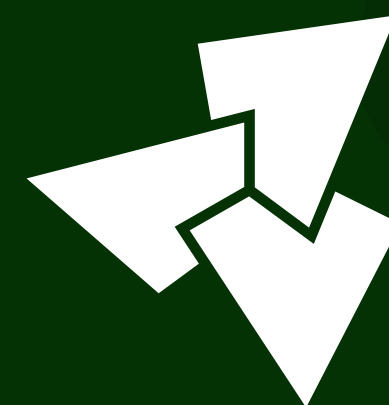


Lesson 3.2

Three-dimensional geometries in geoinformation

GE01004:
3D modelling of the built environment

<https://3d.bk.tudelft.nl/courses/geo1004>



3D geoinformation

Department of Urbanism
Faculty of Architecture and the Built Environment
Delft University of Technology

About GIS standards

Standardisation organisations

- **ISO:** International Standardisation Organisation
- **OGC:** Open Geospatial Consortium
- **INSPIRE:** Infrastructure for Spatial Information in Europe
- **NEN:** *normalisatie en normen* (“Dutch ISO”)

ISO 191xx series of geographic information standards


- A main goal of the ISO 191xx series is to facilitate the interoperability of geographic information systems, i.e. ability to discover, access, understand and use the information and tools, independently from the platform supporting them
- Structured set of standards specifying methods, tools and services for the management of geographic information, including:
 - Definition of data,
 - Access to data
 - Presentation of data
 - Transfer between users
- weirdly, and annoyingly, one has to pay to read these 😞

ISO 191xx series of geographic information standards

| | |
|---|---|
| 6709 - Standard representation of latitude, longitude and altitude for geographic point locations | 19122 - Qualifications and Certification of personnel |
| 19101 - Reference model | 19123 - Schema for coverage geometry and functions |
| 19101-2 - Reference model - Part 2: Imagery | 19124 - Imagery and gridded data components |
| 19103 - Conceptual schema language | 19125-1 - Simple feature access - Part 1: Common architecture |
| 19104 - Terminology Introduction | 19125-2 - Simple feature access - Part 2: SQL option |
| 19105 - Conformance and testing | 19126 - Profile - FACC Data Dictionary |
| 19106 - Profiles | 19127 - Geodetic codes and parameters |
| 19107 - Spatial schema | 19128 - Web Map server interface |
| 19108 - Temporal schema | 19129 - Imagery, gridded and coverage data framework |
| 19109 - Rules for applicaiton schema | 19130 - Sensor and data models for imagery and gridded data |
| 19110 - Methodology for feature cataloguing | 19131 - Data product specifications |
| 19111 - Spatial referencing by coordinates | 19132 - Location based services - Reference model |
| 19112 - Spatial referencing by geographic identifiers | 19133 - Location based services - Tracking and navigation |
| 19113 - Quality principles | 19134 - Multimodal location based services for routing and navigation |
| 19114 - Quality evaluation procedures | 19135 - Procedures for registration of geographical information items |
| 19115 - Metadata | 19136 - Geography Markup Language |

| | |
|--|--|
| 19115-2 - Metadata - Part 2: Extensions for imagery and gridded data | 19137 - Generally used profiles of the spatial schema and of similar important other schemas |
| 19116 - Positioning services | 19138 - Data quality measures |
| 19117 - Portrayal | 19139 - Metadata - Implementation specification |
| 19118 - Encoding | 19140 - Technical amendment to the ISO 191** Geographic information series of standards for harmonization and enhancements |
| 19119 - Services | 19141 - Schema for moving features |
| 19120 - Functional standards | |
| 19121 - Imagery and gridded data | |

OGC: Open Geospatial Consortium®



The screenshot shows the OGC website homepage. The browser address bar displays "https://www.ogc.org". The navigation menu includes "ABOUT", "MEMBERSHIP", "STANDARDS & RESOURCES", "INNOVATION", and "NEWS & EVENTS". The main banner features the text "122ND OGC MEMBER MEETING" and "Connecting Location Globally" with dates "28 February - 4 March, 2022 | VIRTUAL". An AWS logo is present with the text "PROUDLY SPONSORED BY: aws". Below the banner, the text reads "The Home of Location Technology Innovation and Collaboration" and "Your Global Resource for Geospatial Information and Standards". A section titled "Upcoming Events" lists several events with dates.

**The Home of Location Technology
Innovation and Collaboration**

*Your Global Resource for Geospatial
Information and Standards*

Welcome to OGC, a worldwide community committed to improving access to geospatial, or location information. We connect people, communities, and technology to solve global challenges and address everyday needs. The organization represents over 500 businesses, government agencies, research organizations, and universities united with a desire to make location information FAIR – Findable,

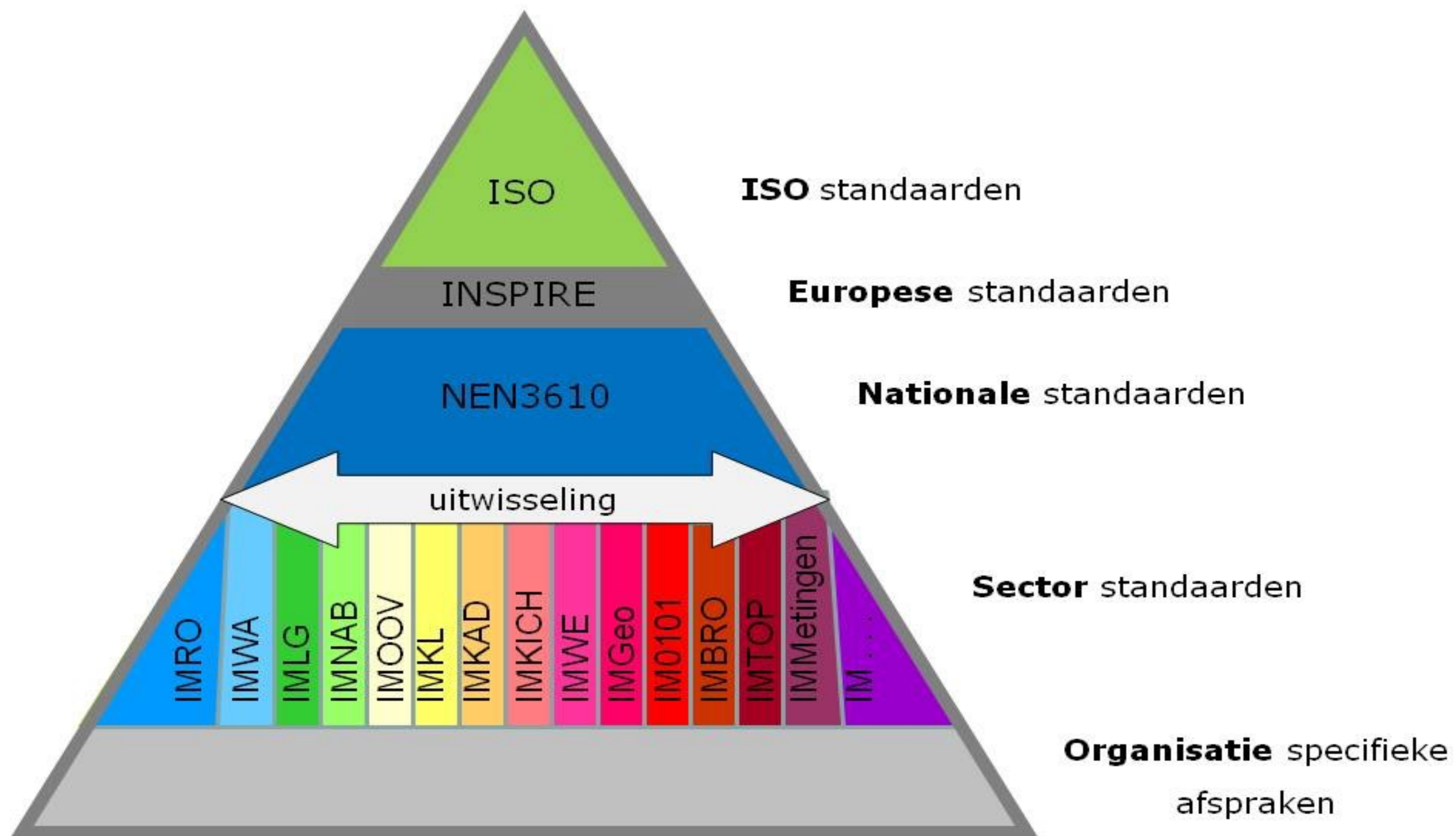
Upcoming Events

- [Pre-Sprint Webinar \[2022 Joint OGC - OSGeo - ASF Code Sprint\]](#)
23 Feb - 23 Feb
- [2nd Geospatial Knowledge Infrastructure Summit – Advancing Industry Adoption](#)
24 Feb - 25 Feb
- [Testbed-18 Bidders Q&A Webinar](#)
24 Feb - 24 Feb
- [AAG 2022 NYC - Annual Meeting](#)
25 Feb - 01 Mar

[View all events...](#)

- many standards are aligned with ISO's (ie, they are exactly the same)
- OGC usually standards closer to implementations than ISO
 - GML
 - KML
 - netCDF
- abstract specifications = ISO
- implementation specification = OGC
- unlike ISO's, OGC's documents are free 😊

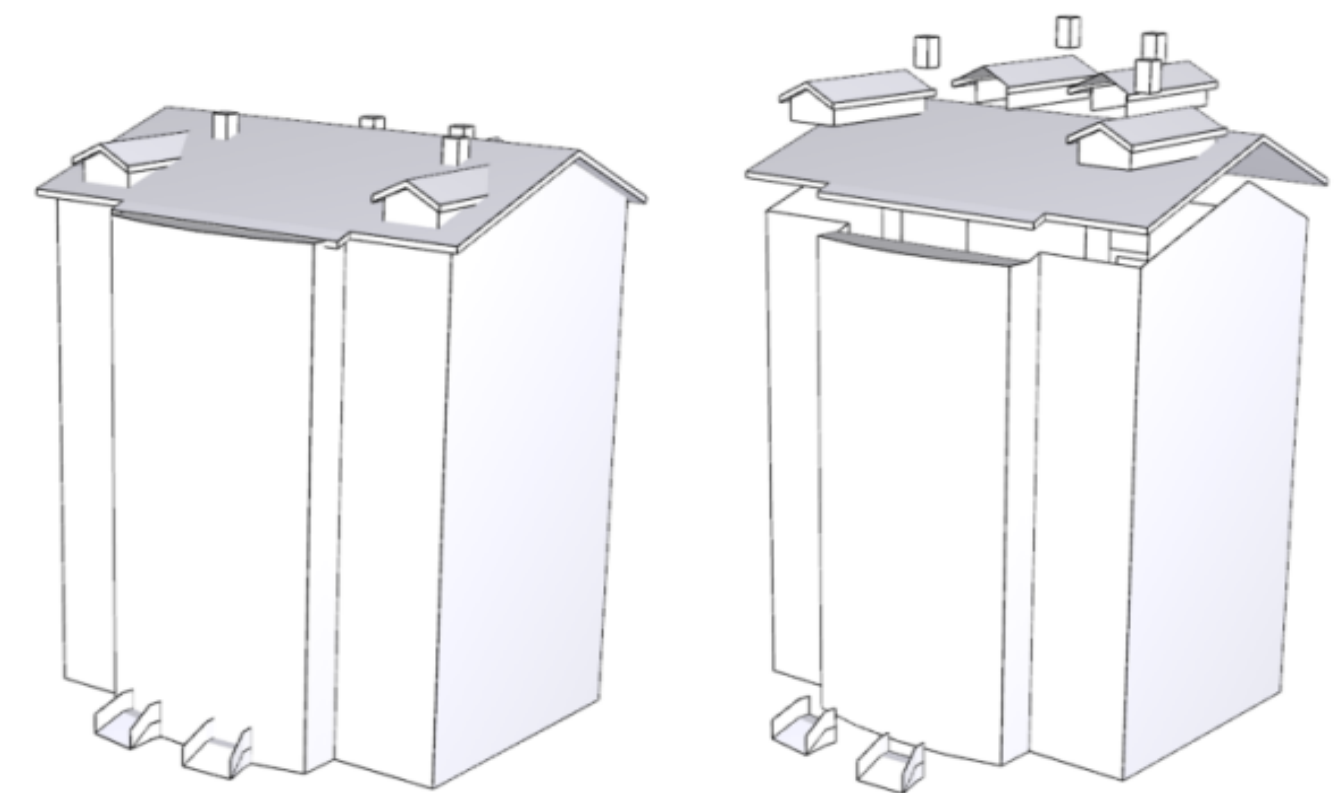
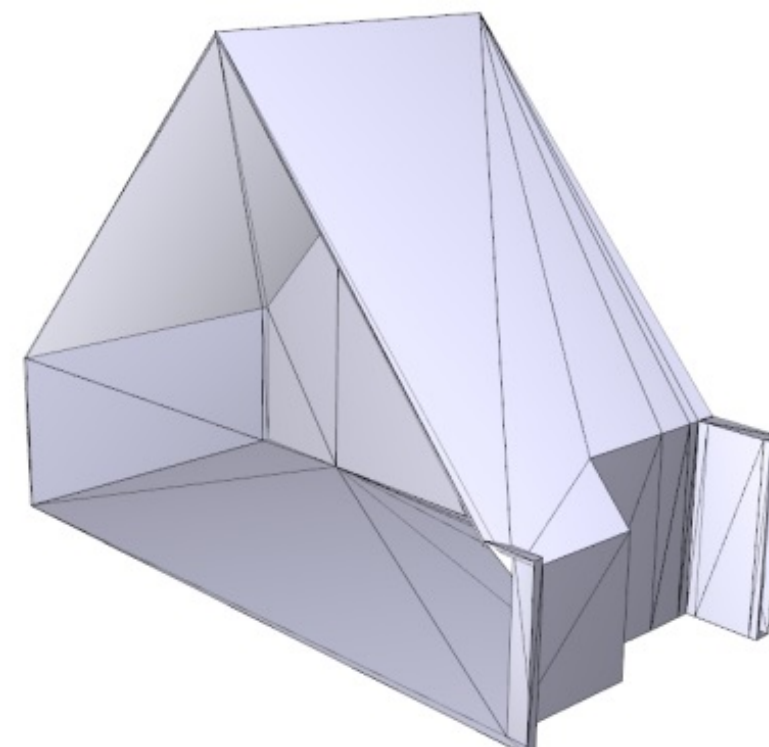
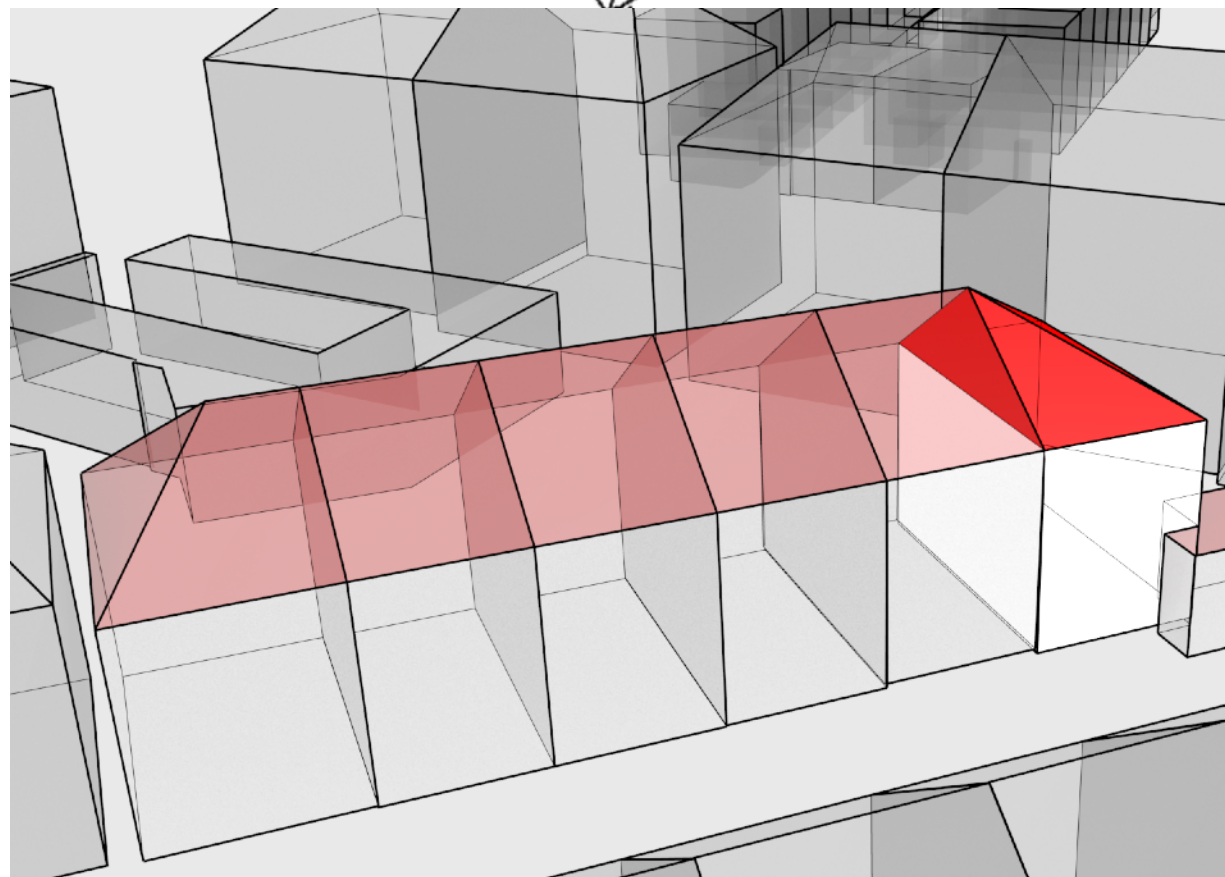
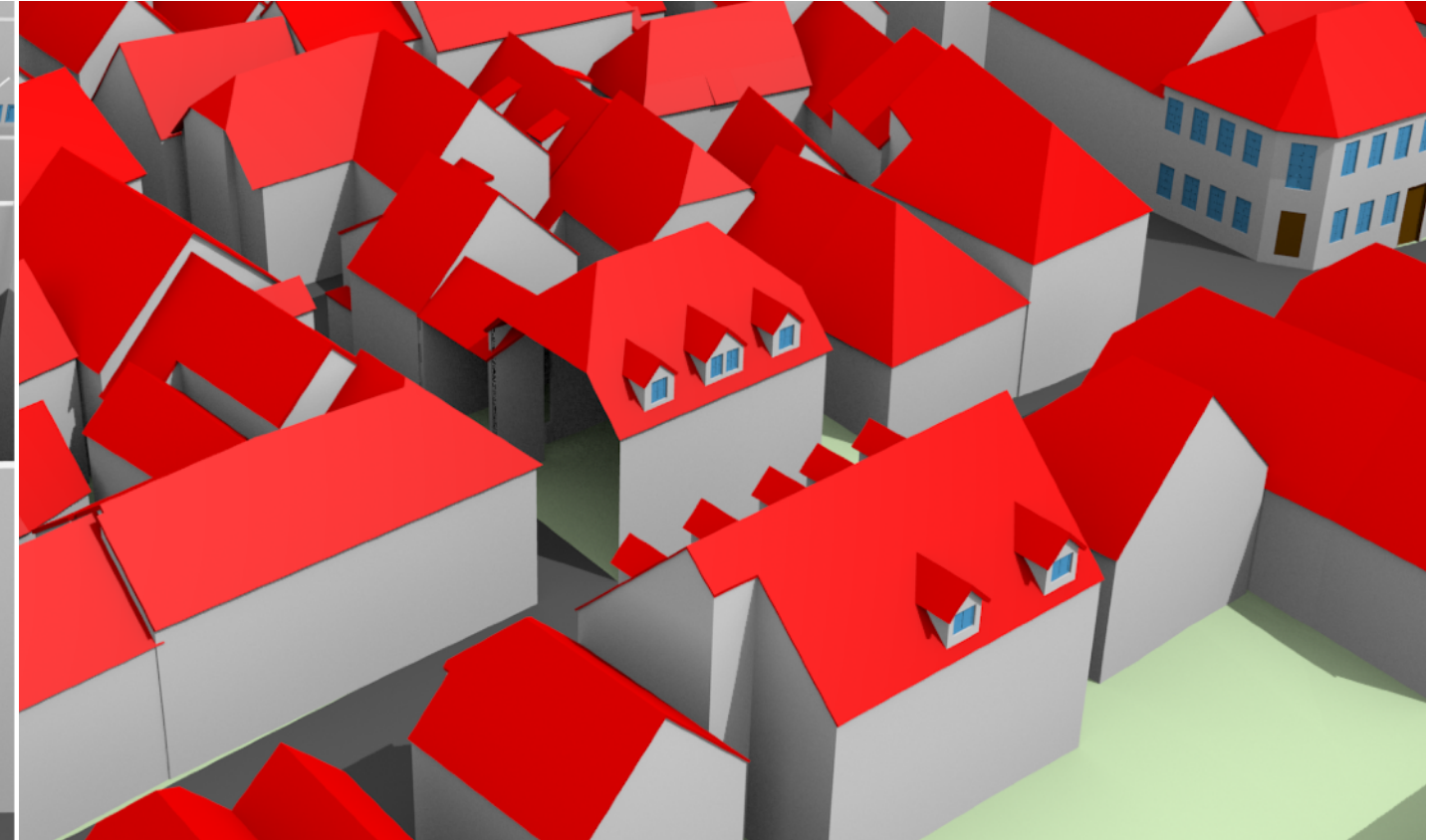
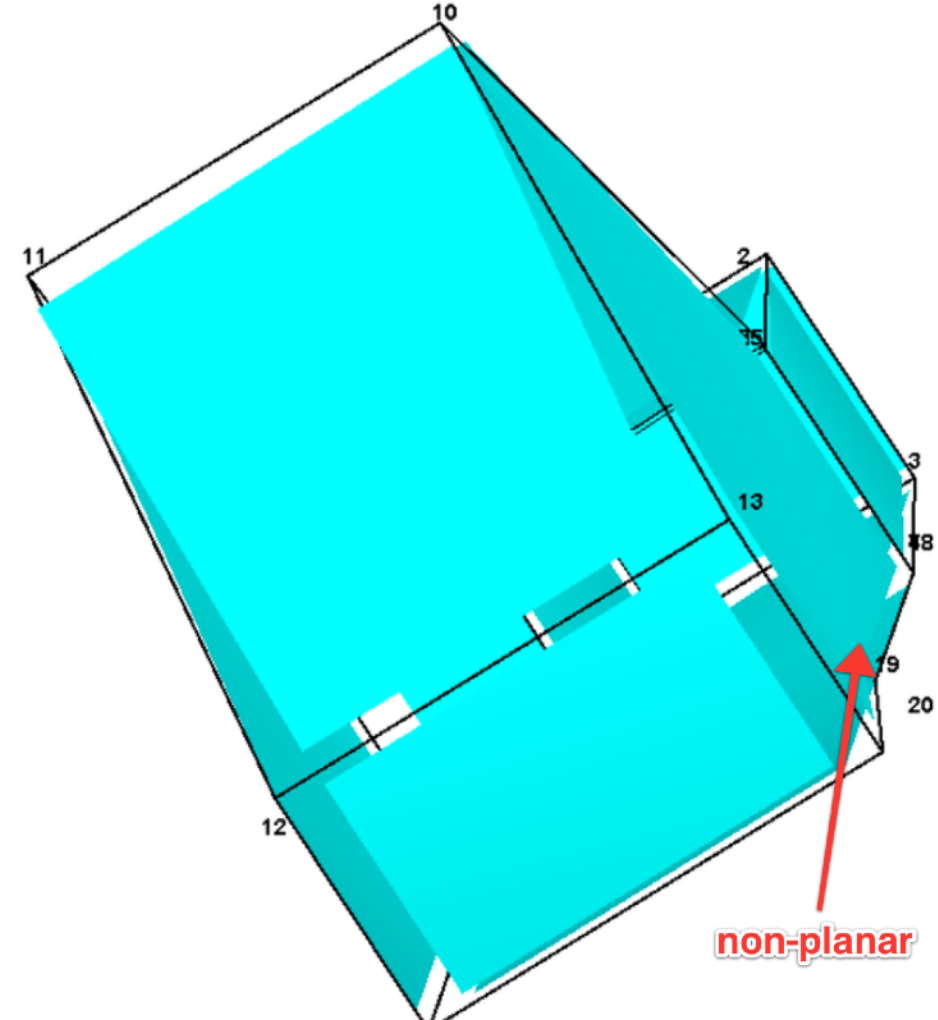
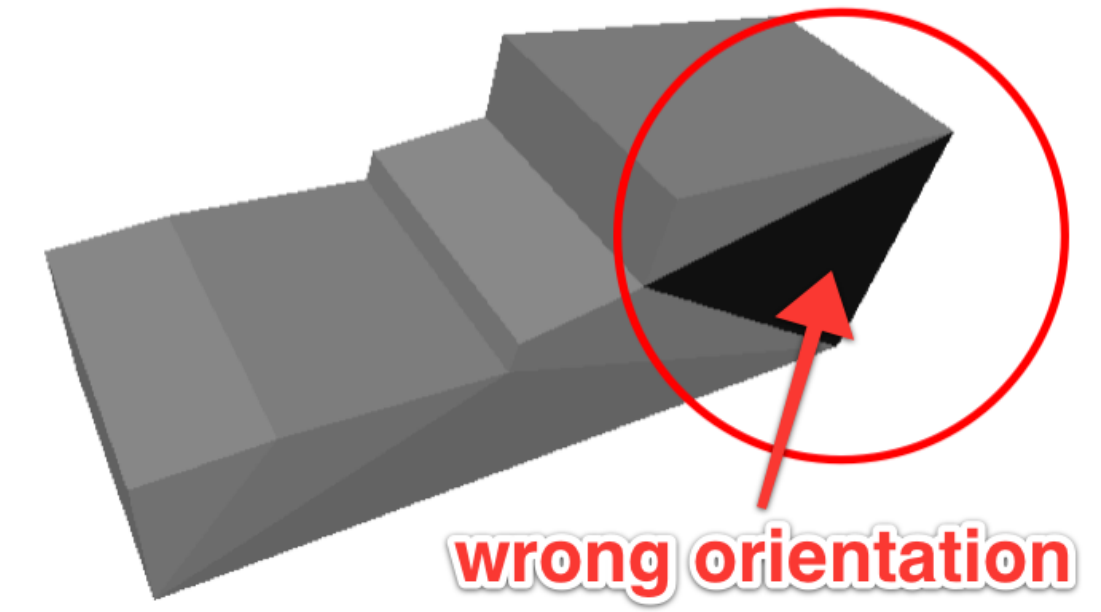
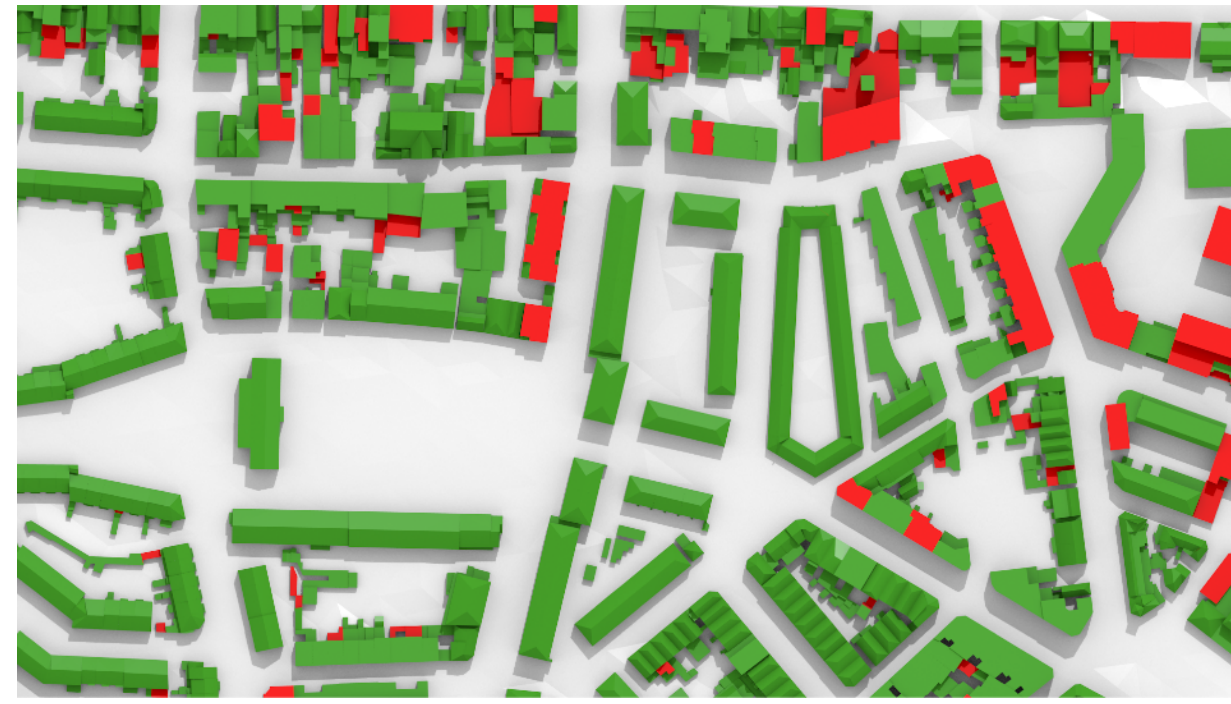
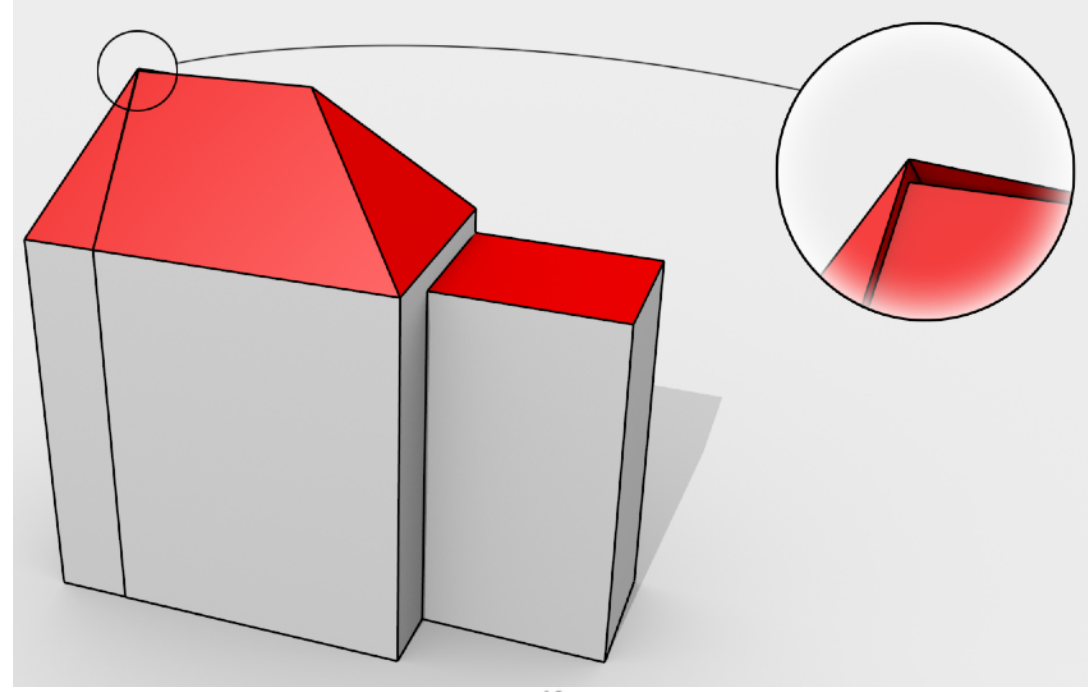
The standards from a Dutch point-of-view



**Do current 3D city models
often contain these
geometric errors?**

tl;dl: **YES.**

Errors are *very* common in 3D models: the wall of shame

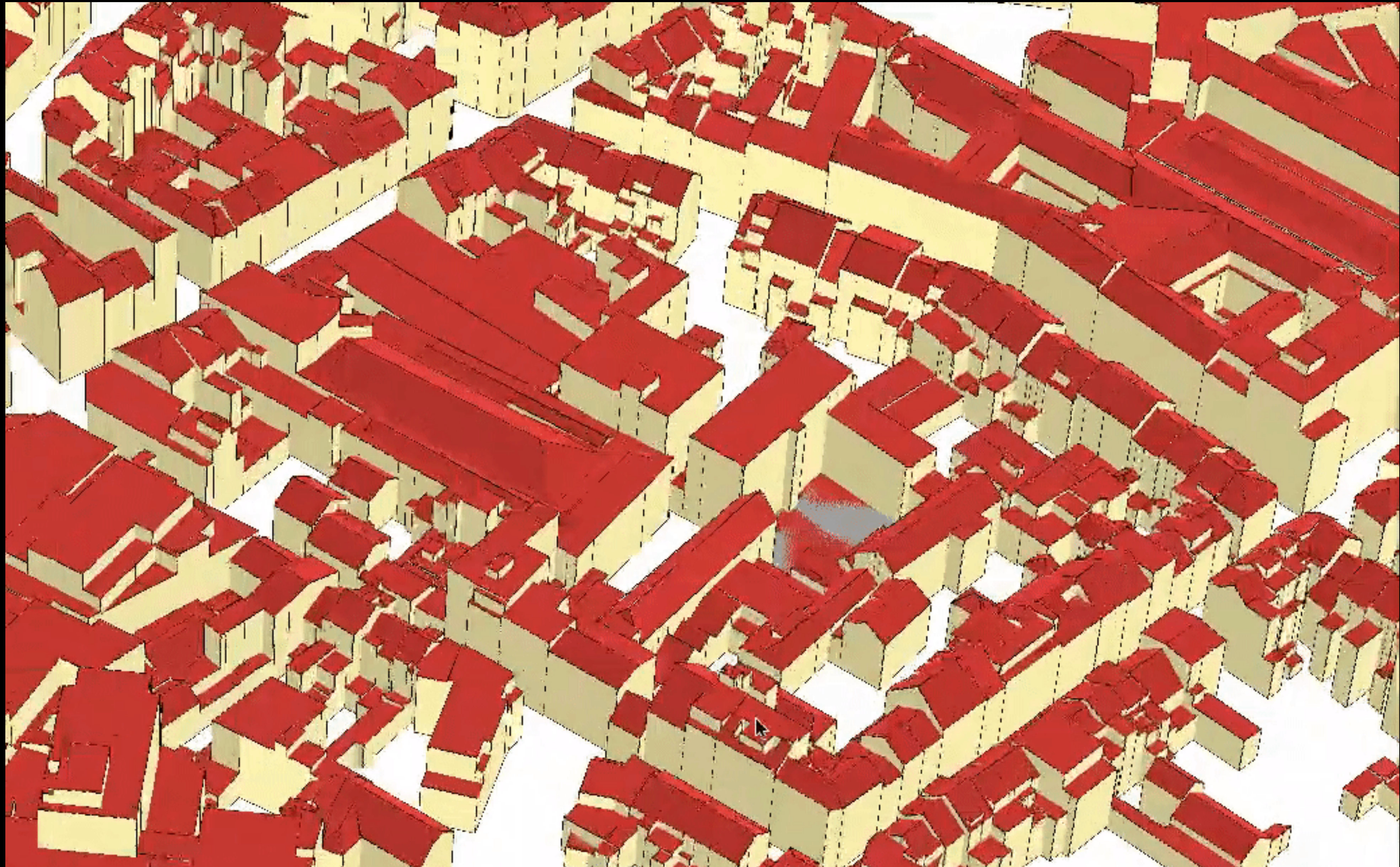


Should we care?

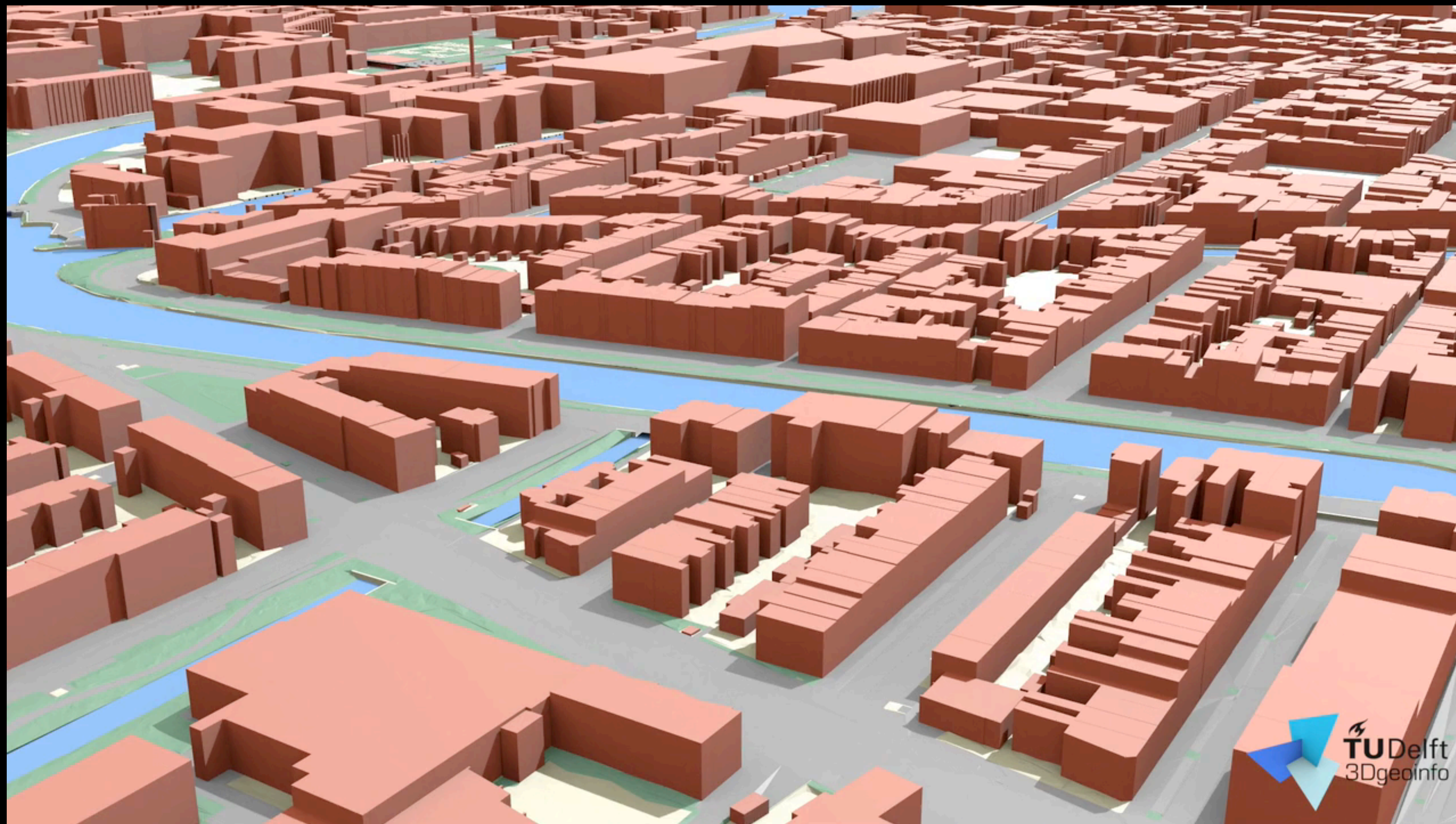
YES!

(especially if you want to pass this course 😄💧)

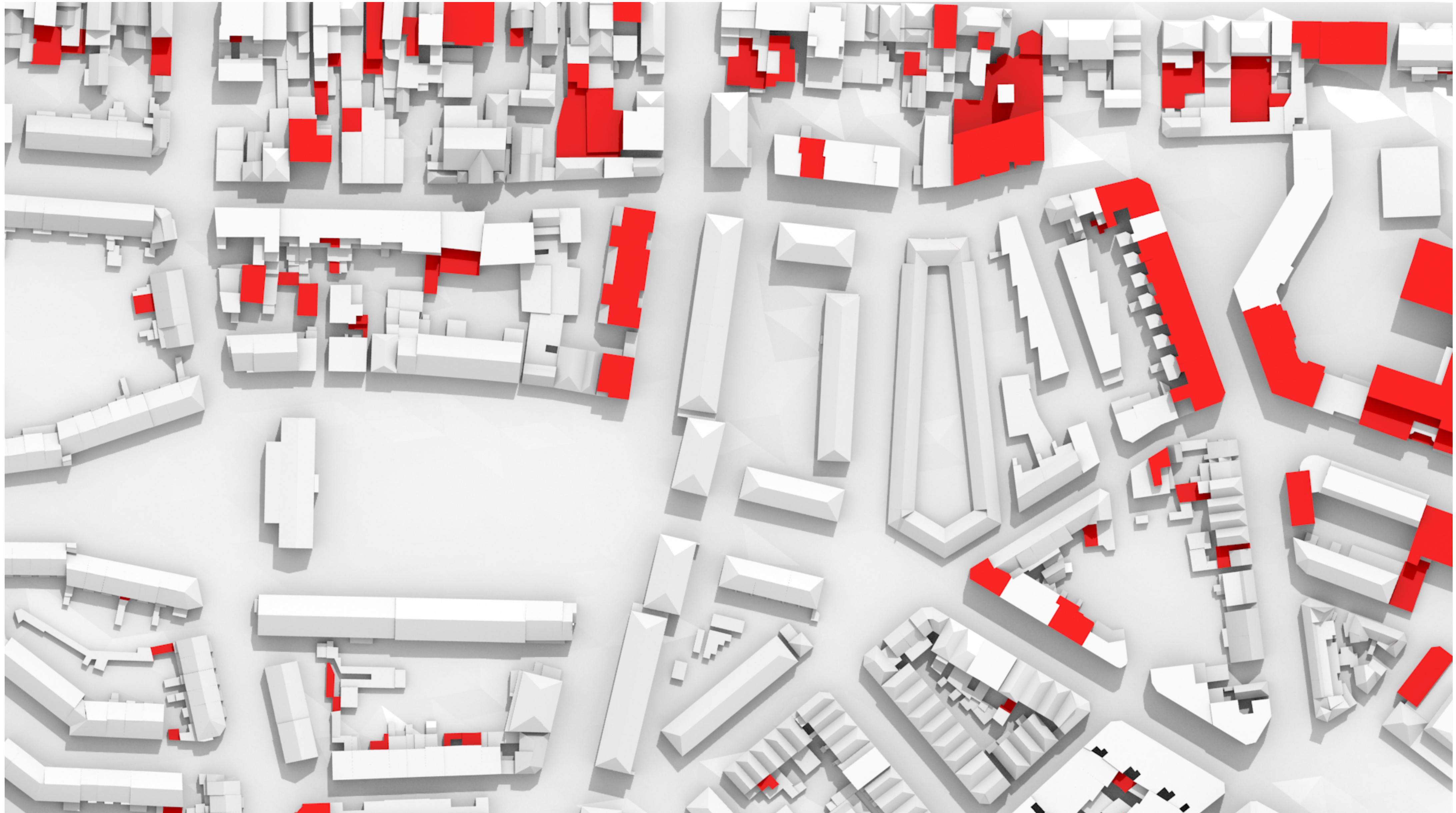
Visualisation – duplicated surfaces == annoying



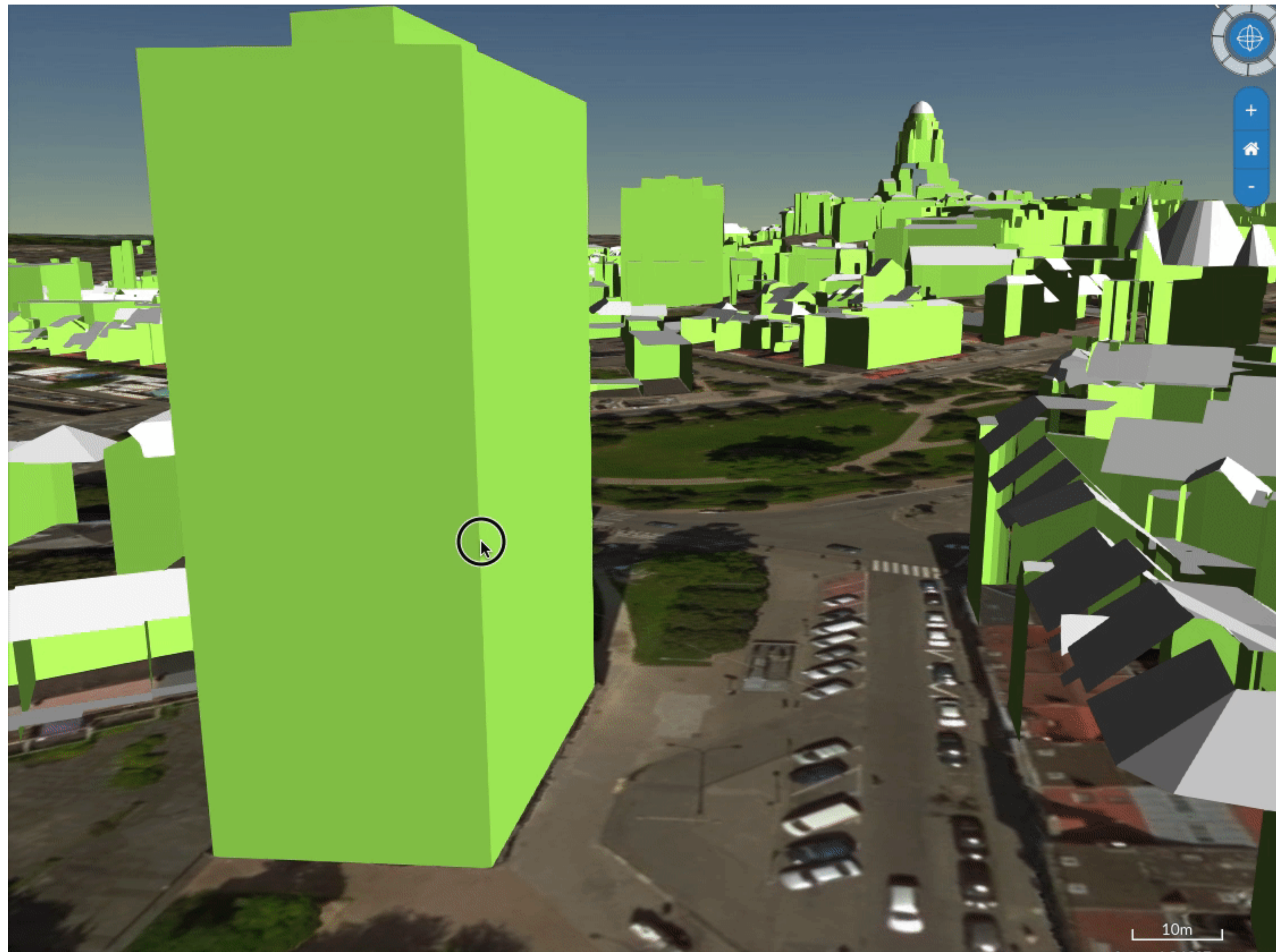
Visualisation – duplicated surfaces == distracting



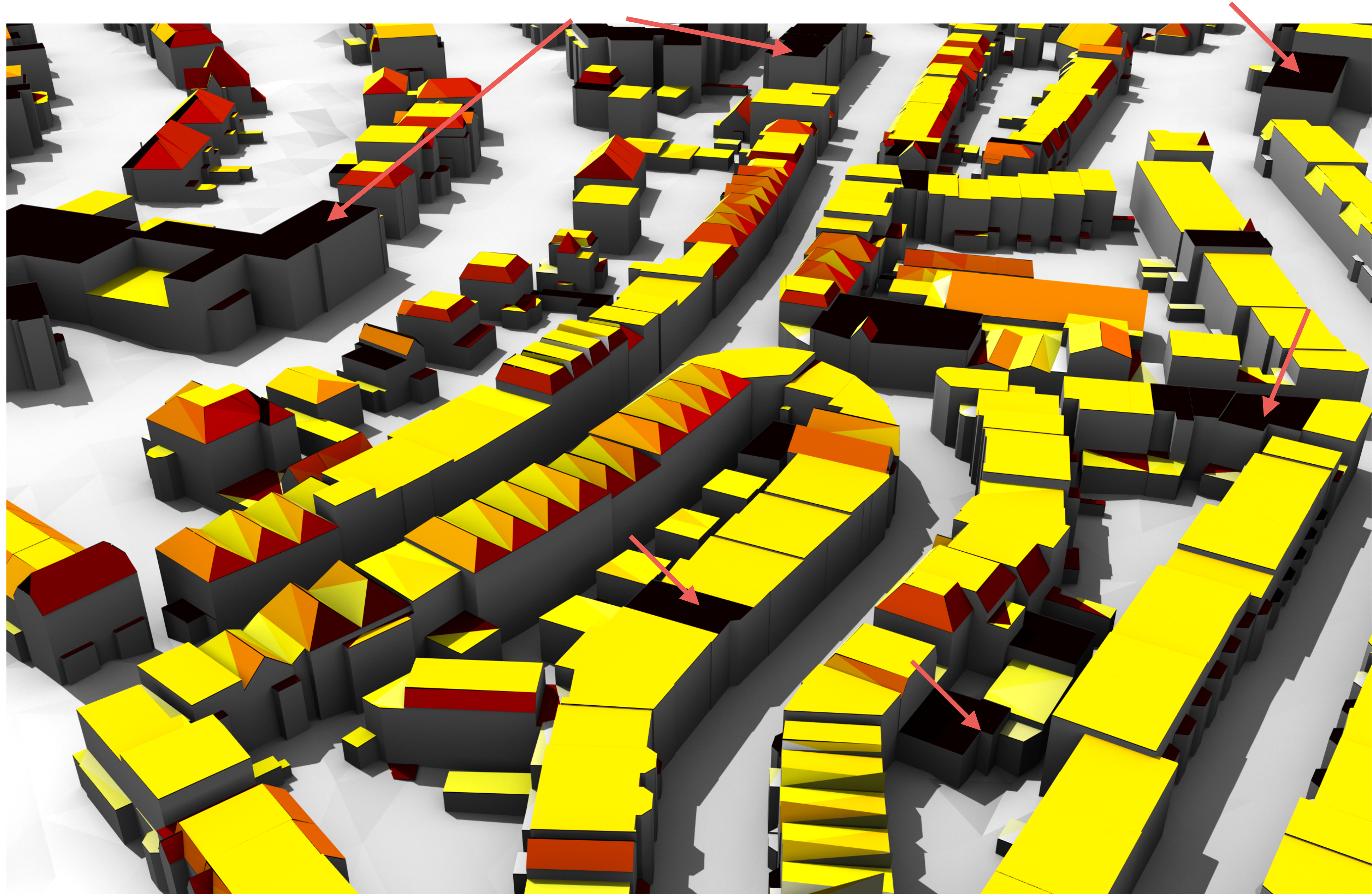
Visualisation – wrong orientation of surfaces (red ones)



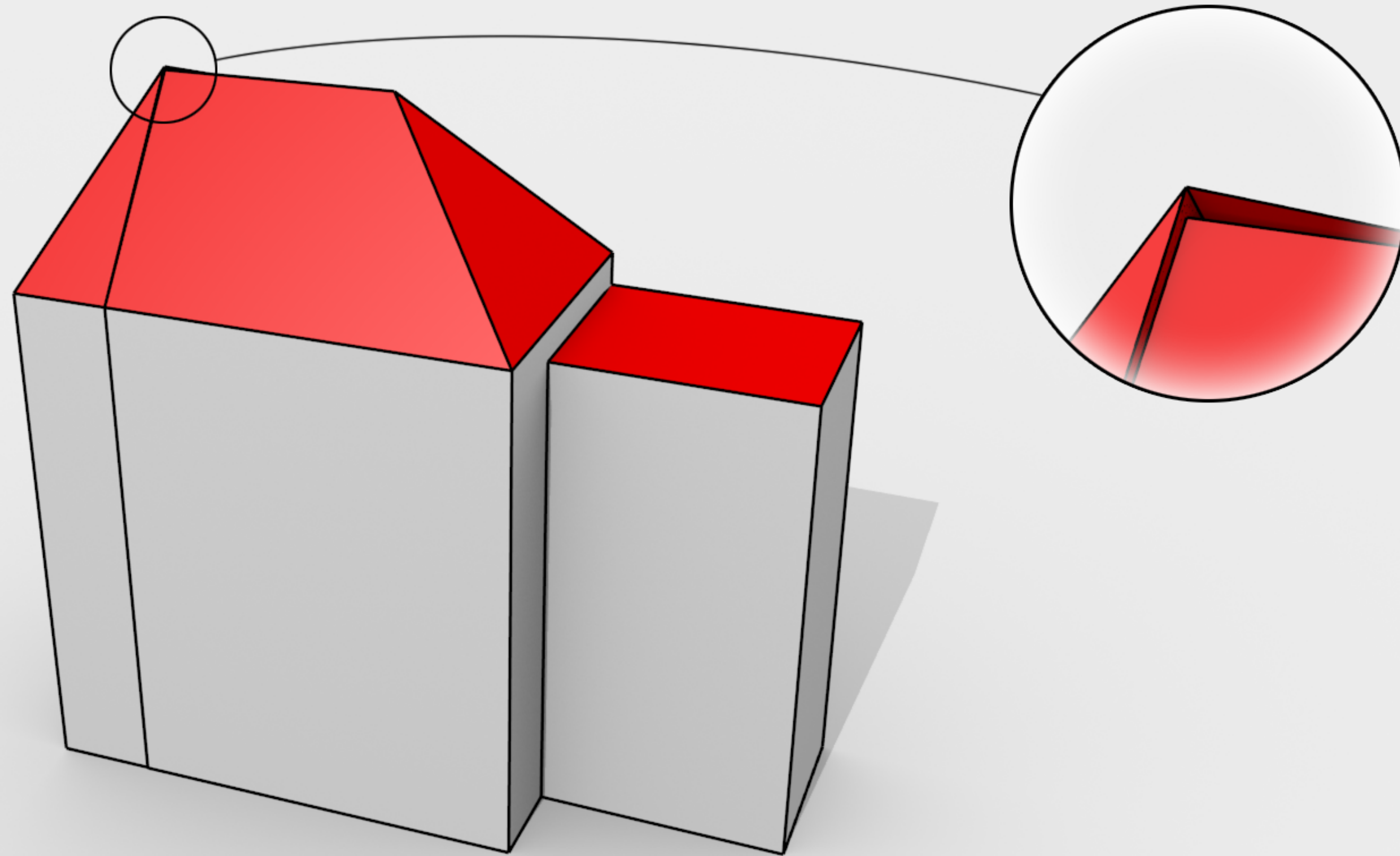
Visualisation – wrong orientation == missing faces



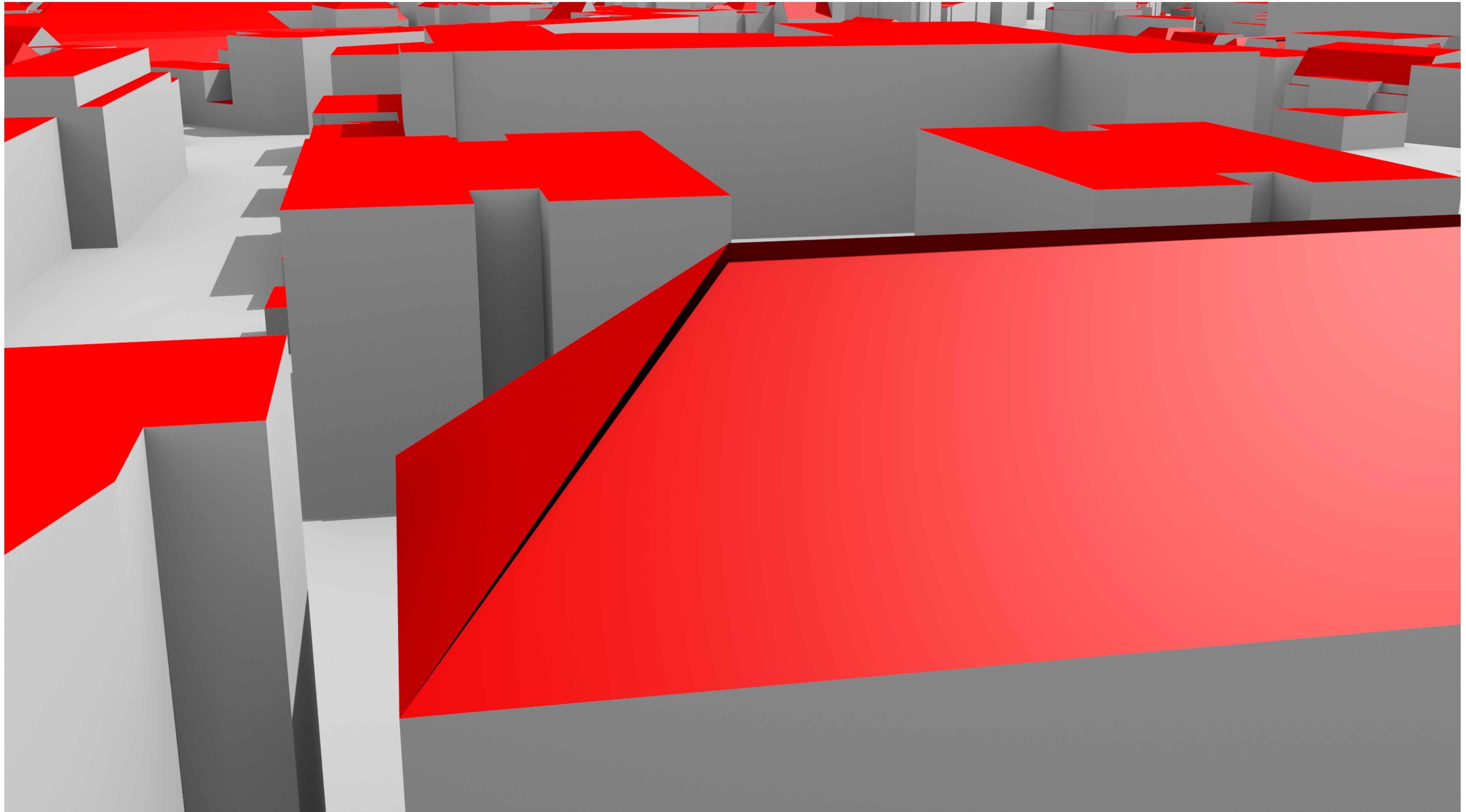
Solar potential – wrong orientation == no potential assigned



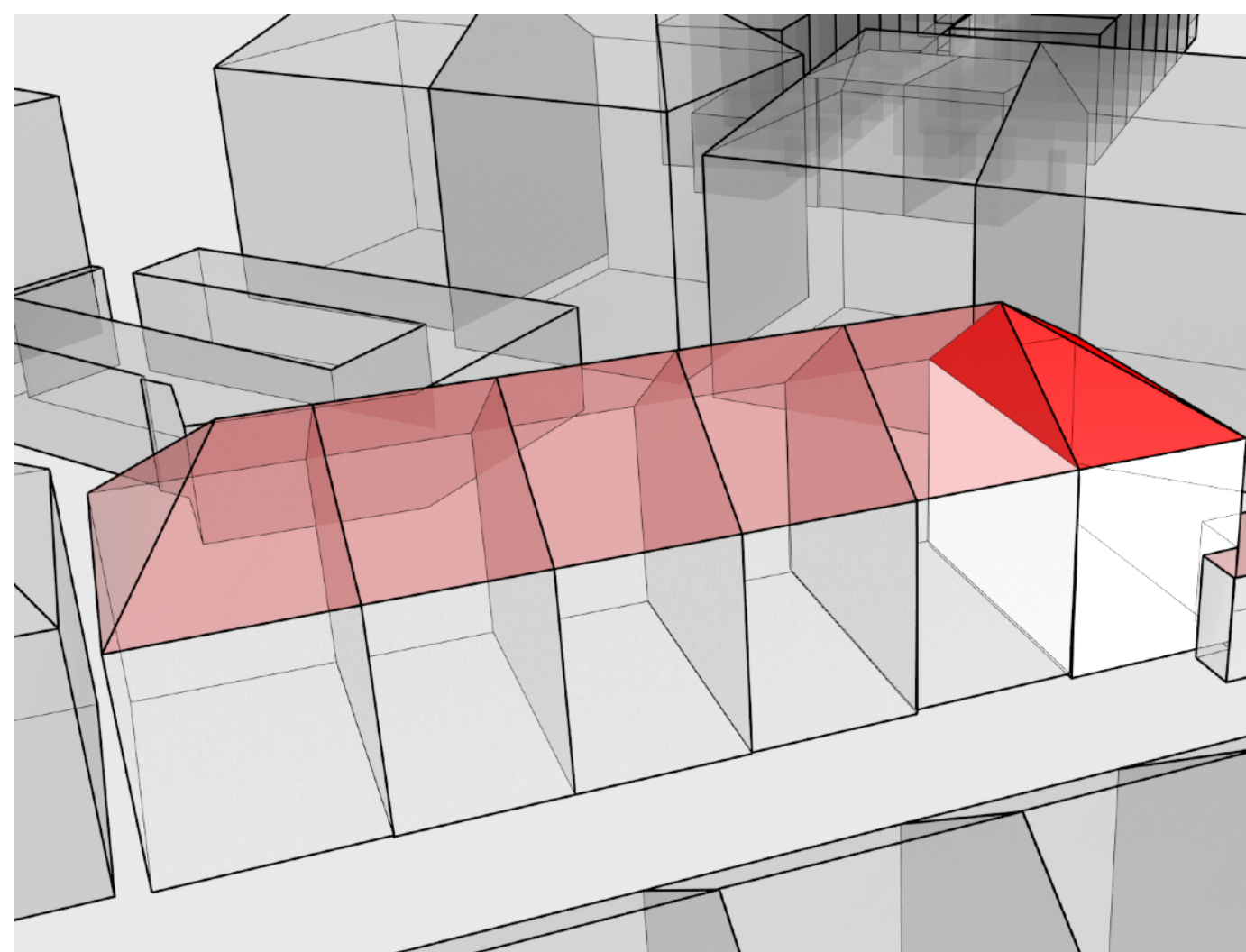
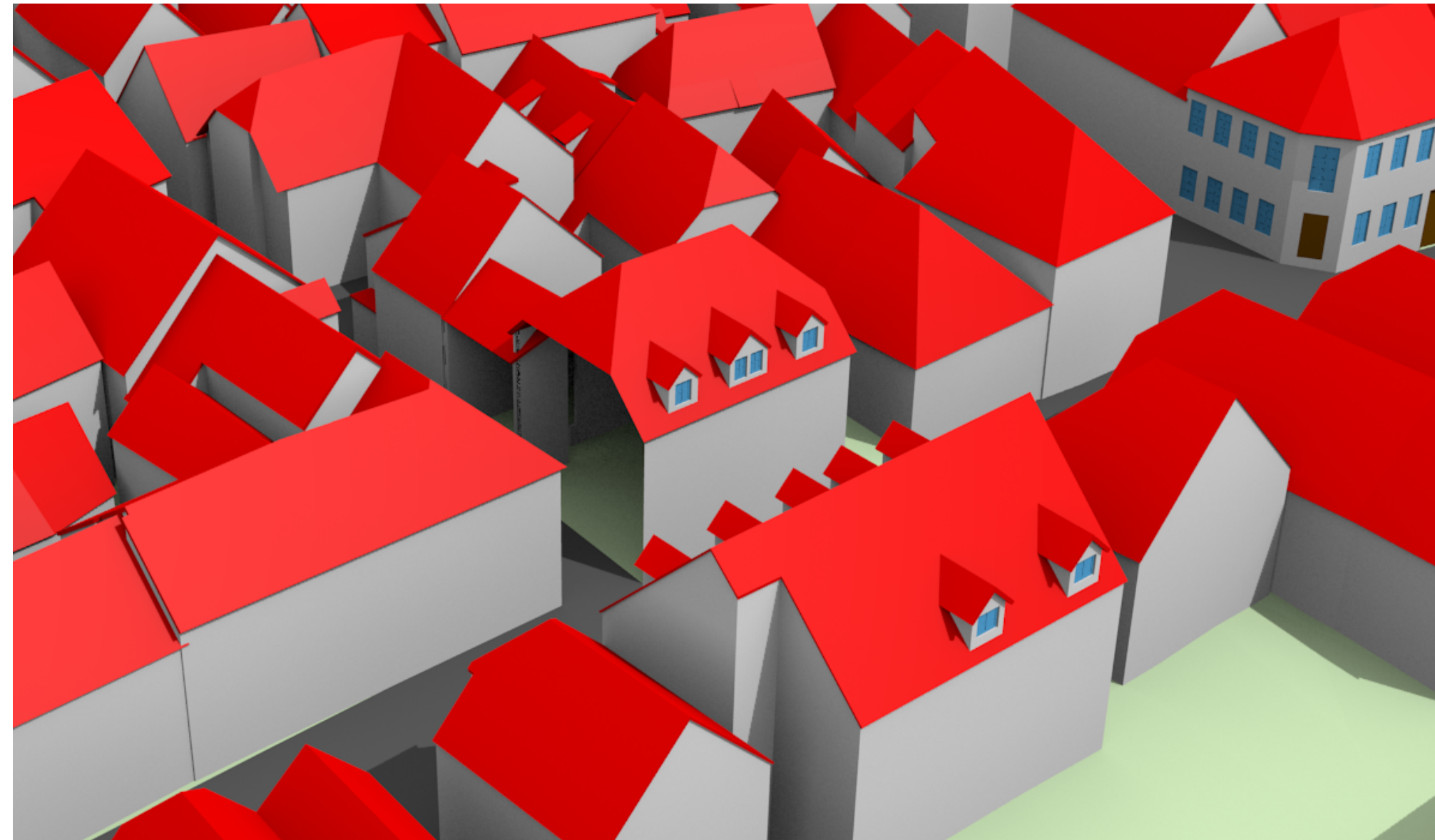
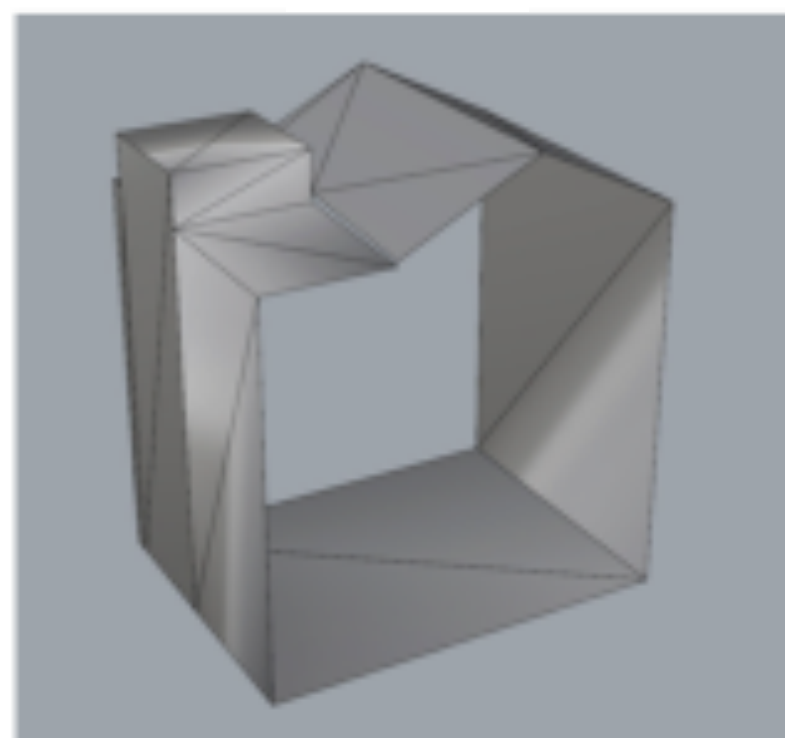
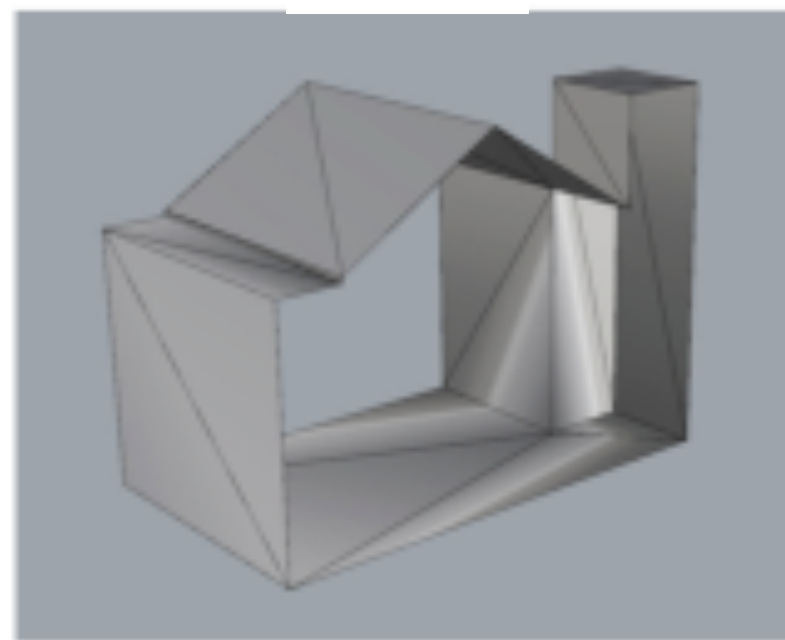
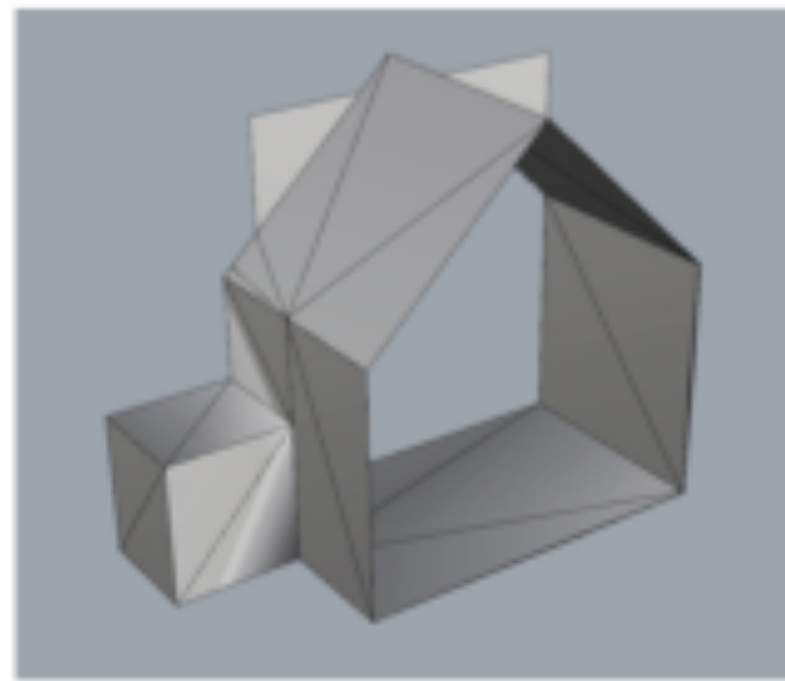
Volume calculation – tiny problems == impossible to calculate



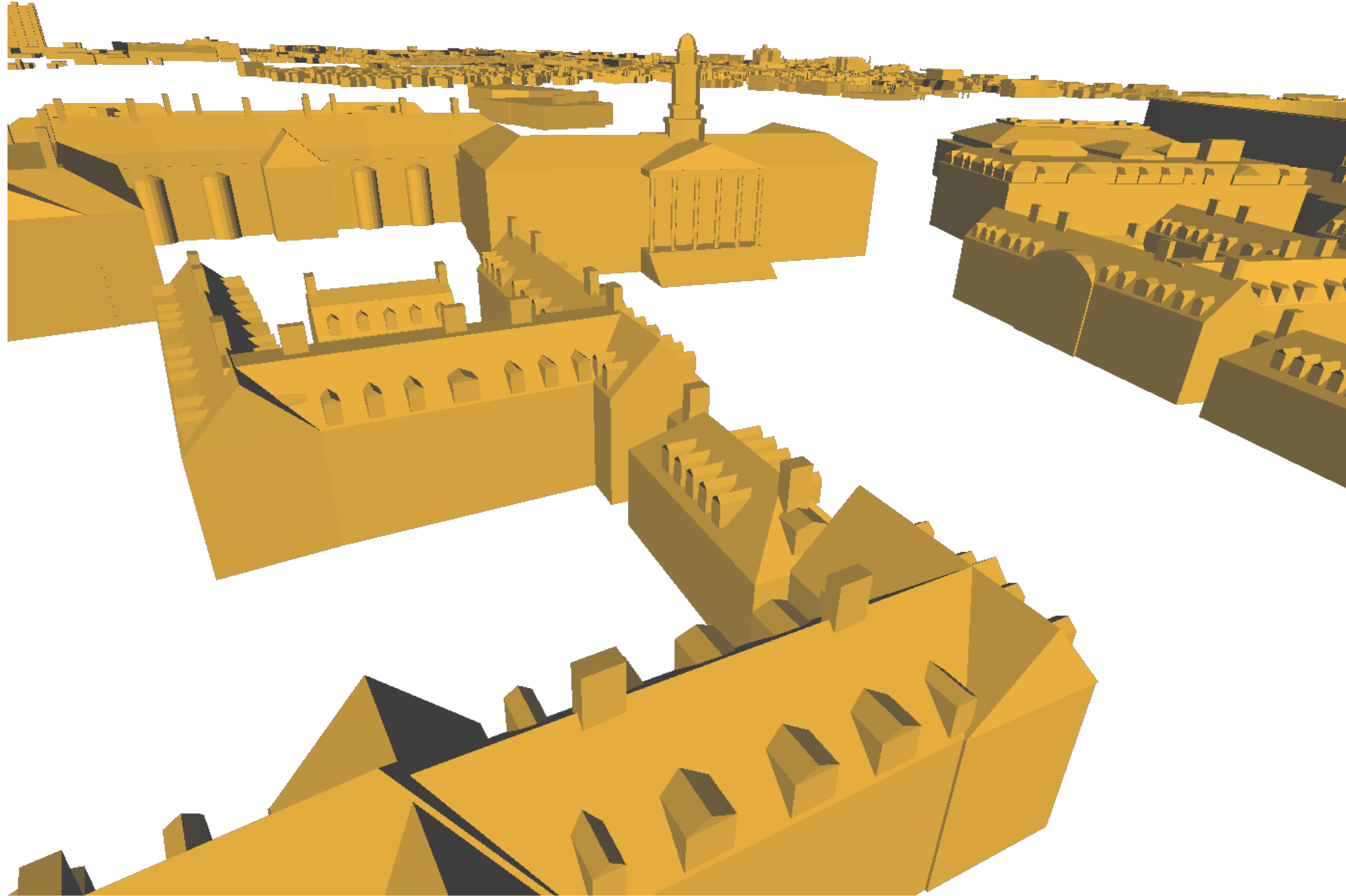
Volume calculation – tiny problems == impossible to calculate



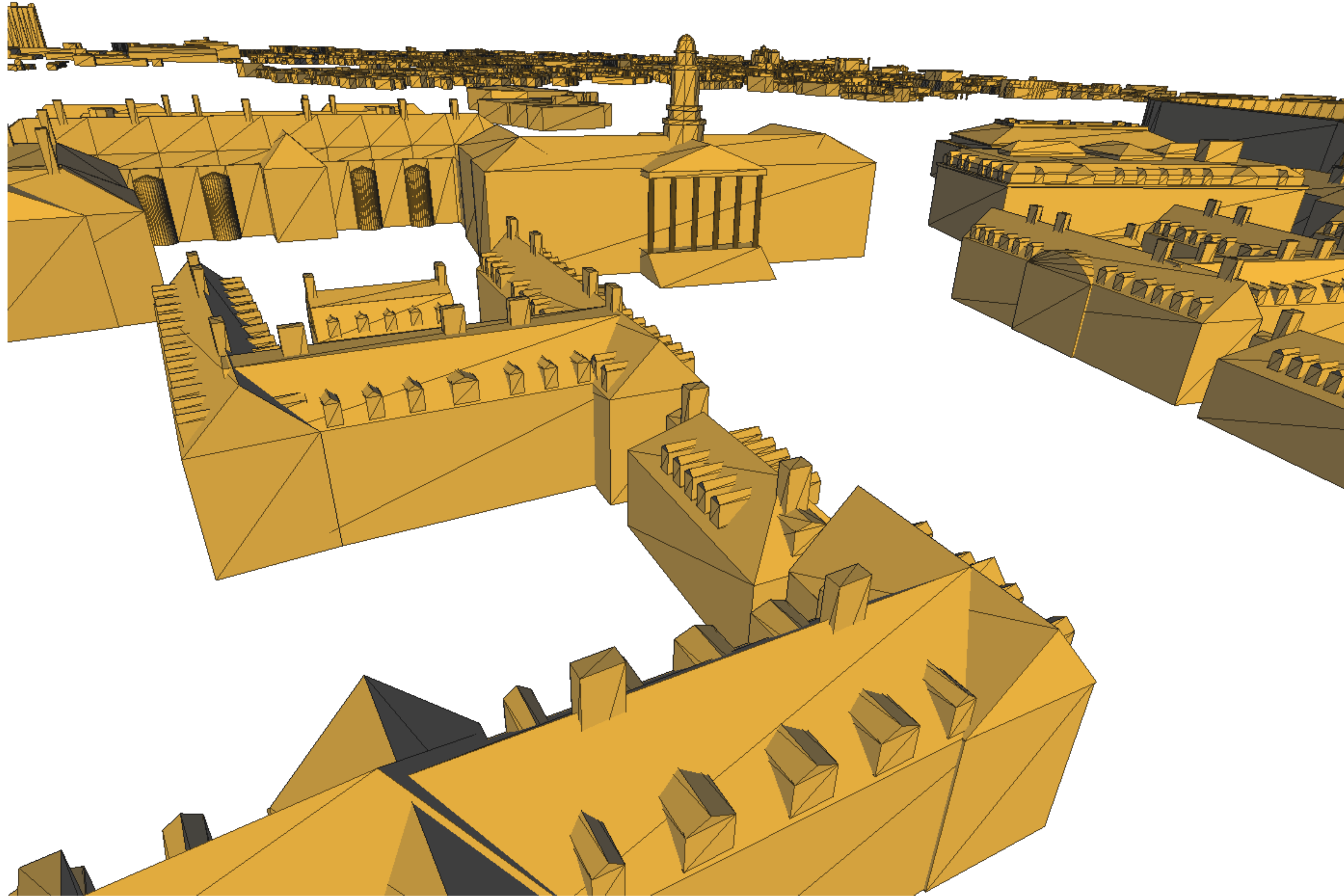
Volume calculation – big problems == also impossible to calculate...



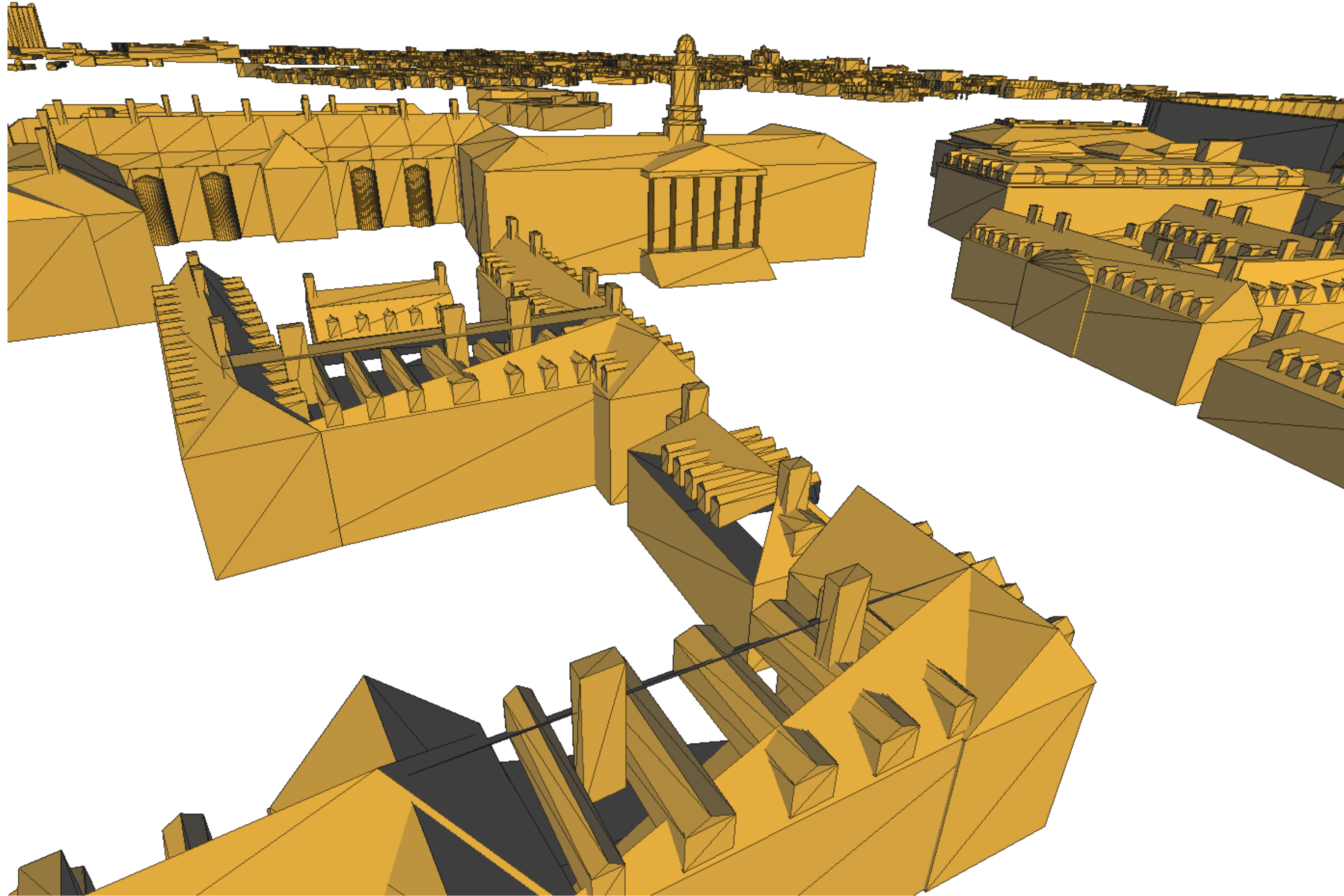
Volume calculation – superstructures not topologically connected



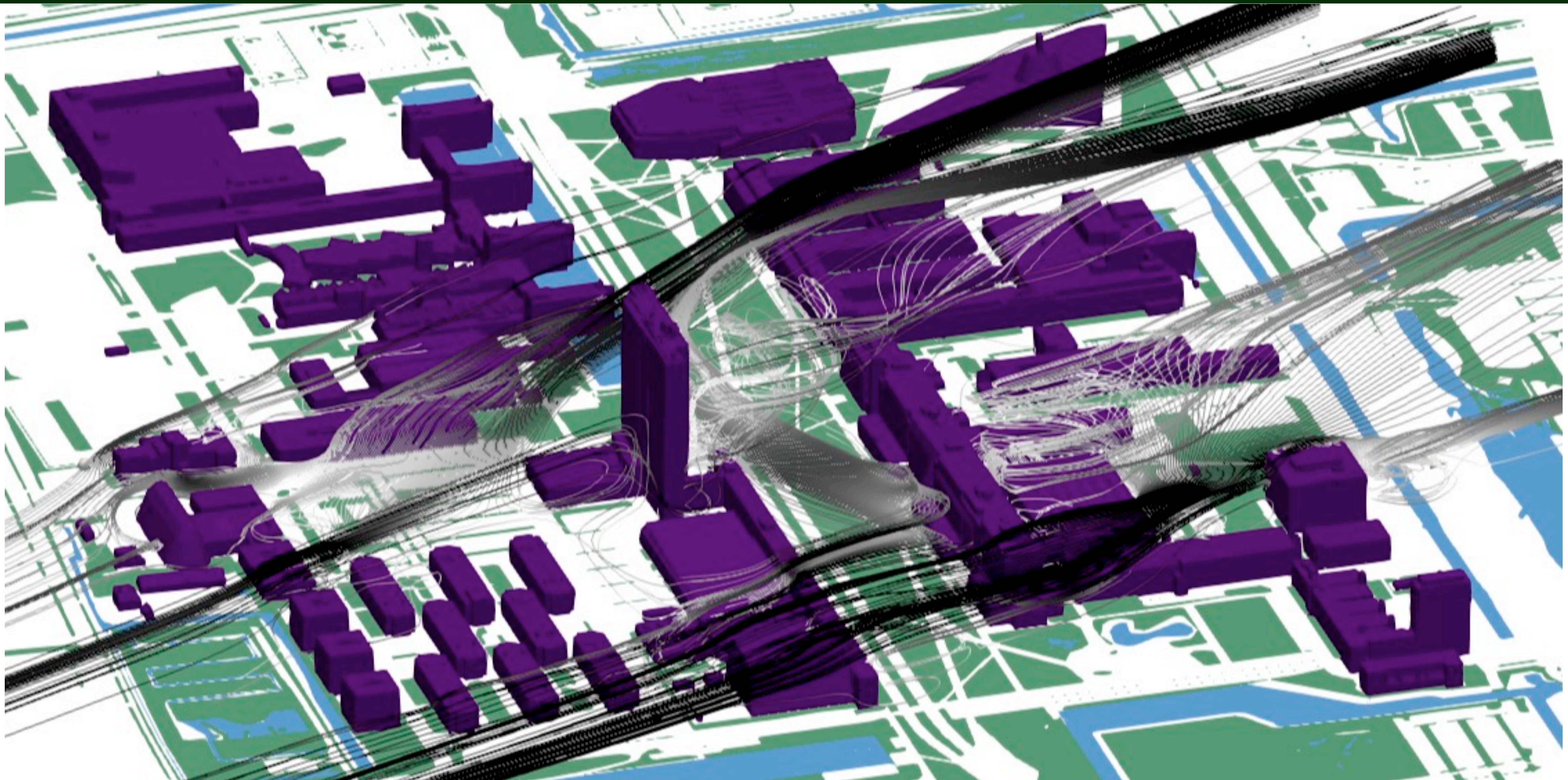
Volume calculation – superstructures not topologically connected



Volume calculation – superstructures not topologically connected



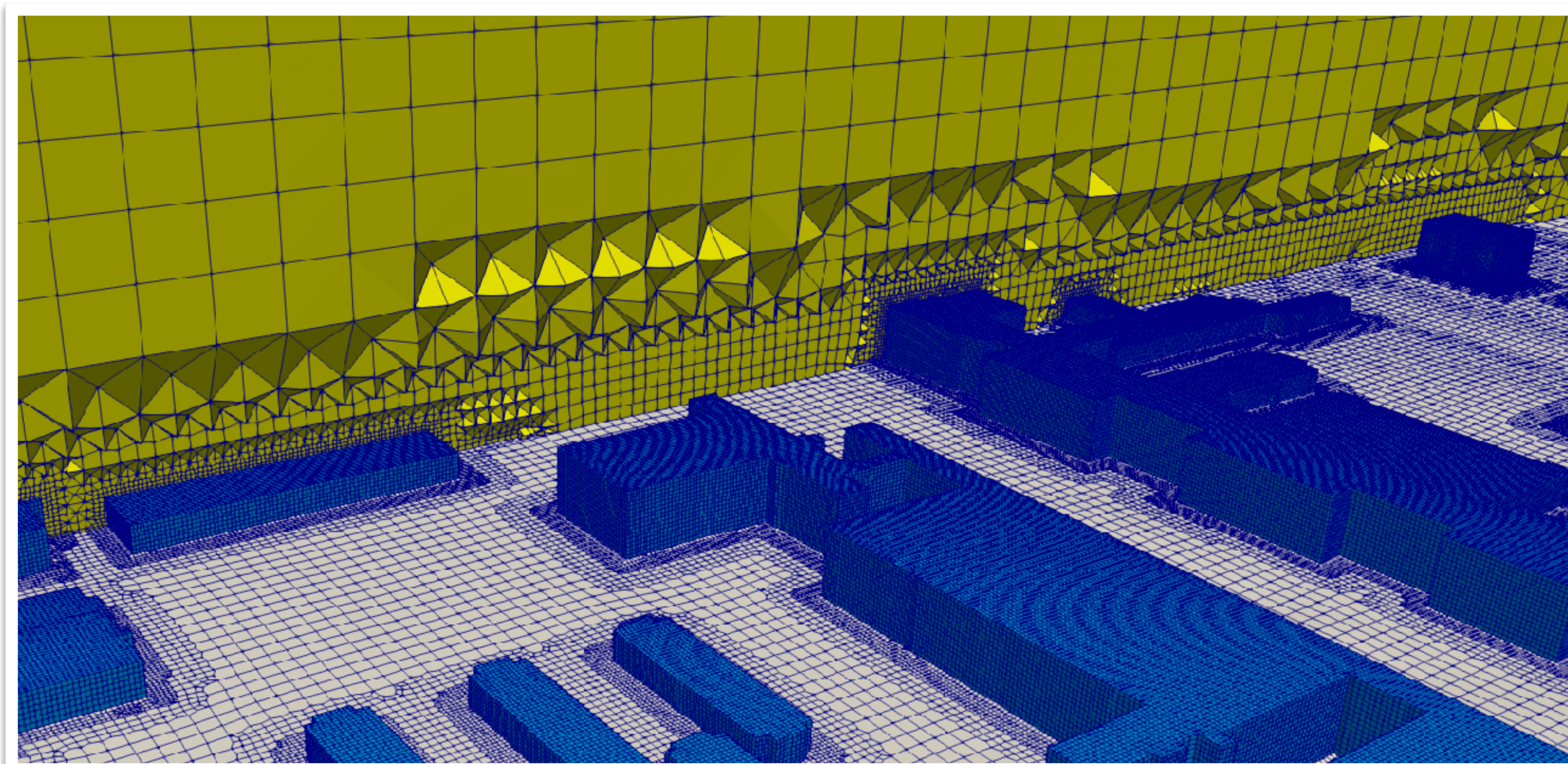
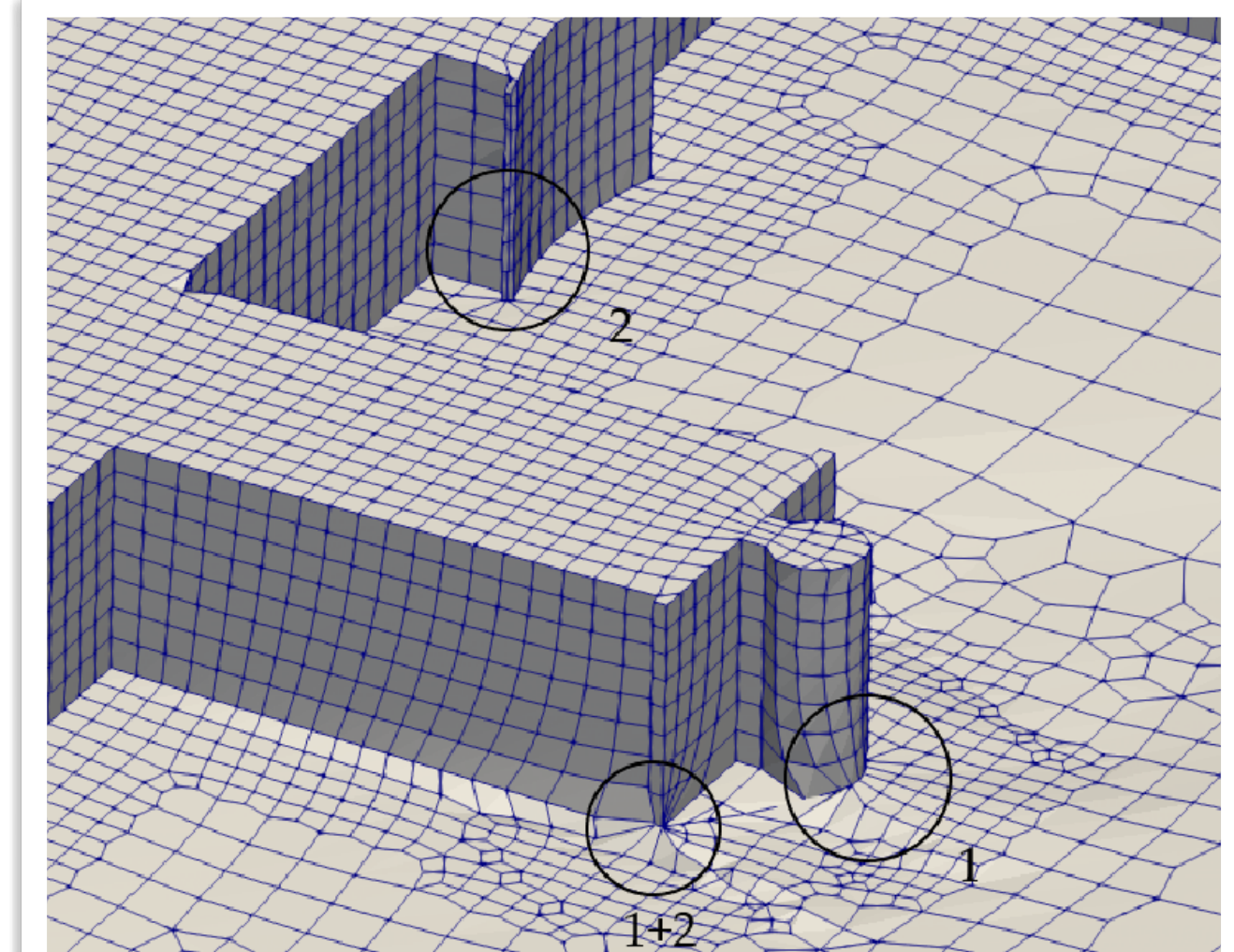
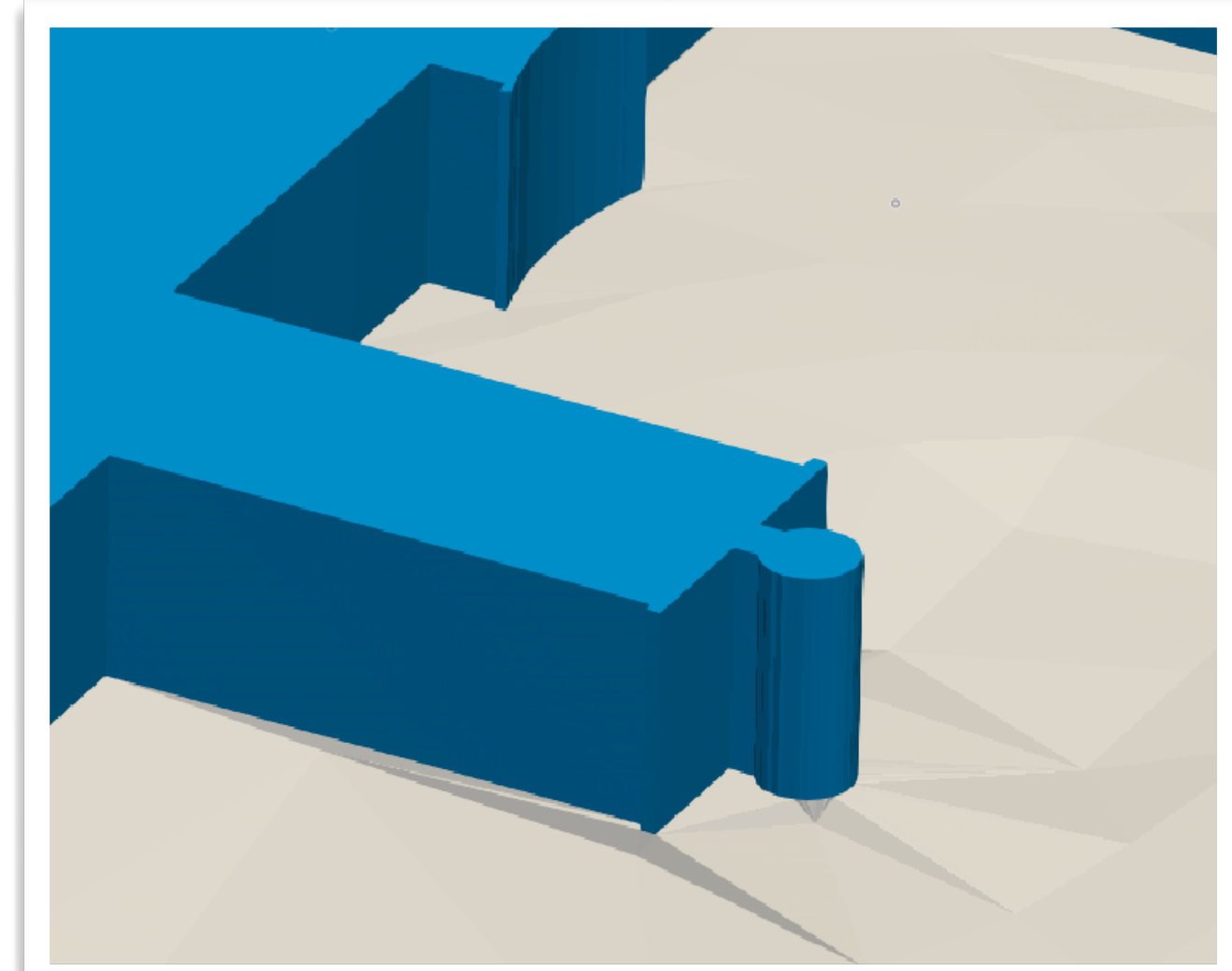
Advanced simulations – wind comfort for pedestrians



Advanced simulations – CFD methods: subdivision of volume (mesh)

computational fluid dynamics

GE05015: Modelling wind and dispersion in urban environments (Q4!)

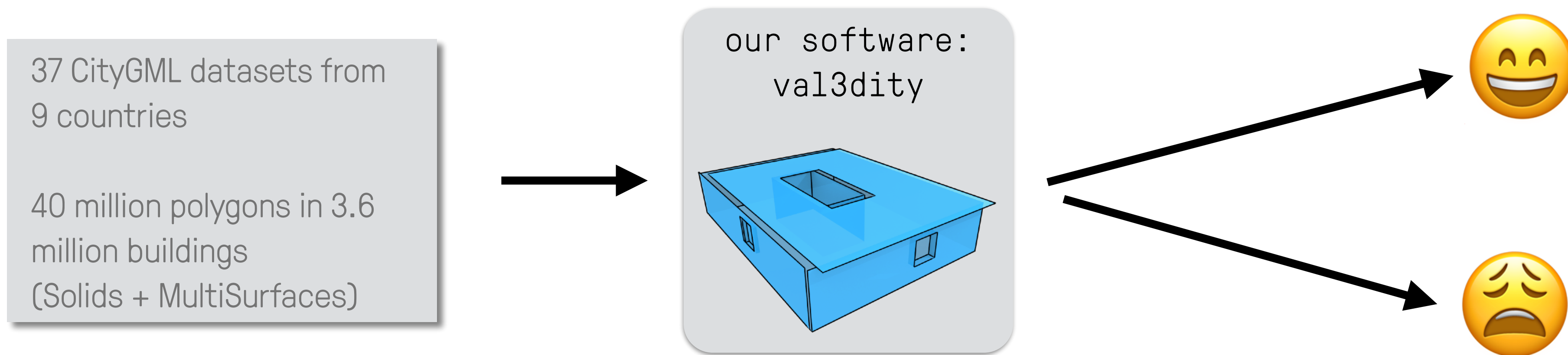


Advanced simulations – very strict input requirements

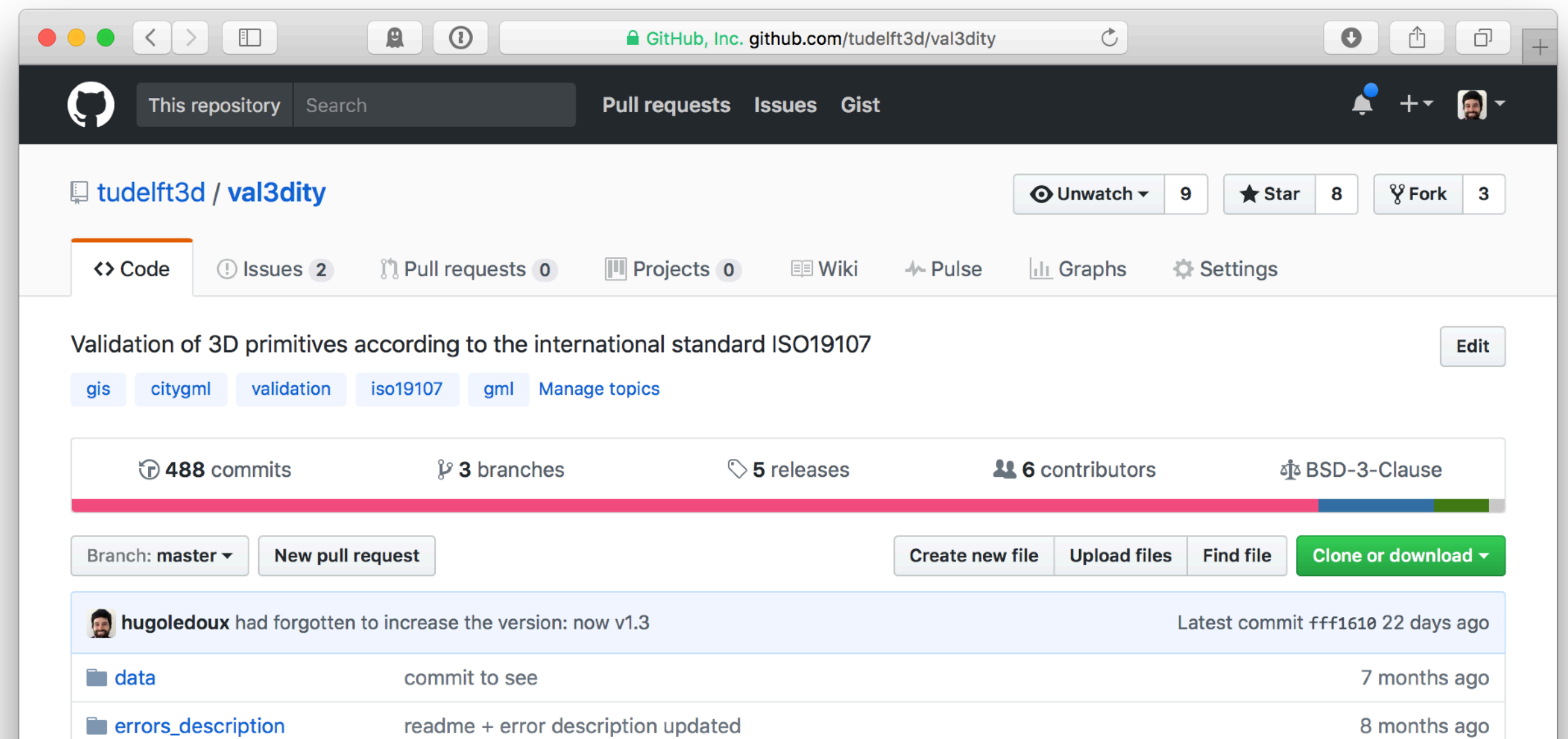
- no holes
- no intersections
- triangles must have certain shape (no *slivers*)
- a “perfect” model is thus required
- in practice, that still means several hours of (semi-)manual repair



Our methodology

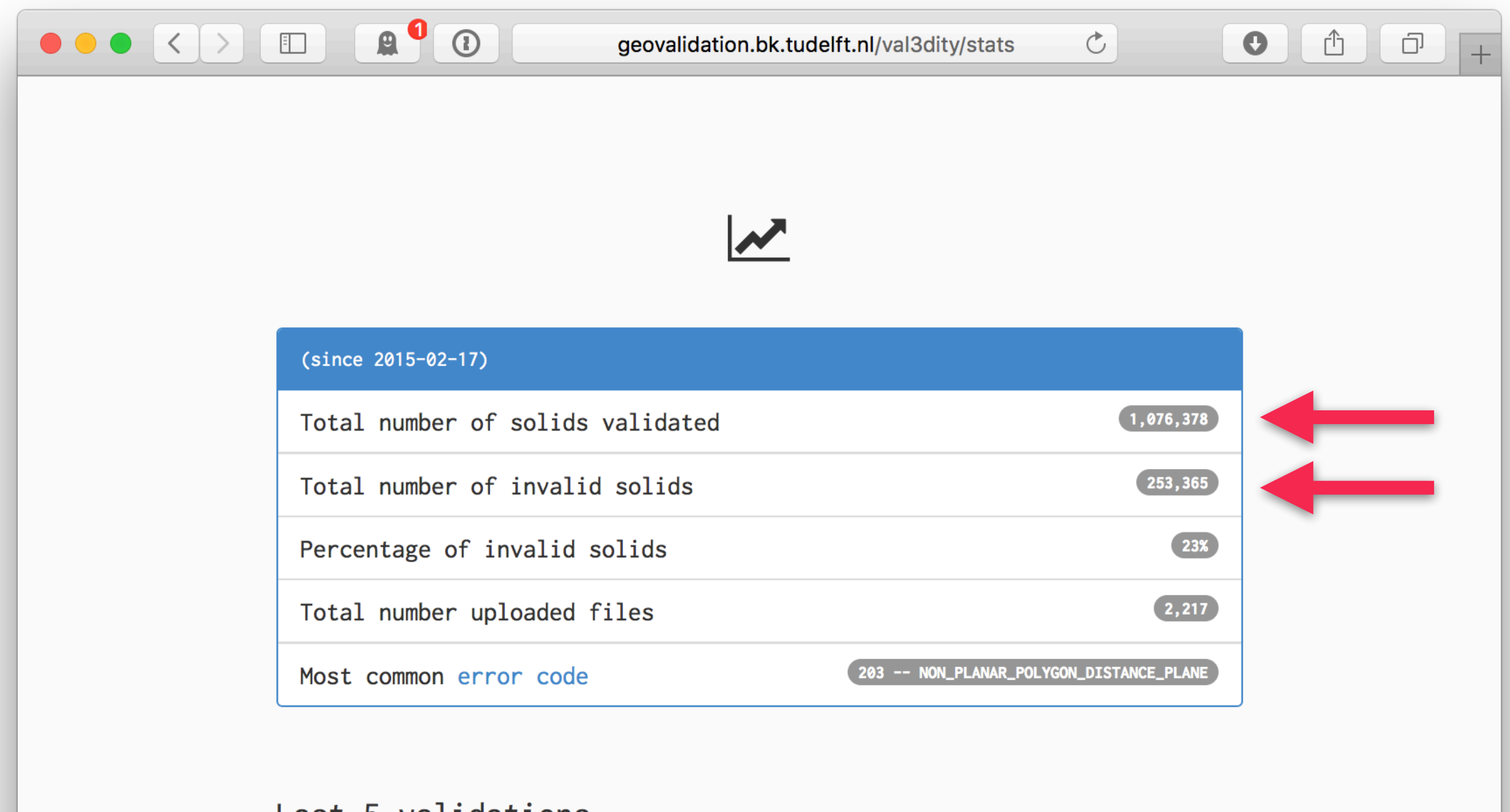


- 37 datasets (3D cities) from 9 countries
- 40 million polygons in 3.6 million buildings



Summary of results

- No 3D city dataset is 100% valid, not even LoD1 😞
- Many simple errors, eg:
 - repeated vertices
 - non-planar polygons (most common error!)
- Notice that these are often not visible



Summary of results

ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume IV-2/W1, 2016
11th 3D Geoinfo Conference, 20–21 October 2016, Athens, Greece

THE MOST COMMON GEOMETRIC AND SEMANTIC ERRORS IN CITYGML DATASETS

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^b Singapore Land Authority, Singapore — (soon_KEAN_huat, victor_khoo)@sla.gov.sg

KEY WORDS: CityGML, 3D city models, Quality control, Validation, Error

ABSTRACT:

To be used as input in most simulation and modelling software, 3D city models should be geometrically and topologically valid, and semantically rich. We investigate in this paper what is the quality of currently available CityGML datasets, i.e. we validate the geometry/topology of the 3D primitives (`Solid` and `MultiSurface`), and we validate whether the semantics of the boundary surfaces of buildings is correct or not. We have analysed all the CityGML datasets we could find, both from portals of cities and on different websites, plus a few that were made available to us. We have thus validated 40M surfaces in 16M 3D primitives and 3.6M buildings found in 37 CityGML datasets originating from 9 countries, and produced by several companies with diverse software and acquisition techniques. The results indicate that CityGML datasets without errors are rare, and those that are nearly valid are mostly simple LOD1 models. We report on the most common errors we have found, and analyse them. One main observation is that many of these errors could be automatically fixed or prevented with simple modifications to the modelling software. Our principal aim is to highlight the most common errors so that these are not repeated in the future. We hope that our paper and the open-source software we have developed will help raise awareness for data quality among data providers and 3D GIS software producers.

1. INTRODUCTION

In recent years, several cities around the world have released their 3D city models (3DGM).

Related work considers additional aspects, e.g. resolvability of `XLinks`; application-specific rules, such as that a building is required to have a ground floor to form a volume (which is, surprisingly, not mandatory in CityGML); and the redundancy of the

| Level of detail | Primitive | ID ^(a) | Geometric validation | | | | Semantics ^(f) | Schema | |
|-----------------|--|-------------------|----------------------|-----|-----|-----|--------------------------|--------|----------------------|
| | | | 1xx | 2xx | 3xx | 4xx | | | Total ^(b) |
| LOD1 | Solid | 1 | 0 | 0 | 0 | 0 | 0 | - | X |
| | | 2 | 0 | 0 | 0 | 0 | 0 | - | ✓ |
| | | 3 | 0 | 0 | 0 | 0 | 0 | - | ✓ |
| | | 4 | 0 | 0 | 0 | 0 | 0 | - | ✓ |
| | | 5 | 0 | 0 | 0 | 0 | 0 | - | X |
| | | 6 | 0 | 0 | 0 | 0 | 0 | - | X |
| | | 7 | 0 | 0 | 0 | 0 | 0 | - | ✓ |
| | | 8 | 0 | 0 | 0 | 0 | 0 | - | ✓ |
| | | 9 | 0 | 0 | 0 | 0 | 0 | - | X |
| LOD2 | MultiSurface | 10 | 1 | 4 | - | - | 5 | (e) | ✓ |
| | | 11 | 0 | 0 | - | - | 0 | 0 | ✓ |
| | | 12 | 2 | 21 | - | - | 23 | 45 | ✓ |
| | | 13 | 10 | 2 | - | - | 12 | 4 | X |
| | | 14 | 0 | 1 | - | - | 1 | 12 | ✓ |
| | | 15 | 0 | 9 | - | - | 9 | 2 | ✓ |
| | | 16 | 4 | 8 | - | - | 12 | 1 | X |
| | | 17 | 5 | 0 | - | - | 5 | 5 | X |
| | | 18 | 0 | 0 | - | - | 0 | 4 | X |
| | | 19 | 0 | 0 | - | - | 0 | 1 | X |
| | | 20 | 0 | 4 | - | - | 4 | 6 | X |
| 21 | 0 | 1 | - | - | 1 | 3 | X | | |
| LOD2 | Solid | 22 | 0 | 42 | 58 | 0 | 100 | - | ✓ |
| | | 23 ^(c) | - | - | - | - | - | - | X |
| | | 24 | 0 | 31 | 1 | 3 | 35 | - | X |
| | | 25 | 4 | 0 | 16 | 2 | 22 | - | ✓ |
| | | 26 ^(c) | - | - | - | - | - | - | X |
| | | 27 | 22 | 17 | 50 | 0 | 89 | - | ✓ |
| LOD2 | MultiSurface and Solid ^(d) | 28 | 0 | 42 | 1 | 1 | 44 | 0 | ✓ |
| | | 29 | 2 | 35 | 54 | 0 | 92 | 4 | ✓ |
| | | 30 | 0 | 10 | 0 | 1 | 11 | 2 | ✓ |
| | | 31 | 0 | 0 | 0 | 0 | 0 | 0 | ✓ |
| LOD3 | MultiSurface | 32 | 2 | 13 | - | - | 15 | 54 | ✓ |
| | | 33 | 6 | 5 | - | - | 11 | 23 | ✓ |
| | | 34 | 8 | 10 | - | - | 19 | 45 | ✓ |
| | | 35 | 5 | 0 | - | - | 5 | 34 | ✓ |
| | | 36 | 0 | 0 | - | - | 0 | 1 | X |
| LOD4 | Solid | 37 | 0 | 0 | 3 | 0 | 3 | 68 | ✓ |

% of invalid

**actually all between
99.5% and 99.9%**

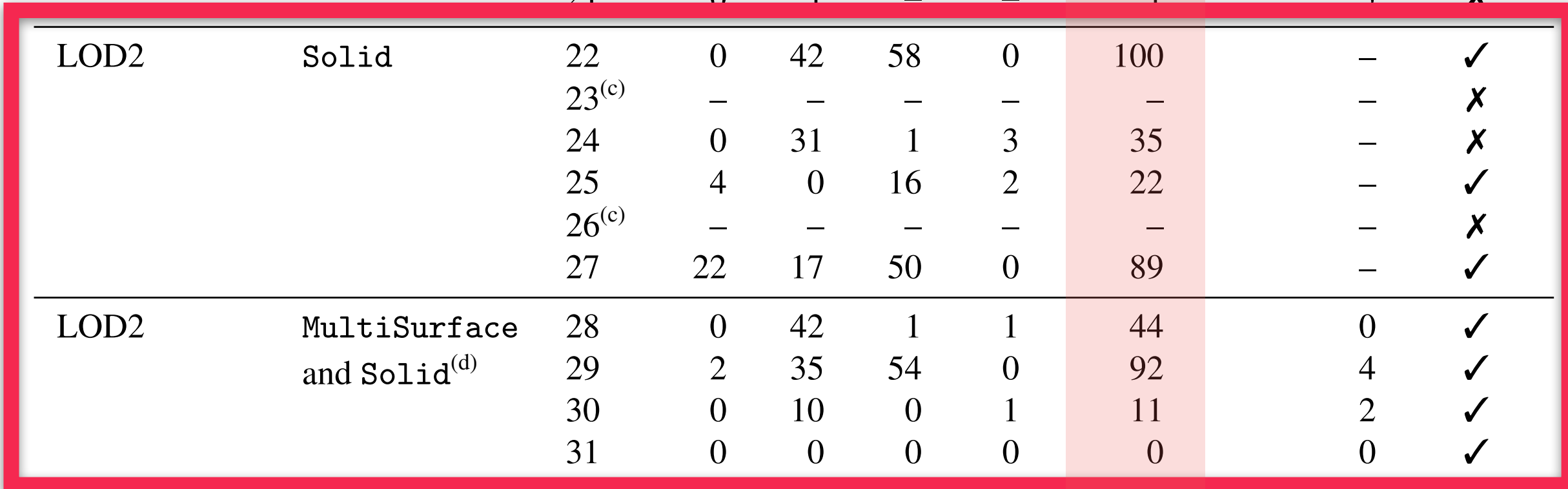
| Level of detail | Primitive | ID ^(a) | Geometric validation | | | | Semantics ^(f) | Schema | |
|-----------------|--|-------------------|----------------------|-----|-----|-----|--------------------------|--------|----------------------|
| | | | 1xx | 2xx | 3xx | 4xx | | | Total ^(b) |
| LOD1 | Solid | 1 | 0 | 0 | 0 | 0 | 0 | - | X |
| | | 2 | 0 | 0 | 0 | 0 | 0 | - | ✓ |
| | | 3 | 0 | 0 | 0 | 0 | 0 | - | ✓ |
| | | 4 | 0 | 0 | 0 | 0 | 0 | - | ✓ |
| | | 5 | 0 | 0 | 0 | 0 | 0 | - | X |
| | | 6 | 0 | 0 | 0 | 0 | 0 | - | X |
| | | 7 | 0 | 0 | 0 | 0 | 0 | - | ✓ |
| | | 8 | 0 | 0 | 0 | 0 | 0 | - | ✓ |
| | | 9 | 0 | 0 | 0 | 0 | 0 | - | X |
| LOD2 | MultiSurface | 10 | 1 | 4 | - | - | 5 | (e) | ✓ |
| | | 11 | 0 | 0 | - | - | 0 | 0 | ✓ |
| | | 12 | 2 | 21 | - | - | 23 | 45 | ✓ |
| | | 13 | 10 | 2 | - | - | 12 | 4 | X |
| | | 14 | 0 | 1 | - | - | 1 | 12 | ✓ |
| | | 15 | 0 | 9 | - | - | 9 | 2 | ✓ |
| | | 16 | 4 | 8 | - | - | 12 | 1 | X |
| | | 17 | 5 | 0 | - | - | 5 | 5 | X |
| | | 18 | 0 | 0 | - | - | 0 | 4 | X |
| | | 19 | 0 | 0 | - | - | 0 | 1 | X |
| | | 20 | 0 | 4 | - | - | 4 | 6 | X |
| 21 | 0 | 1 | - | - | 1 | 3 | X | | |
| LOD2 | Solid | 22 | 0 | 42 | 58 | 0 | 100 | - | ✓ |
| | | 23 ^(c) | - | - | - | - | - | - | X |
| | | 24 | 0 | 31 | 1 | 3 | 35 | - | X |
| | | 25 | 4 | 0 | 16 | 2 | 22 | - | ✓ |
| | | 26 ^(c) | - | - | - | - | - | - | X |
| | | 27 | 22 | 17 | 50 | 0 | 89 | - | ✓ |
| LOD2 | MultiSurface and Solid ^(d) | 28 | 0 | 42 | 1 | 1 | 44 | 0 | ✓ |
| | | 29 | 2 | 35 | 54 | 0 | 92 | 4 | ✓ |
| | | 30 | 0 | 10 | 0 | 1 | 11 | 2 | ✓ |
| | | 31 | 0 | 0 | 0 | 0 | 0 | 0 | ✓ |
| LOD3 | MultiSurface | 32 | 2 | 13 | - | - | 15 | 54 | ✓ |
| | | 33 | 6 | 5 | - | - | 11 | 23 | ✓ |
| | | 34 | 8 | 10 | - | - | 19 | 45 | ✓ |
| | | 35 | 5 | 0 | - | - | 5 | 34 | ✓ |
| | | 36 | 0 | 0 | - | - | 0 | 1 | X |
| LOD4 | Solid | 37 | 0 | 0 | 3 | 0 | 3 | 68 | ✓ |

% of invalid

rather good, but it's
"easy"

| Level of detail | Primitive | ID ^(a) | Geometric validation | | | | Semantics ^(f) | Schema | |
|-----------------|--|-------------------|----------------------|-----|-----|-----|--------------------------|--------|----------------------|
| | | | 1xx | 2xx | 3xx | 4xx | | | Total ^(b) |
| LOD1 | Solid | 1 | 0 | 0 | 0 | 0 | 0 | - | X |
| | | 2 | 0 | 0 | 0 | 0 | 0 | - | ✓ |
| | | 3 | 0 | 0 | 0 | 0 | 0 | - | ✓ |
| | | 4 | 0 | 0 | 0 | 0 | 0 | - | ✓ |
| | | 5 | 0 | 0 | 0 | 0 | 0 | - | X |
| | | 6 | 0 | 0 | 0 | 0 | 0 | - | X |
| | | 7 | 0 | 0 | 0 | 0 | 0 | - | ✓ |
| | | 8 | 0 | 0 | 0 | 0 | 0 | - | ✓ |
| | | 9 | 0 | 0 | 0 | 0 | 0 | - | X |
| LOD2 | MultiSurface | 10 | 1 | 4 | - | - | 5 | (e) | ✓ |
| | | 11 | 0 | 0 | - | - | 0 | 0 | ✓ |
| | | 12 | 2 | 21 | - | - | 23 | 45 | ✓ |
| | | 13 | 10 | 2 | - | - | 12 | 4 | X |
| | | 14 | 0 | 1 | - | - | 1 | 12 | ✓ |
| | | 15 | 0 | 9 | - | - | 9 | 2 | ✓ |
| | | 16 | 4 | 8 | - | - | 12 | 1 | X |
| | | 17 | 5 | 0 | - | - | 5 | 5 | X |
| | | 18 | 0 | 0 | - | - | 0 | 4 | X |
| | | 19 | 0 | 0 | - | - | 0 | 1 | X |
| | | 20 | 0 | 4 | - | - | 4 | 6 | X |
| 21 | 0 | 1 | - | - | 1 | 3 | X | | |
| LOD2 | Solid | 22 | 0 | 42 | 58 | 0 | 100 | - | ✓ |
| | | 23 ^(c) | - | - | - | - | - | - | X |
| | | 24 | 0 | 31 | 1 | 3 | 35 | - | X |
| | | 25 | 4 | 0 | 16 | 2 | 22 | - | ✓ |
| | | 26 ^(c) | - | - | - | - | - | - | X |
| | | 27 | 22 | 17 | 50 | 0 | 89 | - | ✓ |
| LOD2 | MultiSurface and Solid ^(d) | 28 | 0 | 42 | 1 | 1 | 44 | 0 | ✓ |
| | | 29 | 2 | 35 | 54 | 0 | 92 | 4 | ✓ |
| | | 30 | 0 | 10 | 0 | 1 | 11 | 2 | ✓ |
| | | 31 | 0 | 0 | 0 | 0 | 0 | 0 | ✓ |
| LOD3 | MultiSurface | 32 | 2 | 13 | - | - | 15 | 54 | ✓ |
| | | 33 | 6 | 5 | - | - | 11 | 23 | ✓ |
| | | 34 | 8 | 10 | - | - | 19 | 45 | ✓ |
| | | 35 | 5 | 0 | - | - | 5 | 34 | ✓ |
| | | 36 | 0 | 0 | - | - | 0 | 1 | X |
| LOD4 | Solid | 37 | 0 | 0 | 3 | 0 | 3 | 68 | ✓ |

% of invalid



some datasets couldn't be read

high % of invalid

Using val3dity as a library in C++

tudelft3d/val3dity at develop

https://github.com/tudelft3d/val3dity/tree/develop

Search or jump to... Pull requests Issues Marketplace Explore

tudelft3d / val3dity Public

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Code Issues 9 Pull requests 1 Discussions Actions Projects Wiki Security

develop 3 branches 18 tags Go to file Add file Code

This branch is 80 commits ahead of master. #161

hugoledoux Improve readme.md of the API 844380e on 21 Oct 2021 1,492 commits

| | | |
|----------|---|---------------|
| cmake | Update the cmake for using Eigen (new way i... | 7 months ago |
| data | Update demo_lib to show how to validate indo... | 4 months ago |
| demo_lib | Improve readme.md of the API | 4 months ago |
| docs | Fix (yeah again) typo in the table of errors | 17 months ago |
| misc | Add termcap in env, look poster, init? | 8 years ago |

About

Validation of 3D primitives according to the international standard ISO19107

validation gis cgal gml iso19107 3d-gis indoorgml cityjson

Readme GPL-3.0 License 49 stars 12 watching 15 forks

Potential exam question

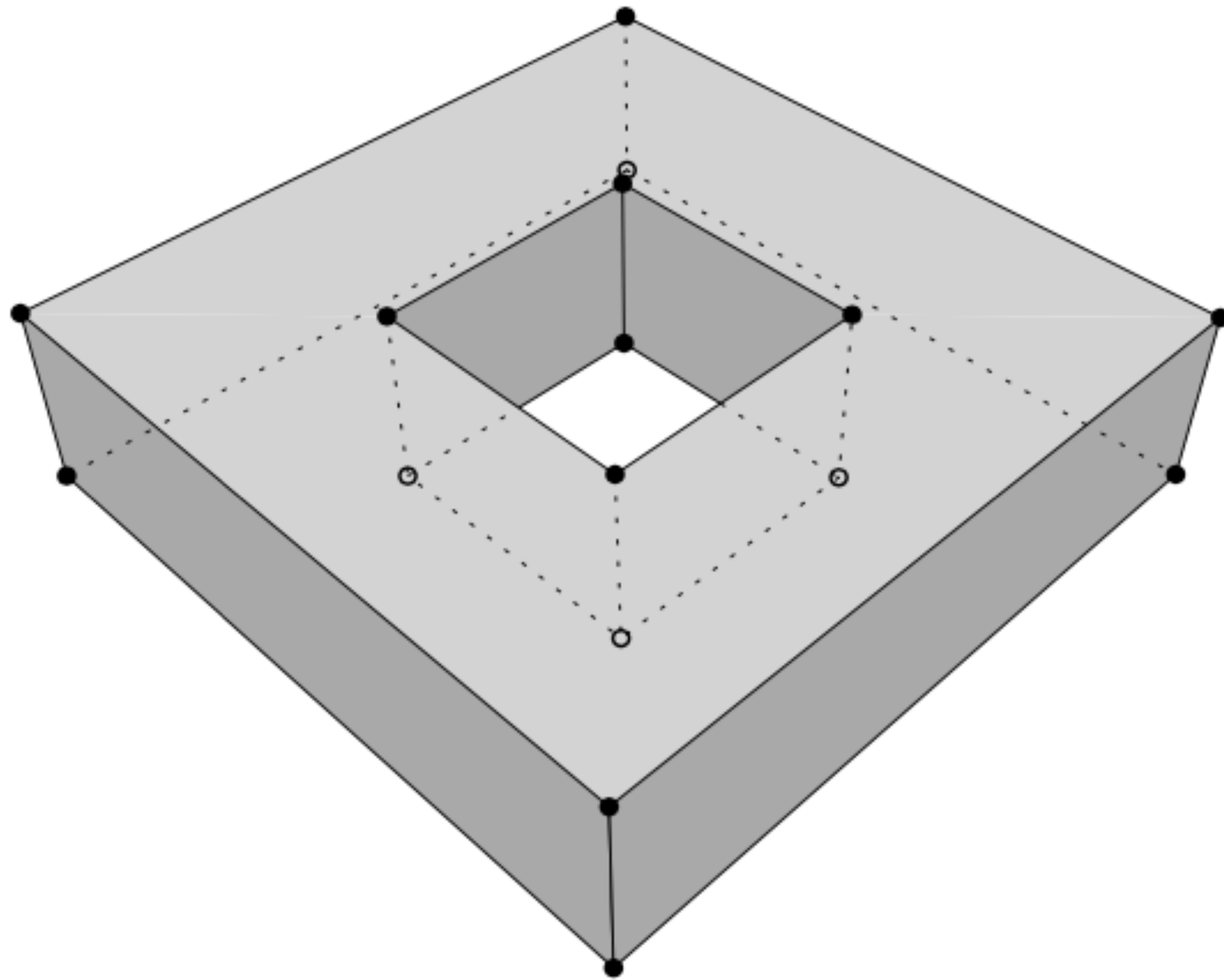


Figure 9.4: A 'squared torus' is modelled with one exterior boundary formed of ten surfaces.

1. How many interior boundaries (shells) does this torus have?
2. List all surfaces for it: how many are there?
3. If I triangulate its surfaces, how many surfaces?