Voxels for underground and above ground

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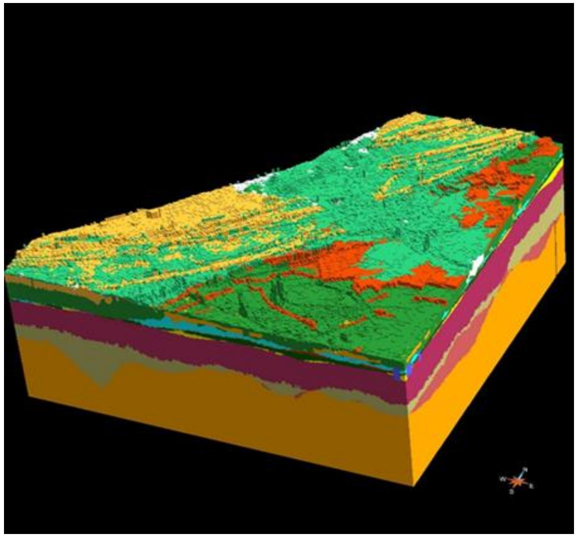
A vector-to-raster perspective



TNO, The Netherlands

Integration of Underground Infrastructure Data

- pipes: water, sewer, gas, steam
- cable & fibre: electricity, telephone, cableTV, internet
- subway: tunnels, stations
- buildings: basements, foundations
- manholes, conduits, ducts

Not so much about what happens *inside* the pipes (etc.) ...

… but about what happens *between* the elements of different systems

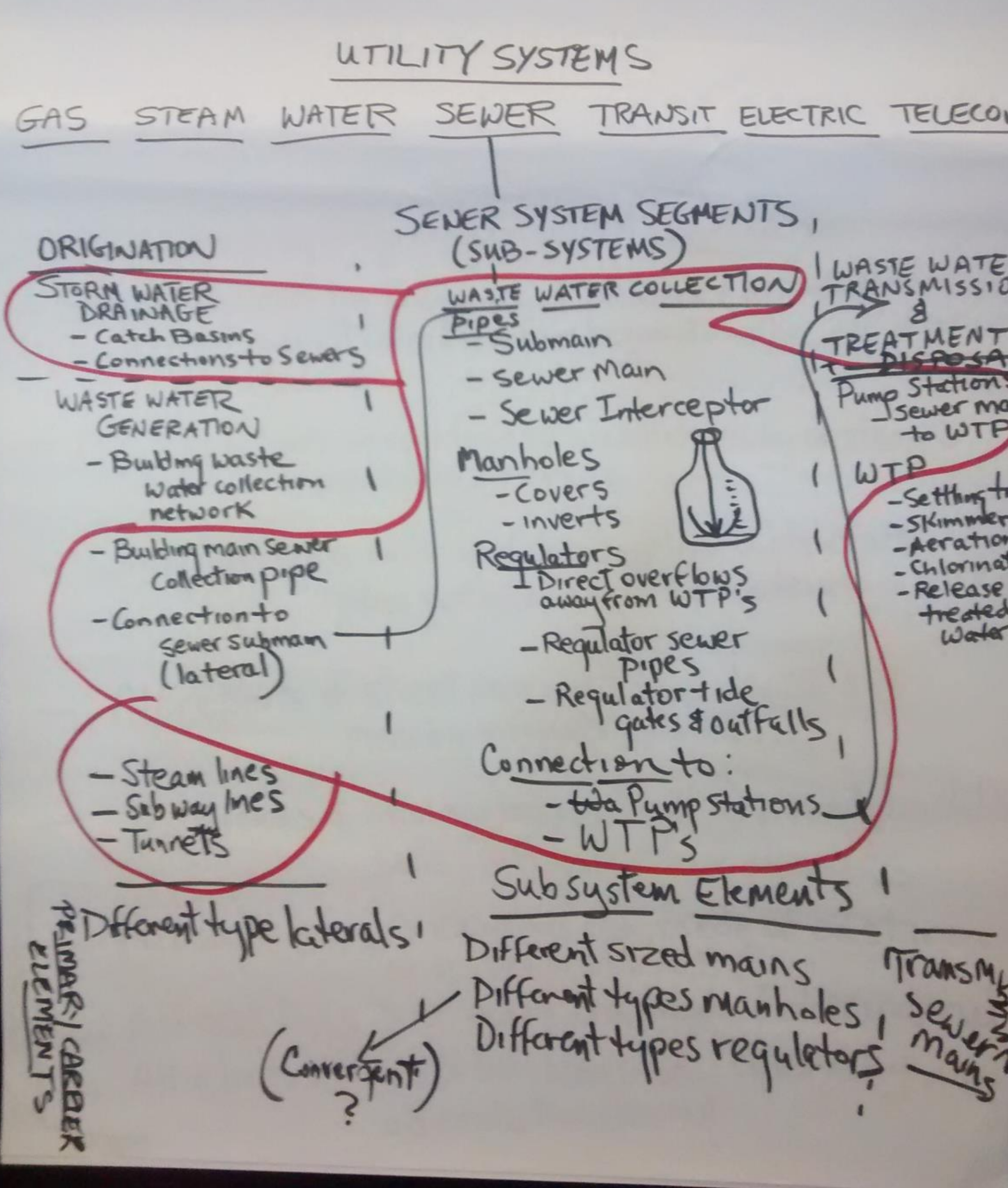
- in relation to their surrounding: soil, salinity, water table
- in case of *events*

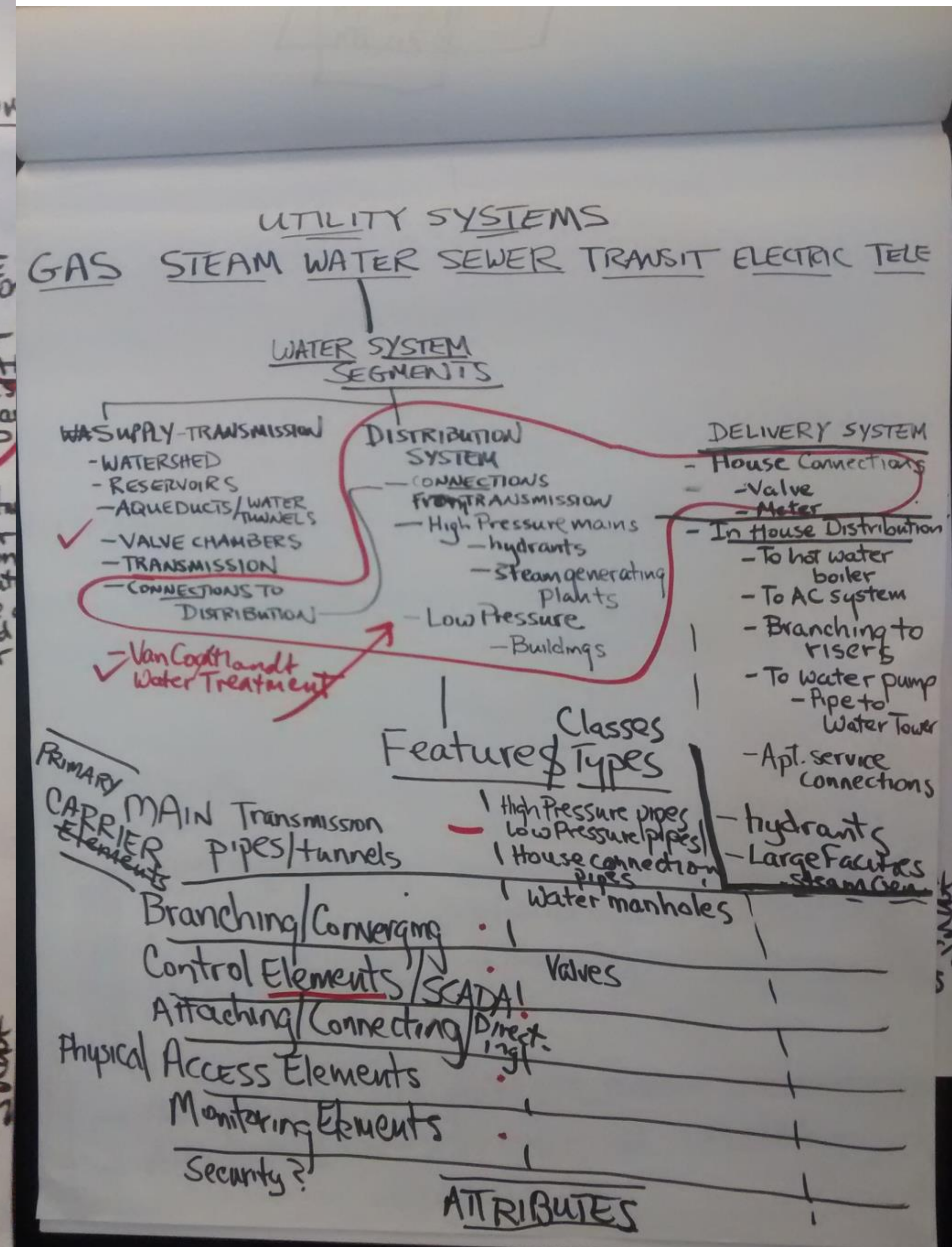
A technical or a political problem?

Certainly an organizational problem!

July – September 2016: Sabbatical at FCNY (Alan Leidner, Wendy Dorf) and OEM (James McConnell) suggested by OGC (George Percivall)

Alan Leidner's Flip-overs





3D Raster (voxel) models, feasibility and performance

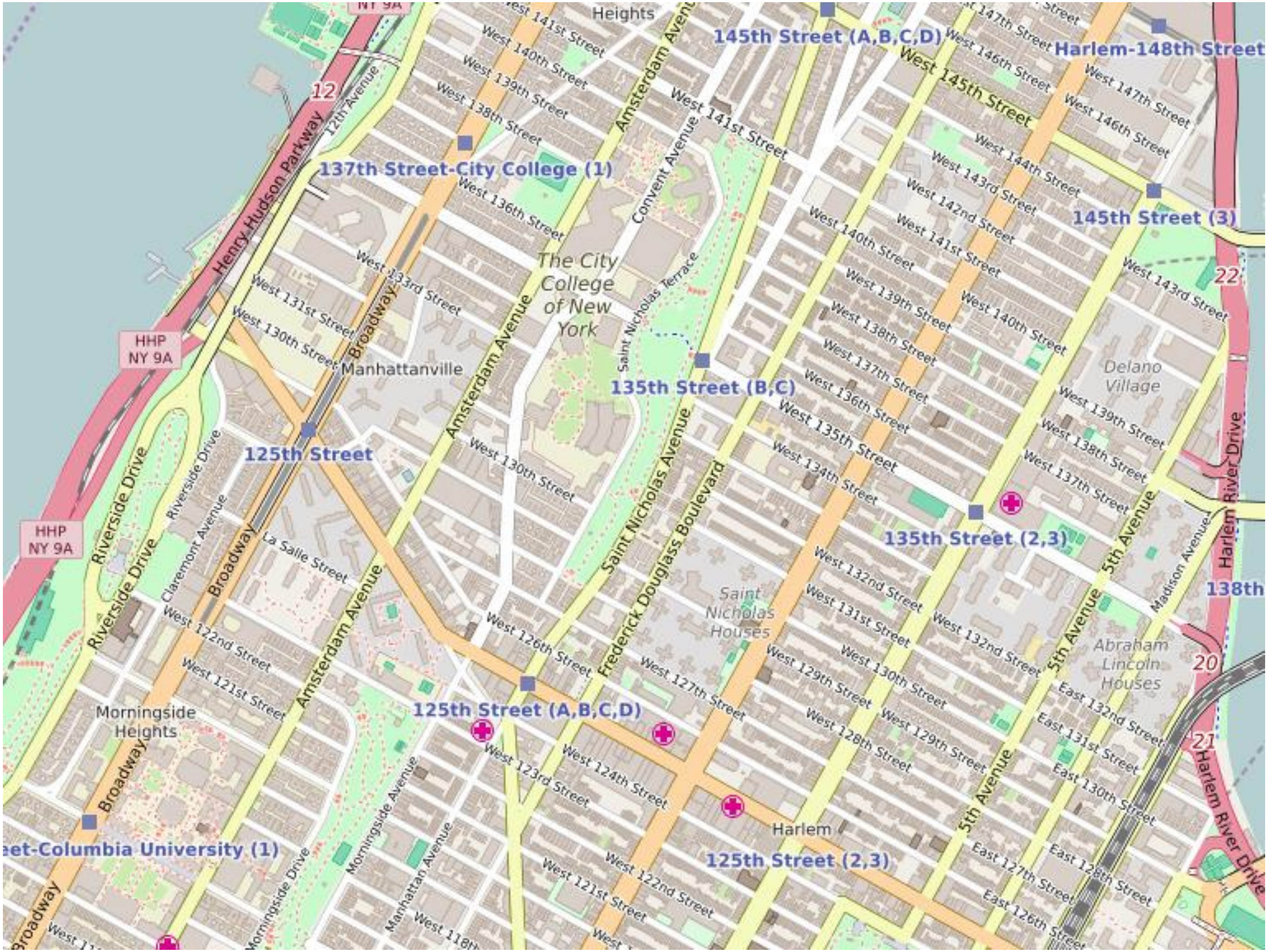
- Conceptual 3D Modelling of geographic features:

  terrain, volumes (buildings), surfaces (roads), lines (subway)
- 3D Raster representation: voxels, octrees
- Storage and management, Multi-resolution database
- Voxels Sweep Algorithm

Case Study

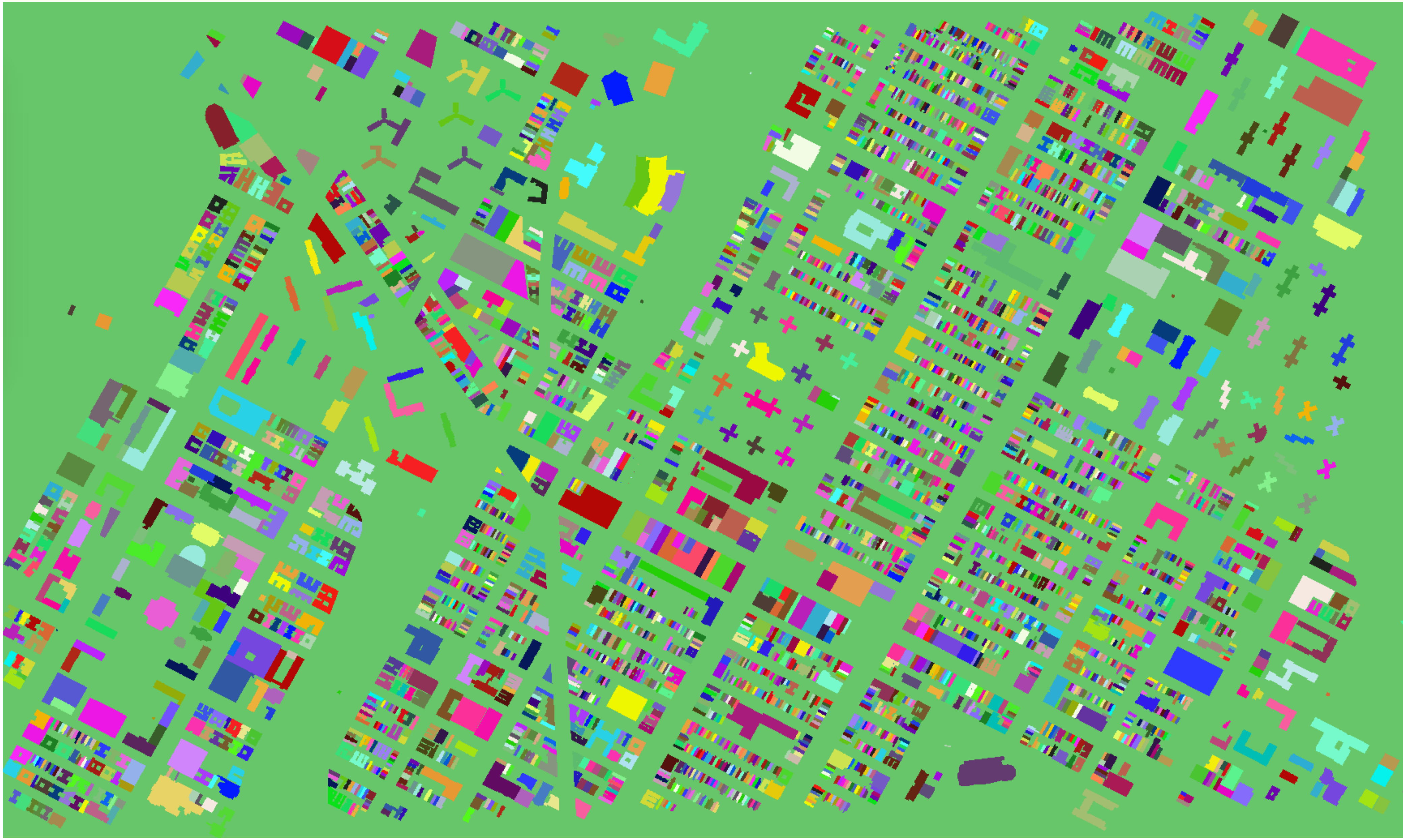
- Terrain from USGS DEM,
- Buildings/heights from OSM
- Roads and subway modelling

NY work: Manhattan on OpenStreetMap.org

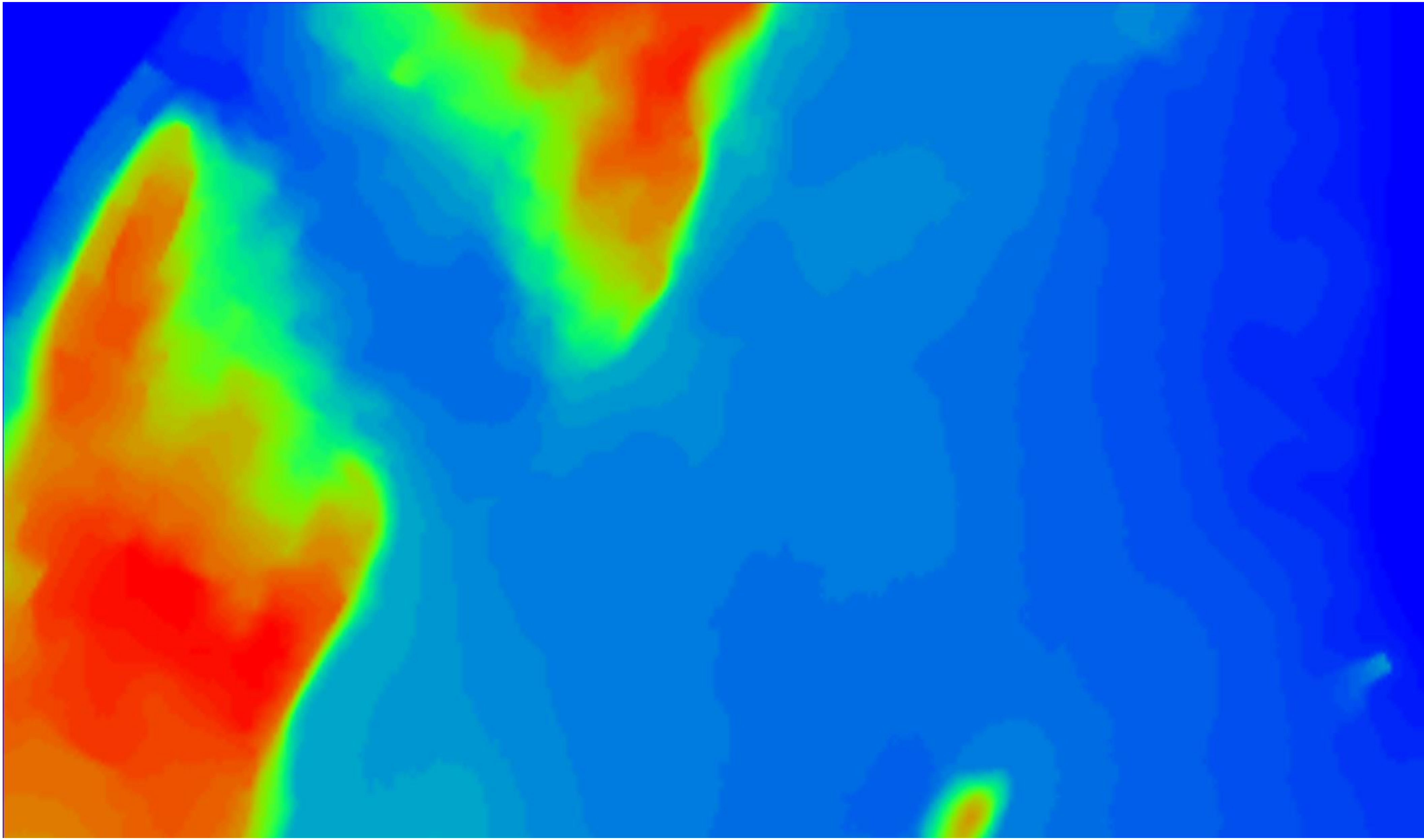


4100 rasterized building objects + heights

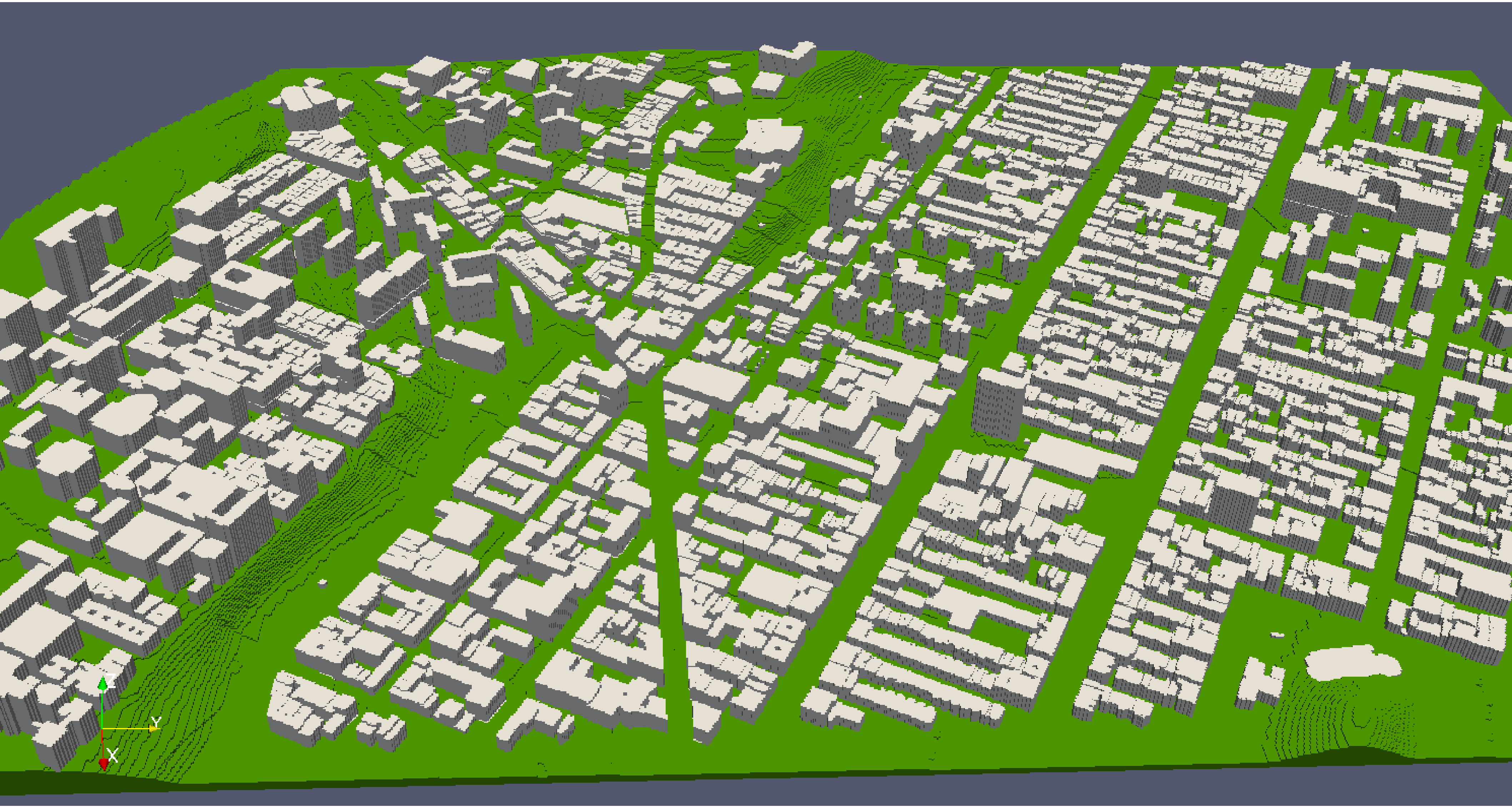
1664m x 2720m @ 0.25m → 6656x10880 pixels



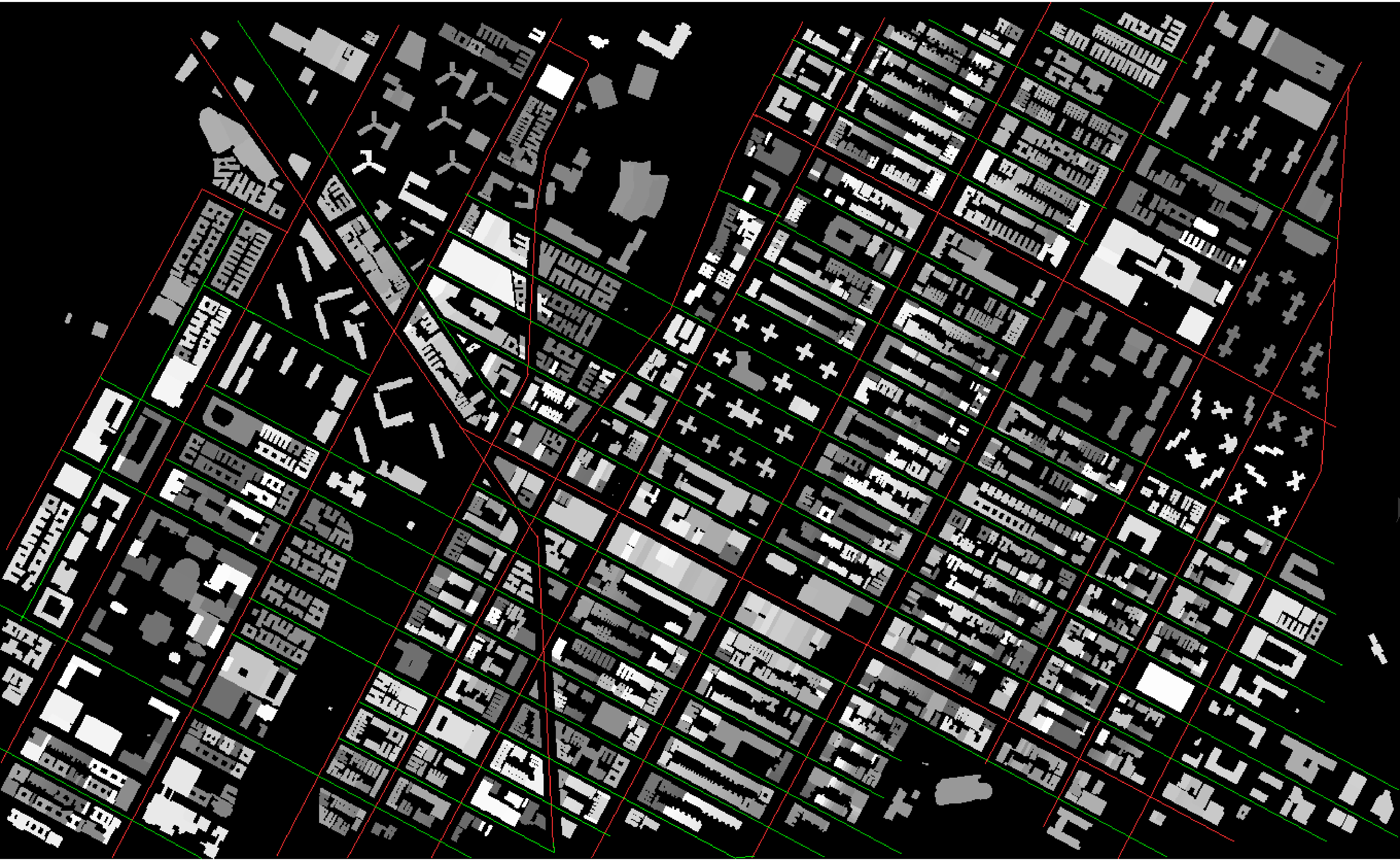
USGS Dem, interpolated



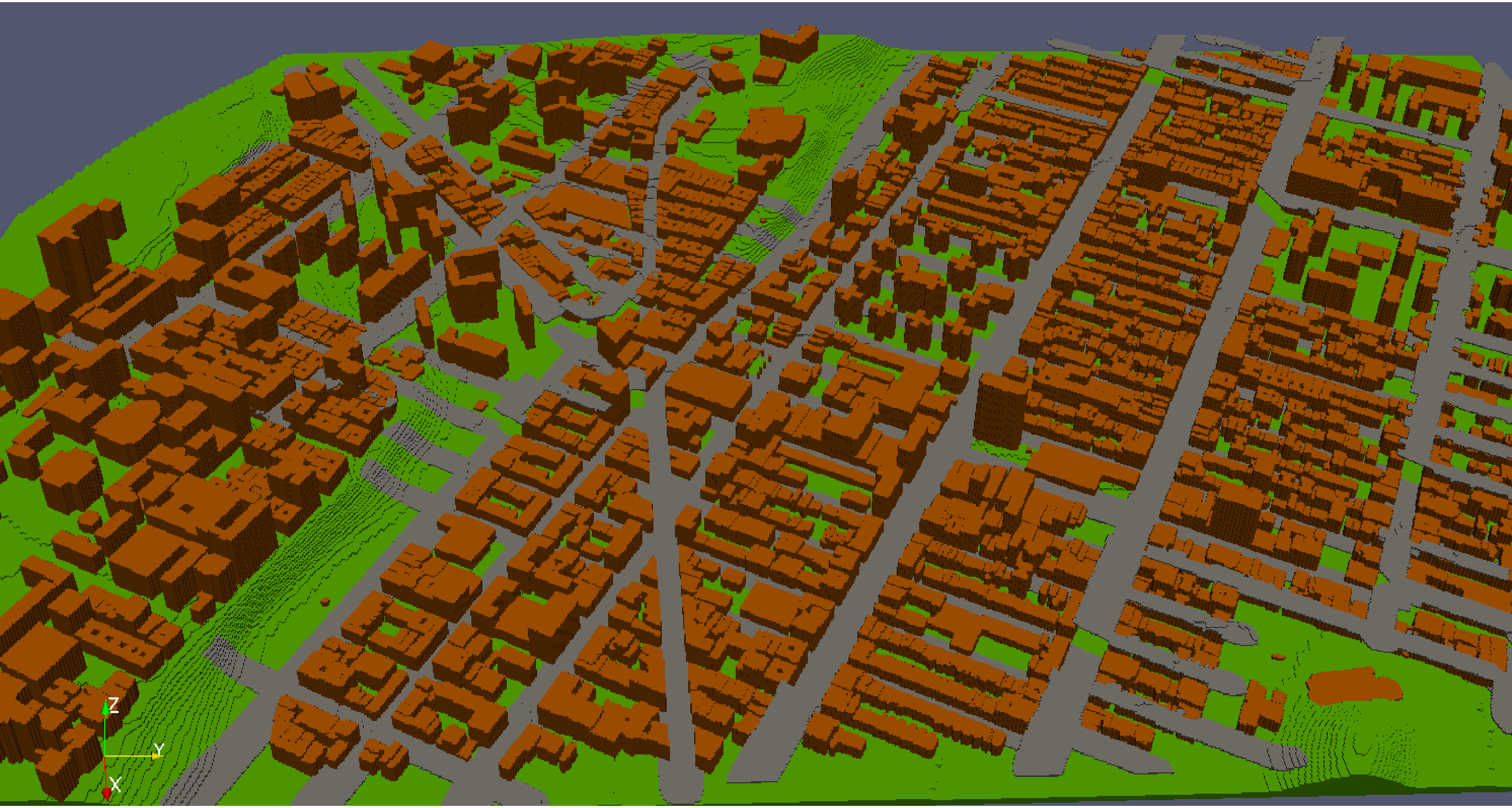
Buildings + Terrain



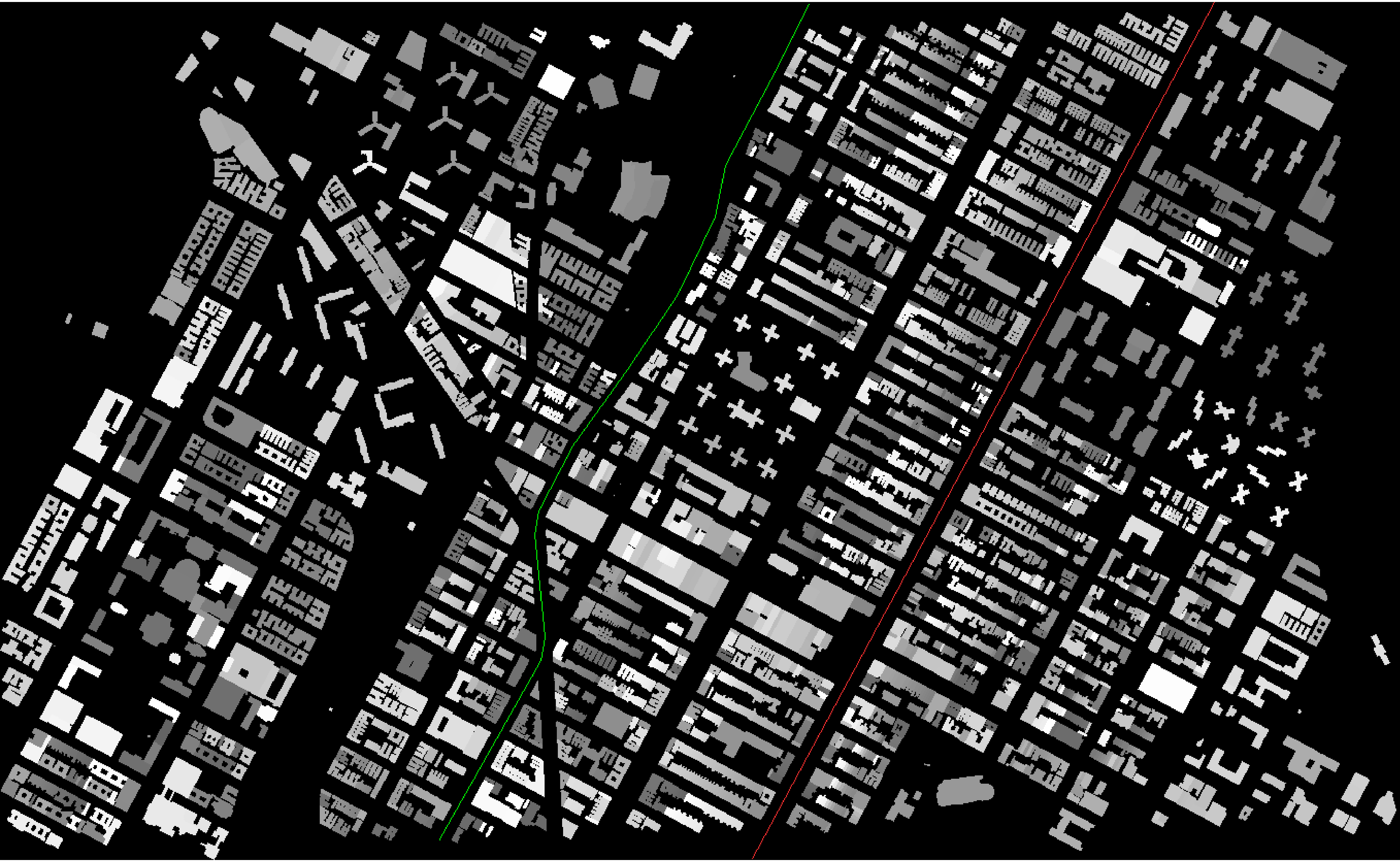
Add Roads: centerlines



Voxels of Buildings, Terrain, Roads
Managed in a DBMS
Query at resolution of 0.25 – 0.5 – 1 – ***2*** – 4 – 8 - 16m

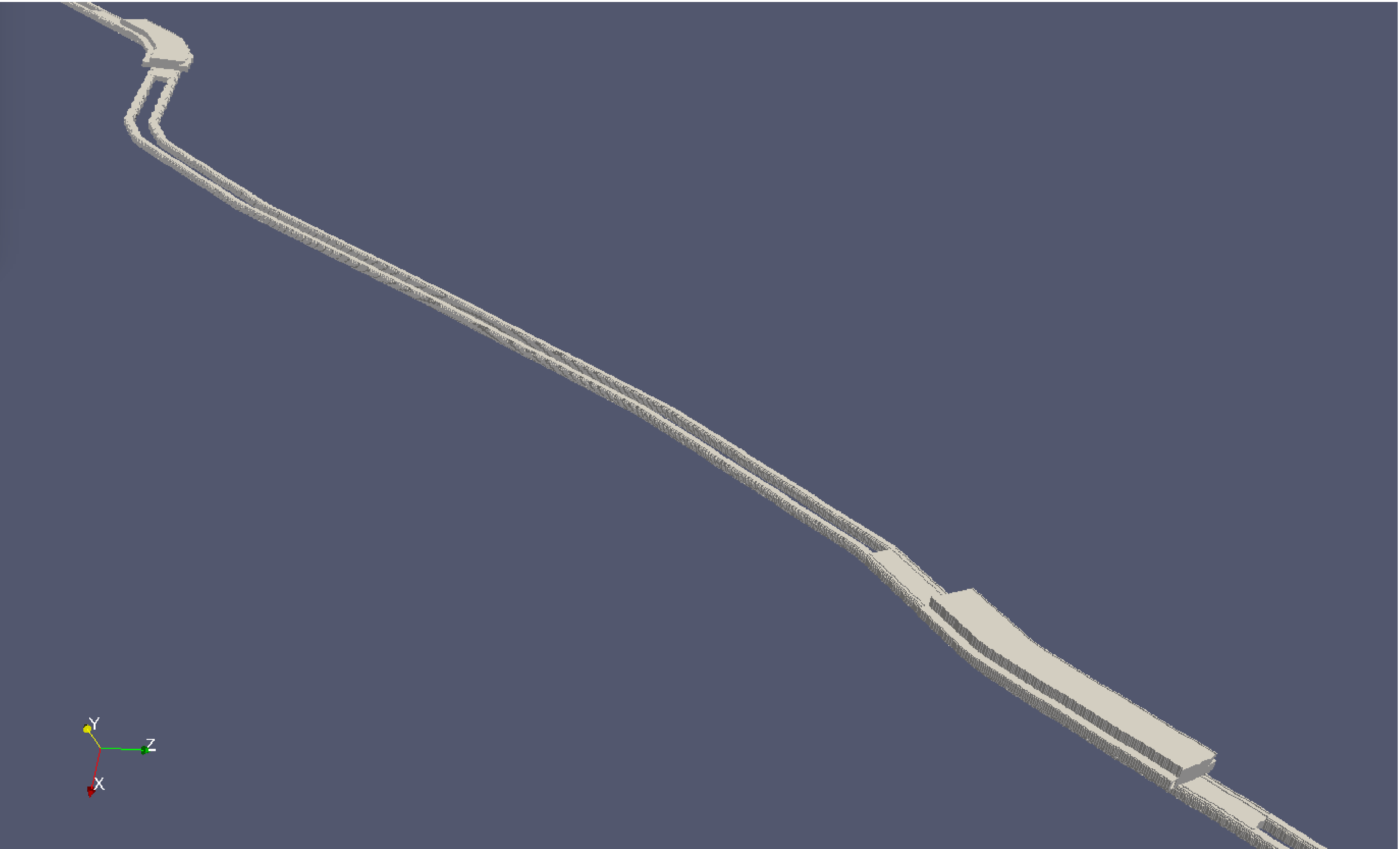


Insert Subway Lines



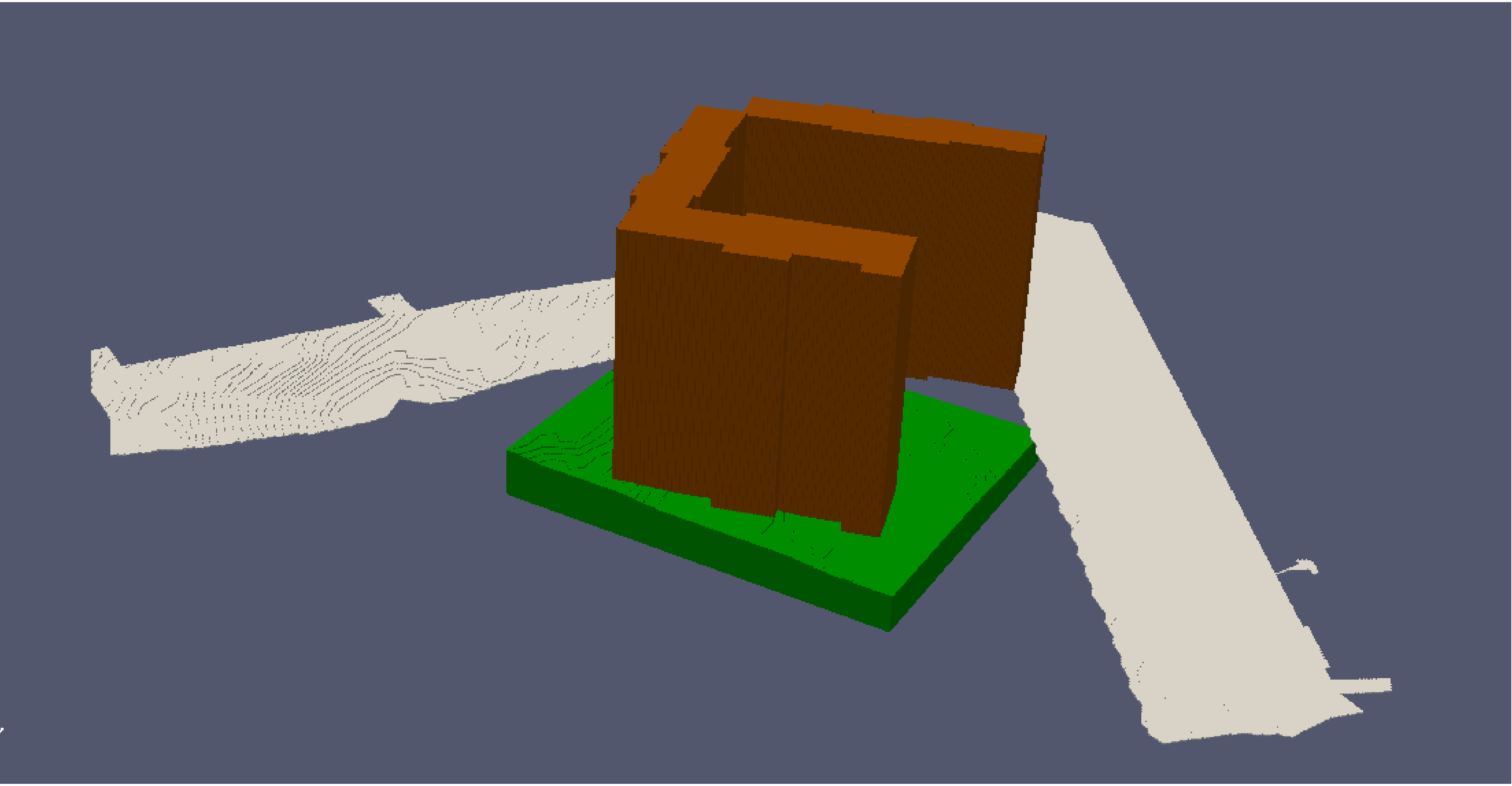
Subway line B,C
145 St and 135 St

(impression)



Multi-resolution Object Database

full res = 0.25m

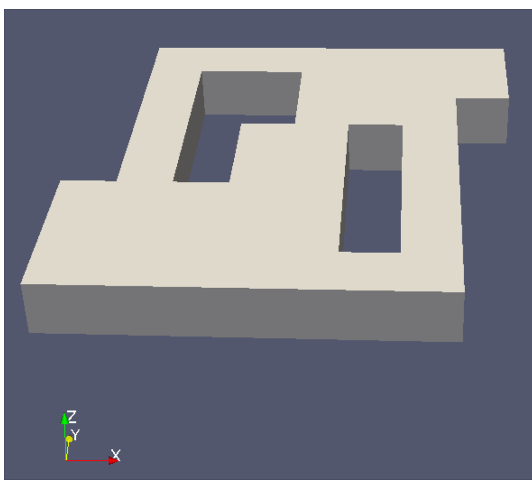


Multi-resolution DB (to be cont'd)

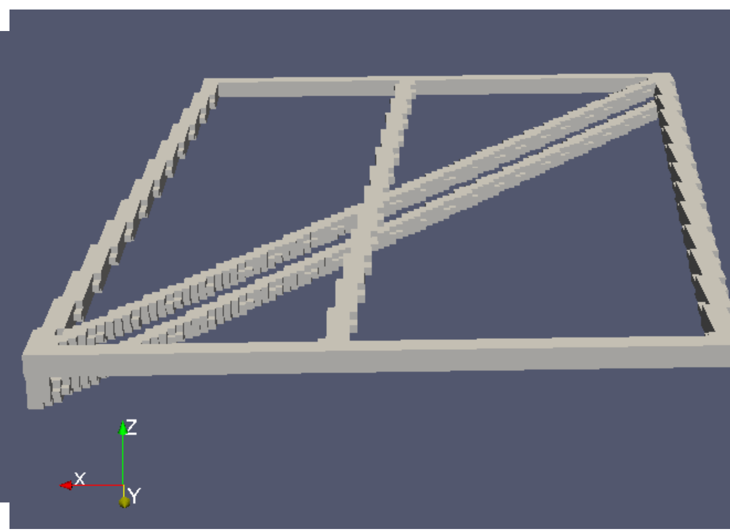
Size of *varbyte* fields in the database record of the geometry of a composite object

64	64	200	344	552	1152	3031	4800	6933	14152	21952	50880	74138

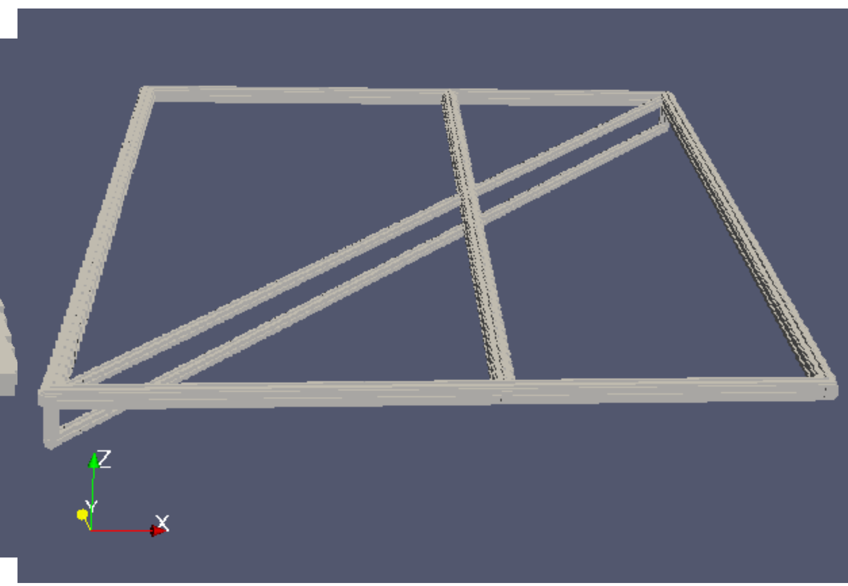
8 x 8 x 1



128 x 128 x 16



512 x 512 x 64



Nominal Wavelet Compression

What is required (and what perhaps isn't)

- The **main purpose** is to record *where* infrastructure elements/objects are located in 3D above-ground and underground space.
- **Topology** matters: connectivity, adjacency etc.
- Geometric **relationships** matter, especially between components of different sub-systems: locations w.r.t. each other, adjacency, inside the same or adjacent ducts / tunnels / conduits. Vertical relationships, distances
- The **environment** matters: phenomena filling the entire three-dimensional underground space (soil type, water content etc.)
- **Query-ability**: Flexibility in information extraction, rather than explicit information storage
- **Visualization** is *not* the main purpose of an integrated information system.
- The purpose of data integration is to allow for **computational models** using **multiple data sources**.

Voxel data structure considerations

- Points, Lines, Surfaces, Volumes, “Scalar Fields”
- One single voxel space or “3D Layers”
- 6-, 18-, 26-connectedness
- Storage order X,Y,Z → p,q,r (as in V[p,q,r])
- Dense vs. Sparse
- Semantics
- Resolution / Multi-resolution

    Geometric Detail: Internal vs. External

    Assumption: Required Precision Depends on Size of AOI

What *is* required: Analysis

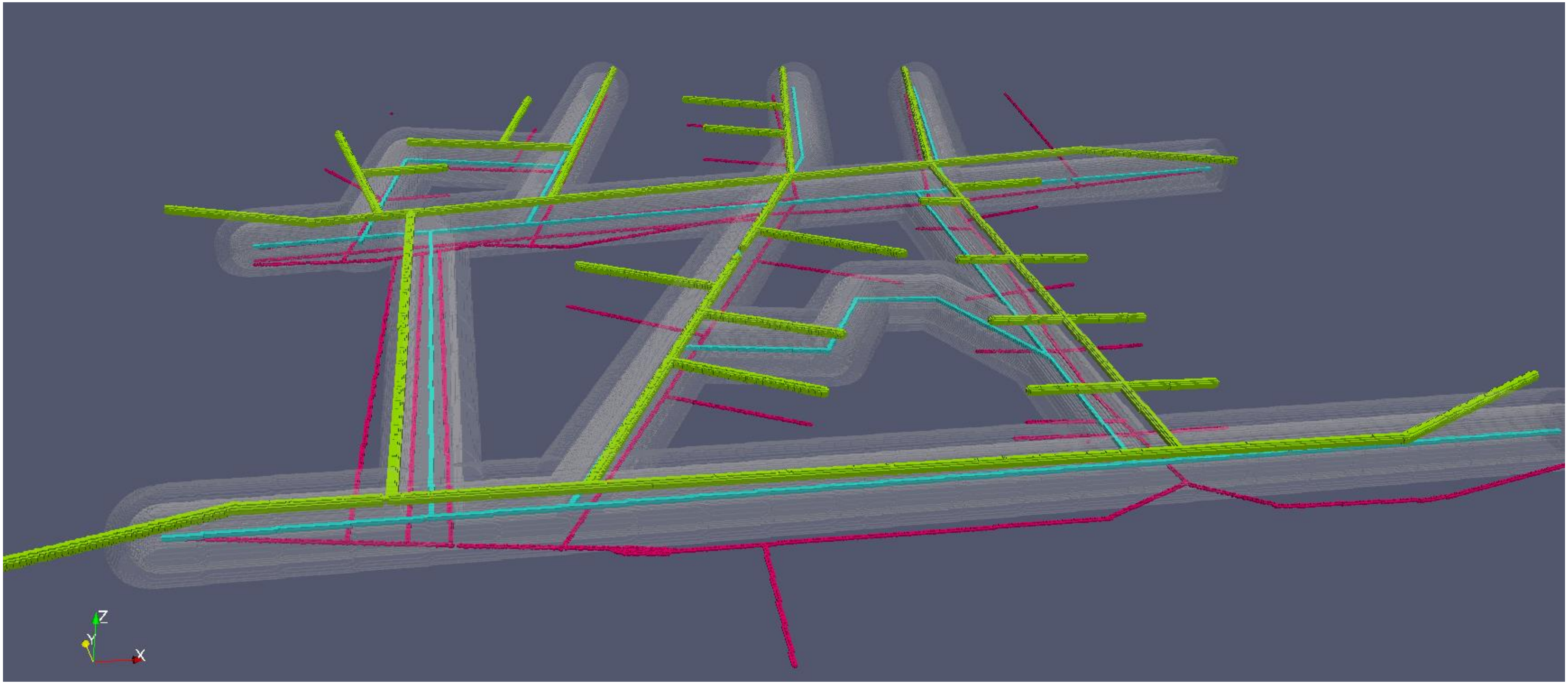
Voxels offer:

- Filtering – Neighborhood operations: Averages, Densities
- Classification – Segmentation – Iso-surfaces
- Voxel adjacencies, Connected components
- Path finding
- Morphological operations: *Erosion, Dilation*
- Skeletons: *Medial Axis* and *Surface*
- Shadows and shadings
- Distance transforms: What is the distance from each *class-A* voxel to the nearest *class-B* object – Resistances – Anisotropy

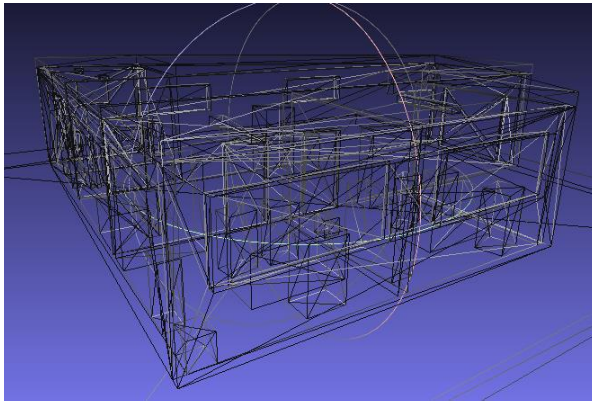
But voxels require:

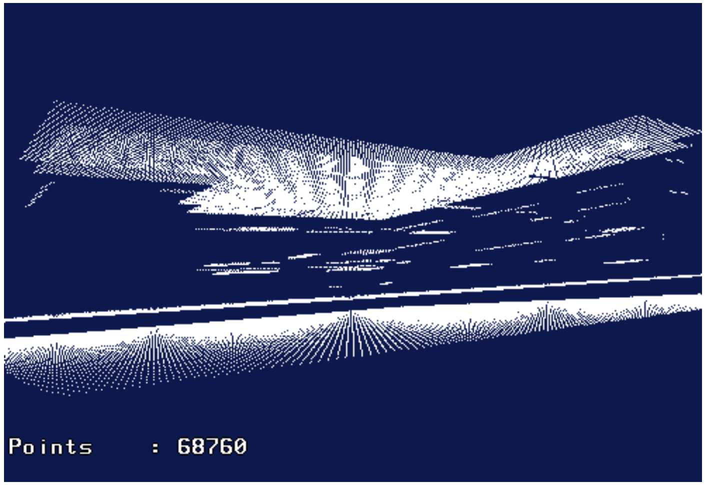
- Vector to raster conversions

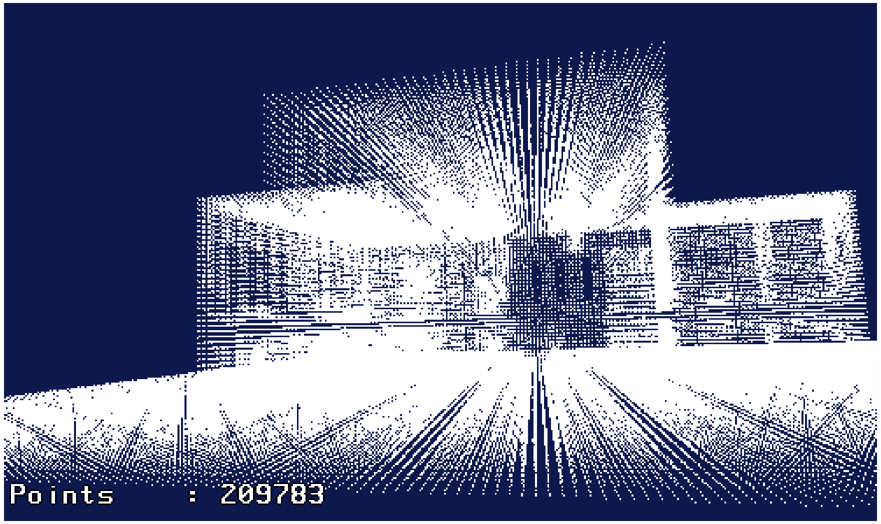
3D Vector to raster conversions
1. Linear objects

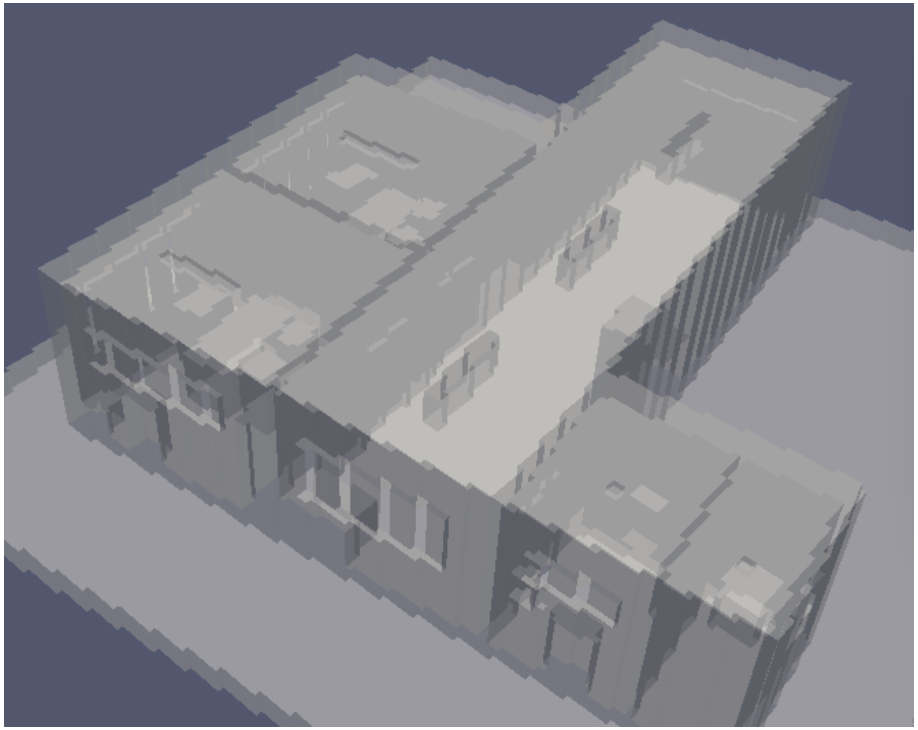


3D Vector to raster conversions
2. Volume objects (polyhedra)

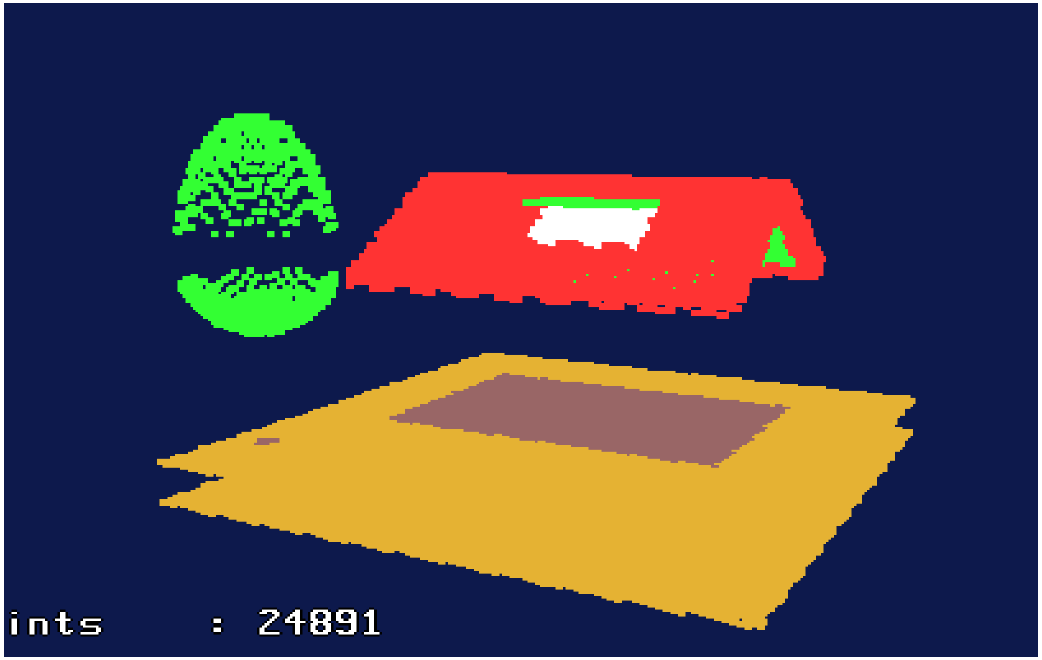








xor infix/prefix, Gorte, Zlatanova (2016).
alternative: *binvox*
or: Eisemann, Décoret (2008)



A

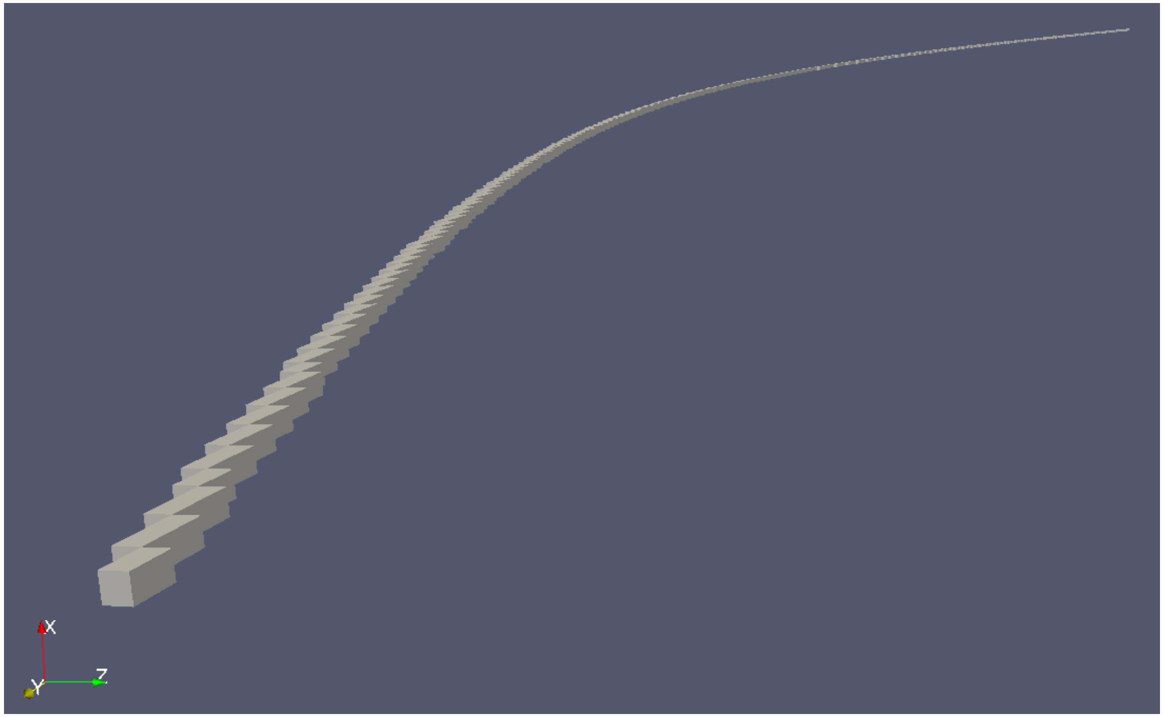
3D Vector to raster conversions
2. Volume objects (polyhedra)

A	1 1 1 1 1 3 3 3 3 1 1 1 1 2 2 2 2 1 1 1 1 1 1 1
B = 1,xor infix A	1 0 0 0 0 2 0 0 0 2 0 0 0 3 0 0 0 3 0 0 0 0 0 0
xor prefix B	1 1 1 1 1 3 3 3 3 1 1 1 1 2 2 2 2 1 1 1 1 1 1 1

B

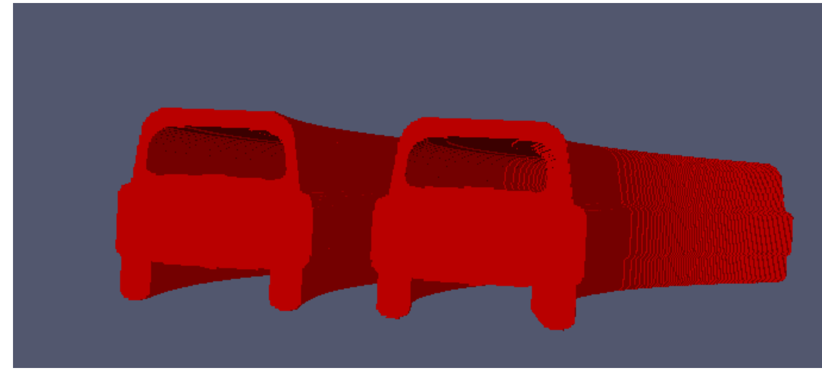
B =: xor infix A
A =: xor prefix B

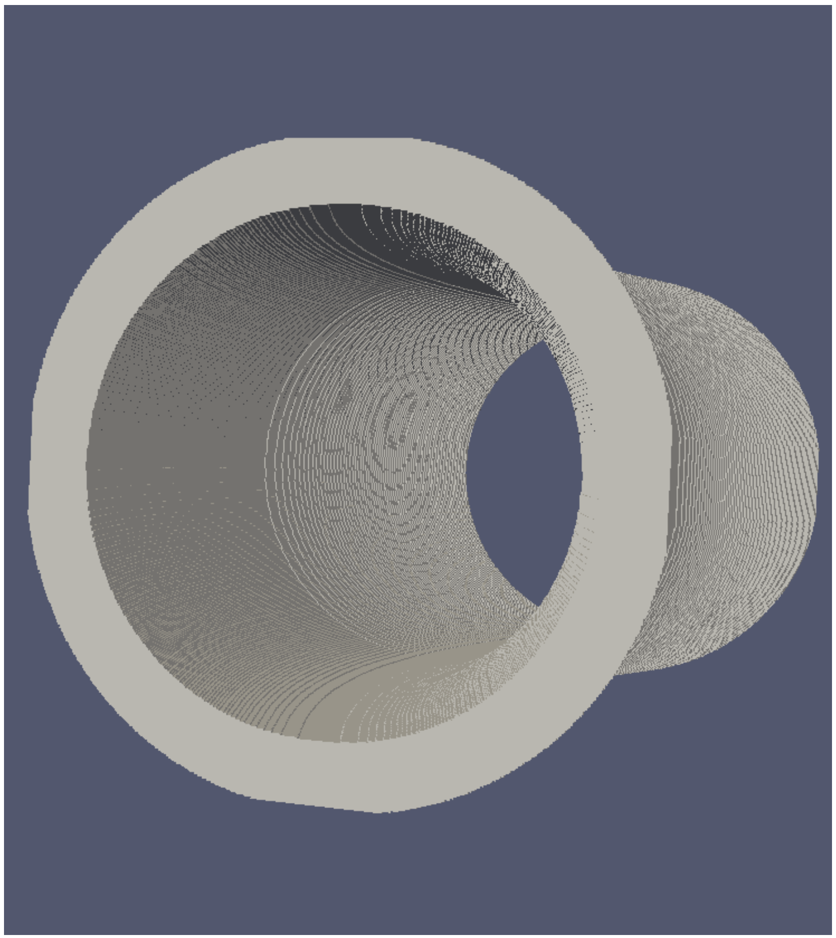
3D Vector to raster conversions
3. Elongated Objects

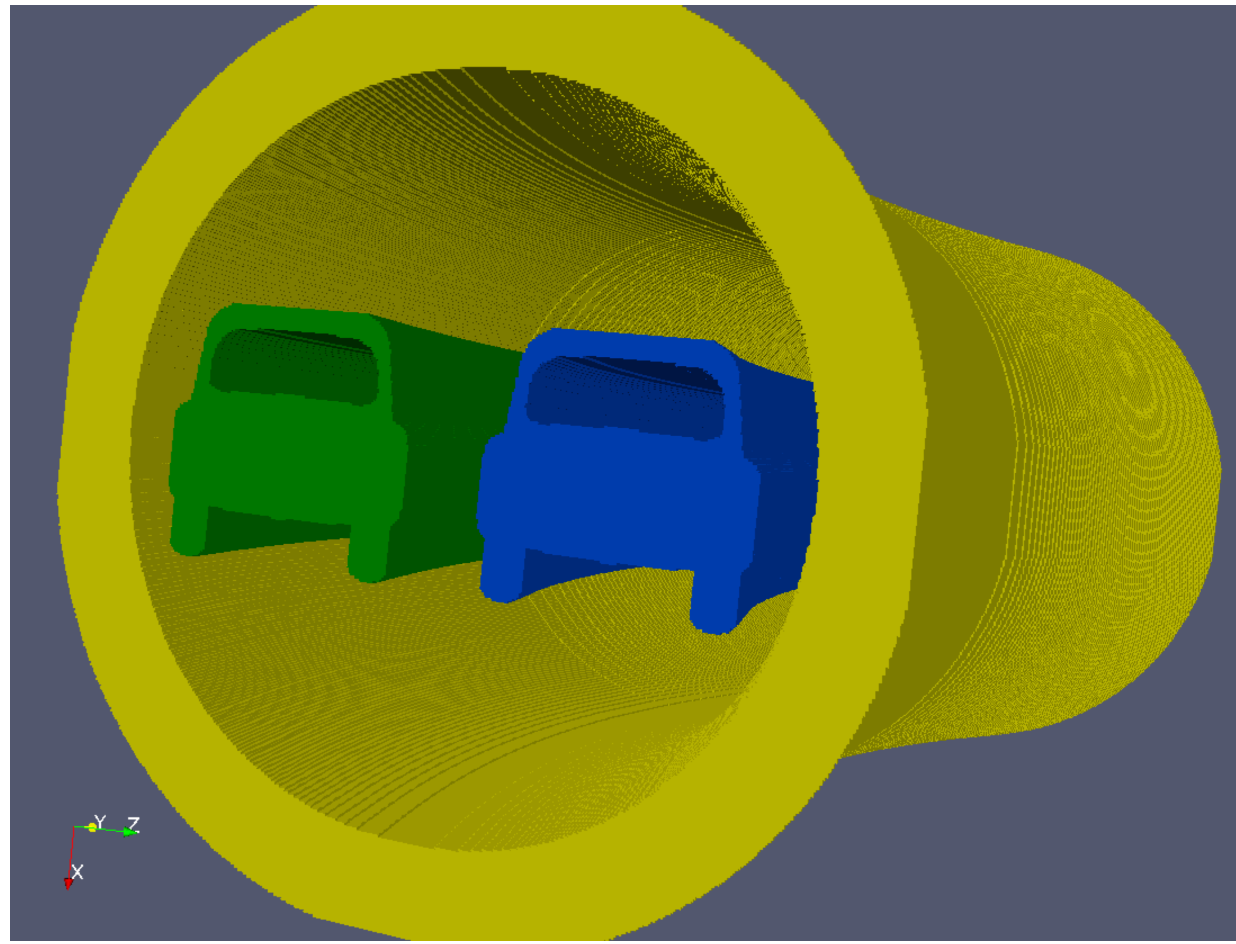


Input: 2D Profile Image + 3D Trajectory

Output: Voxel Sweep

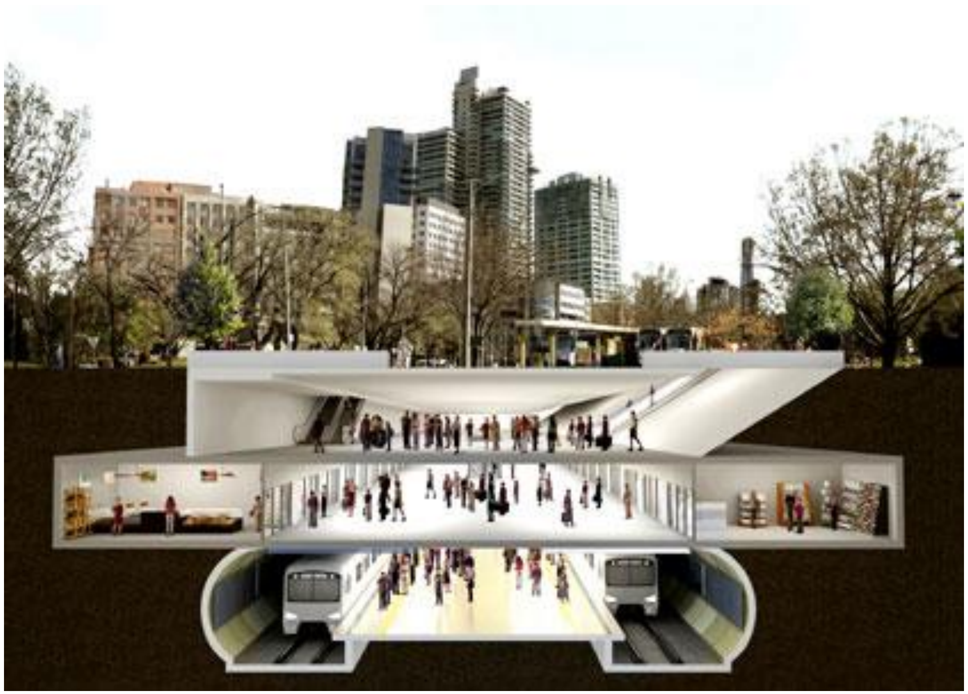


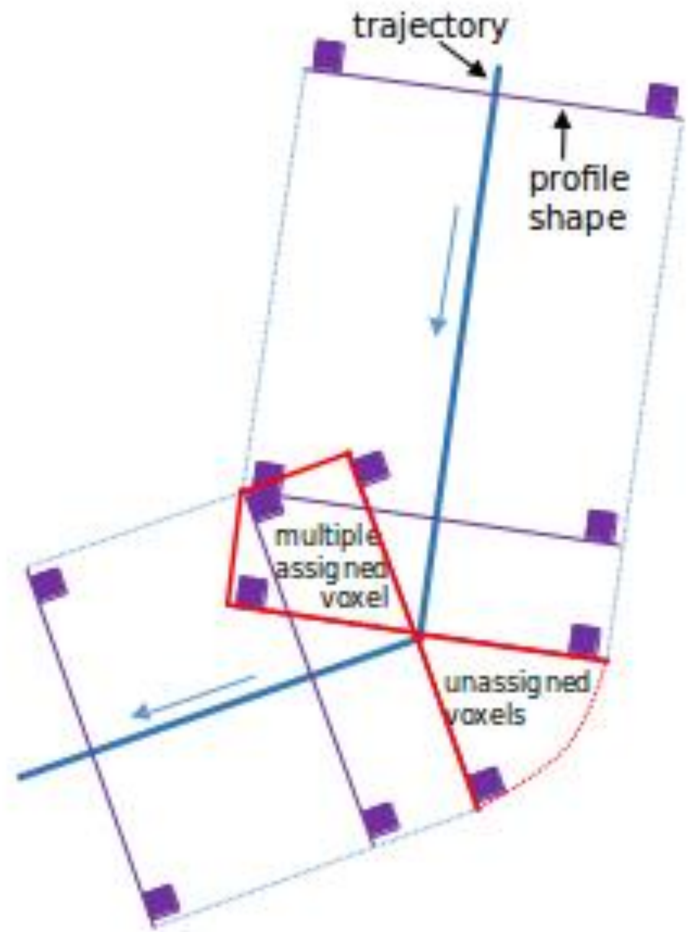


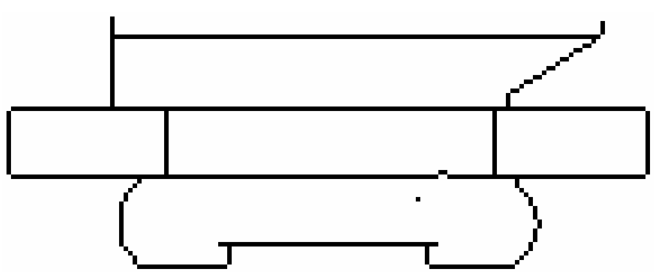


Gorte, Zlatanova and Leidner, 2016

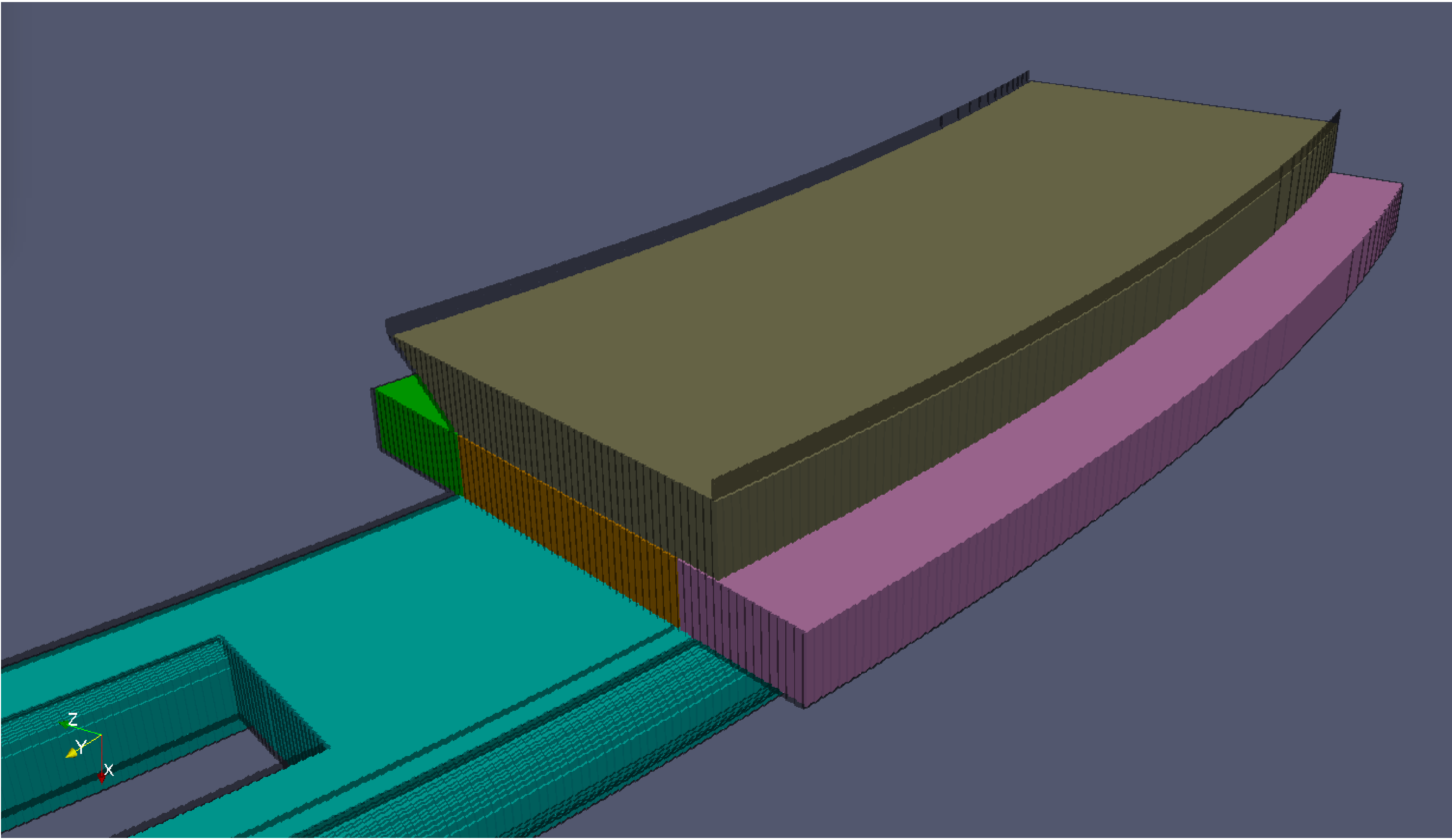
Voxel Sweep




trajectory
profile shape
multiple assigned voxel
unassigned voxels



Multi-segment Voxel Sweep
with Connected Component Labelling



Wrap-up

- common ground for modelling underground infrastructure
- data originates from many different sources
- high-level integration, rather than on analyzing separate utilities
- flexibility is required in unforeseen circumstances

The proposal is: raster data analysis

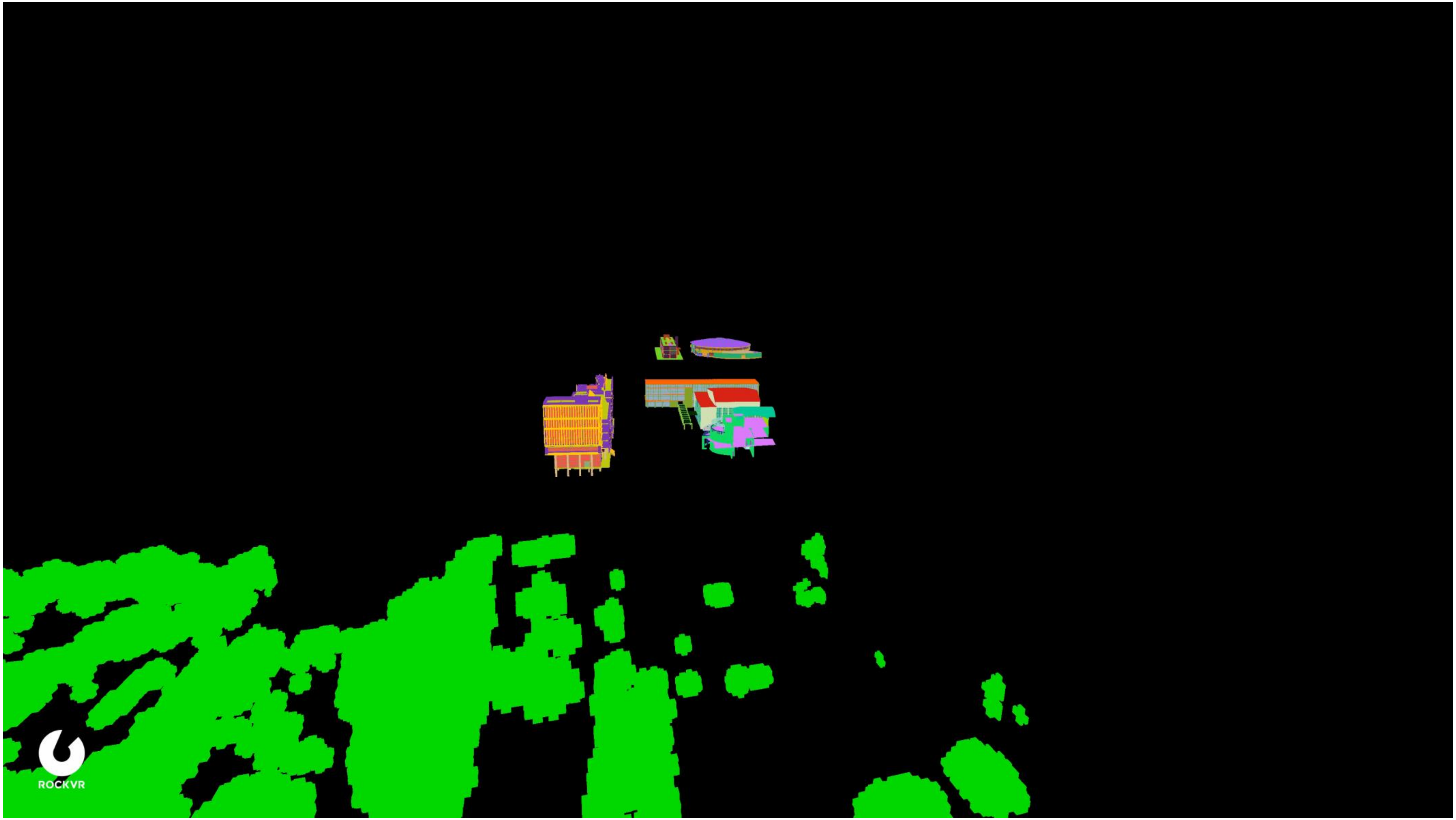
- data sources, however, are usually vector-based
- vector-to-raster conversion is required; a remaining question is *when?*

Meanwhile… lots of experiments with voxels

- Indoor navigation
- Data storage
- Visualisation
- Indoor/outdoor

https://vimeo.com/gridunsw

Red Centre, UNSW



Fuel load:

Barton, J., B. Gorte, M. S. R. S. Eusuf, and S. Zlatanova, 2020, A voxel-based method to estimate near-surface and elevated fuel from dense LiDAR point cloud for hazard reduction burning, ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci., VI-3/W1-2020, 3–10

Eusuf, M. S. R. S., Barton, J., Gorte, B., and Zlatanova, S., 2020, Volume Estimation of Fuel Load for Hazard Reduction Burning: First Results to a Voxel Approach, Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XLIII-B3-2020, 1199–1206

Data storage

Li, W., S. Zlatanova, and B. Gorte, 2020, Voxel data management and analysis in PostgresSQL/PostGIS under different data layouts, ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci., VI-3/W1-2020, 35–42

Indoor reconstruction

Staats, B.R., A.A. Diakité, R.L. Voûte and S. Zlatanova, 2018, Detection of doors in a voxel model, derived from a point cloud and its scanner trajectory, to improve the segmentation of the walkable space, 2018, International Journal of Urban Sciences,pp.369-390

Fichtner, F. W., A.A. Diakité, S. Zlatanova and R. Voûte, 2018, Semantic enrichment of octree structured point clouds for multi-story 3D pathfinding, Transactions in GIS, 22(1), pp. 233-248

Navigation

Xu, W., L. Liu, S. Zlatanova, W. Penard and Q. Xiong, 2018, A pedestrian tracking algorithm using grid-based indoor model, Automation in Construction, vol. 92. August 2018, pp. 173-187

Gorte, B., S. Zlatanova, and F. Fadli, 2019, Navigation in indoor voxel models, ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci., IV-2/W5, 279-283, https://doi.org/10.5194/isprs-annals-IV-2-W5-279-2019, 2019.

Xiong, Q, Q. Zhu, Z. Du, S. Zlatanova, Y. Zhang, Y. Zhou and Y. Li, 2016, Free multi-floor indoor space extraction from complex 3D building models, Earth Science Informatics, 9 (32) , pp. 1-15

Visibility analysis

Aleksandrov, M., S. Zlatanova, L. Kimmel, J. Barton, and B. Gorte, 2019, Voxel-based visibility analysis for safety assessment of urban environments, ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci., IV-4/W8, 11–17, 2019.

Underground

Gorte, B., Zlatanova, S., and Leidner, A., 2016, Sweeping raster cross sections along trajectories in three-dimensional voxel models, ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci., IV-2/W1, 271-276, doi:10.5194/isprs-annals-IV-2-W1-271-2016.

Gorte, B. and S. Zlatanova, 2016, Rasterization and voxelization of 2-d and 3-d space partitioning, Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XLI-B4, 283-288, doi:10.5194/isprs-archives-XLI-B4-283-2016