香港岩土及岩土環境工程專業協會
ASSOCIATION OF GEOTECHNICAL & GEOENVIRONMENTAL SPECIALISTS (HONG KONG)

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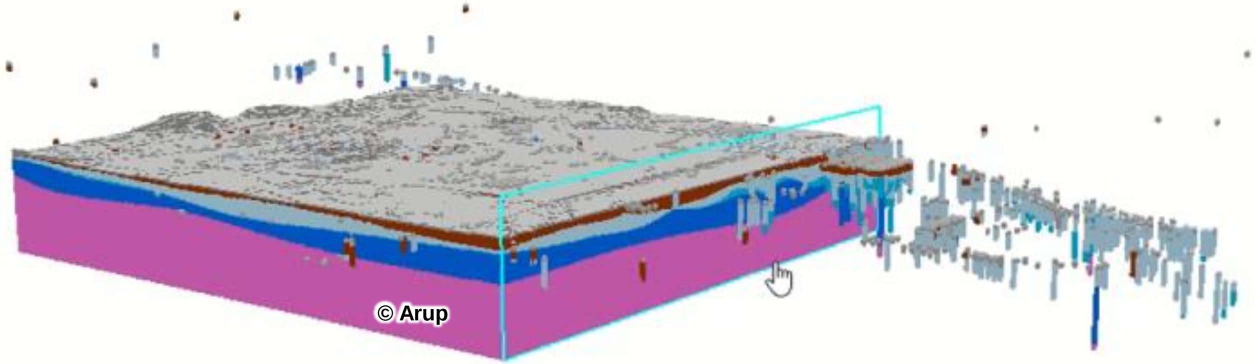
# 3D Geotechnical Voxel Model for Regional-scaled Study

## AGS(HK) Technical Seminar

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# 1. What is Voxel?

# What is Voxel?

## In general

- [**Vo** = Volumetric] [**xel** = pixel]

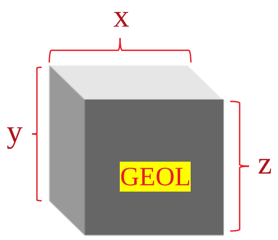
  → Three-dimensional equivalent of a pixel in 2D, representing volumetric gridded data

- A Voxel Cell contains information such as:

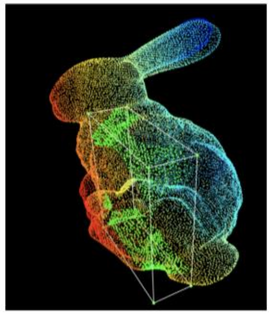
  (1) Position in 3D → X, Y, Z

  (2) Attribute values → temperature, material type, density, geological composition, etc

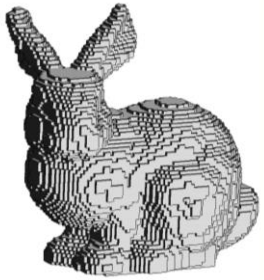
  (3) Resolution → 10m x 10m x 10m



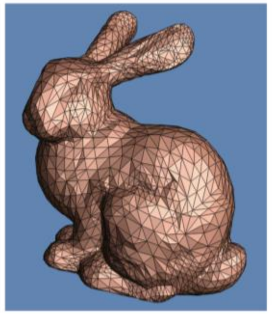

Setting of geological voxel model



Point cloud



Voxel



Triangular mesh

A house in Minecraft

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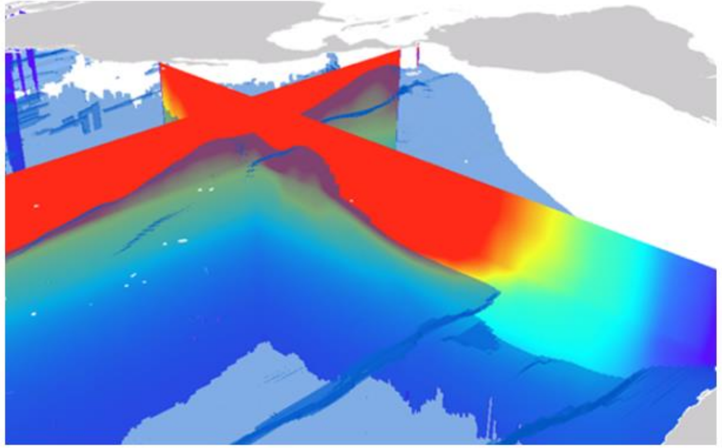
# What is Voxel?

## In ESRI ArcGIS

- **NetCDF** voxel model visualization in **ESRI ArcGIS**: Atmospheric, Oceanic, **Geological**
- Visualize the subsurface conditions as volumes or surfaces, or cross-section diagrams with other GIS data ( e.g., 3D boreholes, construction plans)
- Voxel property in our study : qualitative and discrete (e.g. **Geotechnical Unit**)

An Example of voxel model showing the underground information in ArcGIS Pro



The ecological marine unit voxel layer shows a cross section of temperature with an isosurface of oxygen saturation.

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# 2. Objective and Geotechnical Applications

# Objective and Geotechnical Applications

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<u>Objective:</u>

Understand the **geotechnical** information at **city-level** in the **preliminary stages** for city development planning and engineering construction projects.

At **city-level** in the **preliminary stages:**

- Facilitate planners and practitioners for decision-making, preliminary planning and schematic design of different engineering works:
  - Site Formation
  - Foundation
  - Reclamation
  - Tunnel, Cavern, Quarry

AI-generated image
(#Geotechnicalmodel #Engineer #Cityplanning)

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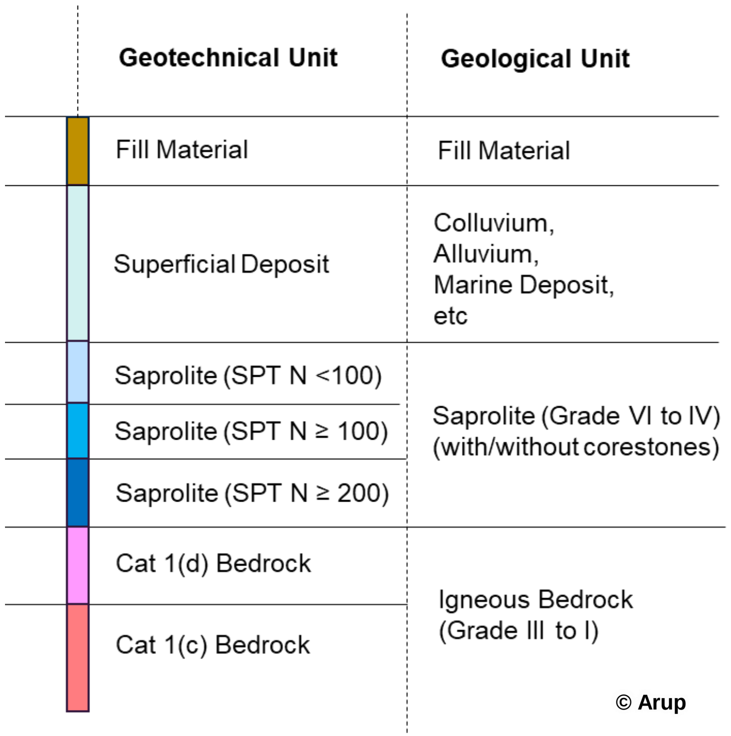
# Objective and Geotechnical Applications

<u>Objective:</u>

Understand the **geotechnical** information at **city-level** in the **preliminary stages** for city development planning and engineering construction projects.

**Geotechnical:**

- Characterize the ground condition as in similar geotechnical engineering properties, such as:
  - Depths of superficial deposits → Weak zone for ground improvement
  - SPT N-value levels → Ground stiffness
  - Bedrock types & levels → Foundation bearing pressures in bedrock



# 3. Methodology

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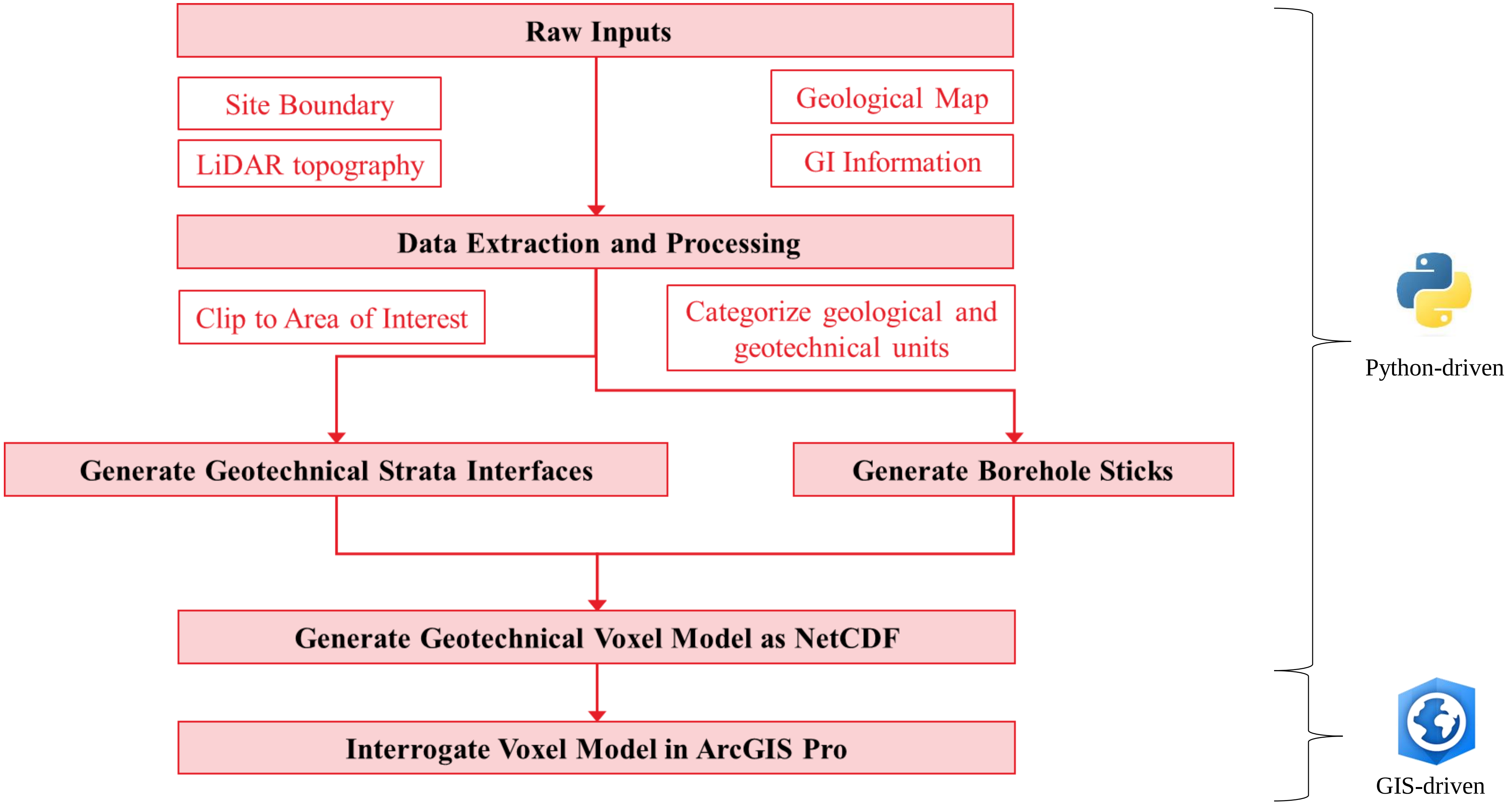
# Methodology

## General Workflow



# Methodology

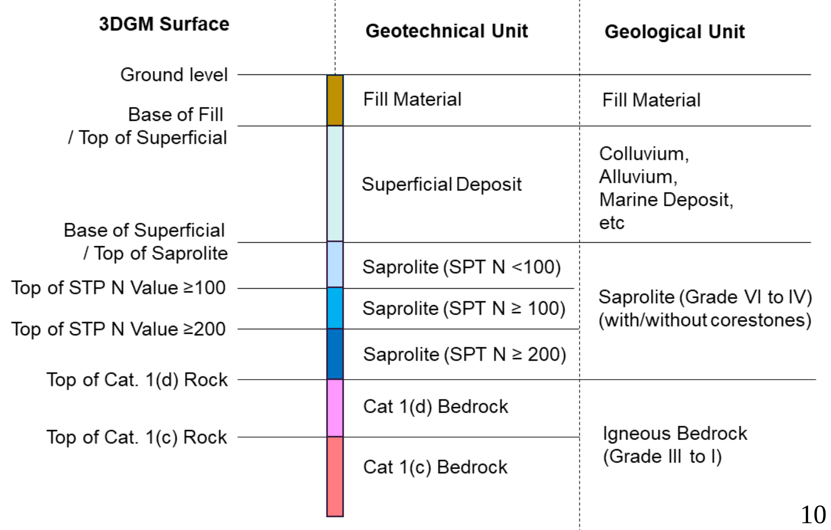
## Data Extraction and Processing

- Collect raw GI information, such as GI Location and basic exploratory information in the data formats of AGS & PDF
- **Categorize and group** the similar geological strata into geotechnical strata, based on information such as:

  Geological description, Core Recovery, Weathering grades, SPT N-values

| Unit | Name | Geological Strata within the Unit | Surface |
|---|---|---|---|
| 1 | Fill | Fill | Base of Fill / Top of Superficial |
| 2 | Superficial | Colluvium, Taluvium, Marine Deposits, Marine Sand, Marine Silt, Marine Clay, Alluvium, Pond Deposits | Base of Superficial / Top of Saprolite |
| 3 | Saprolite (SPT N <100) | In-situ strata with weathering grades of VI, V, or IV and SPT N values less than 100. | - |
| 4 | Saprolite (SPT N ≥100) | In-situ strata with weathering grades of VI, V, or IV and SPT N values between 100 and 200, encountered consecutively at least three times within the drillhole. | Top of SPT N ≥100 |
| 5 | Saprolite (SPT N ≥200) | In-situ strata with weathering grades of V, or IV and SPT N values ≥200, encountered consecutively at least three times within the drillhole. | Top of SPT N ≥200 |
| 6 | Bedrock (Cat 2) | In-situ meta-sedimentary strata with weathering grades of III, II, or I and with not less than 85% TCR proved to a depth of at least 5 m | Top of Cat 2 Rock |
| 7 | Bedrock (Cat 1d) | In-situ granitic/volcanic strata with weathering grades of III, II, or I and with not less than 50% TCR proved to a depth of at least 5 m | Top of Cat 1(d) Rock |
| 8 | Bedrock (Cat 1c) | In-situ granitic/volcanic strata with weathering grades of III, II, or I and with not less than 85% TCR proved to a depth of at least 5 m | Top of Cat 1(c) Rock |

| | B | C | D | E | F | G | H | I | J | K | L |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 3 | Drillhole ID | Easting | Northing | Ground Level (mPD) | Base of Fill (mPD) | Base of Superficial Deposits (mPD) | Top of SPTN100 (mPD) | Top of SPTN200 (mPD) | Top of Cat1d (mPD) | Top of Cat1c (mPD) | Top of Cat 2 (mPD) |
| 4 | 02467/FB1 | 820067.64 | 833903.42 | 4.44 | -7.31 | -10.21 | -22.98 | -27.22 | -29.32 | -33.93 | - |
| 5 | 02467/FB2 | 820072.94 | 833877.91 | 4.57 | -10.18 | -14.15 | -16.22 | -17.13 | -27.45 | -32.11 | - |
| 6 | 02467/N1 | 820907 | 834694 | 0.85 | -14.15 | -18.22 | -34.55 | -42.41 | - | - | -65.22 |

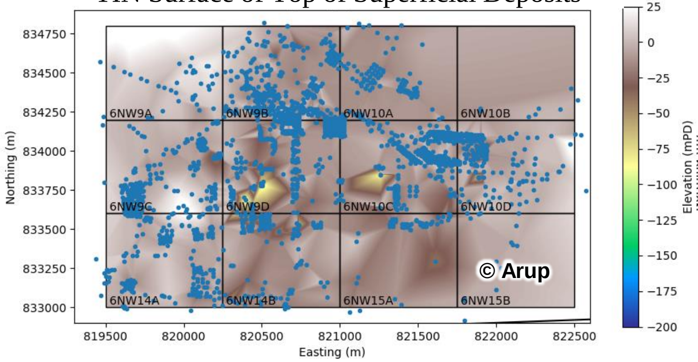


# Methodology

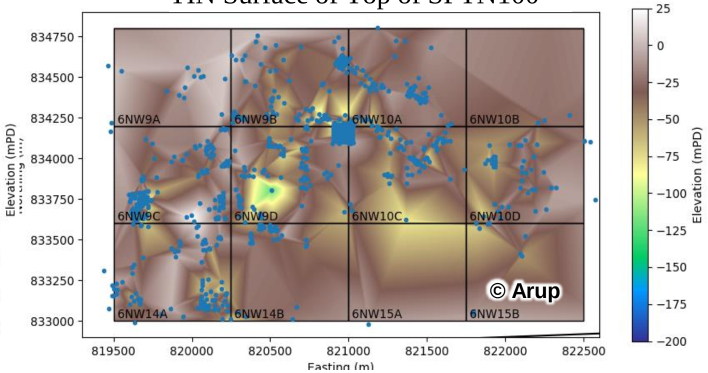
## Generate Geotechnical Strata Interfaces

- Interpolate the geotechnical points into 3D surfaces
- Triangulation with linear interpolation method

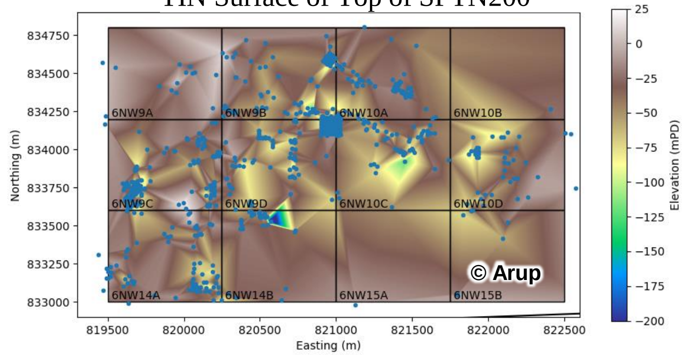
TIN Surface of Top of Superficial Deposits



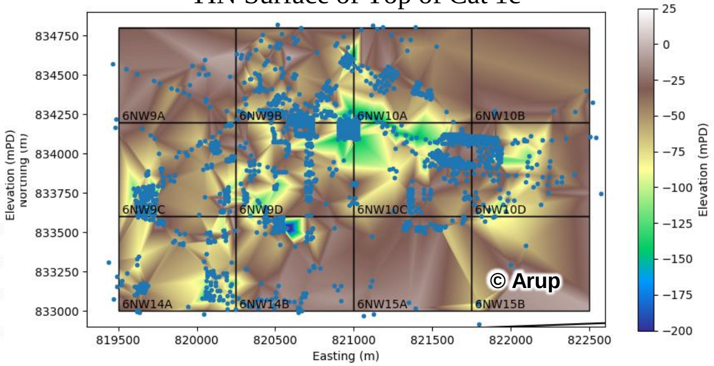

TIN Surface of Top of SPTN100



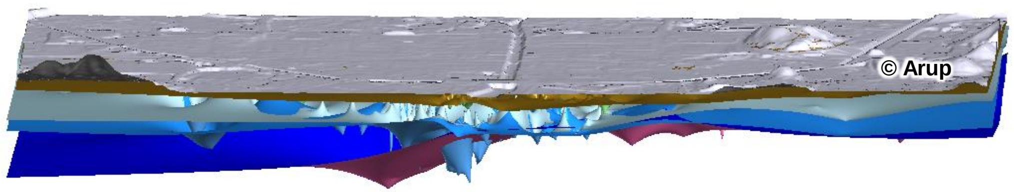

TIN Surface of Top of SPTN200




TIN Surface of Top of Cat 1c




Geotechnical interfaces stacking




Category
- Top of Fill
- Top of Superficial
- Top of Saprolite
- Top of SPT N ≥100
- Top of SPT N ≥200
- Top of Cat1c Bedrock

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# Methodology

## Create Geotechnical Voxel Model

- Assign the geotechnical unit as categorical data into voxel cells based on the geotechnical interface
- Use of Python scripts for the voxel cell assignment, final output: NetCDF file
- Resolution: 1m x 1m x 1m

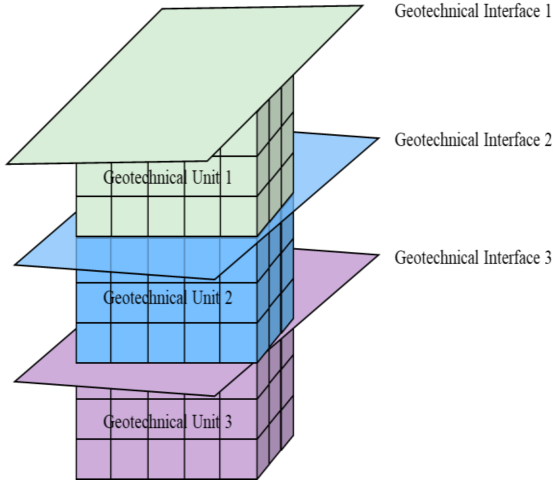
Python script to populate voxel cells

### Initialize voxel model

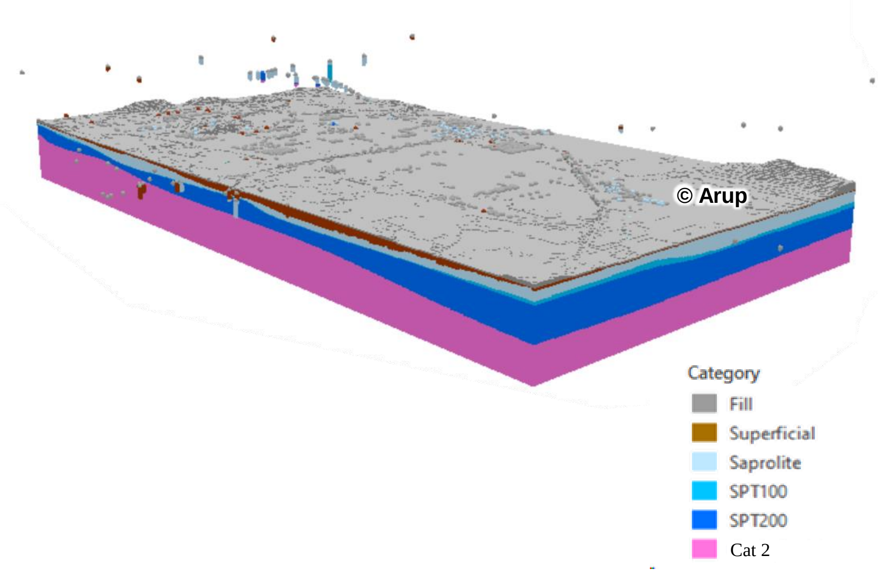
As stated in ESRI's documentation on Supported Voxel Formats and NetCDF Fundamentals, NetCDF data must follow the Climate and Forecast (CF) conventions. In ArcGIS Pro, currently only CF-compliant netCDF data with no auxiliary variables as a data source is accepted as a source for a voxel layer.

```
mapsheet = mapsheets_df[
    mapsheets_df[MAPSHEET_EXTENT_MAPSHEET_FIELD_NAME] == mapsheet_id
].iloc[0]

# Set up a voxel model with the elevation of each voxel as the value of each voxel
# This is done such that afterwards it's easy to check what voxels lay below a geotech interface
x_coords = range(
    mapsheet[MAPSHEET_EXTENT_X_MIN_FIELD_NAME],
    mapsheet[MAPSHEET_EXTENT_X_MAX_FIELD_NAME],
    VOXEL_SIZE
)
y_coords = range(
    mapsheet[MAPSHEET_EXTENT_Y_MIN_FIELD_NAME],
    mapsheet[MAPSHEET_EXTENT_Y_MAX_FIELD_NAME],
    VOXEL_SIZE
)
# height of the model +20m to -200m
# z_coords = range(20, -200, -1)
z_coords = range(100, -150, -1)

lat_dim = ncfile.createDimension("x", len(x_coords))  # latitude axis
lon_dim = ncfile.createDimension("y", len(y_coords))  # longitude axis
level_dim = ncfile.createDimension("level", len(z_coords))  # longitude axis
time_dim = ncfile.createDimension("time", None)  # unlimited axis (can be appended to).

ncfile.title = ""
```

Schematic idea of voxel cell assignment




Geotechnical Voxel Model



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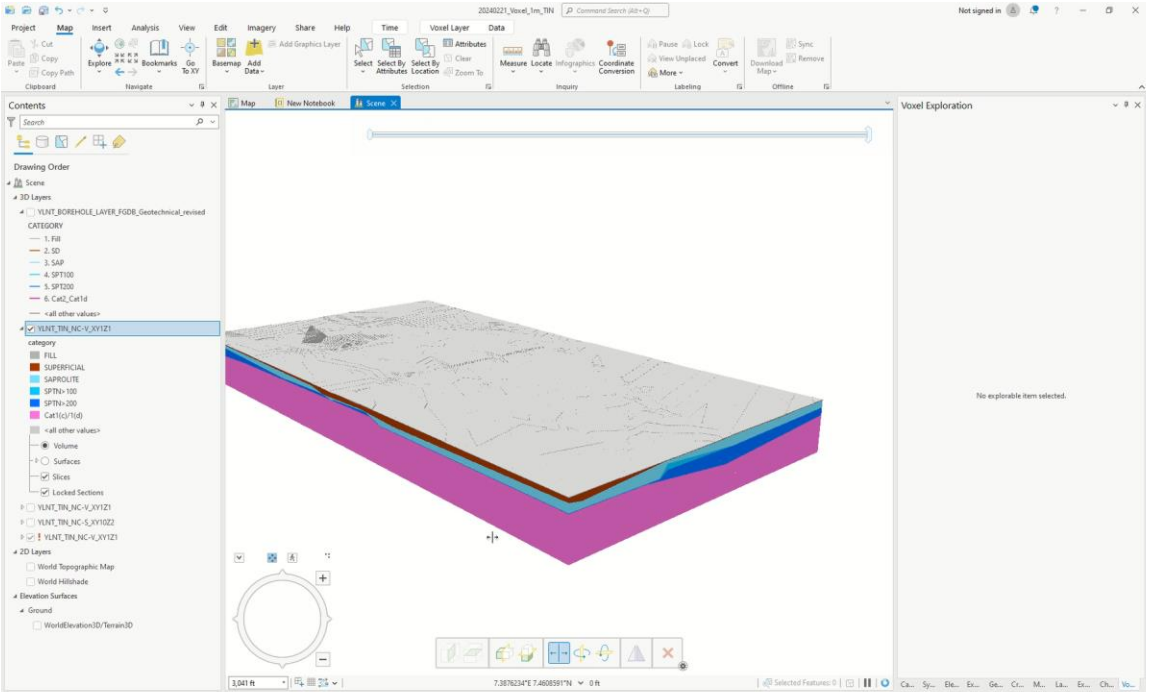
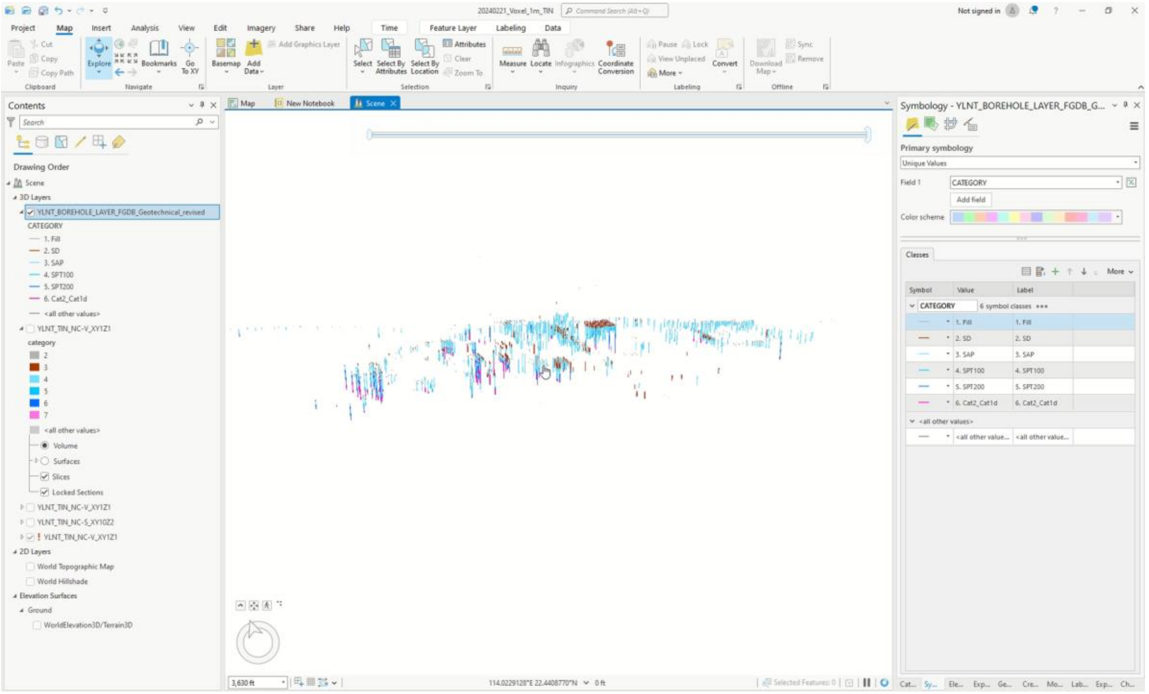
# Visualisation in ArcGIS Pro

- Import the NetCDF file (Voxel Model) and Geopackage (3D Borehole Sticks) into ArcGIS Pro
- Model interrogation, validation and visualisation with borehole data



# 4. Limitations & Development

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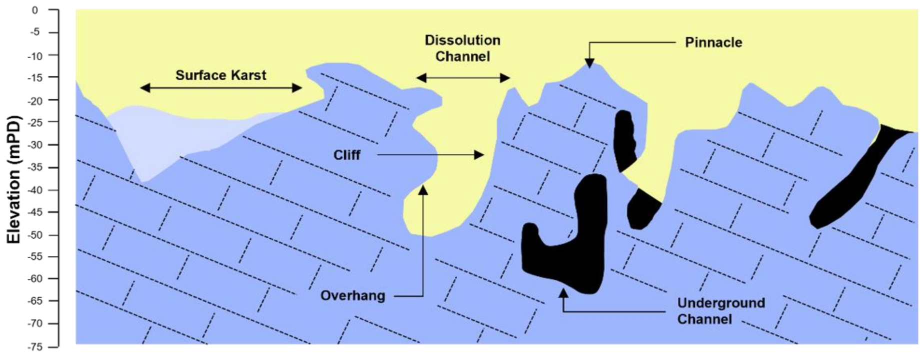
# Limitations

1. The layered approach cannot accommodate **complex geological** conditions:
    - Marble & Karstic Features (e.g. cavities, voids, caves, etc)
    - Faults & Folds

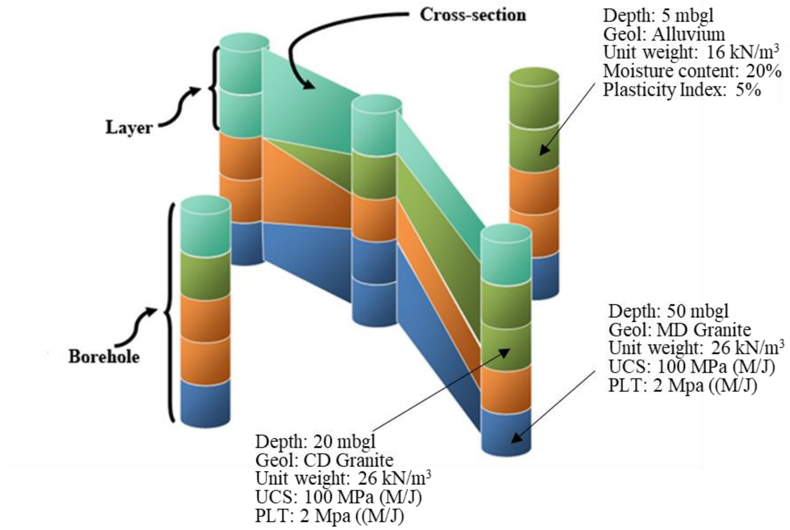


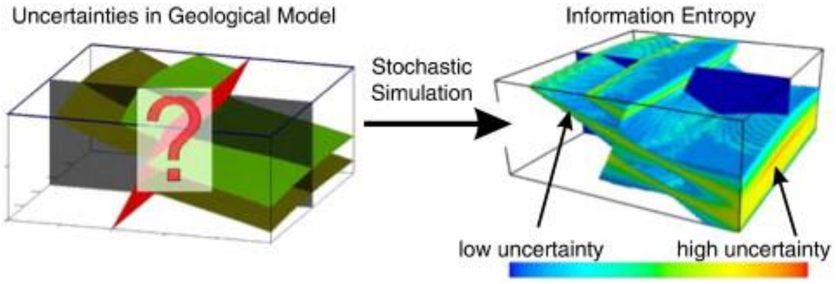

2. Limited flexibility for model refinement and updates
    - No **interactive surface adjustments** available yet, unlike more advanced tools such as Leapfrog.
    - Incorporating new data requires to re-generate the model

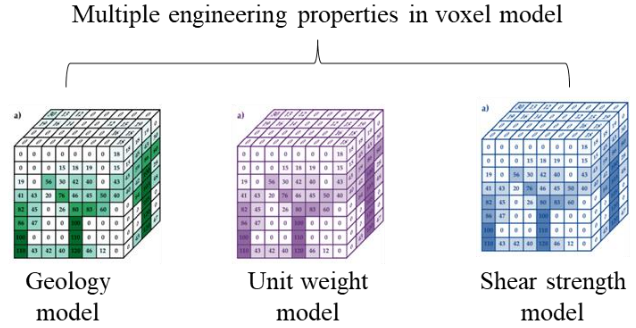
3. **Over-simplification** of geological complexity for detailed/site-specific studies
    - Assumption of **homogenous** materials and properties in between different interfaces, only suitable for **high-level planning** and study.

# Potential future development

- Incorporating **quantitative engineering properties** from laboratory tests
  - Soil/Rock density
  - Shear strength properties
  - Chemical compositions
- Exploring to **quantify the uncertainty** gap between drillholes
  - Random field approach
  - Geostatistical methods
  - Stochastic simulations



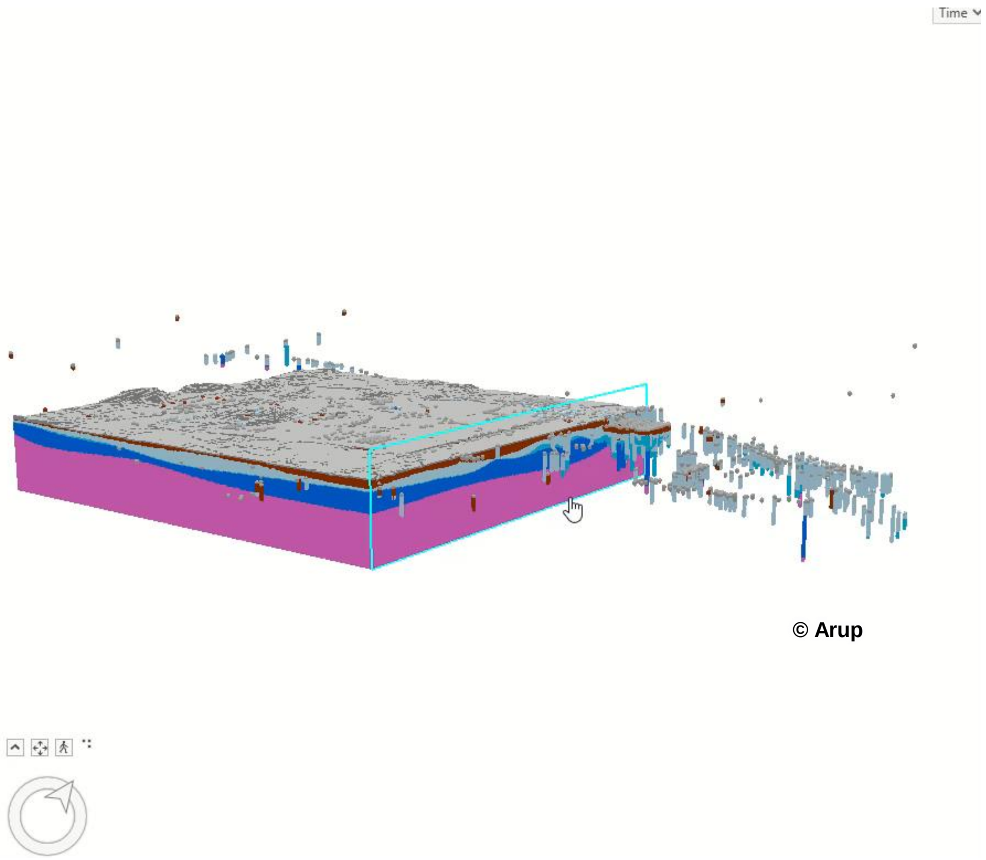
# Conclusion

Discovered the potential of voxel modelling for **regional-scale geotechnical studies** and gaining **early insights for city-level planning**.

Semi-automated workflows and open-source tools enhance **efficiency and scalability**

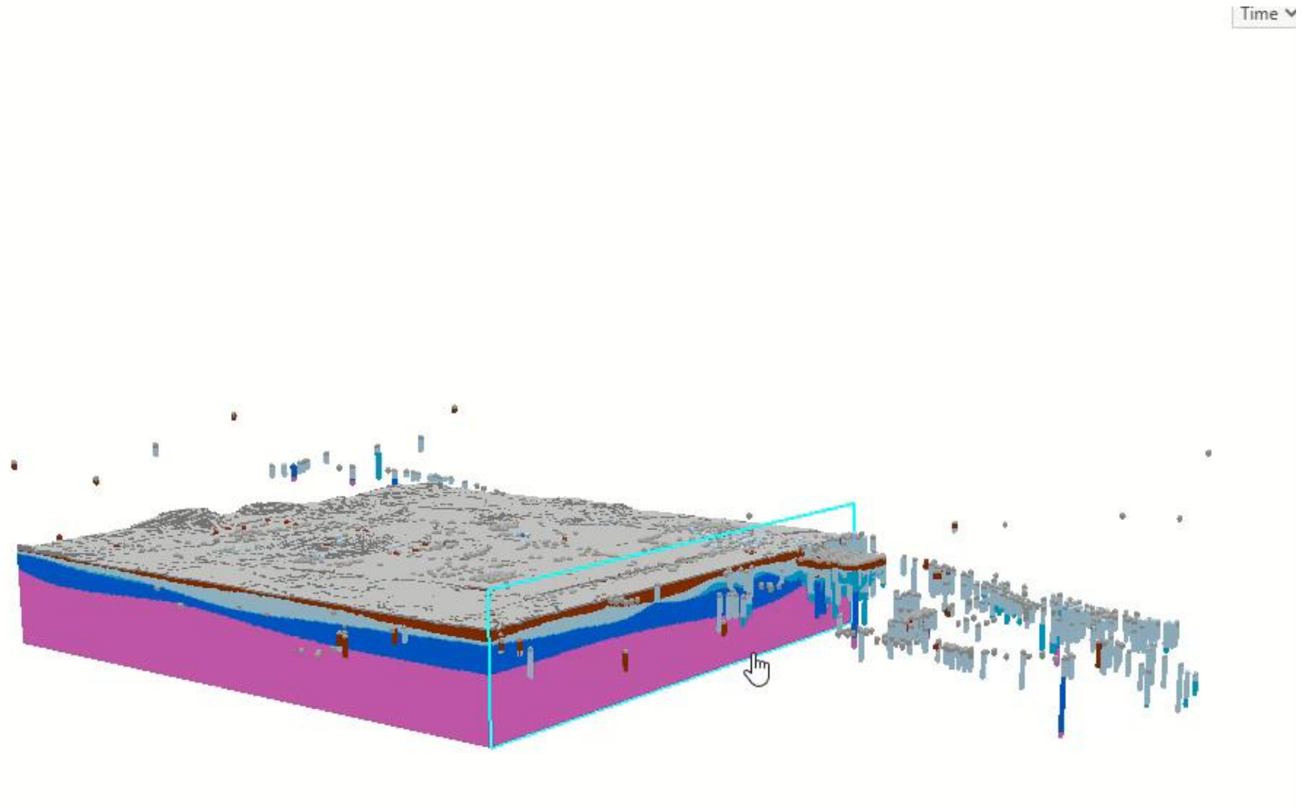
Identified and reviewed the **essential engineering properties** for high-level geotechnical design purpose.

Acknowledged the **limitations** of complex ground conditions and explored the possible **way forward**



# Q & A

Thank you
for your attention



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