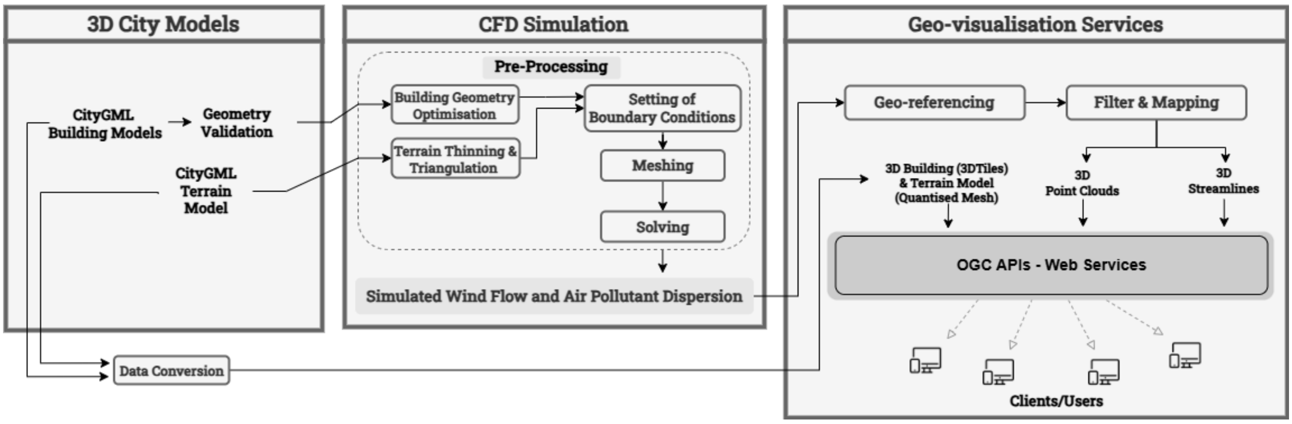

Figure 1. Workflow overview: From 3D city models to geo-visualisation of inner-city air flows and air pollutant dispersion

3. Case Study

Street Schloßstraße adjacent to building 7 of the HFT Stuttgart campus is used as a case study to study the effect of road traffic on the air quality around the HFT Stuttgart campus and in particular in the street canyon near building 7 (Fig. 2)[8]. The rationale behind choosing Schloßstraße as a case study area is due to the fact that Schloßstraße is one of the most important collector roads in the city centre of Stuttgart.

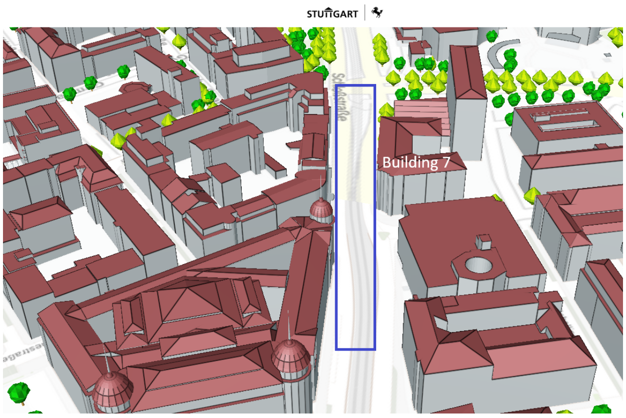

Figure 2. Street canyon near building 7 of HFT Stuttgart campus as visualised on Stuttgart 3D web application

4. Methodology

This study introduces a comprehensive workflow for the interactive exploration of simulated inner-city air flows and air pollutant dispersion. Illustrated in Fig. 1, the workflow comprises of three key components: 3D city models, CFD simulation, and geo-visualisation services.

4.1 3D City Models

The input dataset includes building and terrain information models of the Stuttgart region in CityGML format. The building details correspond to the mixture of LOD1 and LOD2, and the terrain of the region is represented as a TIN surface. To capture the airflow details around the HFT Stuttgart campus, the roof geometries belonging to buildings of the HFT Stuttgart campus were considered (LOD2). The buildings in the surrounding area were kept in LOD1. For CFD simulation, buildings located within a radius of $R = 400m$ from building 7 of the HFT Stuttgart campus were considered (Fig. 3).

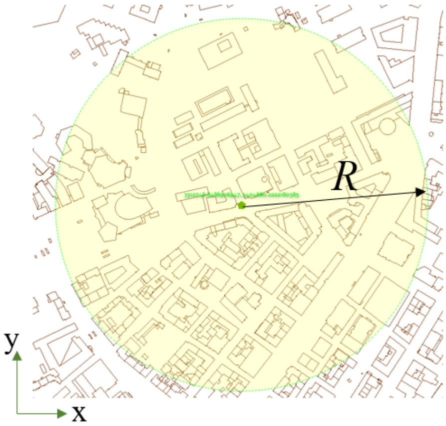

Figure 3. Coverage of buildings considered for CFD simulation. The origin of the coordinate is marked by the green dot

For the use of the CityGML model in CFD simulation, they were first converted to STL format using Ansys SpaceClaim (SC) CAD software. Automatic conversion of the model into CAD formats generally cannot provide the quality of geometry required for numerical simulation such as CFD. The main requirements for the quality of building and terrain models for further CFD modelling can be formulated in a general way:

- Building models should be represented as closed volumes without missing surfaces;

- Small surfaces and geometric features should be removed from the model unless they have a significant effect on the flow parameters around buildings. Fine details of facades and roofs can be taken into account in the CFD model by using equivalent roughness in the numerical simulation step;

- All duplicated surfaces and edges that are not required to define the shape of the buildings should be removed;

- The terrain represented by the TIN surface should be regularised for the fragments with small height gradients, and the number of facets of the TIN surface should be reduced as much as possible while preserving the terrain structure.

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[8] https://3d.stuttgart.de/

The standard errors observed after the import are marked in Fig. 4a-b: the missing faces and the split edges of the buildings are highlighted in red. In the considered case, the healing process was carried out using the standard repair tools implemented in Ansys SC. Some of the buildings in the model have also been restored by hand, creating additional surfaces and bodies. The resulting geometric models of the buildings and terrain used to construct the CFD domain are shown in Fig. 4c.

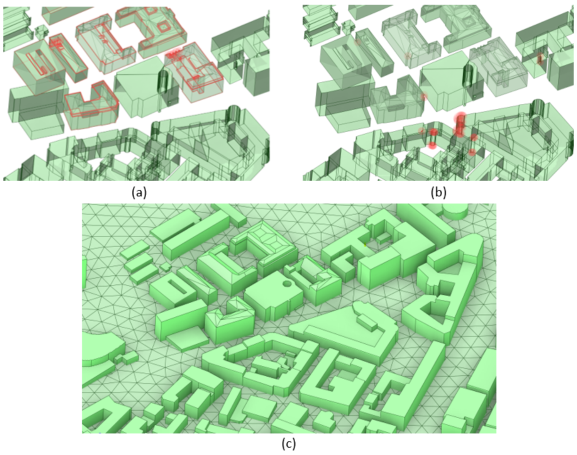
(a) (b)
(c)

Figure 4. 3D geometric model: .stl model after automatic import into Ansys SC (a-b) and solid 3D model after semi-automatic healing (c)

4.2 CFD Simulation

The CFD simulation of the airflow and dispersion of vehicle exhaust air pollutants around the buildings was carried out using the 3D geometric model obtained in the previous step described in section 4.3.1. The CFD domain is shown in Fig. 5 and consists of two parts.

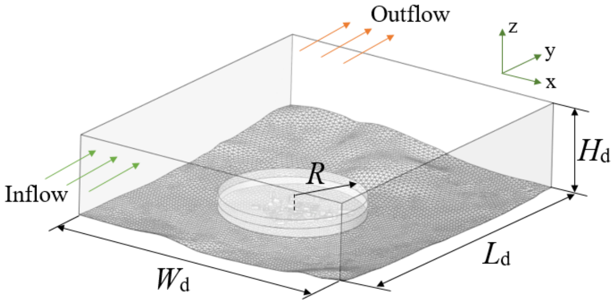

Figure 5. 3D Computational Domain

The first part has a cylindrical shape with a radius of R and includes the considered case study environment. The second part has a rectangular parallelepiped shape and represents the ”outer” zone needed to ensure the absence of influence of the external boundary conditions on the flow in the vicinity of the buildings. The outer part has dimensions W_d x L_d x H_d, where $W_d = 4R$ and $W_d = 5R$. The mean height of the domain was chosen to be $H_d = 20H_b$, where H_b is the height of building 7. The domain is aligned with the main wind direction, and the inlet boundary is perpendicular to the inflow velocity. In addition, we added to the domain two sections of the air pollution sources, located at the bottom of the domain, corresponding to the location of the road (Fig. 6).

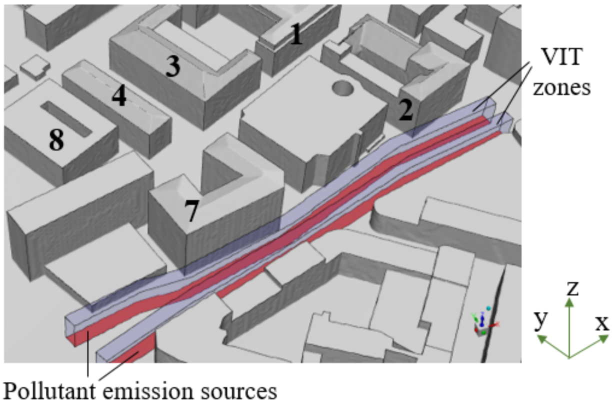

Figure 6. Location of pollutant sources and VIT volume zones along the road in the CFD domain

As can be seen in Fig. 6, two volume zones were also added to the domain, which is required to define the Vehicle-Induced Turbulence (VIT) model. The VIT model allows the consideration of the vehicular motion for the generation of turbulence along the road (Hataya et al., 2017). The VIT numerical model was not included in the current simulation and will be implemented in the next step. The numerical model does not include vegetation zones because the considered part of the street canyon is characterised by the absence of green areas. Vegetation zones could be included to the model in the future. Using the numerical simulation method, we can reproduce the airflow around the building in real climatic conditions or predict the flow in different hypothetical meteorological scenarios described by the set of boundary conditions. In this study, we publish the results for the base scenario with a southerly wind direction and a reference inflow velocity of $U_{\text{ref}} = 5$ m/s at a height of $h_{\text{ref}} = 10$ m. The inflow boundary condition was set as a power-law profile of velocity with the power exponent $\alpha = 0.241$ and roughness length $z_0 = 0.5$ m (Choi, 2009), and the turbulence parameter profiles were defined according to (Tominaga et al., 2008). The ”no-slip” boundary condition was used at the building walls and the ground, while the ”symmetry” boundary condition was chosen for the lateral boundaries of the domain. Taking into account the height difference in the terrain (the difference between the highest and lowest point within the computational domain is $\Delta h = 165$ m), the ”pressure-outlet” condition $\Delta P = P_{st} - P_0 = 0$ atm was specified at the top and outlet boundaries of the domain. The ”mass-flow” inlet conditions were specified to represent pollutant sources along the ground boundaries adjacent to the road. The composition of vehicle exhaust pollutants included carbon monoxide CO, nitrogen oxides NO_x, sulphur dioxide SO_2, hydrocarbons (HC) and benz(a)pyrene (BAP). Emission of the i-th pollutant (g/s) by a moving vehicle stream on a road section of fixed length L_r (km) was determined as:

$$M_{L_i} = \frac{L_r}{1200} \sum_{n=1}^{x} M^L_{k,i} G_k r_i, \tag{1}$$

where $M^L_{k,i}$, g/km is the specific emissions per kilometre of the i-th pollutant of the k-th vehicle category, x is the number of vehicle categories, G_k, 1/hour is the actual maximum intensity of traffic of k-th vehicle category passing through a fixed section of the road in both directions on all lanes, and r_i is the correction factor for the average speed of traffic.

The CFD simulation of airflow and pollutant dispersion in the building environment is performed using the 3D Reynolds-averaged Navier-Stokes equations, supplemented by a k-ϵ turbulence model and convection-diffusion equations for the pollutants. The finite volume mesh contained 6.6 million polyhedral cells and prismatic layers on the building walls to resolve the flow boundary layer parameters (Fig. 7). The Ansys Fluent 2023R3 software was used as the main CFD modelling tool.

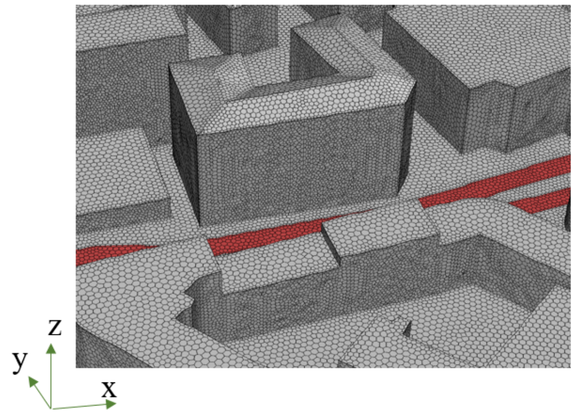

Figure 7. The finite-volume grid on the walls of the building and on the ground

Fig. 8 below shows the vector velocity field inside the street canyon formed by building 7 (Schloßstraße 34) and the opposite building (Schloßstraße 31).

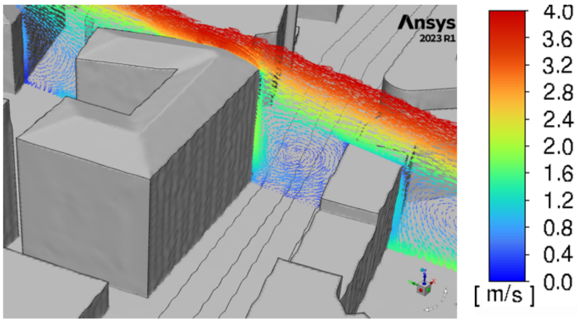

Figure 8. The vector velocity field in the vicinity of building 7 obtained using Ansys Fluent Software

The flow structure obtained in the simulation inside the street canyon is typical of the case where the inflow is perpendicular to the building. This vortex structure, when the air volume moves from the windward to the leeward wall of the canyon, is well described in the wind tunnel experiments for the model configuration of the canyon (Gromke et al., 2008). The vortex structure of the airflow defines the distribution of the gaseous pollutants entering from the road. As seen in Fig. 9, the main concentrations of emissions are observed near the walls of the building.

The results of the CFD simulation are exported from Ansys Fluent as a CSV file representing scalar variables such as distribution of air pressure and vehicular mass fractions of CO, NOx, SO2, HC and BAP; and vector variables such as the distribution of wind velocity at the horizontal and vertical cross-sections around the street canyon, as well as at the building surfaces of the case study area.

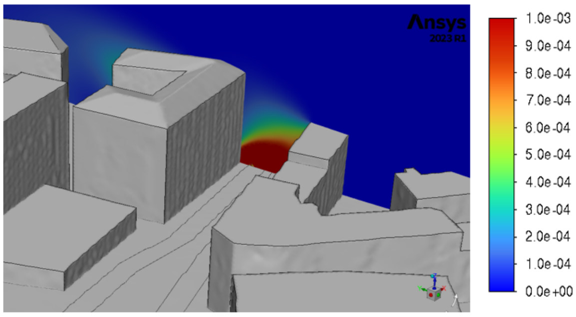

Figure 9. The field of the CO mass fraction at the characteristic cross-section in the vicinity of building 7 obtained using Ansys Fluent software

4.3 Geo-visualisation Services

The geo-visualisation service delivers the CityGML building models, terrain, and CFD simulation results to a web-based 3D application using OGC APIs. The web 3D application is built using the open-source CesiumJS[9] library.

4.3.1 3D City Models The original CityGML building model and terrain dataset are converted to 3D Tiles (3D Objects) and quantised mesh using FME Software[10] (commercial) or using Cesium Ion platform[11] (freeware) and Cesium Terrain Builder[12] (open source) respectively. By default, the Cesium WebGL-based rendering engine is optimised for displaying geographic data using the EPSG:4978 (WGS84) coordinate system. Therefore, to ensure accurate geo-referencing on the Cesium web globe, both buildings and terrain models are transformed from their native projected coordinate system EPSG:31467 (DHDN/3-degree Gauss-Kruger zone 3) to EPSG:4978 as part of the 3D Tiles and quantised mesh production pipelines. Post-production, following the technical developments by (Santhanavanich et al., 2022), building 3D Tiles and terrain quantised mesh of the case study area were hosted on the GeoVolumes data server and delivered to the web client using our publicly available instance of OGC 3D GeoVolumes API[13]. The OGC 3D GeoVolumes API defines a standard way to serve and access 3D data, such as 3D city models on the web.

4.3.2 CFD Simulation Results As mentioned at the end of section 4.2, the outcomes of the CFD simulation are provided in CSV files. These files encompass simulated scalar variables, including air pressure and the mass fraction of vehicular air pollutants (CO, NOx, SO2, HC, and BAP), alongside vector variables such as wind velocity. Additionally, the CSV files specify the emission locations and wind direction using local Cartesian x, y, and z coordinates. Using FME, the location coordinates from the CSV files are initially converted into a point feature. The simulated scalar and vector variables are stored as attributes associated with these point features. To accurately overlay this data on CityGML building and terrain models, a 3D affine transformation matrix is used twice in an FME workbench. First, using the translation component of the affine transformation matrix, the point feature is brought to the origin (0,0,0) so that the origin becomes their new reference

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[9] https://github.com/CesiumGS/cesium

[10] https://fme.safe.com/

[11] https://cesium.com/platform/cesium-ion/

[12] https://github.com/tum-gis/cesium-terrain-builder-docker

[13] https://ogcapi.hft-stuttgart.de/ogc_api_geovolumes

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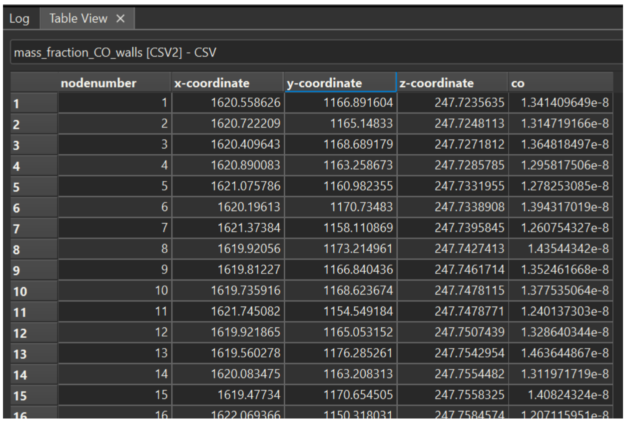
point. Further, another translation operation is used using an affine transformation matrix to position the point feature relative to the origin of CityGML building coordinates as shown in Fig.3. This step is necessary for aligning the points with the CityGML dataset. Post translation, the point features are also assigned EPSG:31467, which is the native coordinate system of the CityGML building and terrain dataset. This completes the geo-referencing of CFD simulation results as part of the geo-visualisation pipeline. CFD simulations are typically conducted over a larger air volume than the actual object of interest to prevent artefacts caused by boundary effects. As part of this process, data points that exceeded twice the height of the buildings were filtered out or removed. This filtering resulted in a significantly reduced number of points, leading to smaller file sizes and clearer visualisations during the later development stages. Post filtering, these point features, along with their attributes, are converted to 3D Tiles (3D Point Cloud Tiles) and thereby to EPSG:4978 to ensure correct geo-referencing of simulation results on the Cesium web globe and its accurate overlay with building 3D tiles and terrain quantised mesh. The produced 3D Tiles of CFD simulation results are also hosted on the GeoVolumes data server and delivered to the web client using our publicly available instance of OGC 3D GeoVolumes API (refer section 4.3.1). The CFD simulation results were also converted to other formats, such as GeoJSON, CZML or back to CSV and served using OGC Features API for its use in other analytical or visualisation platforms. Utilising OGC API - Features and OGC API 3D GeoVolumes provides a modern way to access geospatial data over the web. They use simple, resource-based structures, making them easy to find, retrieve, query and integrate geospatial features like points, lines, and polygons within web applications.

5. First Results

An example of CFD simulation result exported to a CSV file from Ansys Fluent is shown below in Fig.10

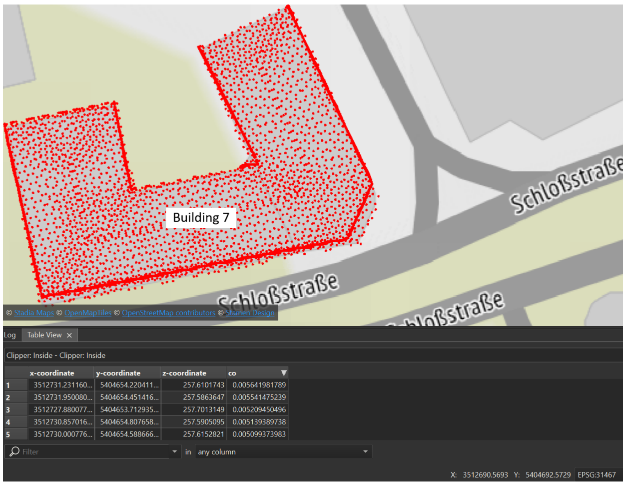


mass_fraction_CO_walls [CSV2] - CSV

	nodenumber	x-coordinate	y-coordinate	z-coordinate	co
1	1	1620.558626	1166.891604	247.7235635	1.341409649e-8
2	2	1620.722209	1165.14833	247.7248113	1.314719166e-8
3	3	1620.409643	1168.689179	247.7271812	1.364818497e-8
4	4	1620.890083	1163.258673	247.7285785	1.295817506e-8
5	5	1621.075786	1160.982355	247.7331955	1.278253085e-8
6	6	1620.19613	1170.73483	247.7338908	1.394317019e-8
7	7	1621.37384	1158.110869	247.7395845	1.260754327e-8
8	8	1619.92056	1173.214961	247.7427413	1.43544342e-8
9	9	1619.81227	1166.840436	247.7461714	1.352461668e-8
10	10	1619.735916	1168.623674	247.7478115	1.377535064e-8
11	11	1621.745082	1154.549184	247.7478771	1.240137303e-8
12	12	1619.921865	1165.053152	247.7507439	1.328640344e-8
13	13	1619.560278	1176.285261	247.7542954	1.463644867e-8
14	14	1620.083475	1163.208313	247.7554482	1.311971719e-8
15	15	1619.47734	1170.654505	247.7558325	1.40824324e-8
16	16	1622.069366	1150.318031	247.7584574	1.207115951e-8

Figure 10. CO mass fraction results from CFD simulation of case study area visualised using FME

Similar to the example shown in Fig.10, results on scalar variables such as air pressure and mass fractions of NOx, SO2, HC, and BAP obtained from the CFD simulation of the case study area follow the same CSV schema when exported from Ansys Fluent. For wind velocity, which is a vector variable, in addition to its x,y, and z location coordinates, velocity values in each x,y and z direction are available at the y-z cross-section in the CSV file. A graphical representation of wind velocity at the y-z cross-section plane is shown in Fig.8. Following the explanation in section 4.3.2, simulation values from CSV files are converted to point features, georeferenced (EPSG:31467) and filtered to accurately overlay on the CityGML building and terrain model. For a better understanding, Fig.11 presents below a simulation result stored in CSV format, which has been geo-referenced, filtered, and correctly overlaid onto a map displaying the footprint of building 7 on the HFT Stuttgart campus.



Clipper: Inside - Clipper: Inside

	x-coordinate	y-coordinate	z-coordinate	co
1	3512731.231160...	5404654.220411...	257.6101743	0.005641981789
2	3512731.950080...	5404654.451416...	257.5863647	0.005541475239
3	3512727.880077...	5404653.712935...	257.7013149	0.005209450496
4	3512730.857016...	5404654.807658...	257.5905095	0.005139389738
5	3512730.000776...	5404654.588666...	257.6152821	0.005099373983

X: 3512690.5693 Y: 5404692.5729 EPSG:31467

Figure 11. Geo-referenced CO mass fraction results overlaid on the footprint of building 7

Post geo-referencing and filtering of the simulation results, they are converted to different formats such as 3D Tiles, GeoJSON, CZML and CSV format. 3D Tiles dataset is hosted on the 3D GeoVolumes data server and delivered to the web client along with the 3D Tiles of buildings and quantised mesh of terrain using the OGC 3D GeoVolumes API (Fig.12). The remaining data formats are delivered to the users using the OGC Features API for its use in other analytical or visualisation platforms.

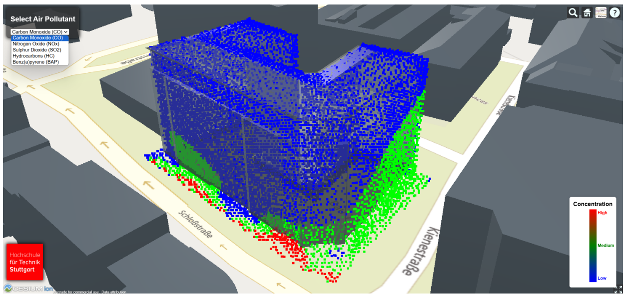


Figure 12. CO mass fraction around building 7 visualised on Cesium web-globe in varying concentration: low (blue), medium (green) and high (red)

6. Conclusion and Outlook

In this research, we investigated the synergy between 3D city models and CFD simulation to analyse the dispersion of air pollutants within a street canyon near Building 7 of the HFT Stuttgart campus, influenced by sources such as road traffic emissions. A detailed explanation of the concept and the initial implementation of a web-based 3D geo-visualisation framework are documented in the paper. The outcomes derived from CFD simulations provide quantitative insights into wind pressure, velocity, and the dispersion of air pollutants. By rendering the simulation results back on the 3D city models, decision-makers can better understand how factors like building height, street layout, vegetation and traffic flow (in future) can impact the local air quality. This immersive visualisation capability not only aids in identifying air pollution hotspots but also supports the evaluation of urban design strategies to mitigate air pollution effectively.

The initial implementation of the geo-visualisation pipeline integrates the 3D building models, terrain, and simulation results of scalar variables such as air pressure and mass fraction of different air pollutants using OGC 3D GeoVolume APIs within a web-based 3D application built using CesiumJS. Simulation outcomes of vector variables such as wind velocity were also processed and geo-referenced during the initial implementation cycle. However, they were not processed for geo-visualisation in the current implementation. Therefore, for the next development cycle, OGC APIs such as Moving Features API and data formats such as CZML will be used to evaluate for data delivery and visualisation of vector variables such as wind velocity using 3D streamlines on Cesium web globe. CZML data format supports the storage of dynamic and time-varying data, which is essential for the creation of animated streamlines that visually represent the dispersion of air pollutants over time. This will allow us to animate streamlines in Cesium and show how pollutants move and disperse within the street canyon under varying atmospheric conditions. In terms of system performance, OGC APIs will be evaluated for their response time, data processing speed, network usage and overall efficiency in handling requests during the next development cycle.

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