

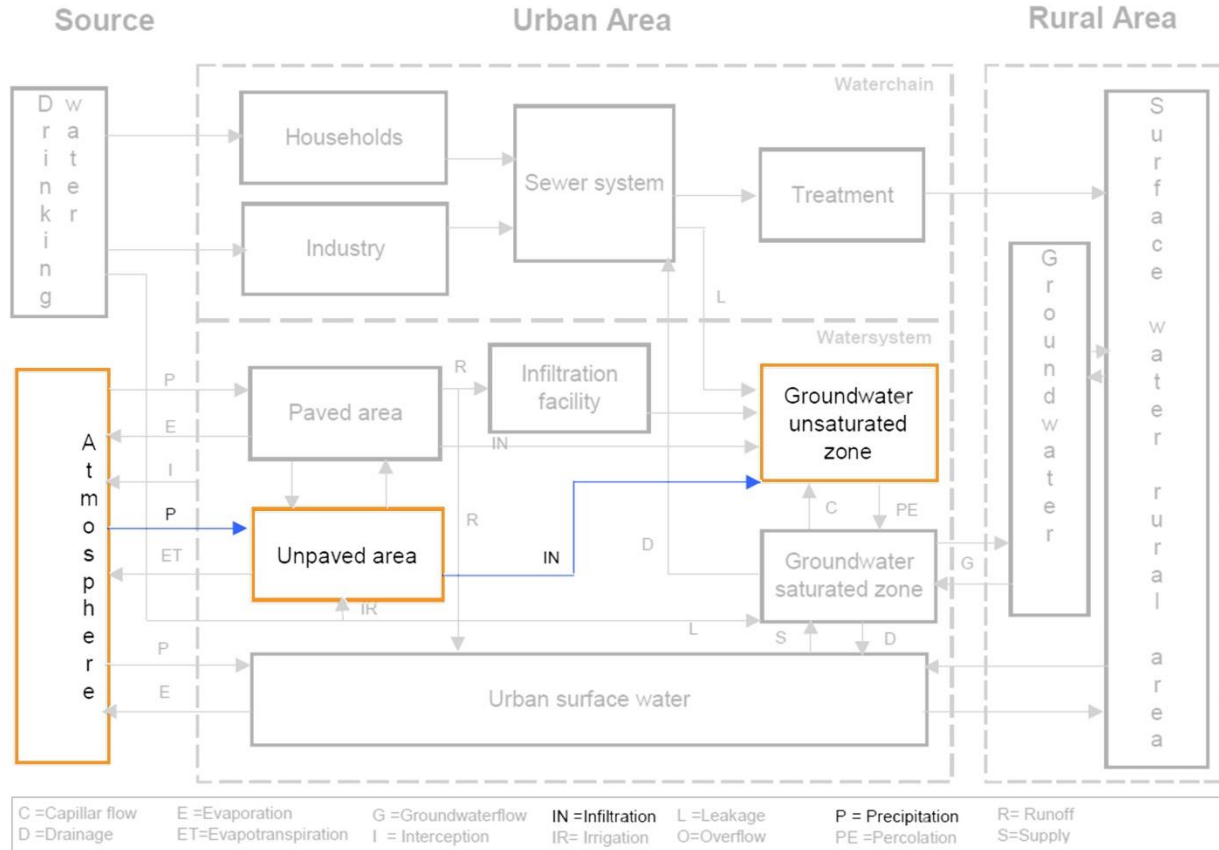
P5 Geomatics

Milo Janssen 4020928 02-11-15

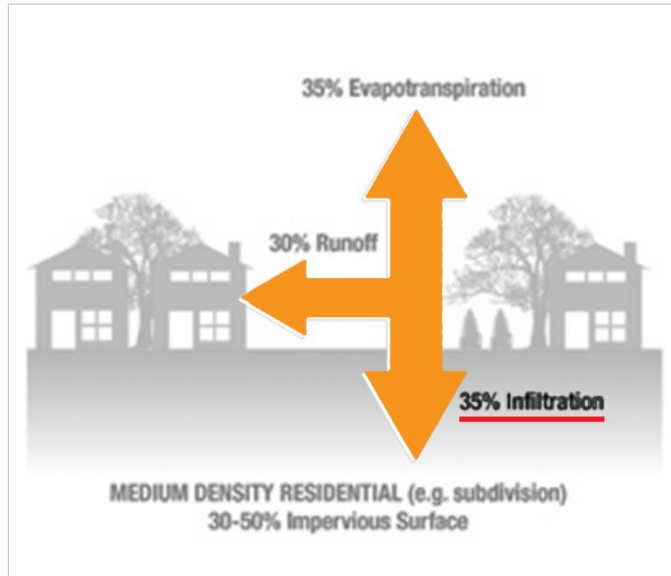
3D Intersection operations for voxel data represented as surfaces in ArcGIS



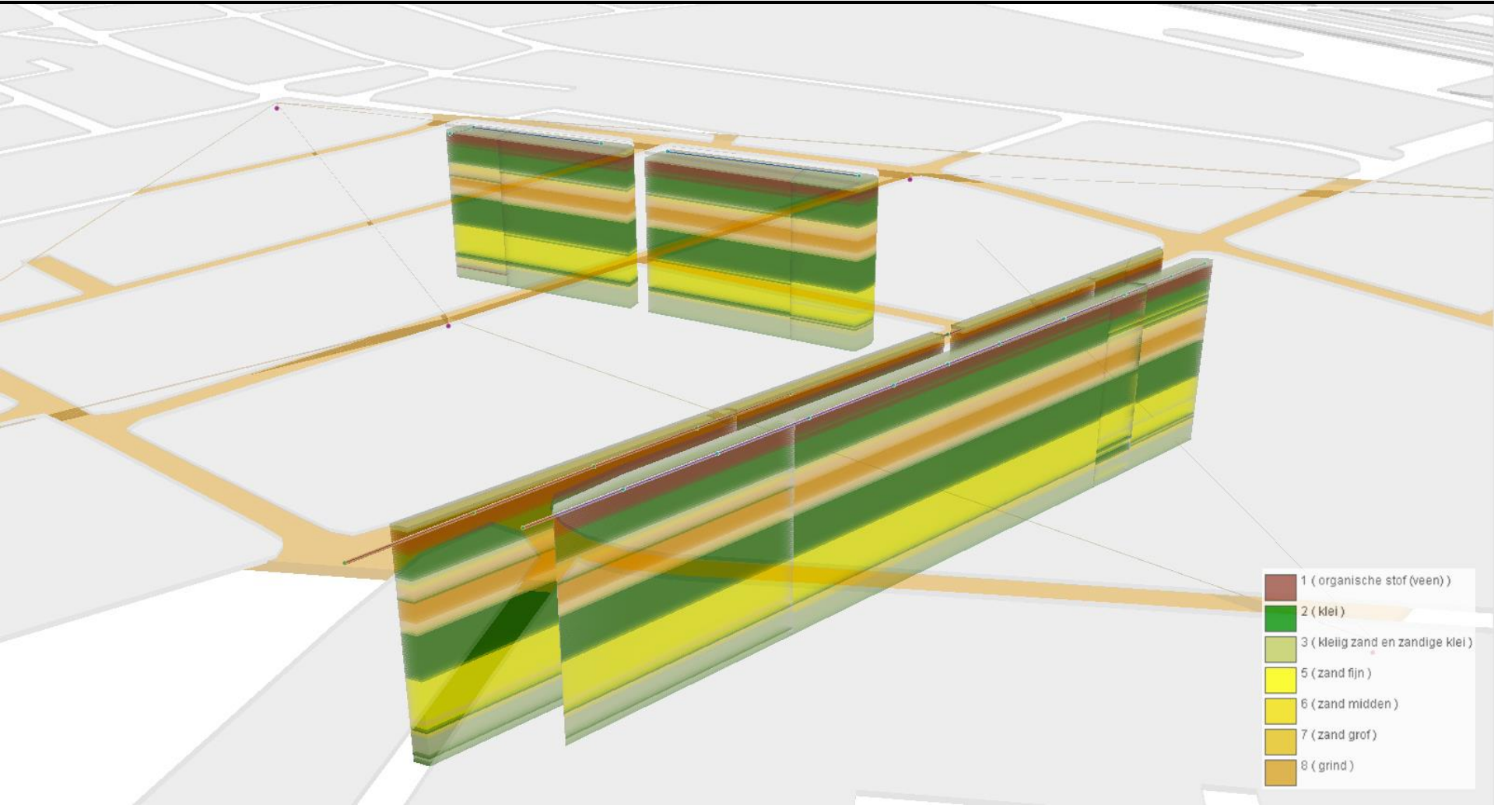
Urban Water System



Precipitation: Water Infiltration



Application Preview



- 1 (organische stof (veen))
- 2 (klei)
- 3 (kleilig zand en zandige klei)
- 5 (zand fijn)
- 6 (zand midden)
- 7 (zand grof)
- 8 (grind)

Content of this presentation

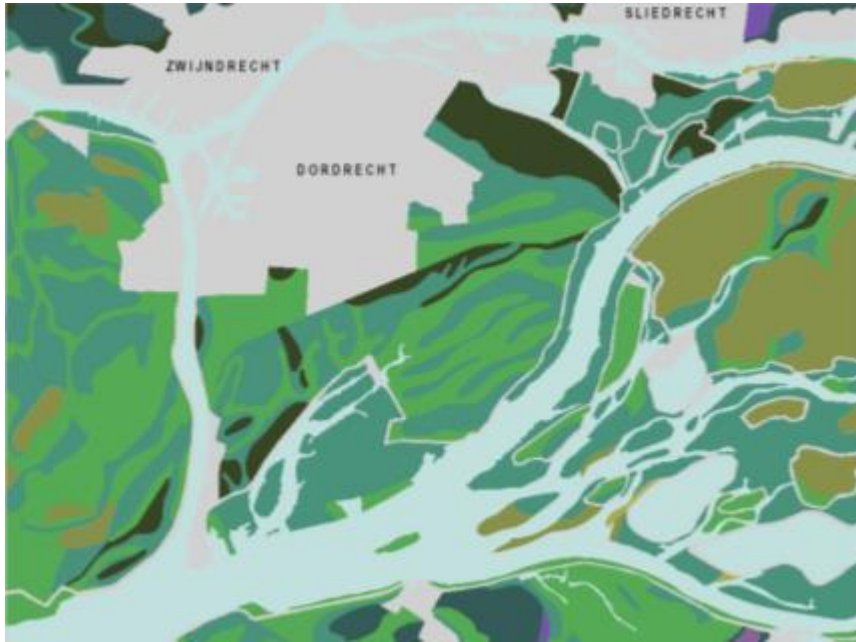
*3D Intersection operations for voxel data represented as surfaces in ArcGIS:
spatial, subsurface analysis for geohydrological purposes*

1. Introduction
2. Background Information
 - Data
 - 3D Intersection operations
3. Used Data
4. Conceptual Workflows
5. Evaluation and Testing
 - Implementation
 - Test Cases
6. Application
7. Conclusions

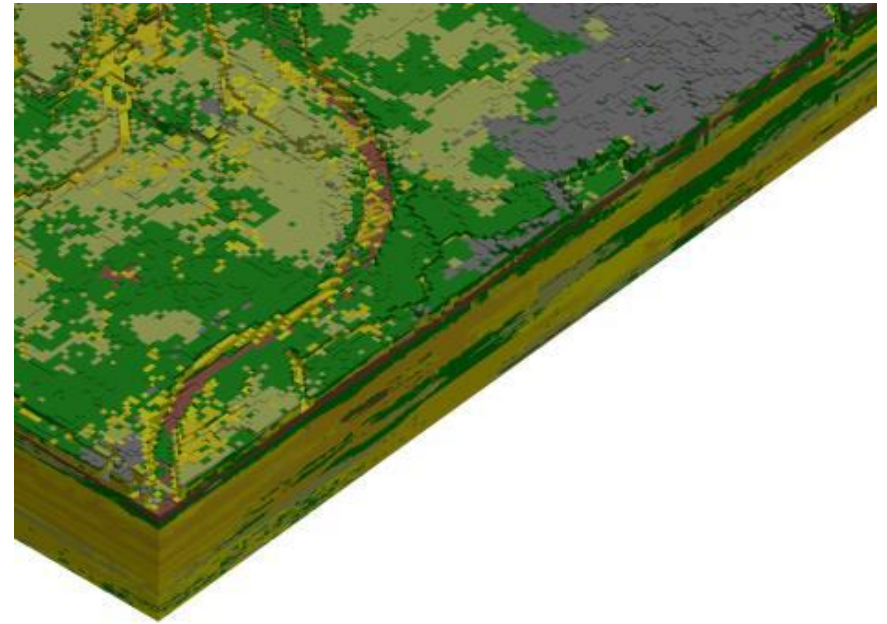
1. Introduction – Motivation and Relevance

- The upper part of the subsurface in The Netherlands, yields the natural potential to take in abundant rainwater.
- In the context of a changing climate, rainstorm patterns have changed causing more heavy rainfall in shorter periods of time, which results in pluvial flooding especially in dense urban areas.
- Besides man-made interventions (sewerage), a proper use of the upper part of the subsurface in and around cities can positively contribute in rainwater discharge issues.
- Specific knowledge about the subsurface is required.

1. Introduction – Motivation and Relevance



2D Soil Map:
soil classification at approx. 1m depth



3D GeoTOP voxel dataset:
geological features of the soil per voxel of 50m depth

1. Introduction – Motivation and Relevance

- Three dimensional spatial analysis in GIS on the GeoTOP model can reveal new insights in the **water infiltration** and **storage capacity** of the subsurface in urban areas.
- The result of the 3D spatial analysis through 3D intersection operations in GIS, can provide part of the explanation – regarding soil type properties – on why certain areas in the city suffer from pluvial flooding after heavy rainfall.
- The novelty of this research is that 3D Boolean intersection operations in GIS are tested in their **geometric validity** and their ability to incorporate **semantic** and **attribute information** in the output.

1. Introduction – Research Requirements

- Focus on 3D intersection (Boolean) operation in GIS.
- ArcGIS of vendor ESRI is used as the test environment because of the available *3D Intersect* set operation.
- The following input data is needed:
 - **GeoTOP (3D voxels)** that provides information about the soil types
 - **TOP10NL (2D surfaces)** that indicates open soil locations in the built environment
 - **KLIC data (2D lines and points)** which can be used to model the subsurface sewers

1. Introduction – Research Requirements

Data Requirement:

- All three different input data require preprocessing steps to be converted to the same data representation and dimension: *3D surface based vector data*

→ **Three conversion workflows**

3D Intersection Requirements:

- Attribute preservation is necessary to be able to link geohydrological principles to the 3D intersection output

- Semantic preservation is needed to convey the meaning of the 3D intersection output

- Valid geometry is required to make volume and surface area calculations on the output possible

→ **3D Intersection workflow**

1. Introduction – Problem Statement

The datasets that are required for the aim of this thesis research, are georeferenced datasets that can be processed in a GIS.

Three-dimensional intersection operations on solid and surface based geometry, can be achieved in CAD, not in commonly used GISs.

Therefore, 3D intersection operations should be performed within a widely used GIS, in order to be accessible by the users of the Application of this research.

1. Introduction – Research Questions

Main research questions:

In what manner can a GIS facilitate 3D intersection operations for voxel data represented as surfaces, while maintaining semantic and attribute information in the output?

- What conceptual, generic workflow is required to retrieve a 3D intersection with surface represented objects?
- How can 3D intersection operations be performed in GIS?
- How can semantic and attribute information of the 3D intersection output be maintained in GIS?

1. Introduction – Application

- 3D intersection operations on **vectorized GeoTOP** with **TOP10NL** and **KLIC**, all data in the same 3D surface-based vector data representation.
- 3D Intersection operations in GIS that meet with the evaluation criteria (valid output, with semantics, correct assignment of attributes, and volume, or surface areas calculation).
- Determination of the unsaturated zone/ **drainage depth** via the **phreatic surface** level (groundwater level data).
- With the Application of this research, better decisions for urban water management can be made.

1. Introduction – Method Description

1. Investigate the possibilities of 3D intersection operations in GIS
2. Define a conceptual, generic workflow for 3D intersection of surface represented objects
3. Implement 3D intersection operations on vectorized voxel data with vector data in a chosen GIS (ESRI ArcGIS), while maintaining semantic and attribute information
4. Compare and evaluate the conceptual generic workflow for 3D intersection with the implemented 3D intersection in a GIS

1. Introduction – Expected Results

3D Intersection operations performed on voxel data represented as surfaces in GIS, where the output geometry is valid geometry with maintained correct semantics and attributes.

Regarding the Application:

- Insights retrieved out of the linkage between geohydrologic principles and the 3D intersection output of vectorised GeoTOP.

1. Introduction – Related Work

1. The 3D Pilot – ESRI: voxel with 3D geo- objects, case RandstadRail tunnel Rotterdam, 2011:

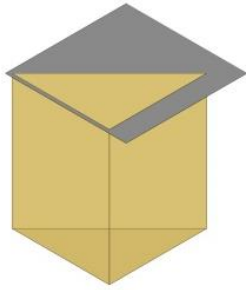
- No automatic assignment of the attributes of the input geometry, to the intersecting output geometry.

2. Geohydrological modeling, predictions for an area- orientated approach for groundwater contamination in the City of Utrecht, 2013:

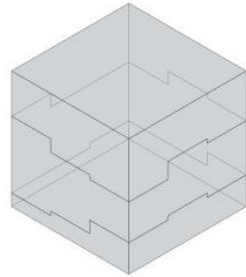
- An existing groundwater flow model was used and enriched by GeoTOP.

1. Introduction – Main method

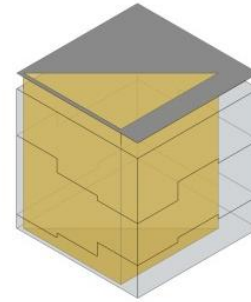
OBJECT 1



OBJECT 2

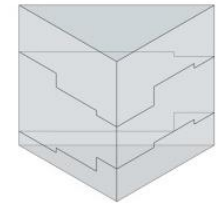


3D INTERSECTION



RESULTING OBJECT

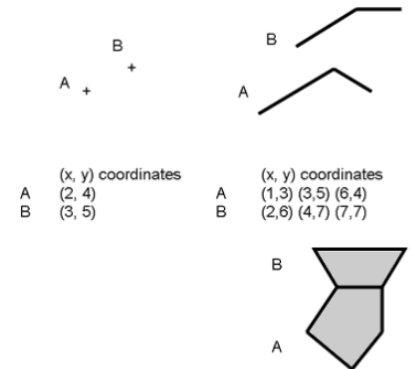
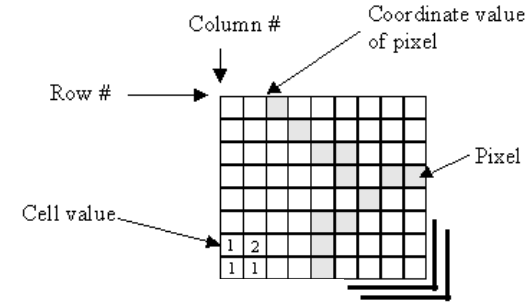
PLUS MAINTAINING:
- SEMANTICS
- ATTRIBUTES



2. Background Information – Data: Vector - Raster

- **Raster data** is represented by cells, pixels, or 2D/3D squares/cubes describing a continuum.

- **Vector data** uses point, lines and polygons for representation: mainly used for (3D) objects that are internally homogeneous and discrete.

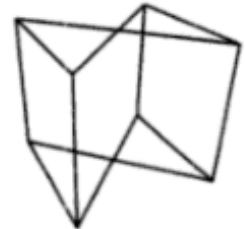
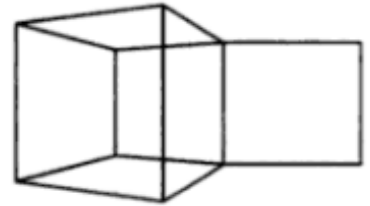
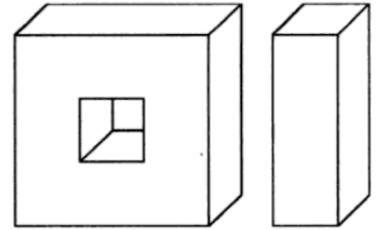


2. Background Information – Data: Polyhedron

Polyhedron (surface based), is a 3D primitive represented by boundaries.

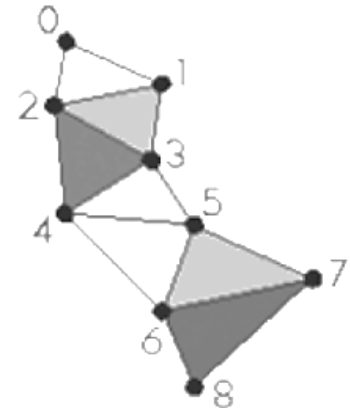
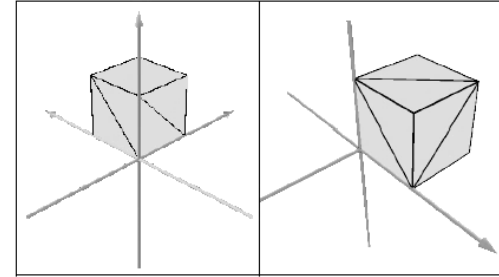
Polyhedron Validity:

- A polyhedron that bounds one single volume
- Comprises out of simplicit faces



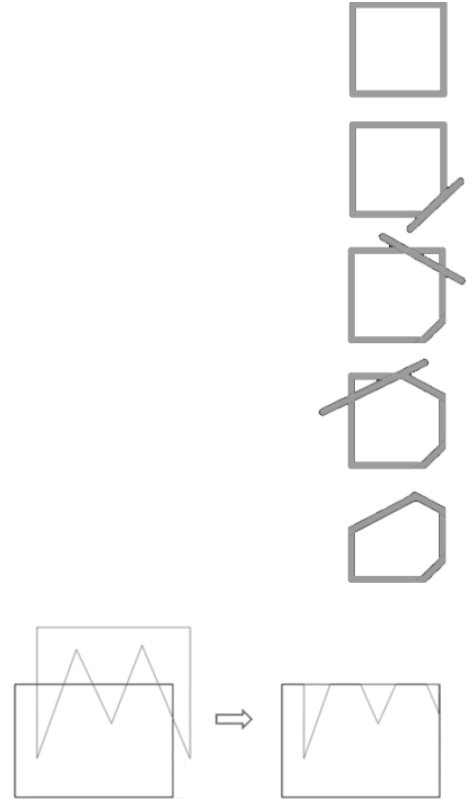
2. Background Information – Data: Multipatch

- The Multipatch geometry is the available 3D geometry for solids in ArcGIS.
- A Multipatch feature represents a 3D object via its boundary (**B-Rep**).
- Builds upon rings or triangle primitives in the form of either strips or fans.



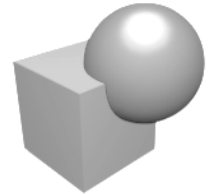
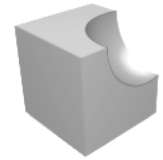
2. Background Information – 3D Intersect: Clipping

- Used in the field of computers graphics.
- Relevant in the context of 3D intersections of surface represented geometry and regarded as an algorithm for a Boolean operation on polygons.
- The methodology of 3D Clipping describes the principles on how to perform a 3D intersection operation.



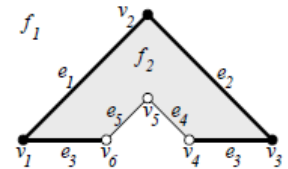
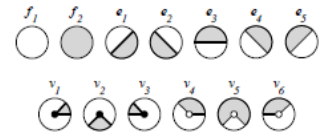
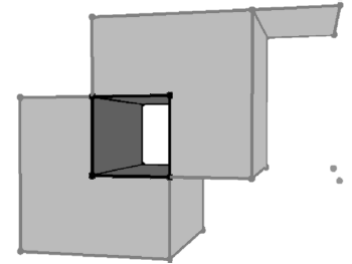
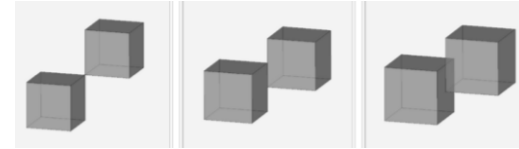
2. Background Information – 3D Intersect: Boolean

- The 3D Boolean set operations on geometry are **difference**, **union** and **intersect** operations.
- The boundary representation (B-Rep) is a commonly used surface-based representation to perform Boolean operations on.



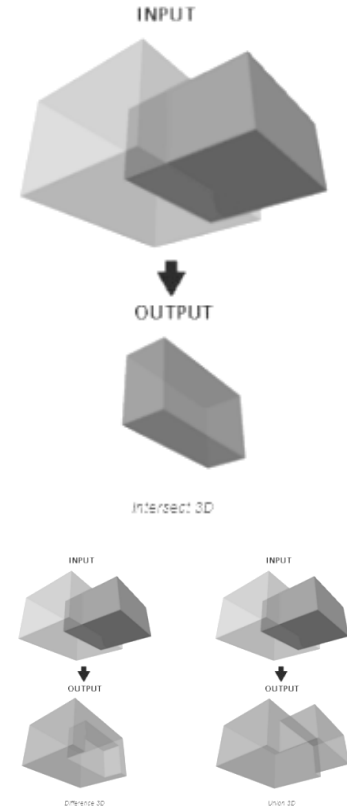
2. Background Information – 3D Intersect: Nef

- A Nef Polyhedra is a complete and precise mathematical description of polyhedra in any arbitrary dimension.
- Represents different dimensional features and **non-manifold conditions**.
- CGAL provides data structures that are able to model with 3D Nef Polyhedra, and execute Boolean operations on them, in B-rep.



2. Background Information – 3D Intersect: Analyst

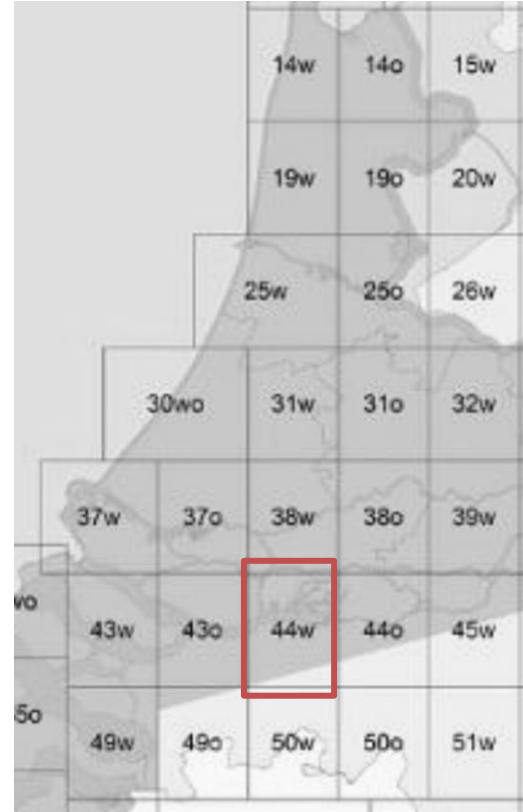
- Three main set operations *Difference 3D*, *Union 3D* and *Intersect 3D*.
- Adopts CGAL source code to perform 3D Boolean operations on B-reps. Conversion to CGAL data structures belonging to the `Nef_Polyhedra_3` class.
- Incremental polyhedron builder can be used – `Polyhedron_incremental_builder_3`.



3. Used data – Voxel: GeoTOP

The GeoTOP model describes in **voxels** that part of the subsurface that is most extensively used by people: the upper part of the subsurface. **3D raster data.**

- GeoTOP doesn't have nationwide coverage yet as GeoTOP is still being modelled.
- Interpolation techniques provide the conversion of drilling description towards voxel.



3. Used data – Voxel: GeoTOP

The actual voxel data is developed by TNO and is based on the ArcASCII format of ESRI, with a 3D expansion:

- The .csv file of a GeoTOP voxel dataset, contains a header of 14 rows which completely describes the structure of the voxel data.
- The two main attributes of a GeoTOP voxel are the lithostratigraphic unity and **litho class attribute**.

Header:
(14 rows)

```
gridtype regular
sorting +Z +Y +X
nx 200
ny 250
nz 185
xllcenter 100050.0
yllcenter 400050.0
zllcenter -49.75
dx 100.0
dy 100.0
dz 0.5
nodata_value 999.0
lithostrat,lithoklas
_5_zand_fijn,kans_6_
int,int,float,float,
35,6,0.0,0.04,0.06,0
28,6,0.04,0.02,0.04,
28,1,0.09,0.02,0.09,
12,3,0.0,0.14,0.76,0
```

Voxel data:
(9.25mlj rows)

3. Used data – 2D Surface: TOP10NL

The TOP10NL is a 2D vector dataset of the **topographic** map of The Netherlands.

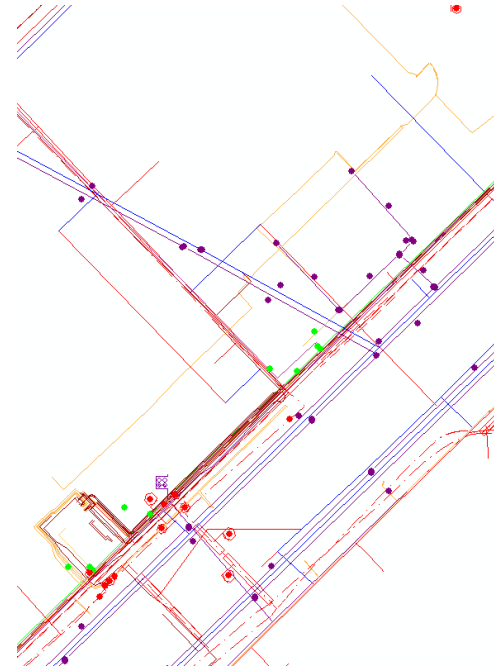
- Currently, TOP10NL is accessible as open data in the OpenGIS standard GML: Geography Markup Language.
- The object class 'terrain' is adopted, providing areas of either built or open terrain, represented as 2D surfaces.



3. Used data – 2D Line and point: KLIC

KLIC data which holds information about the location of **cables and pipes** in the subsurface.

- Often read and exported to .dgn or .dwg format by CAD software.
- The connection parts of multiple sewer tubes are represented as (multiple) 2D points.



4. Conceptual Workflows – Voxel

Text

1. Retrieve 'raw' voxel dataset [.txt / .csv] together with the distinct ordering of the file [ArcASCII sorting, or other]

Diagram



2. Interpret each voxel as being built up out of eight vertices (defining a cubic shape), or as having a centroid, Point Geometry



3. Convert via a script the listed raw voxel dataset into 3D Point Geometry with x, y, z coordinates and with the attributes



4. 'Build' each distinct set of points or each centroid point as a cubic B-rep – representing the boundary surfaces of a voxel

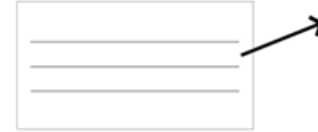


4. Conceptual Workflows – 2D Surface

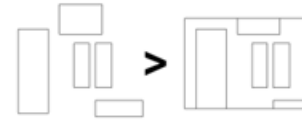
Text

1. Retrieve the original surface data consisting of polygons, load/import in a CAD or GIS format

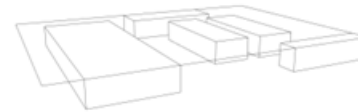
Diagram



2. Clip in 2D the relevant part of the data



3. Extrude the clipped map, meaning to expand a 2D surface in vertical direction to generate a 3D shape, where the fixed surface footprint remains intact.



4. Conceptual Workflows – 2D Line and point

Text

1. Load/ import the 2D line and point data in a CAD or GIS readable format

2. Retrieve the 2D coordinates of the points that the line is built of, and retrieve additionally the z coordinate of these points (as attribute or in text)

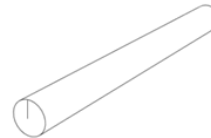
3. Convert via a script to output x, y, z points

4. Construct a line between the 3D points

5. Buffer the lines with the correct diameter, meaning a bounding shape is defined at a specified distance alongside all points on the line

6. Ensure closure of the buffered geometry, if necessary, enclose via COLLADA.

Diagram



ArcGIS export to COLLADA



SketchUp import COLLADA, edit, and export



Import COLLADA in ArcGIS

4. Conceptual Workflows – 3D Intersection

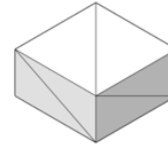
Text

1. Both objects should be represented as surfaces (B-REP)

Else, pre-conversion steps needed

Diagram

Outer_Object

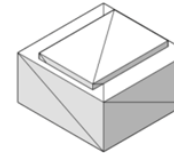
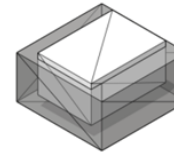


Inner_Object

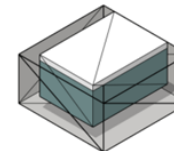


2. Place B-REP Inner_Object and B-REP Outer_Object within each other

2.5 Include semantic and attribute information of both geometries (object-oriented)

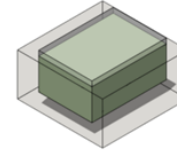


3. Cut Outer_Object with the boundaries of Inner_Object

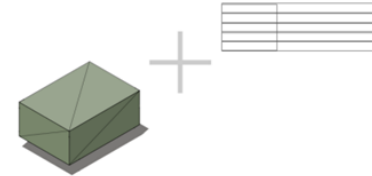


4. Conceptual Workflows – 3D Intersection

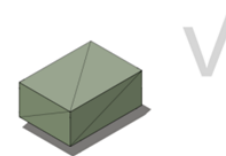
4. Create new Points in the Outer_Object which define the outline that was generated in step 3.



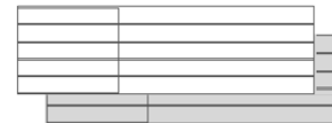
5. Generate the new Intersection_Object that adopts the semantic and attribute information of Out_Object



6. Validate Outer_object with new surfaces to close its geometry on the outline

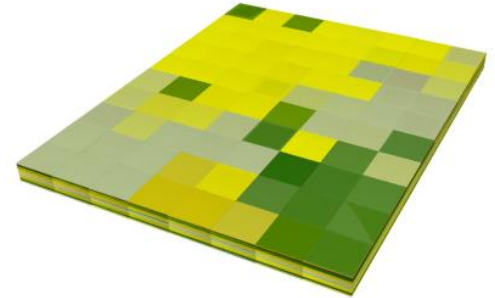


7. Analyse attribute information based on volume content calculation of Intersection_Object



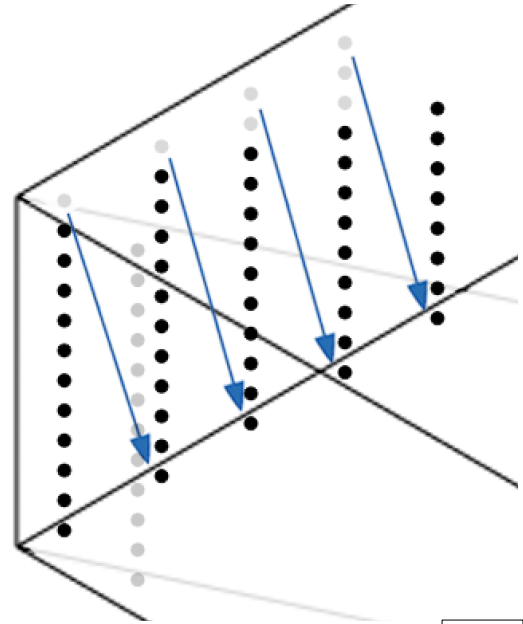
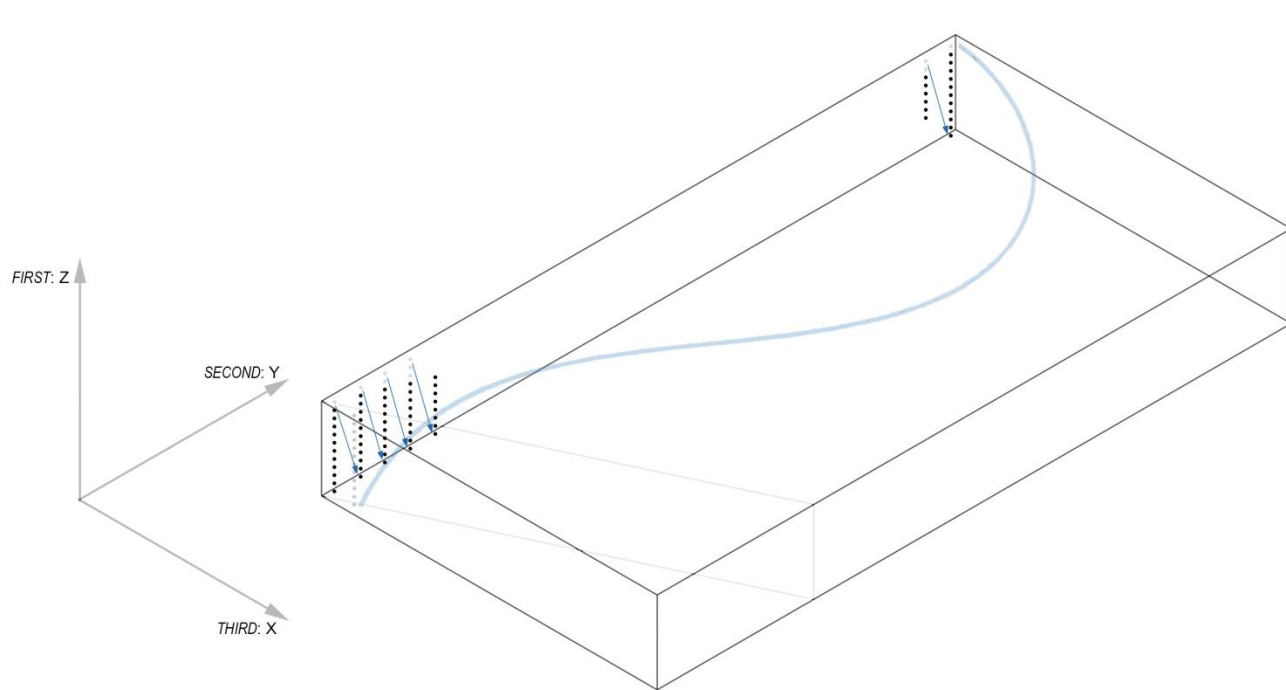
5. Testing and Evaluation – Implementation voxel

- Preprocessing steps (that subdivide the overall dataset) in a database software is required.
- A Python script that adopts the voxel data in .txt and converts in Point geometry with x, y, z coordinates, and with the selected attribute.
- The output of points of the conversion can be loaded in GIS – here in ESRI's ArcScene, symbolized as being cubes, converted to Multipatch geometry.

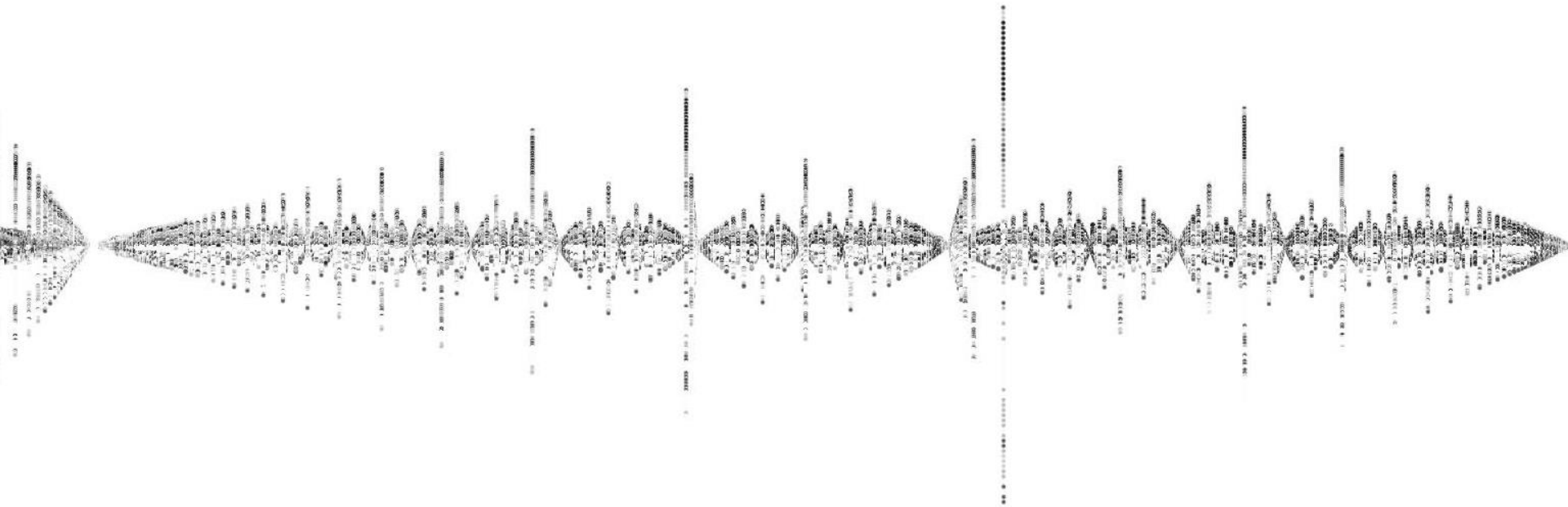


5. Testing and Evaluation – Implementation voxel

Voxels [as .txt] → Python script (sorting + attribute) → 3D points



5. Testing and Evaluation – Implementation voxel

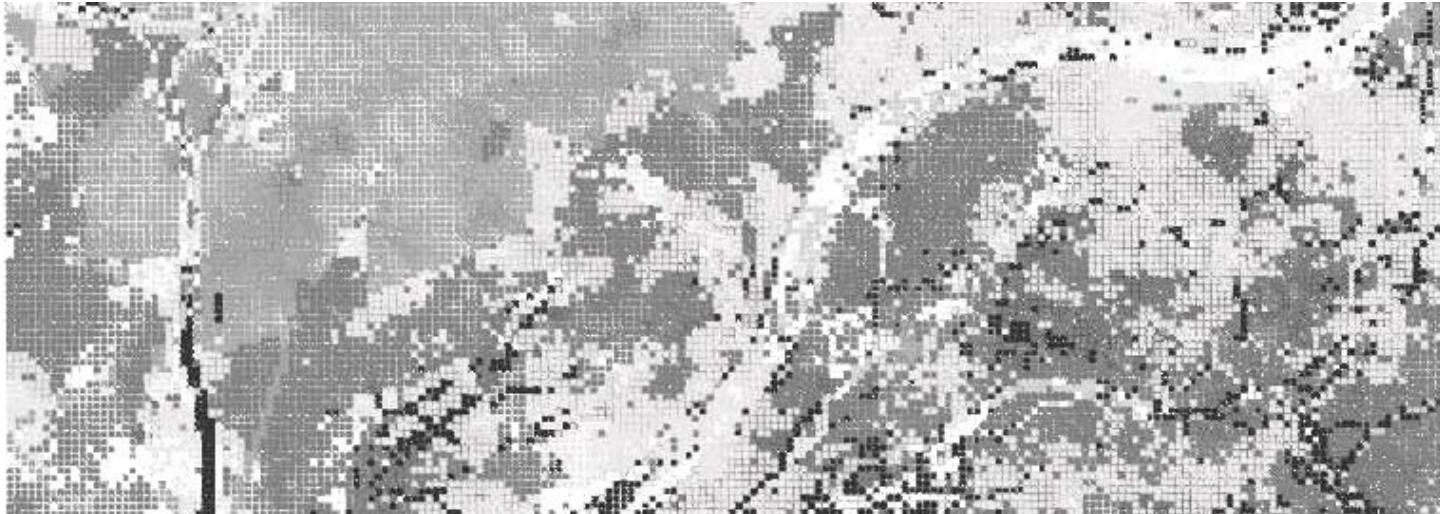


5. Testing and Evaluation – Implementation voxel

Map sheet 44w:

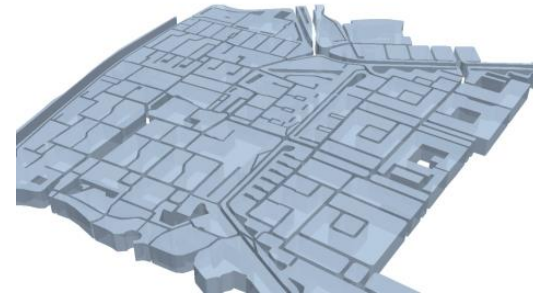


Dordrecht pointed out:



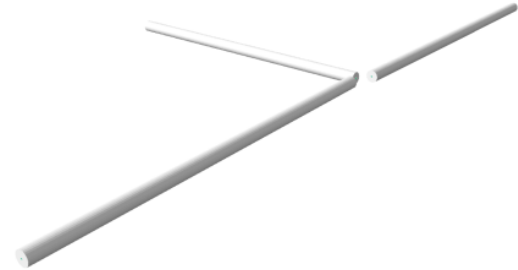
5. Testing and Evaluation – Implementation surface

- Clipped, to retrieve only the relevant 2D surfaces belonging to the same object class.
- ‘Clip output’ .shp file of step two can be extruded. In order to do so, the 2D surface can be symbolized as extrusion, and converted to Multipatch geometry.



5. Testing and Evaluation – Implementation line

- In GIS, the data can be projected on an applicable Coordinate Reference System (CRS).
- Into a Python Script that outputs the points accurately in 3D, with x, y, z coordinates. The script delivers a .shp file as output.
- 3D Lines can be constructed between the points. And buffered via the Buffer 3D operation.



5. Testing and Evaluation – 3D intersect operations

The workflow that covers semantic and attribute preserving 3D intersection operations, is implemented via Test Cases that test and evaluate the workflow on three evaluation criteria:

1. geometry validity with semantics
2. correct assignment of attributes
3. the possibility to determine volume and surface area of the output

5. Testing and Evaluation– 3D intersect operations

3D intersection operations

1. Simple objects

1.1 Vertical

1.2 Oblique

3D intersection operations

2. Complex objects

2.1 With many surfaces

2.2 Cylinder long

2.3 Cylinder curved path

2.4 Cylinder low/high detailed

3D intersection operations

3. Overlapping surface/edge/point

3.1 Via a Multipatch with Multipatch

3.2 Via a Multipatch with a surface

3.3 Via a Multipatch with an edge

3.4 Via a Multipatch with a point

Experiments:

3D difference operation

4. Complex objects

4.1 Subtracted cylinder object

3D union operations

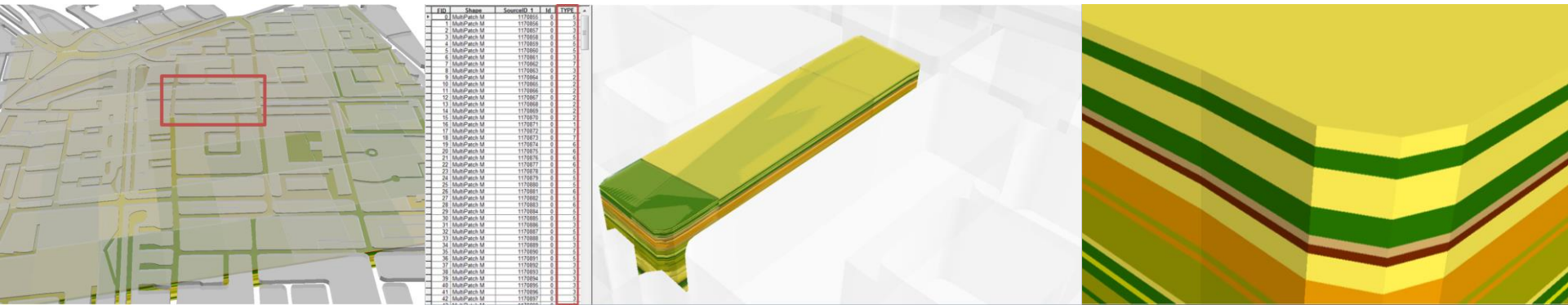
5. Construct or subtract objects

5.1 Non-manifold point

5.2 Non-manifold edge

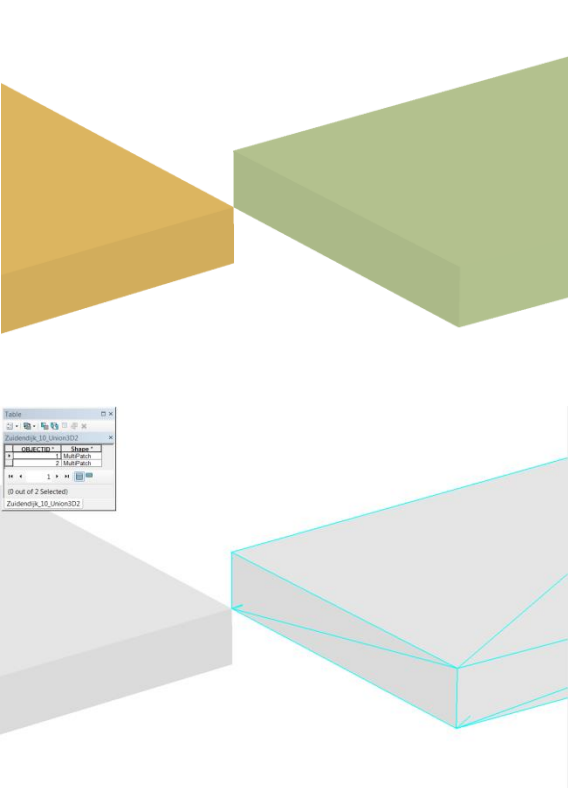
5.3 Non-manifold surface

5. Testing and Evaluation – Case 1.1



case number	Geometry	Attributes	Volume/surface area
1.1 (vertical)	Valid, all features that together form the intersection output are closed geometry	Correct assignment, the TYPE attribute belonging to GeoTOP is assigned to correct features. Colors can be linked to the value in TYPE, value '5' is sand and colored as yellow	Possible. Both volume and surface area calculations can be made, which are listed per distinct feature in the attribute table. Furthermore, a summarize can be made TYPE attribute value.

5. Testing and Evaluation – Case 5.1



case number	Geometry	Attributes	Volume/surface area
5.1	Valid. Though the geometry is not unified and two features remain. A warning indicating the features share a complex relationship; only a vertex or edge.	Not assigned to the output.	Possible, for two separate features.

5. Testing and Evaluation – Case conclusions

Semantics Ok: output is always placed in a new layer that can be saved as .shp.

Attributes Ok: for the set operation *Intersect 3D*.

Volume calculation not on all valid geometry.

The polyhedron rules do not apply entirely: e.g. 3D operations can output non-closed geometry.

The Nef Polyhedra properties do not apply entirely: no non-manifold Nef Polyhedra could be adopted.

6. Application – Geohydrology

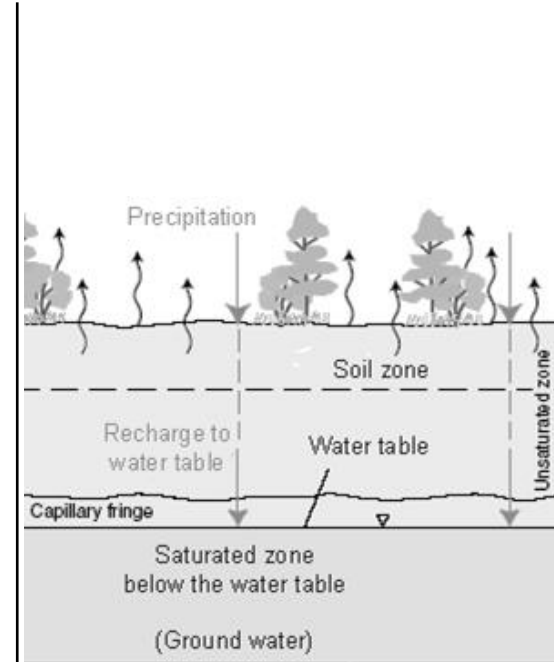
- A complex field: various theories and models exist to describe the hydrology flows through the subsoil.

- Via the Application it is possible to determine two geohydrology aspects:

- Water **infiltration capacity** [m/d]
- Water **storage capacity** [m³]

both of the unsaturated zone / **drainage depth**

- Focus on precipitation as main 'water input'



6. Application – Water infiltration capacity

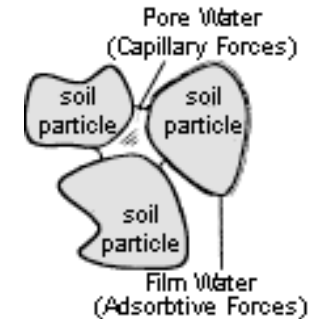
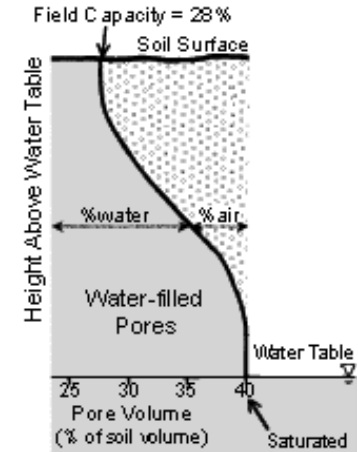
Based on:

- Expressed in length per time
- Permeability coefficient K , which expresses the hydrologic conductivity
 - *Soil type dependent*
 - The vertical permeability K_v is dealt with in the working demo
- Groundwater levels: phreatic surface.
 - Determine the unsaturated zone/ drainage depth of the subsurface
 - Average levels (GLG and GHG)
 - Modeled at a static moment in time via surfaces between measuring points

6. Application – Water storage capacity

Based on:

- Expressed in volume
- Porosity of the soil, pores can be filled with water or with air
 - *Soil type dependent*
 - Volume of the drainage depth
 - Effective porosity, the porosity value available for fluid flow
- Groundwater levels: phreatic surface



6. Application – Working demo



6. Application – Working demo

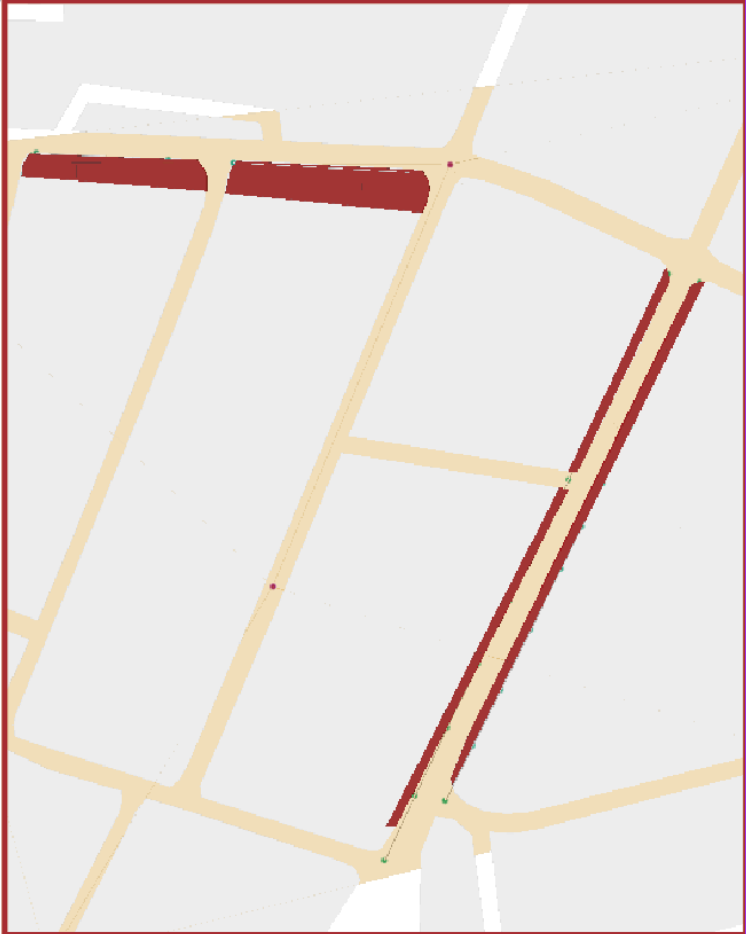
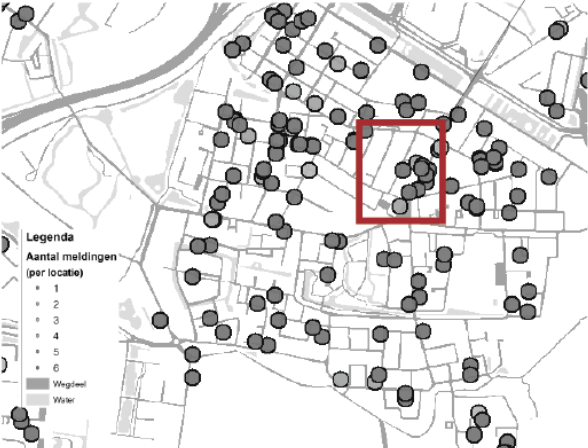
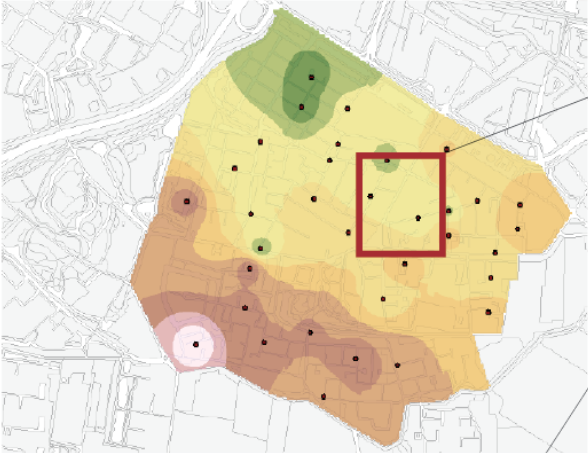
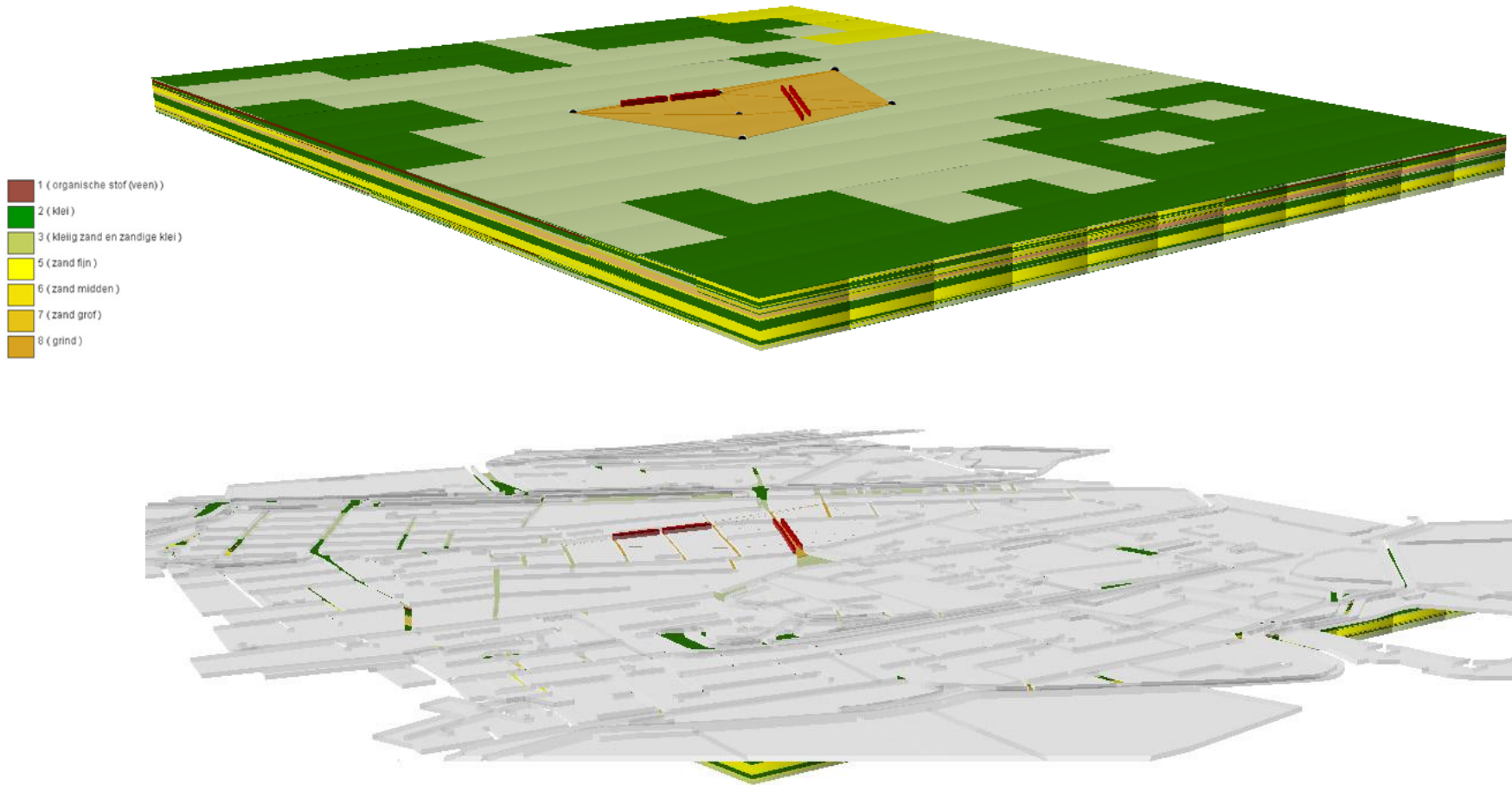
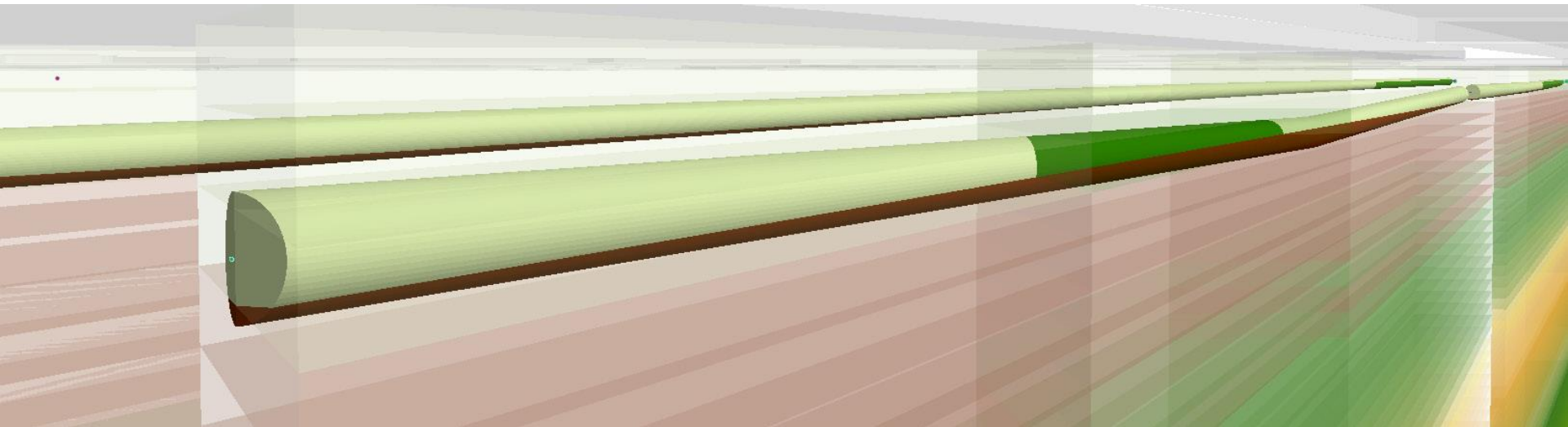


Image source: Municipality of Dordrecht (2015) – lower left image.

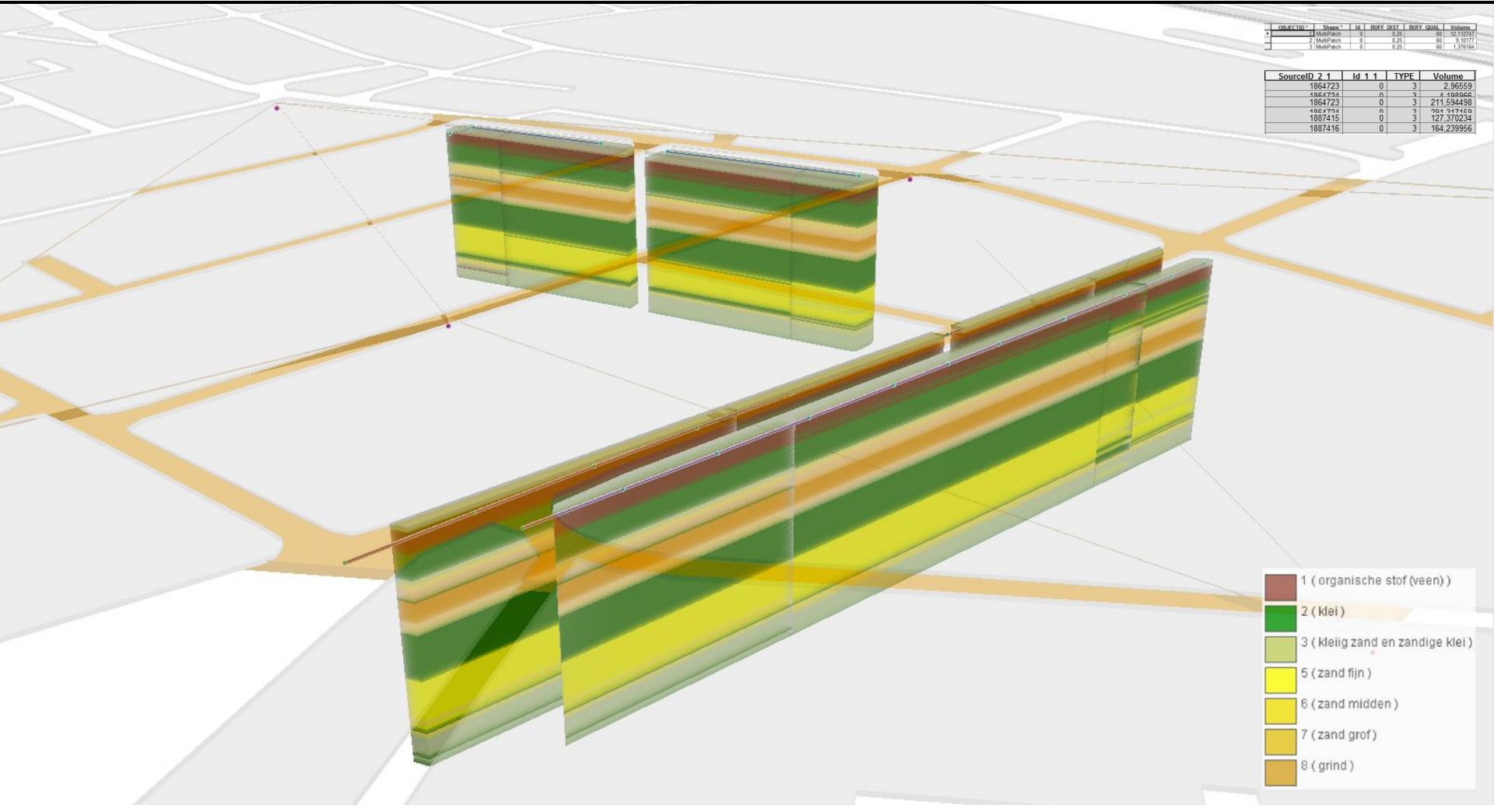
6. Application – Working demo



6. Application – Working demo

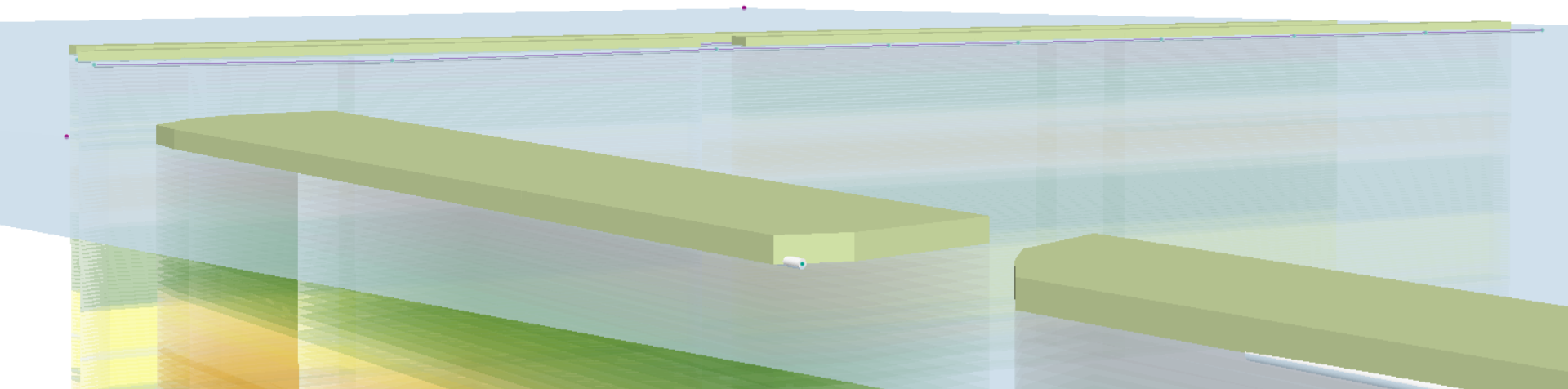


6. Application – Demo results



6. Application – Demo results

The drainage depth at the 'Nijhofflaan' green zone Litho class 3:



6. Application – Demo results

Calculated for a T1000 peak rain – 80 mm in 24 hours:

Infiltration capacity:

precipitation take in: 0.032m

permeability Kv: 0.02 – 0.2m

→ analyzed area suffices in infiltration

Storage capacity:

18.24 m³ water to be stored via soil infiltration

86.79 m³ is available to for water storage via soil infiltration

→ analyzed area suffices in storage

6. Application – Demo findings

The working demo of the 'Nijhofflaan' green zone showed that this open soil location is capable – due to the soil type and volume content of the unsaturated zone – to infiltrate and store precipitation of a heavy T1000 shower.

Urban water management possibilities in this area:

- Keep the open soil areas

Additionally in the perpendicular street:

- Extend the green zone
- Apply permeable paving

7. Conclusions – General

- Voxel data, 2D surface data and 2D line and point data can be converted to **3D surface based vector data**, via different workflows.
- The **Nef Polyhedron is a suited data structure** to perform 3D Boolean set operations with, and to attached attributes with geometry applied in the field of GIS.
- The implemented Nef_Polyhedra_3 class of CGAL by ArcGIS does not account for all Nef Polyhedra, with respect to the theory.
- 3D Intersection operations on subsurface data represented as surfaces in commonly used GIS, offer a **sound base for geohydrology principles**.

7. Conclusions – Main research question

In what manner can a GIS facilitate 3D intersection operations for voxel data represented as surfaces, while maintaining semantic and attribute information in the output?

- The conversion of 2D surface data and 2D line and point data is straightforward, the voxel conversion to 3D vector data is more extensive.
- Based on CGAL's Nef Polyhedra description, ArcGIS can perform 3D Boolean operations that *can* provide closed geometry as output.
- Thus, voxel data represented as 3D vector surfaces can output valid geometry, with semantics and assigned attributes – when intersected in 3D.

7. Conclusions – Sub question 1

What generic workflow is required to retrieve a 3D intersection with surface represented objects?

- Convert a voxel datasets to centroid points with x, y, z coordinates together with their attributes.
- 2D Surface data requires vertical extrusion, that ensures the preservation of the footprint.
- 2D Line data requires buffering / 2D point data requires – here – COLLADA.
- 3D Intersection operations: for each distinct overlapping object at a time the semantic and attribute information of the input objects is adopted.

7. Conclusions – Sub question 2

How can 3D intersection operations be performed in GIS?

- Perform a 3D intersection operation on the same data representation – here 3D vector data surface based.
- ArcGIS includes the B-rep Multipatch geometry and offers 3D Boolean set operations as the Difference 3D, Union 3D and Intersect 3D set operations. ArcGIS uses the CGAL implementation of the Nef Polyhedra data structures on the background.
- *Intersect 3D* locates as the geometry objects that intersect, and then assigns per object the attributes of both of the input geometries to the intersecting output.

7. Conclusions – Sub question 3

How can semantic and attribute information of the 3D intersection output be maintained in GIS?

Semantic information as the layer of the output of the 3D operation, possible to store as separate data – .shp.

→ *In all test cases were the input was considered closed.*

Attributes should be found and obtained of the input geometry – one intersecting feature at a time – and placed in the new output geometry.

→ *In all cases were the input was considered closed and a 3D intersection operation was possible.*

7. Conclusions – Discussion & Recommendations

- The map sheets of a GeoTOP voxel dataset contains approximately 9.2 million voxels and is thus of extensive size once loaded and modified.
- The voxel resolution is of a $100*100*0,5\text{m}$, an order of magnitude that might lead to misinterpretations of the analysis.
- Misplacements of some sets of voxels.
- A more accurate level of detail of the GeoTOP dataset would benefit the spatial analysis as performed in this thesis research via 3D intersection operations.
- Incorporating or import the entire groundwater database of larger areas.

7. Conclusions – Reflection

- Sound connection with the Geomatics Core Courses.
- Conversion of voxel to 3D surface based vector data was more elaborate than initially imagined.
- Opened my view on the potential of 3D Boolean set operations performed on real – life datasets.
- Unveiled the power of spatial analysis on three dimensional geo-data.
- In this research I could literally set refined theories against various cases.

Thank you all.

