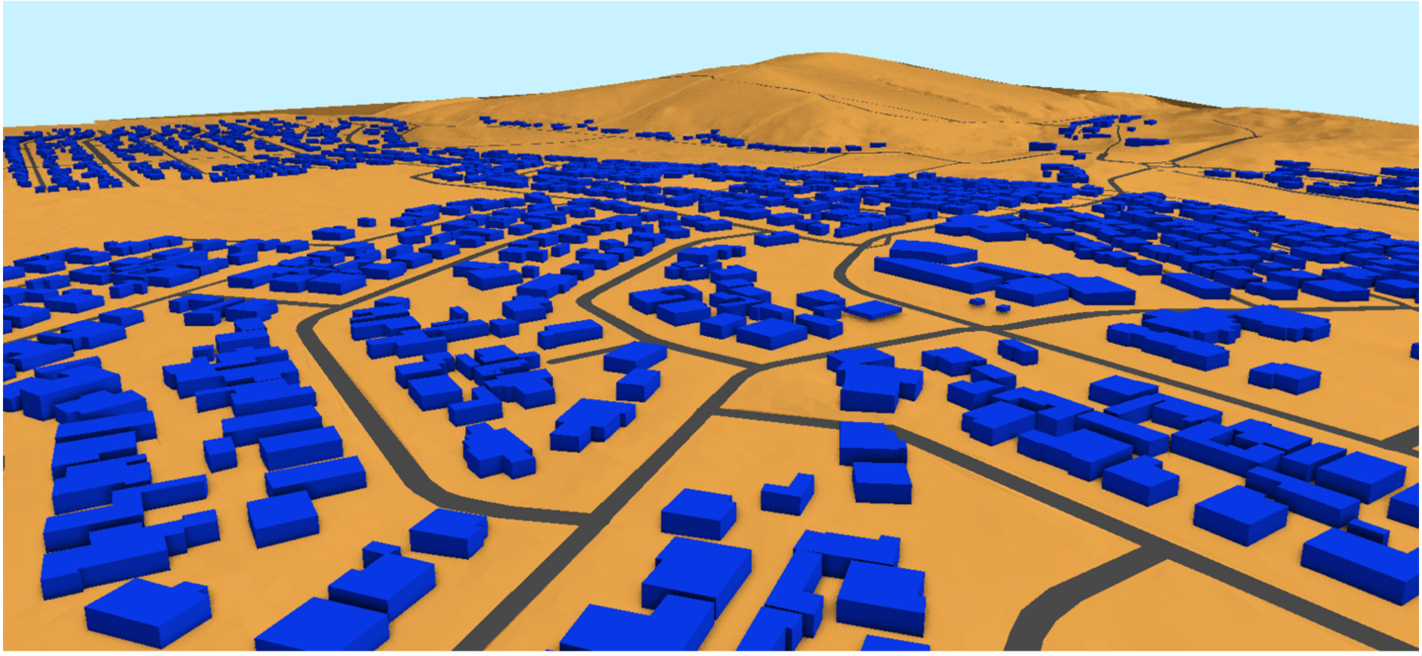
geo3D. 3D City Models for Geography and Sustainable Development Education

OpenStreetMap for urban data science and microclimate physics.

Recommended Ages/Grades
High School and University Students

Course Time Needed
Preparation: 0.5 hours
Execution: 60 - 120 minutes of class time



Materials Needed

For the educator:
⇢ Computer (laptop or desktop)
⇢ Reliable Internet
⇢ Computer mouse
⇢ Web Browser

For the student(s):
Same as above

Have questions or comments?
Join the discussion

Learning Objectives

With this *geo3D* Lab, students will learn *how open geospatial data,* harvested from OpenStreetMap, *and local knowledge can:*

i. estimate population,
ii. measure overcrowding, housing inequality, and
iii. evaluate rooftop solar potential.
iv. Advanced uses can simulate pedestrian wind- and thermal comfort.

A **Model and Evidence Card**, **Educator Rubric** and **Field Audit and Interpretive Boundaries** worksheet is provided to help students and educators record and evaluate their contributions, what ***geo3D*** produced, how reliable the evidence is, and what they can **responsibly** conclude.

***geo3D* Lab** Module	Derived Output / Metrics	Target Audience
Lab 1. Village Track	Interactive 3D Web Map, population, BVPC, rooftop solar stats.	Secondary Level
Lab 2. Suburb Track	ISO 19107 `3D.cityjson` city model, population, BVPC, rooftop solar stats. and Interactive 3D Web Map	Tertiary Level
Lab 3. Advanced Track	Wind Vector Maps, Pedestrian Wind Comfort (PWC), and Universal Thermal Comfort (UTCI)	Advanced Undergraduate

The ***geo3D* Lab** provides a structured introduction to the modular ***geo3D*** framework. Both online and offline workflows are available for the **Village** and **Suburb Tracks.**

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Curriculum Alignment

geo3D balances the use of technology in the classroom with hands-on community mapping and citizen science to support geography and sustainable development education at the local level. Students contribute to **OpenStreetMap**, create three-dimensional representations of their communities and then explore the models to investigate real-world geographic questions.

The ***geo3D*** framework aligns with both the National Geography Standards and Advanced Placement Human Geography (APHG) through the following curriculum outcomes:

Lab 1. Village Track - Secondary / High School Level and **Lab 2. Suburb Track** - Tertiary / University Level

National Geography Standards
Standard 1: *How to use maps and other geographic representations, geospatial technologies, and spatial thinking to understand and communicate information.*
Standard 3: *How to analyse the spatial organisation of people, places and environments.*
Standard 9: *The characteristics, distribution, and migration of human populations on Earth's surface.*
Standard 11: *The patterns and networks of economic interdependence on Earth's surface.*
Standard 14: *How human actions modify the physical environment.*
Standard 18: *How to apply geography to interpret the present and plan for the future.*

APHG.
Unit 1: *Thinking Geographically*
Unit 2: *Population and Migration Patterns and Processes*
Unit 6: *Cities and Urban Land Use*
Unit 7: *Industrial and Economic Development Patterns and Processes*

Lab 3. Advanced Track – Advanced Undergraduate

National Geography Standards
Standard 15: *How physical systems affect human systems.*

Preparation

- **Teacher should review, execute and inspect the Notebooks.** *fundamental and basic Python knowledge is necessary.*
- Students should have OSM accounts and have completed the Getting Started with OSM modules

Activity 1: Add buildings and renewable rooftop solar to OpenStreetMap – Lab 1, 2 and 3.

i. Students should add building and rooftop solar to OpenStreetMap using local knowledge.
ii. Please use the Drawing Polygons in Getting Started with OpenStreetMap: Module 3 to show students how to complete them.

Activity 2: Where necessary an `osm.pbf`, raster Digital Elevation Model (DEM) **and** `POWER_Regional_Monthly_xxxx.csv` **should be harvested** - Lab 2 and 3

i. Students should harvest an `osm.pbf` via the links provided in the appropriate Jupyter Notebook.
ii. An ALLSKY_SFC_SW_DWN (All Sky Surface Shortwave Downward Irradiance) dataset to estimate **Annual Average Solar Potential, per home** can be harvested via the link provided in the CityJSONdataScience-noInternet.ipynb Jupyter Notebook.

Activity 3: Software necessary for CFD simulations - Lab 3

i. Students must install OpenFOAM. Instructions are provided in the urbanFlow-noInternet.ipynb Jupyter Notebook.

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geo3D. Model and Evidence Card

Use this card to record what you contributed, what the model produced, how reliable the model is and what you can responsibly say

1. PLACE

Place / Area of Interest (AOI) ______________________________ **Date:** ______________________

City / Region / Country ______________________________ **Track:** ☐ **Village** ☐ **Suburb** ☐ **Advanced**

2. OUR CONTRIBUTION

What did we add and / or improve
Tick all that apply

- ☐ **OSM building footprints** (added / edited)
- ☐ **Building attributes (e.g.: levels, type)**
- ☐ **Rooftop solar**
- ☐ **Other**

Data sources we used
Tick all that apply

- ☐ **OpenStreetMap** (building footprints)
- ☐ **Local knowledge** (observations)
- ☐ **Climate Data** (solar radiation, wind, temp., etc.)
- ☐ **DEM** (terrain / elevation)

3. EVIDENCE SPECTRUM

Observed (seen and measured)	**Estimated** (educated guess / rough calculation)	**Calculated** (calculate based on strict rules and formula from data and / or assumptions)	**Predicted** (simulated by the model)
Examples			
Buildings, building type, level, rooftop solar	Average occupancy / household size	Population, BVPC, Annual Average Solar Potential (AASP)	PWC, UTCI
______________	______________	______________	______________
______________	______________	______________	______________
______________	______________	______________	______________
______________	______________	______________	______________

NOT ALL TYPES OF EVIDENCE ARE THE SAME. Observed evidence is usually stronger than estimated, calculated and predicted.

4. RESULTS AND QUALITY AUDIT

Model outputs

Population	BVPC (m^3)	AASP (MWh/year)
______________	______________	______________
PWC	UTCI	
______________	______________	

LoD1 City Model - Validation (val3dity)

☐ **pass** ☐ **warnings** ☐ **fail**

Overall quality

Data completness

☐ **good** ☐ **partial** ☐ **poor**

Model reliability

☐ **good** ☐ **partial** ☐ **poor**

5. REFLECTION

What did the model say / what agreed with reality (local knowledge)?

____

____

____

How did the model DISAGREE with reality (local knowledge)?

____

____

6. OUR INTERPRETATION AND WHAT NEXT?

Based on 5. REFLECTION: we therefore think (actionable insights):

____

____

BUT we CANNOT conclude (limits and gaps):

____

____

What should we investigate next / NEW questions to explore:

____

____

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geo3D. Model and Evidence Card: Educator Rubric

Use this rubric to evaluate students' critical spatial literacy, data provenance auditing, and epistemic rigour.

EVALUATION MATRIX

Dimension	**Developing** (1 pt.)	**Proficient** (2 pt.)	**Good** (3 pt.)	Score
1. Evidence Spectrum Classification (Sec 2 & 3)	Blurs boundaries between data types (e.g., treats population estimates as and direct empirical facts).	Correctly categorizes most variables across Observed, Assumed, Calculated, and Predicted tiers.	Impeccably distinguishes empirical ground truth from assumptions, formulas, and simulations.	/ 3
2. Quality & Validation Audit (Sec 4)	Skips validation steps or provides generic ratings without checking data completeness or val3dity.	Accurately records output metrics and completes quality checkboxes based on lab checks.	Thoroughly audits quality notes geometric checks (val3dity), and identifies specific data gaps.	/ 3
3. Local Knowledge & Reflection (Sec 5)	Repeats model numbers without comparing them to local knowledge or field experience.	Identifies 1–2 areas where model outputs agree or disagree with local experience.	Clearly contrasts model with lived experience, identifying specific drivers. (e.g., occupancy/shade).	/ 3
4. Interpretation (epistemic) Boundaries (Sec 6)	Draws sweeping, unsupported conclusions that exceed what the model can prove.	States actionable insights while acknowledging broad limits and missing data.	Articulates precise insights while detailing hard limits; proposes clear next steps.	/ 3
			TOTAL SCORE: __ / 12	

ILLUSTRATIVE EXAMPLES. Dimension 4 (INTERPRETIVE BOUNDARIES & ACTION)

Use these benchmark answers to guide grading for Section 6 across the three lab tracks.

VILLAGE TRACK (Mamre — Secondary Level)

Developing (1 pt): ‘*Because Mamre gets lots of sun, every house should buy solar panels immediately and we can completely replace coal power for the whole town.*’
[**Flaw:** Unrealistic leap that ignores household income, grid capacity, and roof pitch and inclination]

Proficient (2 pts): ‘*Mamre's unshaded residential roofs offer strong rooftop solar potential, but we cannot conclude exact household energy savings because we lacked electricity bill data and roof pitch tags.*’
[**Strength:** States actionable insights while acknowledging broad analytical limits and missing data.]

Good (3 pts): ‘*Single-storey homes along Main Road show high potential for decentralized rooftop solar micro-grids, but we CANNOT conclude individual household financial ROI, structural load capacities, or peak evening demand. Next step: Conduct a survey of 15 households to measure real-time energy use.*’
[**Strength:** Articulates precise insights, details hard limits, and proposes a logical follow-up.]

SUBURB TRACK (Woodstock — Tertiary Level)

Developing (1 pt): ‘*The 3D model shows low BVPC in historic Woodstock, proving these buildings are illegally overcrowded slums that municipal authorities must clear.*’
[**Flaw:** Confuses physical volumetric density with legal status or social quality.]

Proficient (2 pts): ‘*Low Building Volume Per Capita (BVPC) values highlight spatial housing density in Woodstock, but we cannot conclude actual indoor living conditions because LoD1 flat roofs simplify true volume.*’
[**Strength:** States actionable insights while acknowledging technical geometric limits.]

Good (3 pts): ‘*Low BVPC clusters reliably isolate historic residential blocks suffering from high volumetric density, but we CANNOT conclude internal room counts, multi-family living arrangements, or code compliance due to flat-roof LoD1 volume approximations. Next step: Re-run the spatial pipeline using an LoD2 roof-resolved workflow to refine volumetric calculations on sloped Victorian roofs.*’
[**Strength:** Identifies precise spatial patterns, declares technical bounds, and proposes a coding next step.]

ADVANCED TRACK (Salt River — Advanced Undergraduate)

Developing (1 pt): ‘*OpenFOAM proves that the wind at the corner of Victoria Road is dangerously high and the city must demolish the corner building to fix the microclimate.*’
[**Flaw:** Draws a radical, unsupported conclusion from a static CFD model that omits urban features.]

Proficient (2 pts): ‘*OpenFOAM CFD simulations indicate strong wind jetting along narrow street canyons, but we cannot conclude exact daily wind speeds because vegetation and boundary walls were omitted.*’
[**Strength:** Identifies wind dynamics while noting missing physical domain layers.]

Good (3 pts): ‘*Simulated wind vectors confirm localized SE wind acceleration (>5 m/s) near key transit stops, but we CANNOT conclude real-time pedestrian cold stress risk or gust frequencies under dynamic weather fronts because atmospheric stability was assumed neutral and trees were omitted from the model. Next step: Integrate 3D vegetation canopy geometries into OpenFOAM boundary conditions.*’
[**Strength:** Delivers precise physical insights, explicitly bounds the simulation, and offers a clear modelling step.]

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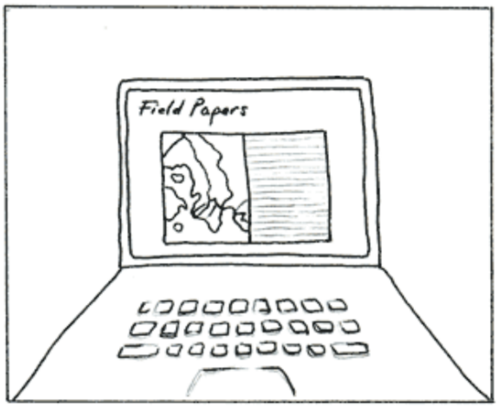
geo3D. Field Audit and Interpretive Boundaries

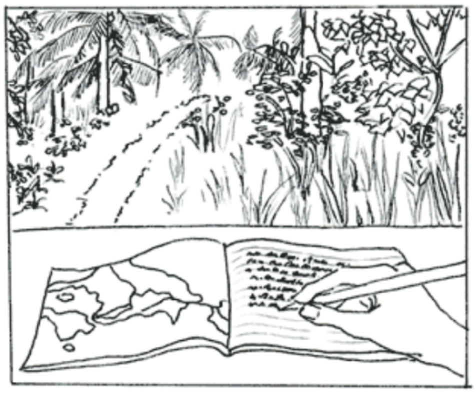
Students can use this worksheet to help: record their work -- evaluate OpenStreetMap data, contributions (observed evidence) -- and inform reasoning.

NAME / GROUP: ____

geo3D recommends Field Audits and community mapping with Field Papers



Make a .pdf printable map



Take it to the field and make notes and record observations

1. PLACE: check whether the geographic data (evidence) represents and place you are investigating

Place / Area of Interest (AOI) ______________________________ **Date:** ____________________

City / Region / Country ______________________________ **Track:** ☐ **Village** ☐ **Suburb** ☐ **Advanced**

2. FIELD AUDIT (Walk 1–2 blocks to audit ground reality **BEFORE** adding contributions to OpenStreetMap)

Unlike mapping; you do not need to survey (check / audit) the entire neighbourhood.
Walk one block or a small, manageable area and validate several (5–30) buildings/features.

What to look out for

- ☐ **Building footprint:** missing / incorrect
- ☐ **Building levels:** missing / incorrect
- ☐ **Building type:** missing / incorrect
- ☐ **Visible roof top solar:** missing / incorrect
- ☐ **Ground-Level Microclimate:** windy / sheltered / exposed / sunny / etc.
- ☐ **Other:** ____________________

3. STUDENT GUIDE TO SECTION 6 (Interpretive – epistemic -- **Boundaries & Action)**

3D models, whether basic or ISO 19107 certified, and wind simulations are powerful, but their **results are often built on assumptions and missing data.** Use this formula to complete Section 6 of your Model Card ***responsibly***:

[STEP A] ACTIONABLE INSIGHT (Based on 5. REFLECTION: we therefore think...)
- What spatial pattern or priority does the model reliably show? (e.g., density clusters, wind canyons)

[STEP B] EPISTEMIC BOUNDARY (BUT we CANNOT conclude...)
- What assumptions or missing data / evidence stop you from making an absolute claim?
- Name specific missing variables (e.g., household income, electricity bills, roof pitch, tree foliage).

[STEP C] NEXT STEPS (What should we investigate next / NEW questions to explore...)
- What field action, dataset / evidence, or technical step is needed to bridge the gap?

BEFORE & AFTER EXAMPLE

POOR (Sweeping claim / Over-confidence): *'The model shows low BVPC in Woodstock, proving these homes are overcrowded slums the city must clear.'* **(Flaw:** Confuses physical building volume with social status and legal conditions.**)**

GOOD (Bounded spatial reasoning): *'Low BVPC values reliably highlight blocks with high physical density. BUT we CANNOT conclude actual indoor overcrowding or living conditions because our LoD1 model assumes flat roofs and uniform height. Next step: Re-run the pipeline with an LoD2 roof-resolved model and conduct a field survey.'*

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Lab 1. Village Track — Secondary Level (Spatial Data Science and Interactive Exploration)

Materials & Prerequisites

- **Software/Environment Required:**
  - Browser (for JupyterBook / WebGL).
  - Python / Jupyter Notebooks (pandas).
- **Datasets Used:** OpenStreetMap building footprints and local knowledge
- **Direct Links:**
  - **Hosted JupyterBook:** interactiveOnly.ipynb
  - **Code Repositories:** *geo3D Lab*, *geo3D*.

Task 1.1: Execute the interactiveOnly.ipynb Jupyter Notebook and estimate population metrics, Building Volume Per Capita (BVPC), and calculate rooftop solar stats. Inspect the WebGL viewer and navigate the 3D scene.

Possible conversations starters / discussion and questions

Geography	- Talk about the main difference between a globe and a map, and why we use map projections to represent the Earth on a flat surface - Explain why different map projections are used for different purposes. For example, why might a Mercator projection be useful for navigation, but not for comparing the sizes of countries?
Basic understanding and observations	- What types of buildings are most common in the area (houses, apartments, retail, etc.)? - Can you identify any patterns in the distribution of different types of buildings (e.g., are retail stores concentrated in certain areas)?
Spatial Relationships and Impacts	- How does the location of residential areas compare to the location of retail and commercial areas? - What impact might the density and distribution of buildings have on local traffic and transportation? - How might the population distribution affect the demand for local services such as schools, hospitals, and parks?
Socioeconomic and Environmental Considerations	- Are there any correlations between the types of housing available and the household size? *additional demographics (e.g., income level) for the area will strengthen the analysis!* - How might the current building stock and population influence the local economy? *demographics (e.g., age distribution, household size) for the area will strengthen the analysis!* - What are some potential environmental impacts of the current building distribution, such as green space availability or pollution levels?
Future Planning and Development	- Based on the current building stock and population metrics, what areas might benefit from additional housing or commercial development? - How could urban planners use this information to improve the quality of life in the area? - What changes would you recommend to better balance residential, commercial, and recreational spaces?

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geo3D. 3D City Models for Geography and Sustainable Development Education

Lab 2. Suburb Track — Tertiary Level (Offline 3D city model Creation, Spatial Analytics and Interactive Exploration)

Materials & Prerequisites

- **Software/Environment Required:**
    - Browser (for JupyterBook / WebGL, CityJSON viewer and quality control).
    - Python / Jupyter Notebooks (pandas, triangle, cjio).
- **Datasets Used:** OpenStreetMap building footprints via an `osm.pbf`, local knowledge, raster DEM, and an `ALLSKY_SFC_SW_DWN` (All Sky Surface Shortwave Downward Irradiance) dataset from NASA POWER
- **Direct Links:**
    - **Hosted JupyterBook:** osm_LoD1_3D-noInternet.ipynb and CityJSONdataScience-noInternet.ipynb
    - **Code Repositories:** *geo3D Lab*, *geo3D*.

Task 2.1: Combine offline OSM footprints and a raster Digital Elevation Model to create an **OGC** compliant **ISO 19107** Level-of-Detail (**LoD1**) **3D city model,** via a Constrained Delaunay Triangulation (CDT), with the osm_LoD1_3D-noInternet.ipynb Jupyter Notebook.
Task 2.2: Explore the 3D city model in ninja the CityJSON viewer.
Task 2.3: Investigate the quality of the 3D city model with val3dity
Task 2.4: Execute the CityJSONdataScience-noInternet.ipynb Jupyter Notebook and estimate population metrics, Building Volume Per Capita (BVPC), and calculate rooftop solar stats. Inspect the WebGL viewer and navigate the 3D scene.

Possible conversations starters / discussion and questions

Geography	- Talk about the main difference between a globe and a map, and why we use map projections to represent the Earth on a flat surface - Explain why different map projections are used for different purposes. For example, why might a Mercator projection be useful for navigation, but not for comparing the sizes of countries?
Basic understanding and observations	- How does the building stock composition (e.g., ratio of houses) correlate with the population? *demographics (e.g., age distribution, household size) for the area will strengthen the analysis!* - Analyze the relationship between building density and population. What urban planning theories can explain this relationship?
Spatial Relationships and Impacts	- Evaluate the accessibility of essential services (e.g., healthcare, education) in relation to the population and building types. - Assess the potential social and economic impacts of a proposed new residential or commercial development in the area.
Socioeconomic and Environmental Considerations	- How does the current building stock support or hinder sustainable development goals (e.g., energy efficiency, reduced carbon footprint)? - What strategies could be implemented to increase the resilience of the community to environmental or economic changes?
Future Planning and Development	- How might different zoning regulations impact the distribution of residential, commercial, and industrial buildings in the future? - Propose urban design solutions that could improve the sustainability and livability of the area, considering both current metrics and future projections.
Quantitative and Qualitative Research	- Design a research study to investigate the impact of building type diversity on community wellbeing. What methodologies would you use? - Analyze historical data to understand trends in building development and population growth. How have these trends shaped the current urban landscape? - Conduct a SWOT analysis (Strengths, Weaknesses, Opportunities, Threats) of the area based on the building stock and population metrics.

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Lab 3. Advanced Track — Advanced Undergraduate (Physics & Microclimate)

Materials & Prerequisites

- **Software/Environment Required:**
  - Browser (for JupyterBook / WebGL, CityJSON viewer and quality control).
  - Python / Jupyter Notebooks (pandas, triangle, cjio, trimesh, OpenFOAM).
- **Datasets Used:** OpenStreetMap building footprints via an osm.pbf, local knowledge, and raster DEM
- **Direct Links:**
  - **Hosted JupyterBook:** urbanFlow-noInternet.ipynb
  - **Code Repositories:** *geo3D Lab*, *geo3D*.

Task 3.1: Combine offline OSM footprints and a raster DEM to create an **OGC** compliant **ISO 19107** Level-of-Detail **(LoD1) 3D** CityJSON **city model and an .obj** with the urbanFlow-noInternet.ipynb Jupyter Notebook.
Task 3.2: Explore the 3D city model in ninja the CityJSON viewer.
Task 3.3: Investigate the quality of the 3D city model with val3dity
Task 3.4: Follow the instructions in the urbanFlow-noInternet.ipynb Jupyter Notebook to execute a Computational Fluid Dynamics (CFD) simulation via OpenFOAM
Task 3.5: Complete the urbanFlow-noInternet.ipynb Jupyter Notebook to visualise wind vectors, estimate Pedestrian Wind Comfort (PWC) and a Universal Thermal Comfort Indicator (UTCI)

Possible conversations starters / discussion and questions

Feeling the Wind in Place	- How do the simulation results compare with your own experience of wind in this area? - What features of the built environment (e.g., building height, street width) might explain these differences? - How could local knowledge help improve or validate the simulation?
Streets, Buildings & Wind	- Identify patterns in the simulation where wind is channelled, blocked, or redirected. - How does the arrangement of buildings shape these patterns? - What might this mean for how the area was designed or developed?
Comfort in Everyday Spaces	- Using the simulation, identify areas that may be uncomfortable for pedestrians. - How could these conditions affect different groups of people (e.g., elderly, children)? - What small changes could make these spaces more comfortable?
Wind, Temperature & How We Feel	- How can wind speed influence perceived temperature (e.g., wind chill or thermal comfort)? - How might combining wind data with weather conditions change our understanding of comfort? - What kinds of places might be most affected during very hot or cold days?
Comparing Places	- Use the simulation to compare wind conditions across different locations. - What spatial patterns emerge (e.g., exposed vs sheltered zones)? - How could this influence movement, activity, or land use in the area?
Improving Local Spaces	- Test or propose design changes based on the simulation results. - How might interventions (e.g., vegetation, barriers) change wind patterns? - What trade-offs might exist between airflow (cooling) and comfort?
People, Place & Environment	- How can understanding wind and comfort support better public space design? - What role can local communities play in identifying environmental challenges? - How could this analysis support more inclusive and livable urban spaces?
Understanding the Model	- What are the limitations of this type of simulation? - How sensitive are results to inputs like wind direction or building data? - How could field observations be used to improve the model?

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