

# Applications of 3D modelling of the built environment

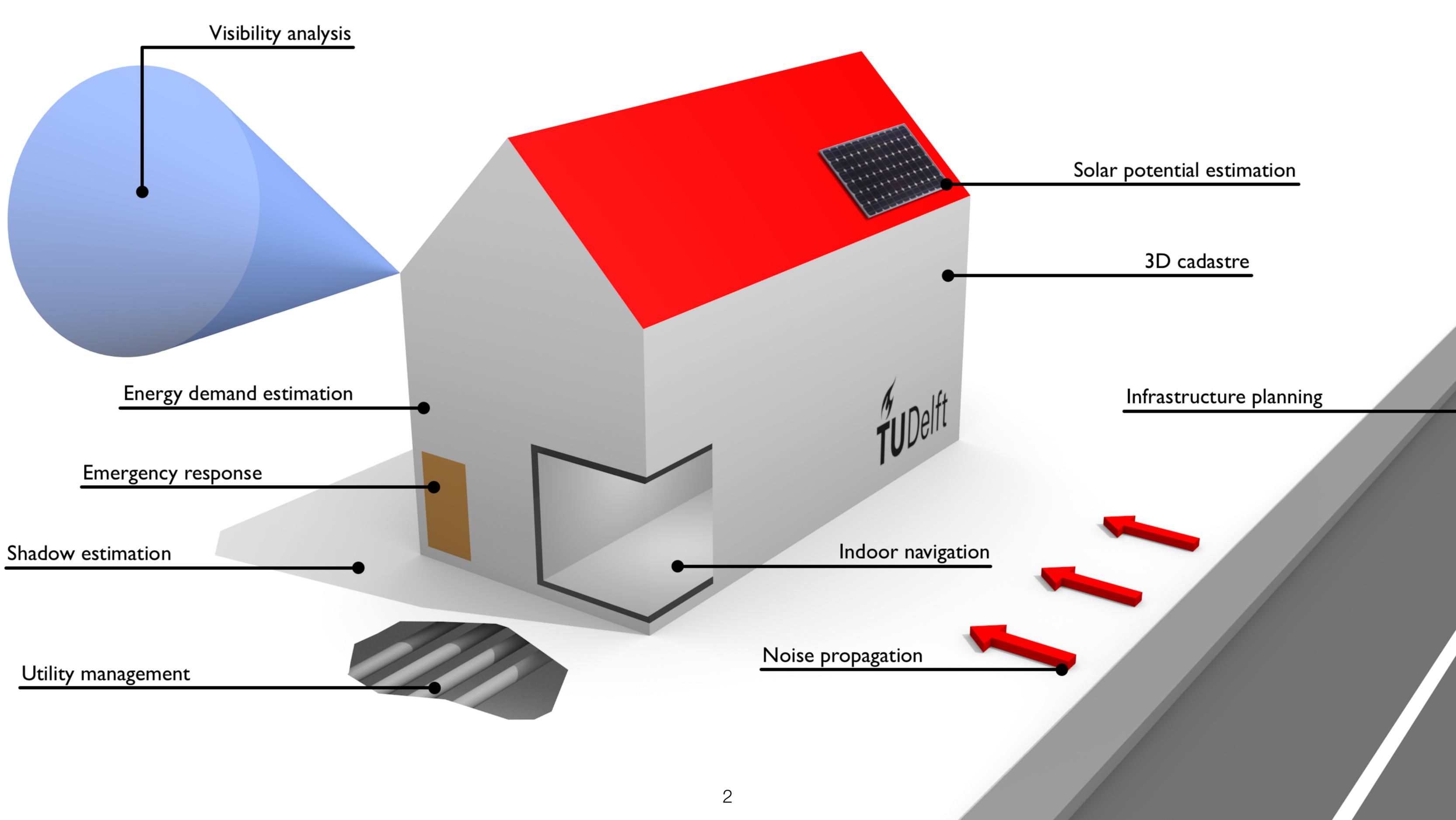
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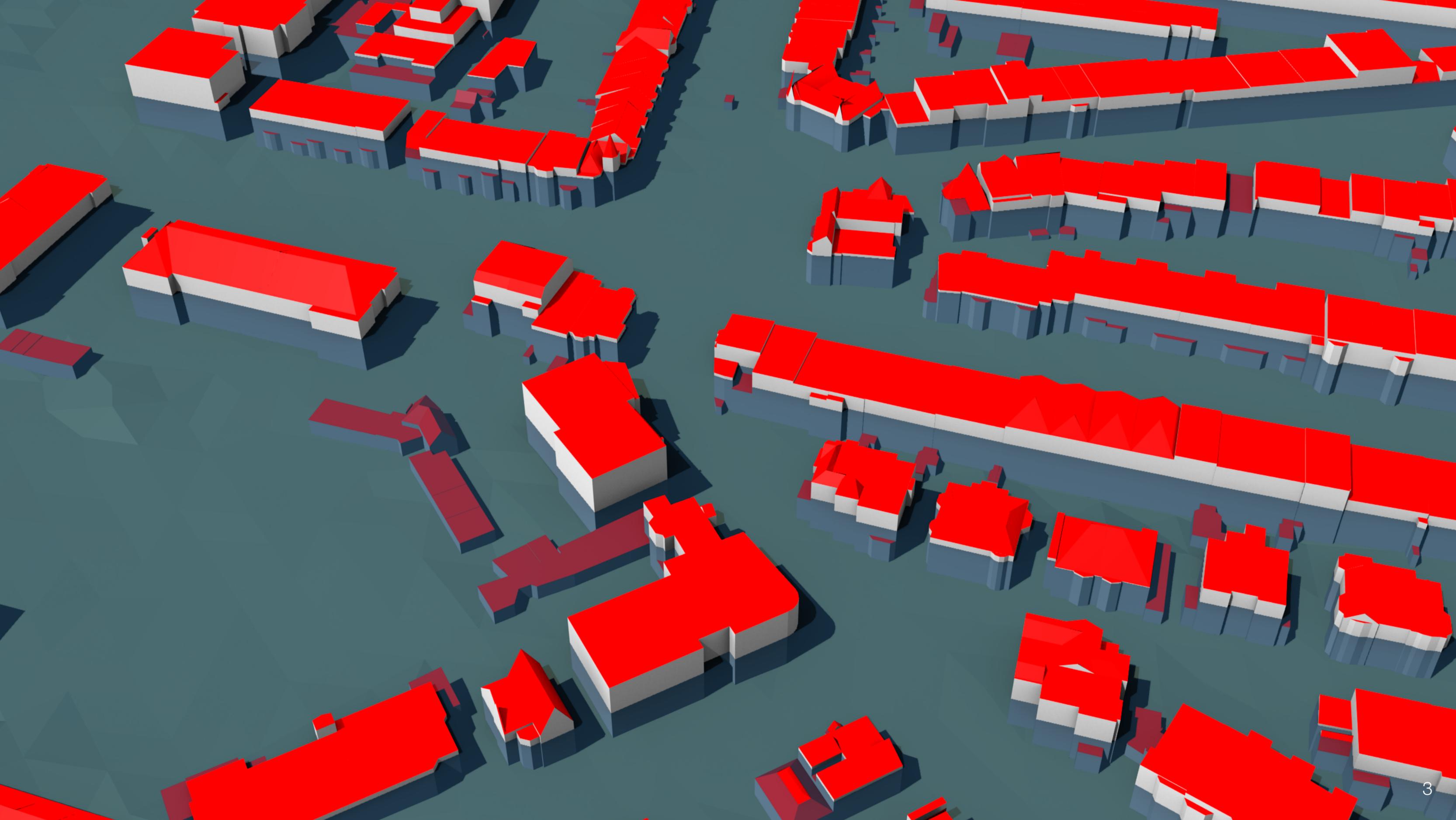
GEO1004:  
3D modelling of the built environment



3D geoinformation

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







dB

60

45

30



$W/m^2$

600

500

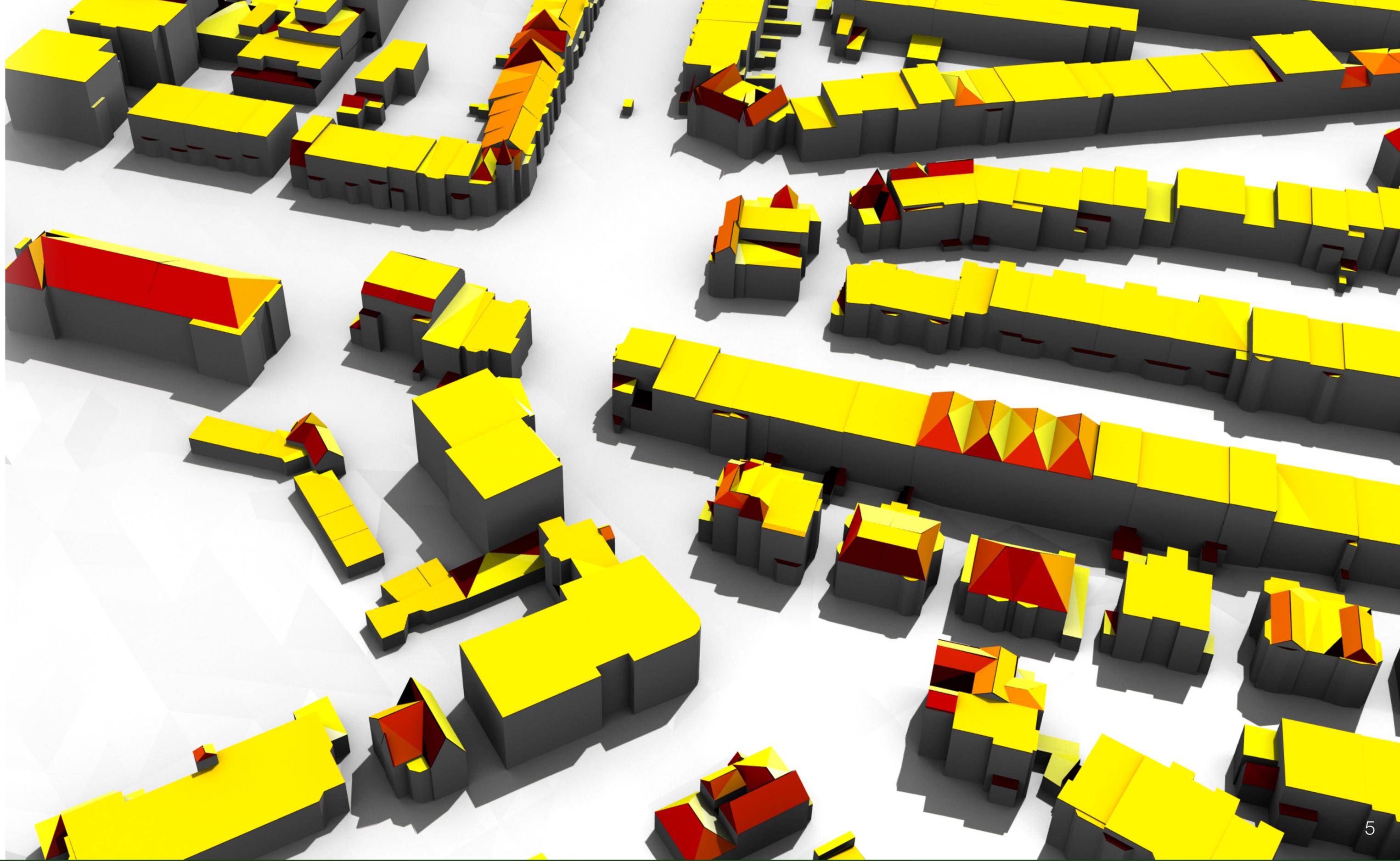
400

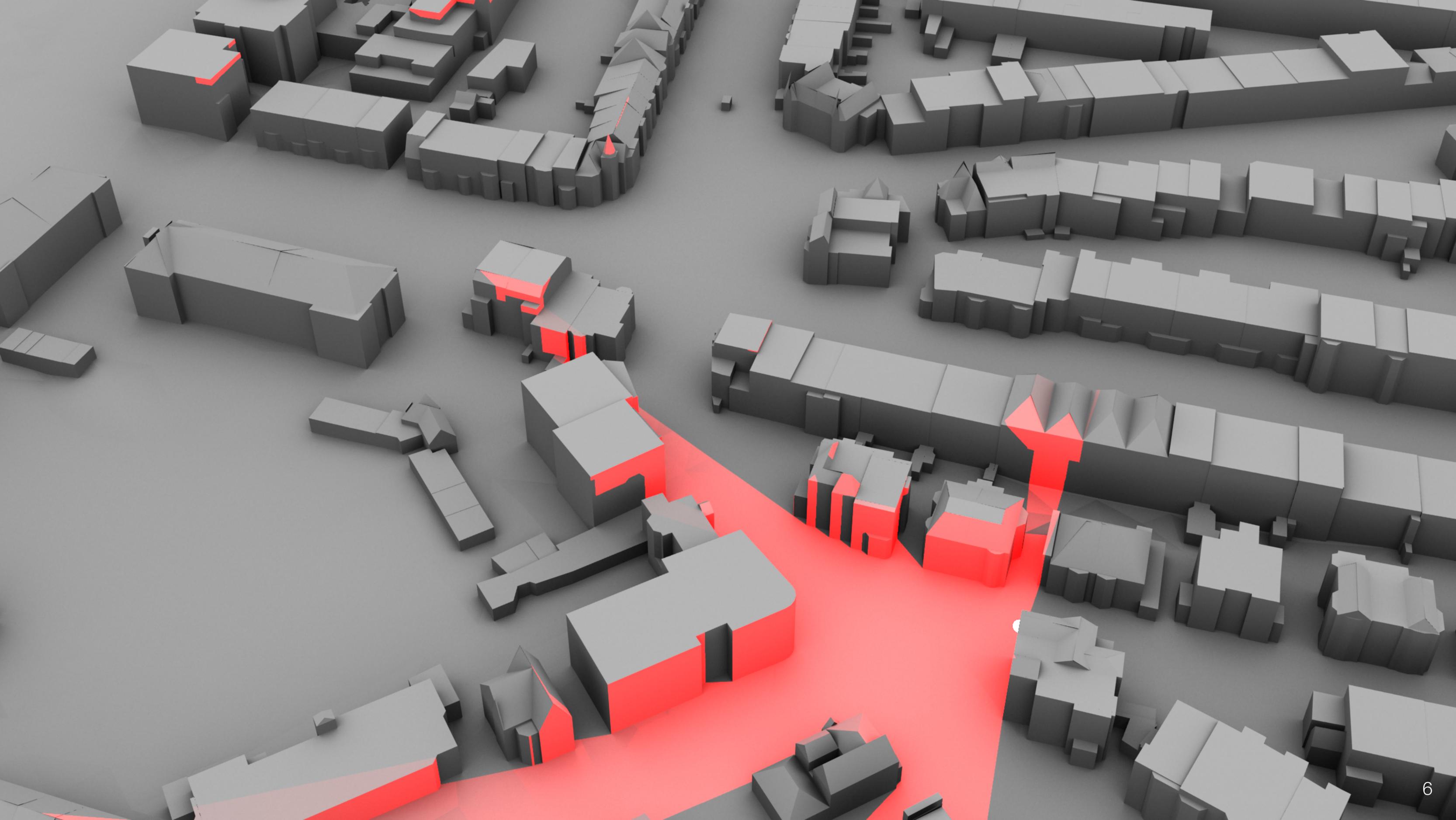
300

200

100

0



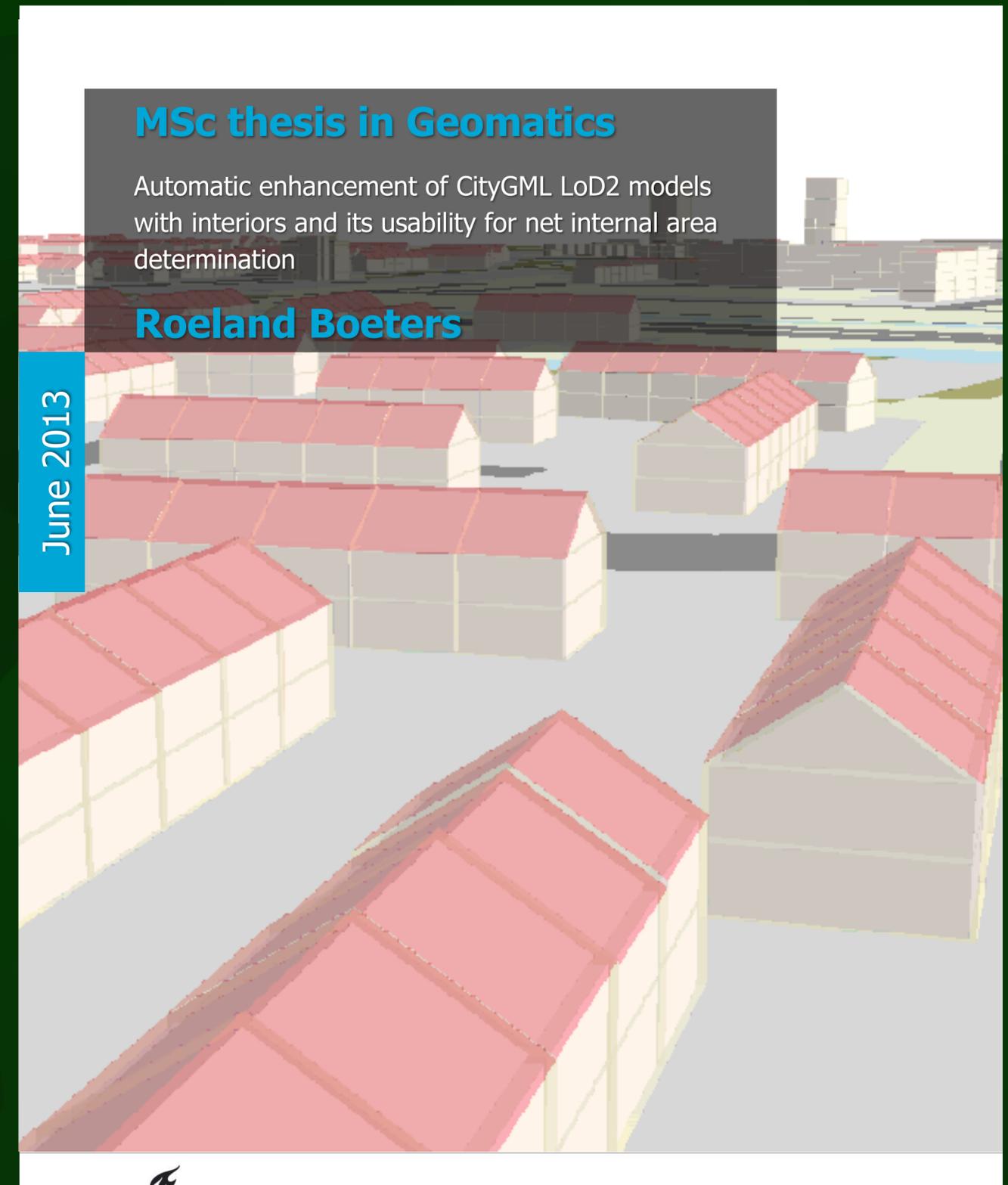


# Other applications

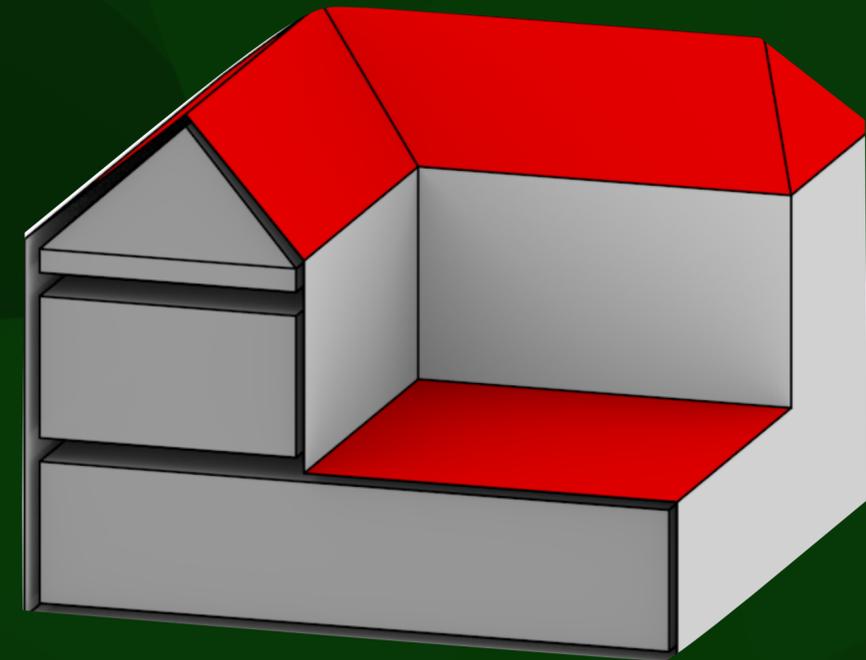
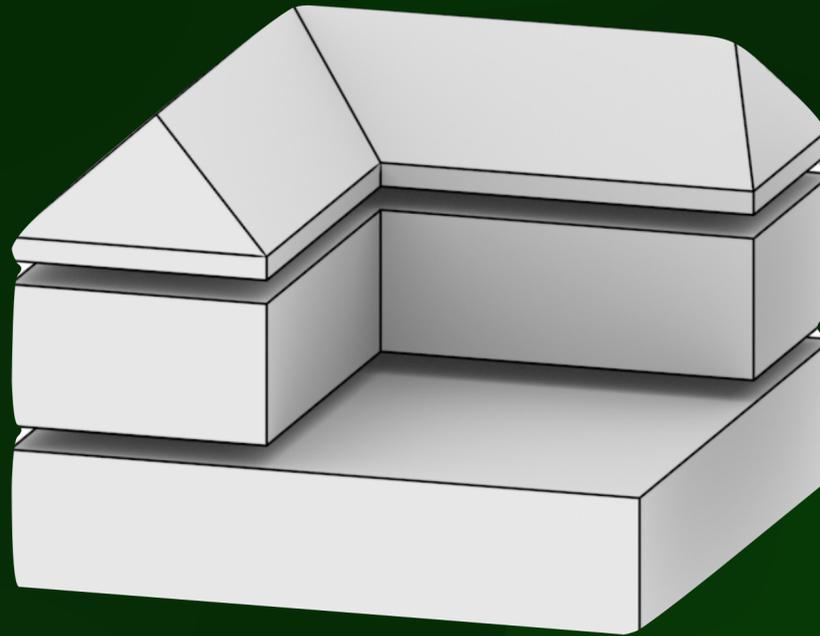
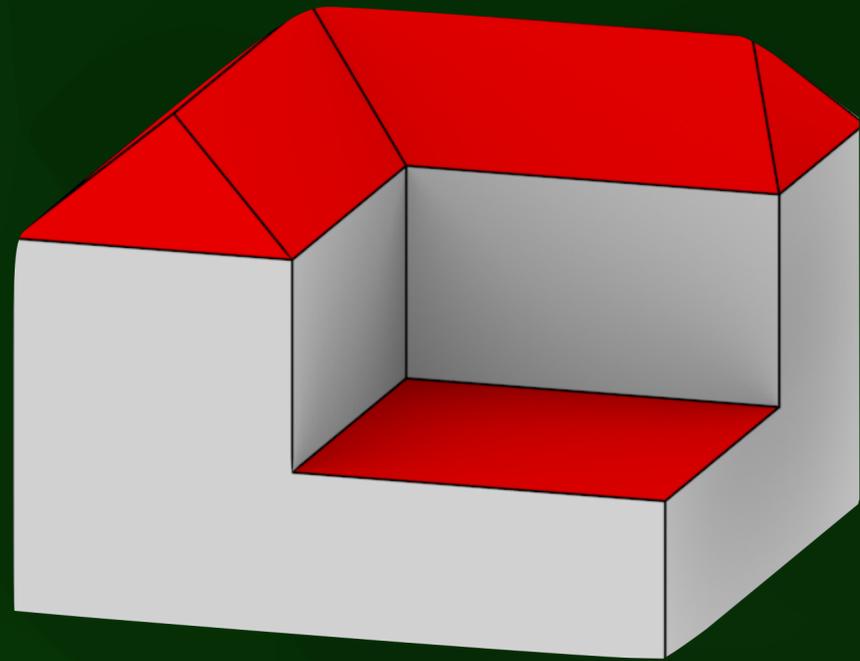
- Visualisation (eg for gaming, tourism, navigation, etc)
- Energy demand estimation (and potential for retrofiting)
- Computational fluid dynamics (eg for wind speeds, air quality, effects on buildings, etc)
- Shadow casting (eg for building permits, visibility analysis, improving energy demand/solar potential calculations, etc)

# Some MSc Geomatics theses

- Motivation: create (rough) indoor geometry from widely available outdoor geometry
- Definition of a CityGML LOD2 with interiors (LOD2+)
- Compute interior geometry from exterior geometry + number of storeys
- Compute net internal area



# LOD2+



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## Exterior in LOD2

Buildings bodies are prisms  
Simple roof shapes  
Thematically classified boundary surfaces  
No openings in the exterior geometry

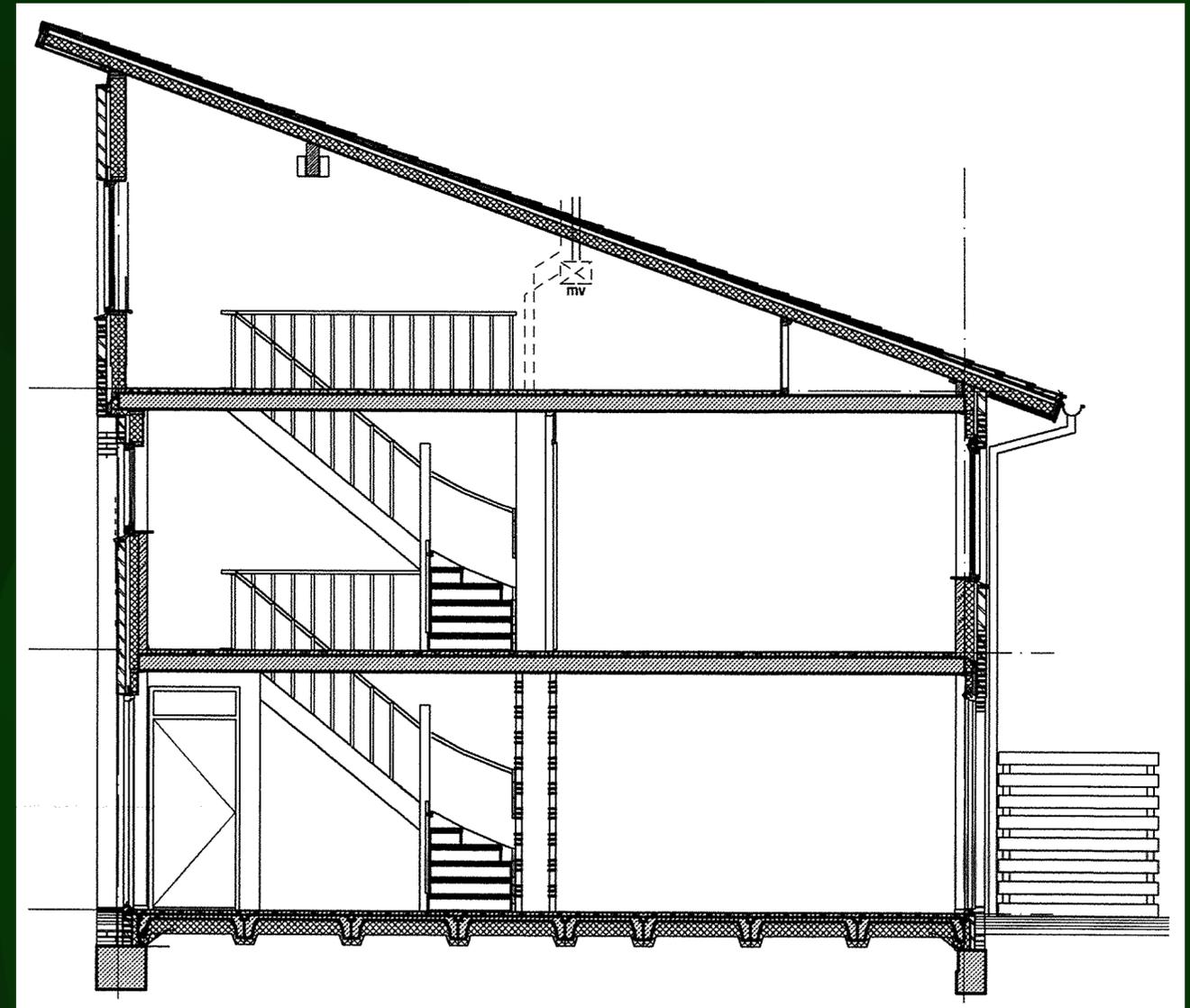
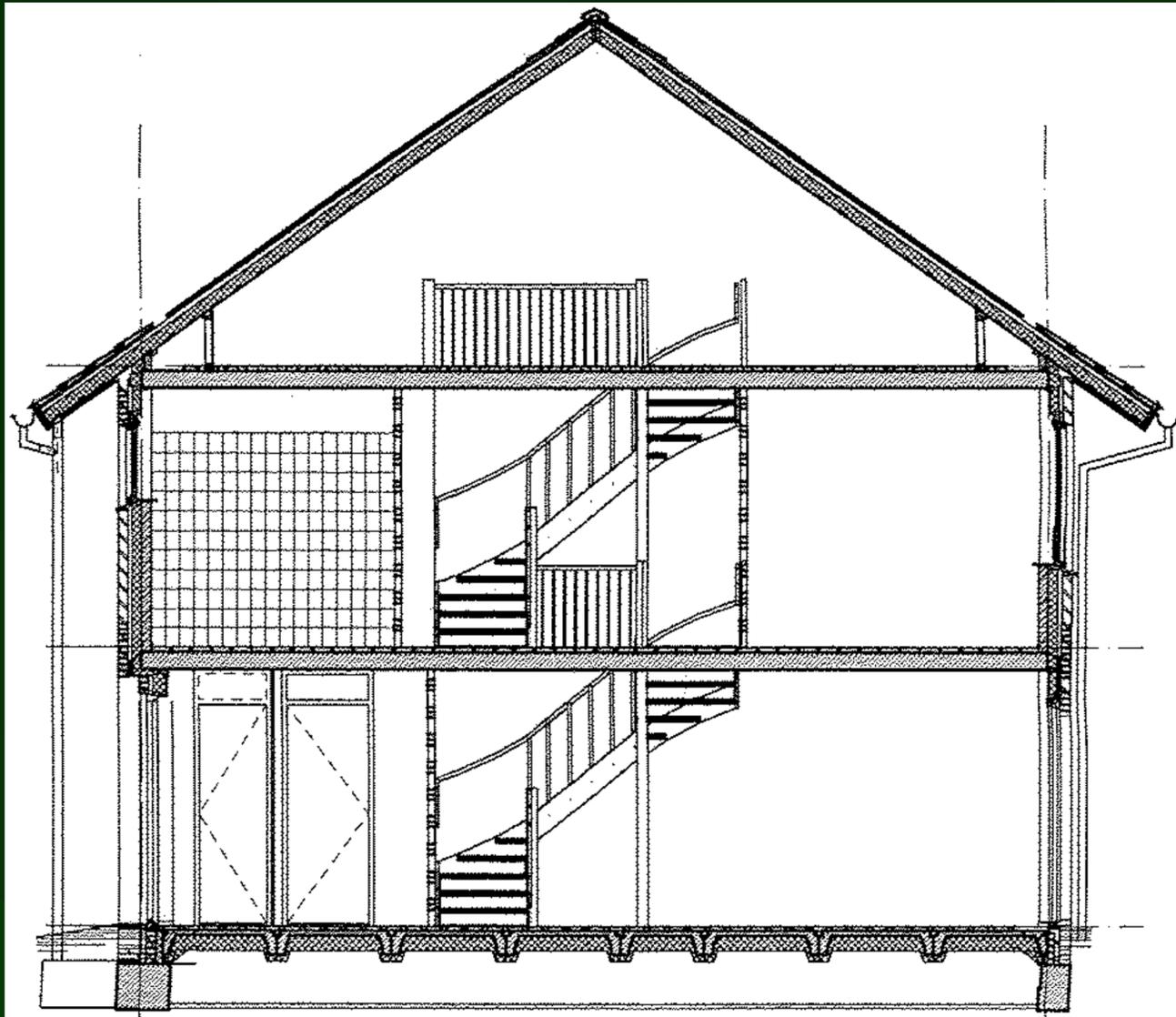
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## Interior in LOD2+

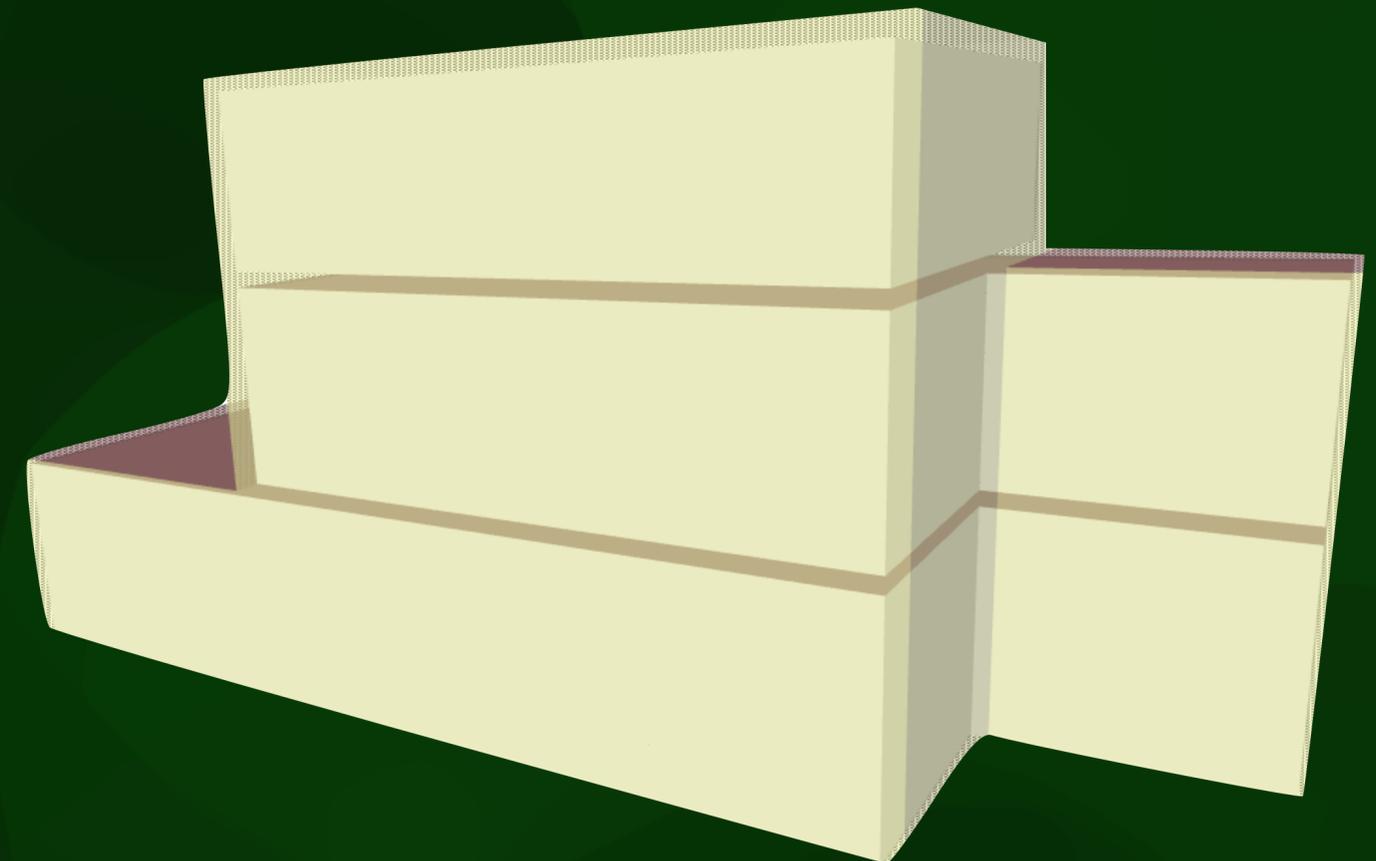
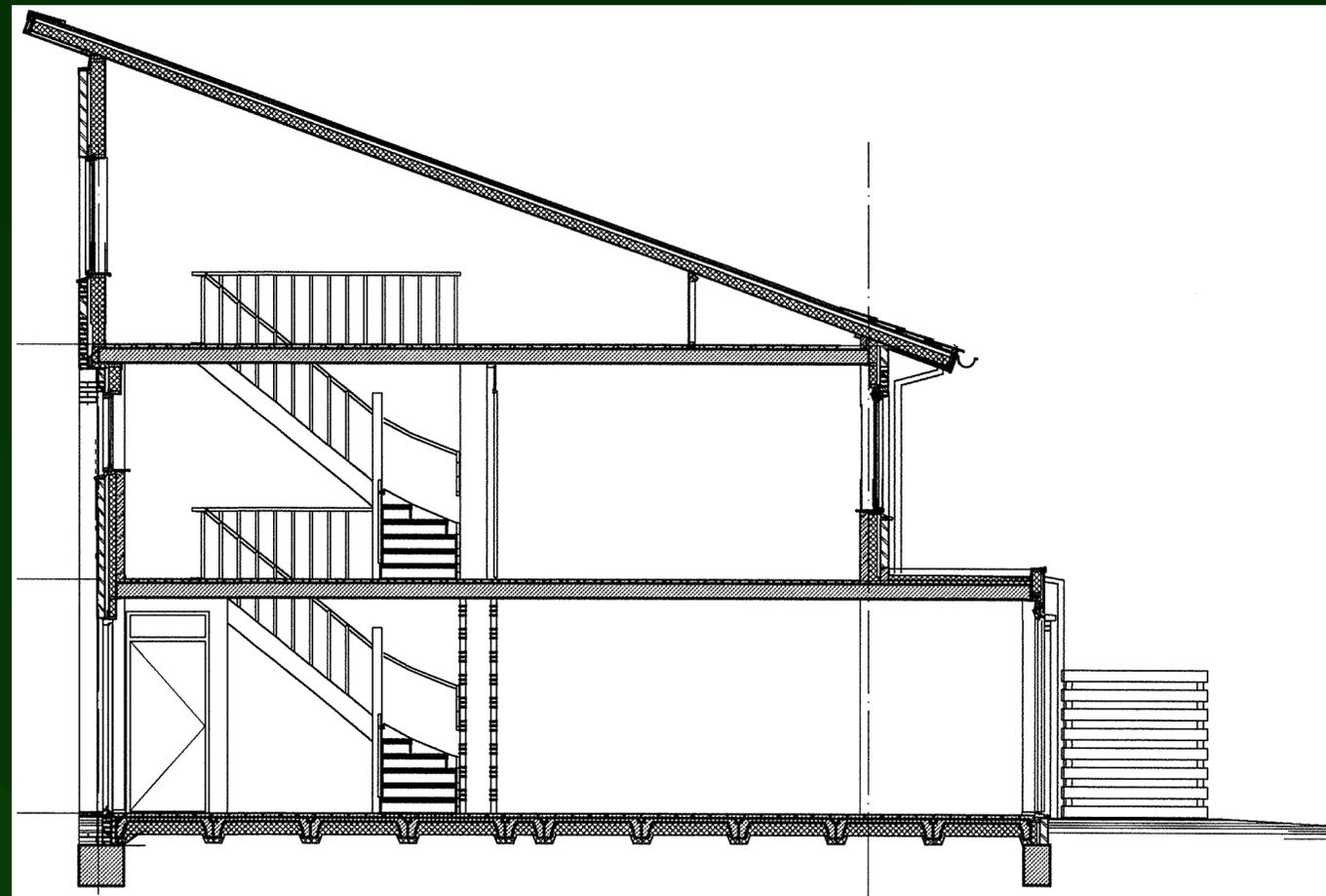
Storeys within building bodies are prisms  
Attic storey shapes corresponding to roof shapes  
Thematically classified boundary surfaces  
No openings in the indoor geometry

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# Indication of storeys



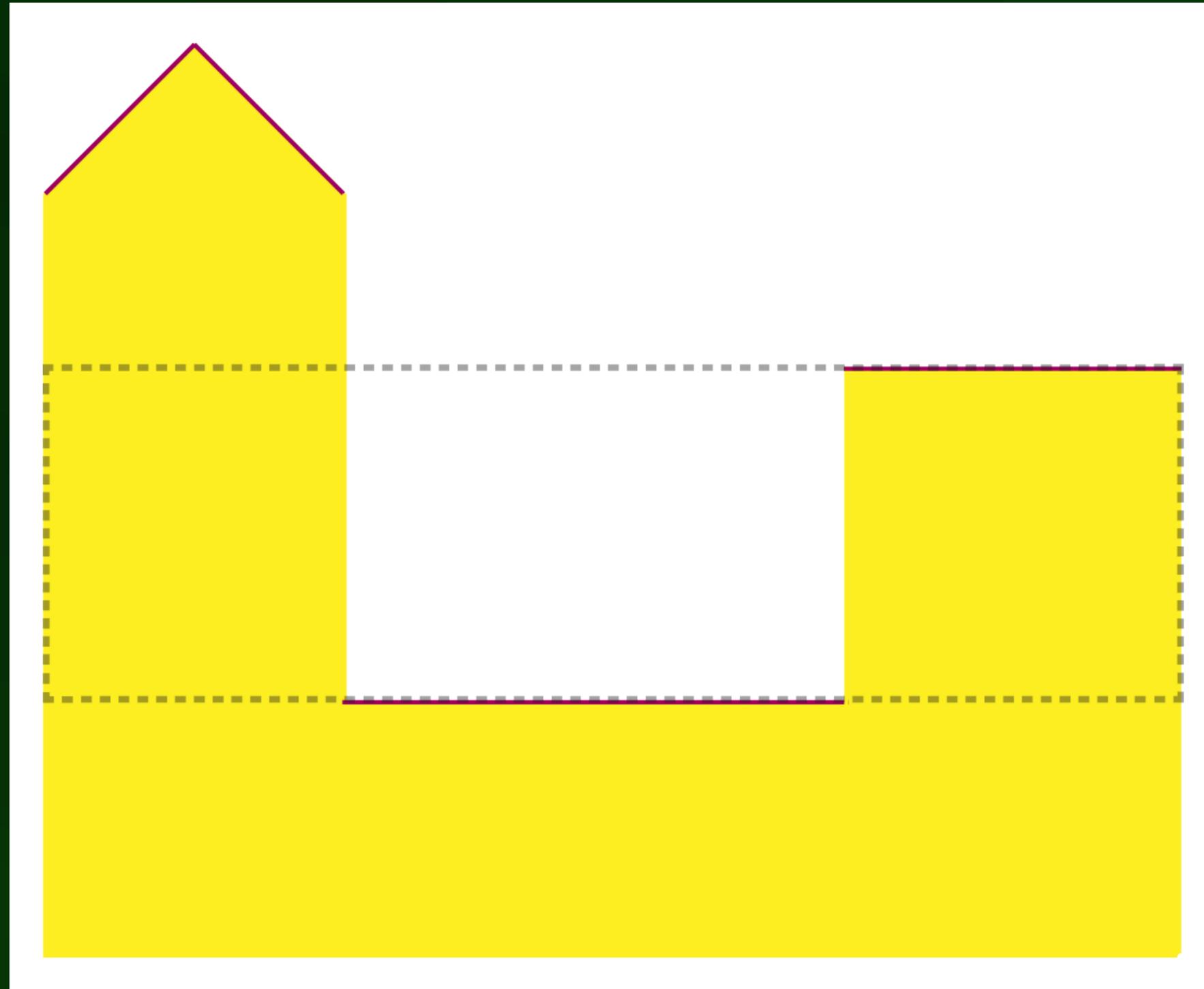
# Indication of storeys



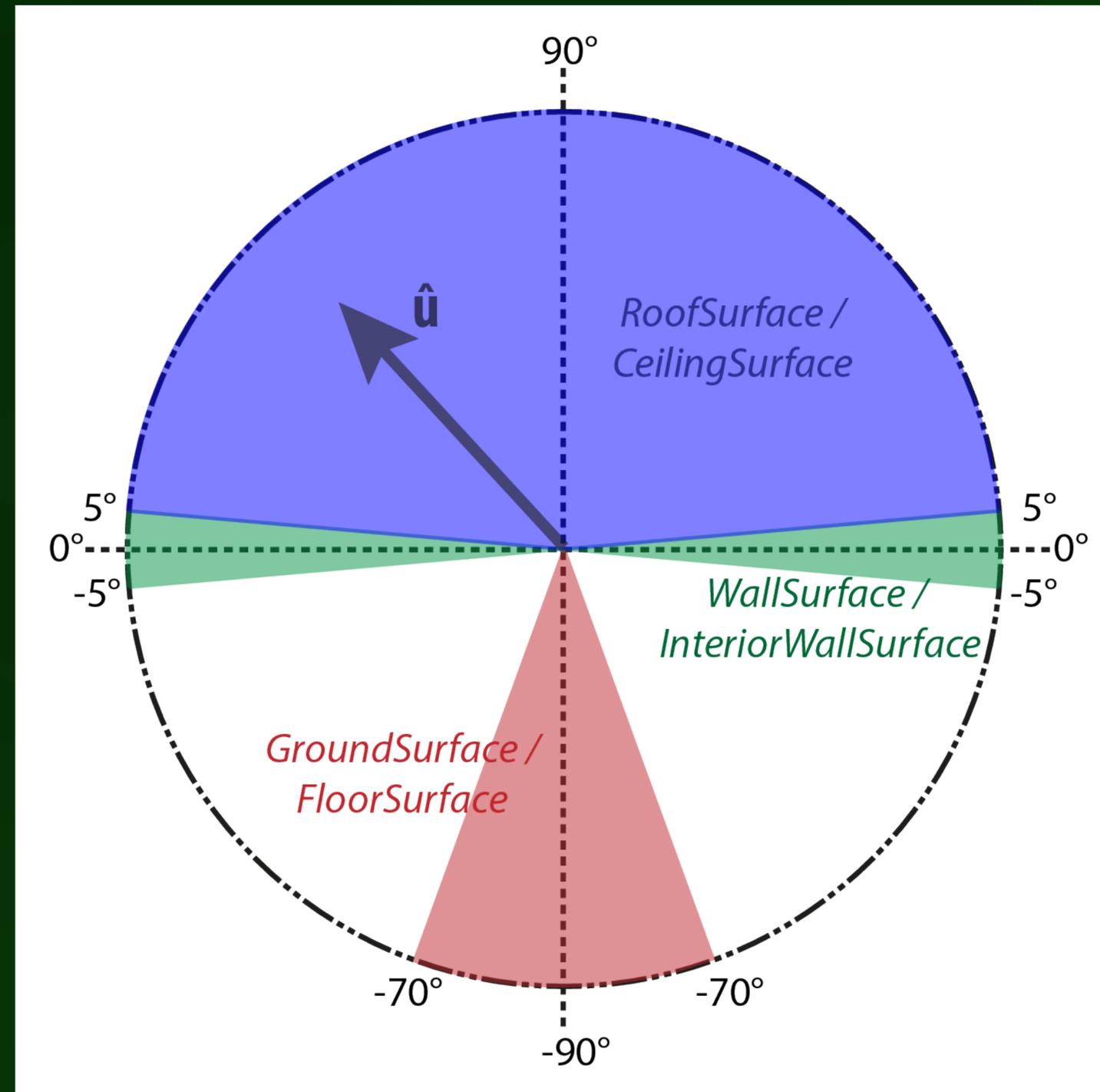
# Wall thickness

Type	year $y$	storeys $x$	$t_{\text{ext}}$ [cm]	$t_{\text{shared}}$ [cm]
Non-stacked	$y < 1970$	$x \leq 2$	27	11
		$x \geq 3$	27	12
	$1970 \leq y \leq 1985$	$x = 2$	27	10
		$x = 3$	28	12
		$x = 4$	27	9
	$y > 1985$	$x = 2$	28	13
		$x = 3$	30	12
$x = 4$		25	12	
Stacked	$y < 1970$	$x \leq 5$	29	12
		$5 < x \leq 10$	38	11
		$x > 10$	25	9
	$1970 \leq y \leq 1985$	$x \leq 5$	28	11
		$5 < x \leq 10$	26	11
		$x > 10$	29	12
	$y > 1985$	$x \leq 5$	30	12
$5 < x \leq 10$		38	13	
$x > 10$		35	15	
Other types	$y < 1970$	$x = 1$	14	14
		$x \geq 2$	31	11
	$1970 \leq y \leq 1985$	$x = 1$	14	14
		$x \geq 2$	30	10
	$y > 1985$	$x = 1$	14	14
		$x \geq 2$	36	13

# Boolean set intersection



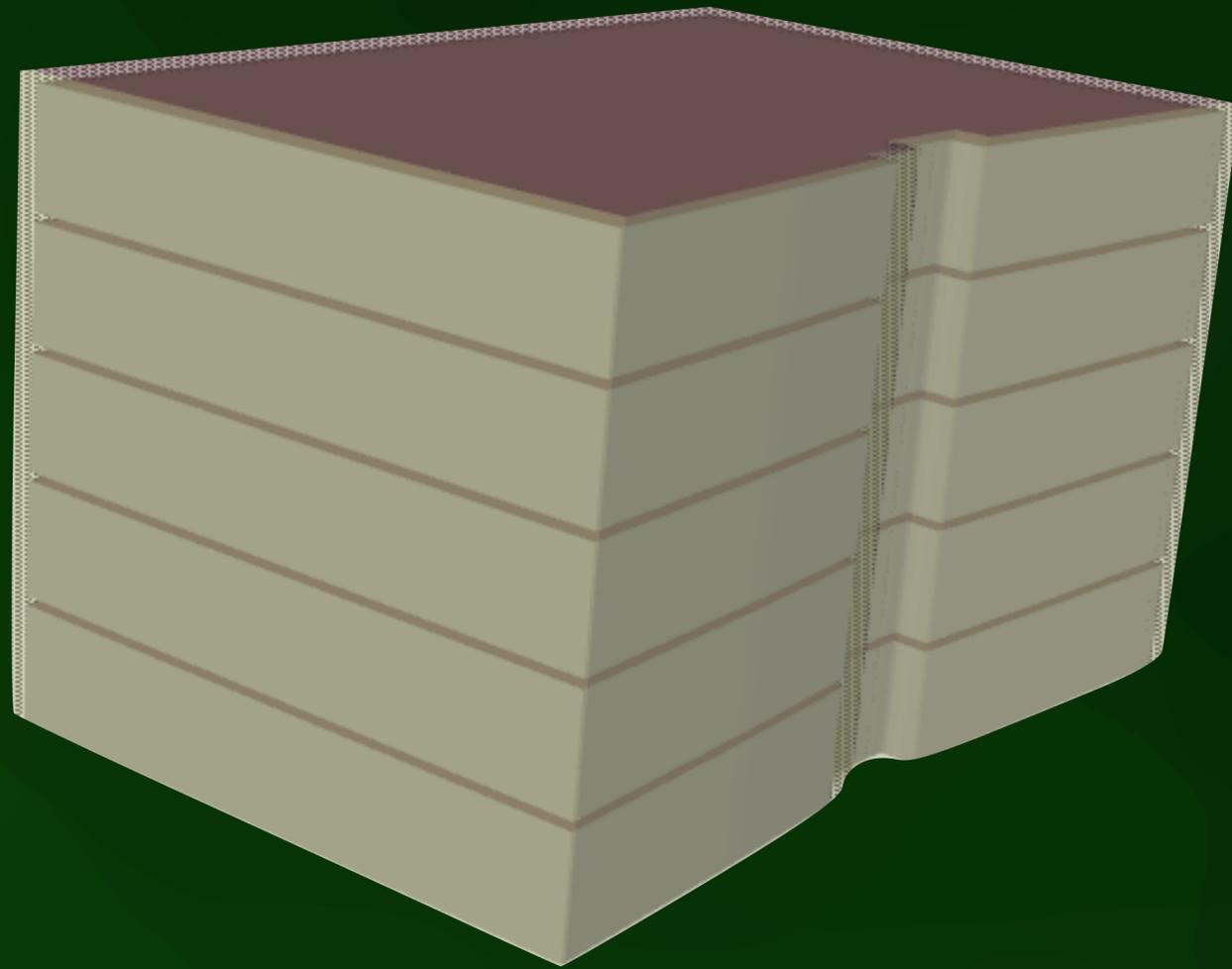
# Classifying surfaces



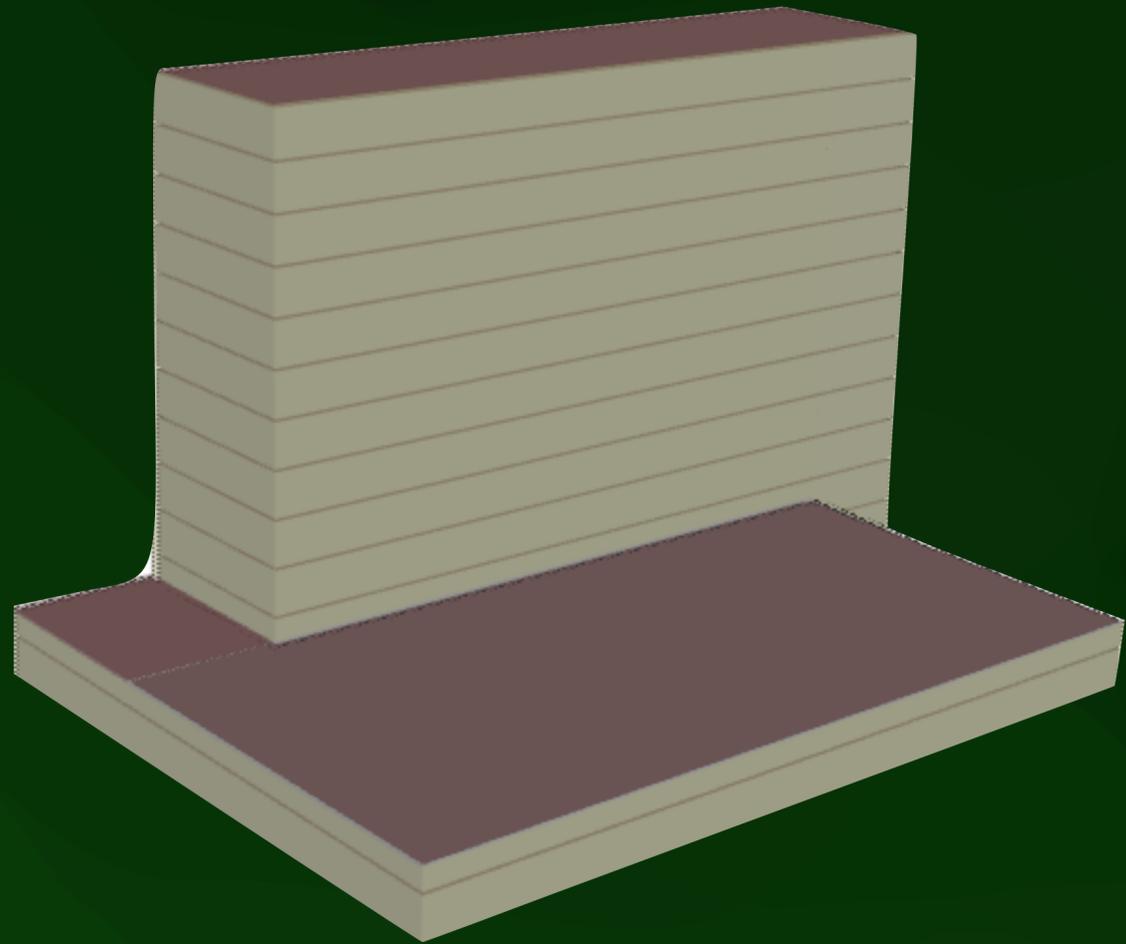
# Results



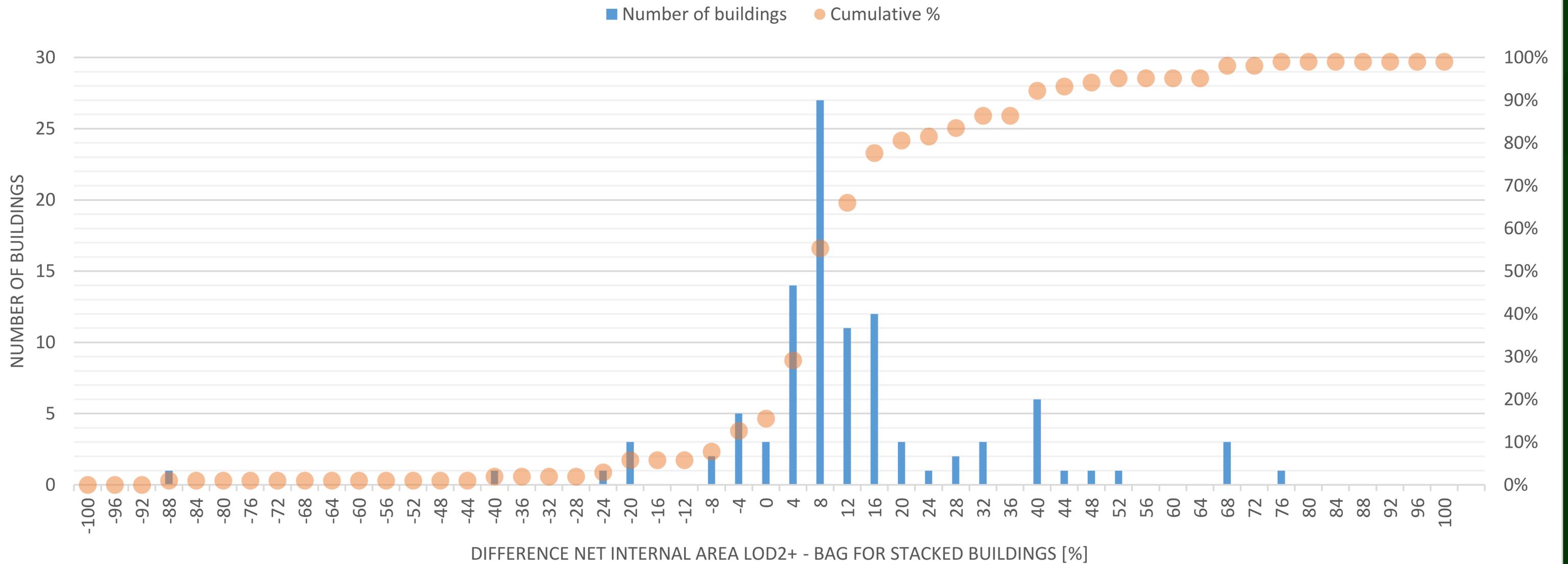
# Results



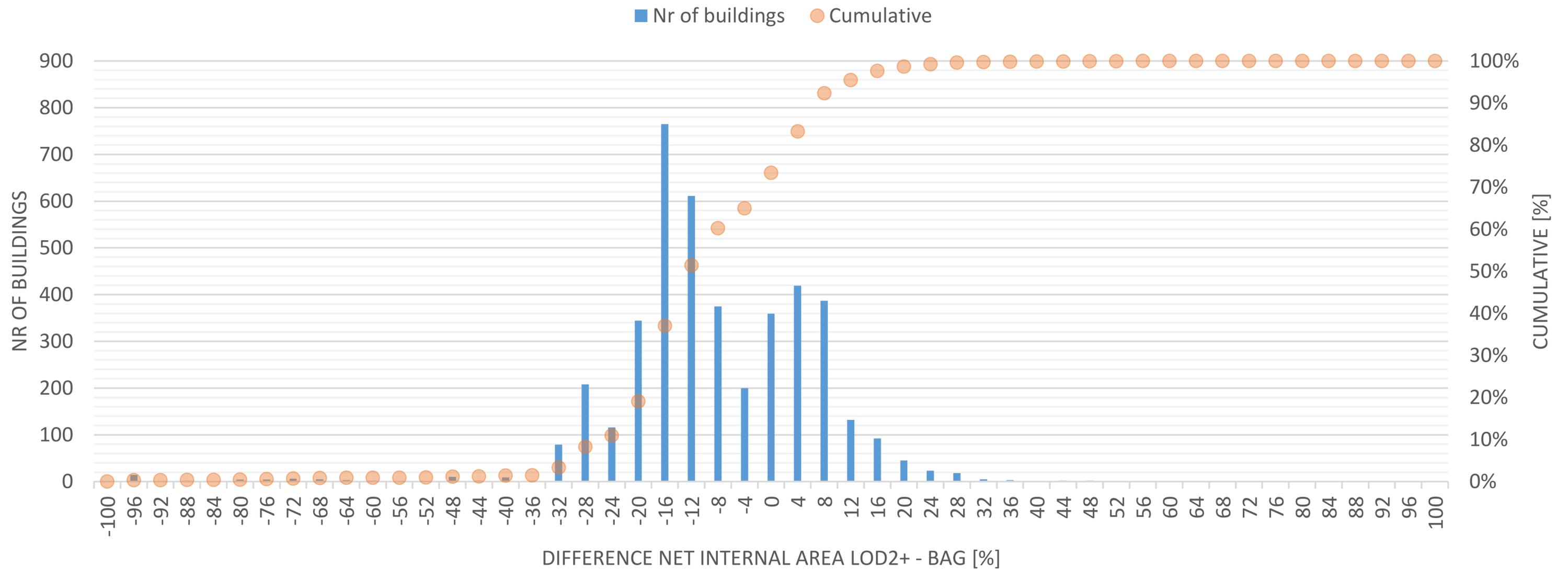
# Results



# Net internal area (stacked)



# Net internal area (non-stacked)



- Motivation: update 3D city models from designed BIM models (including potentially interiors)
- Fill gaps using Minkowski sum to increase size of elements
- Merge elements using Boolean set union
- Reclassify surfaces

## Automatic generation of CityGML LoD3 building models from IFC models

MSc thesis in Geomatics  
by Sjors Donkers



December 2013

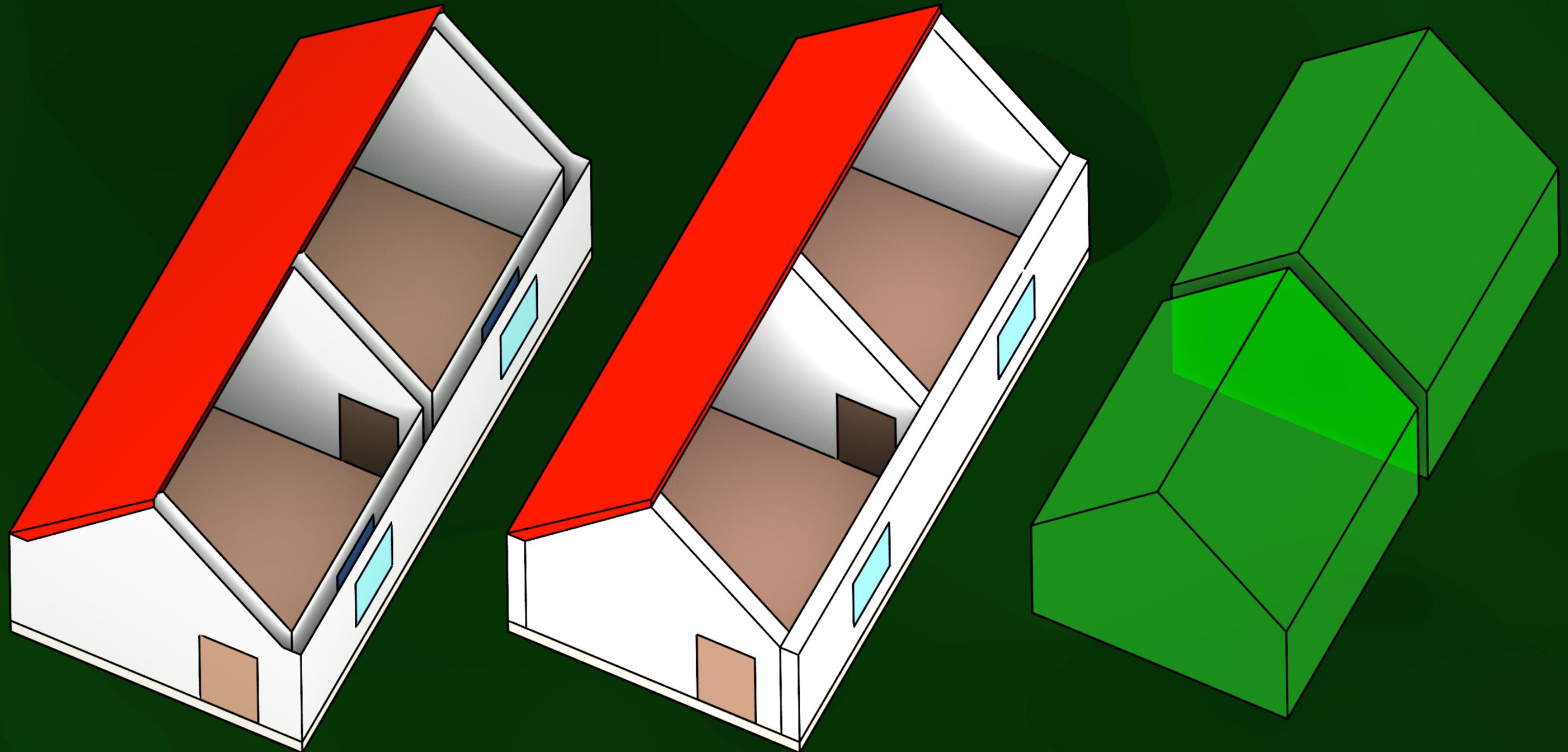


Department of GIS Technology  
OTB Research Institute for the Built Environment

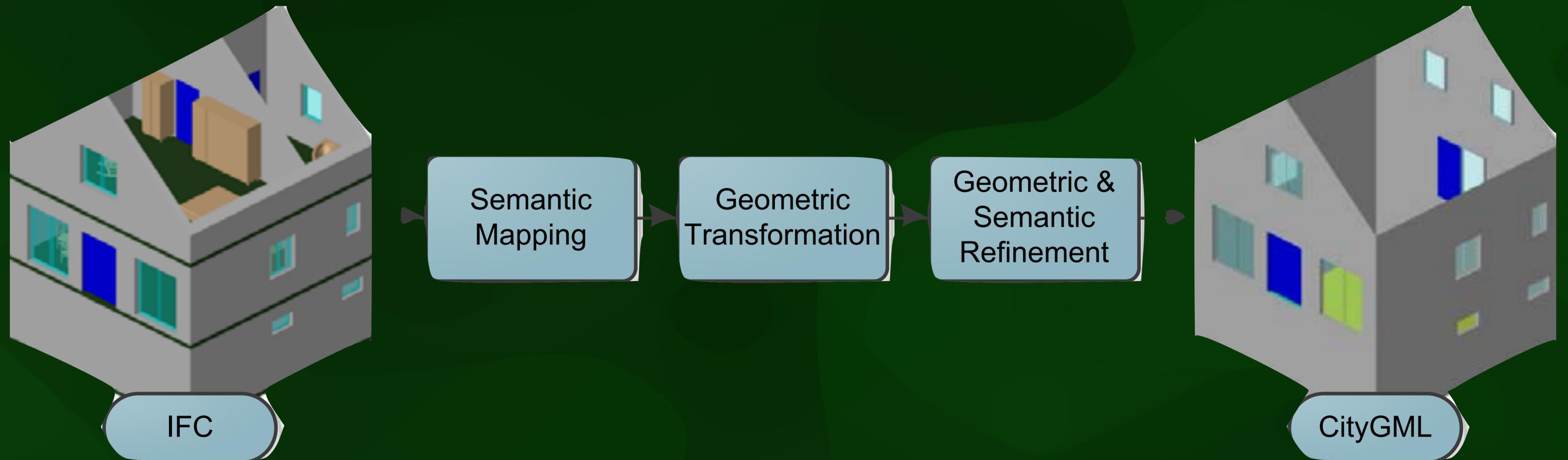
# Goal



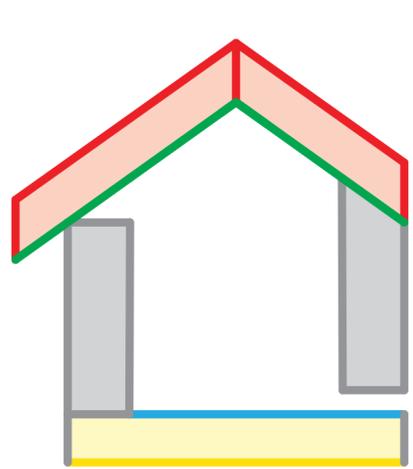
# 3DCM vs BIM



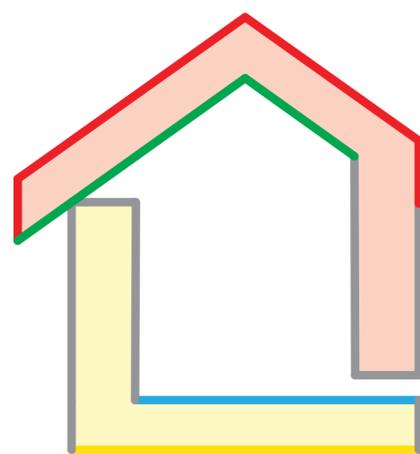
# Methodology (semantics)



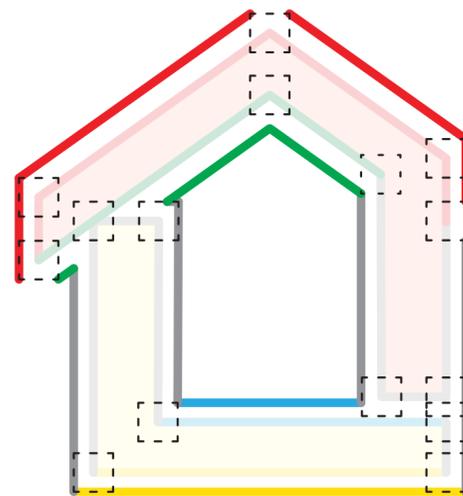
# Methodology (geometry)



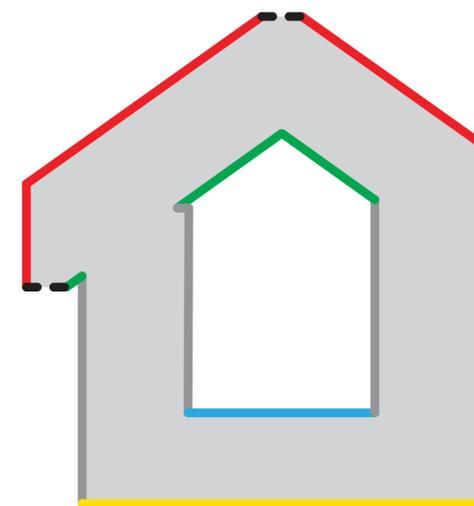
(a) input



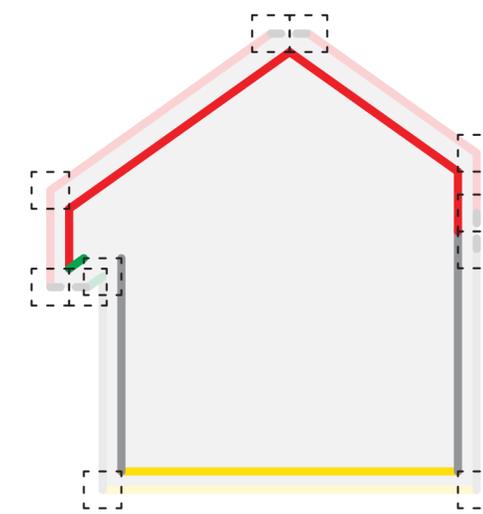
(b) union



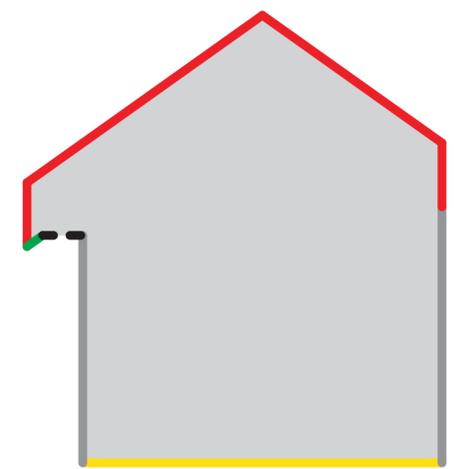
(c) dilation



(d) result



(e) erosion



(f) final result

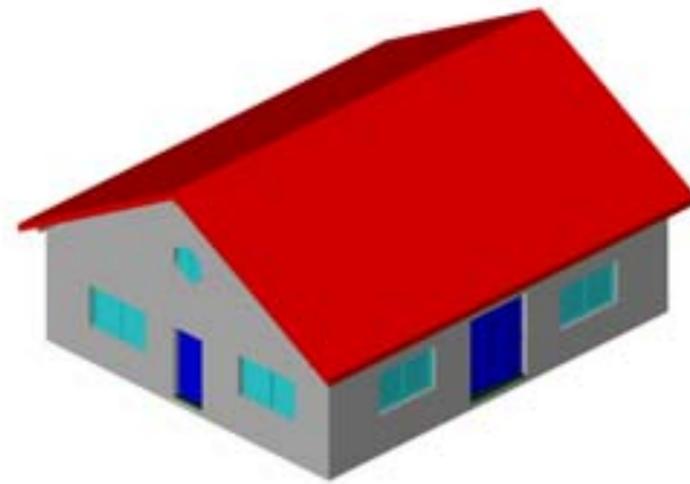
# Results



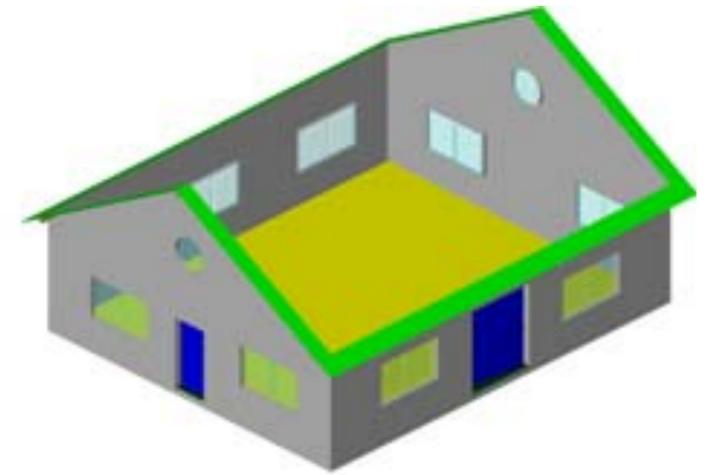
(a) input IFC



(b) IFC without roof



(c) output CityGML

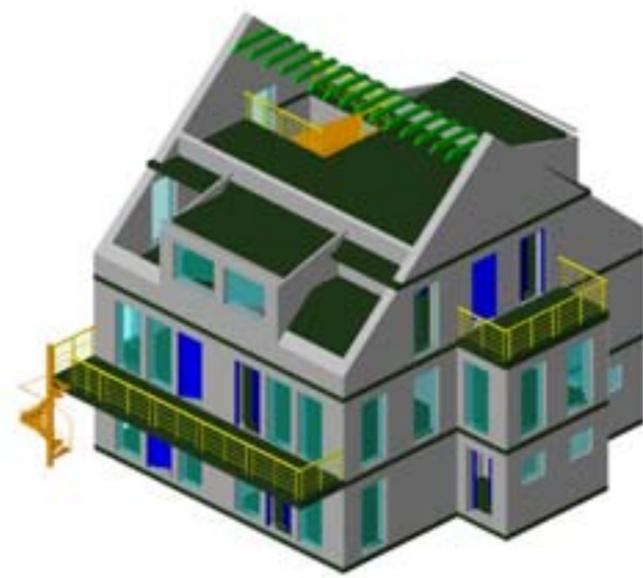


(d) CityGML without roof

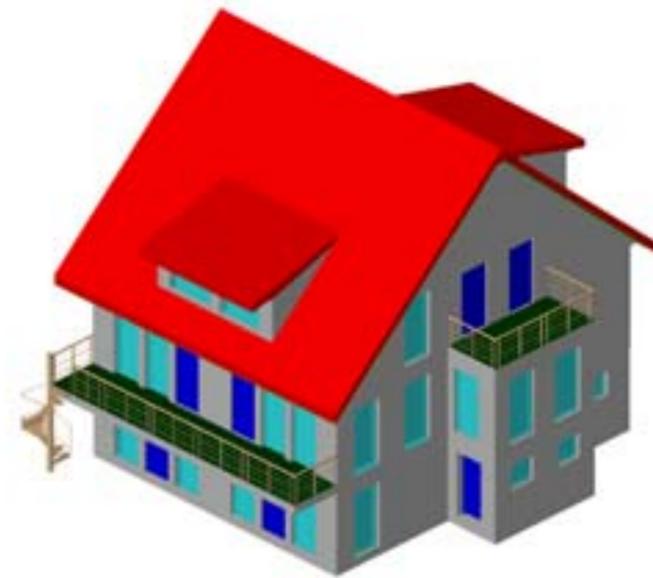
# Results



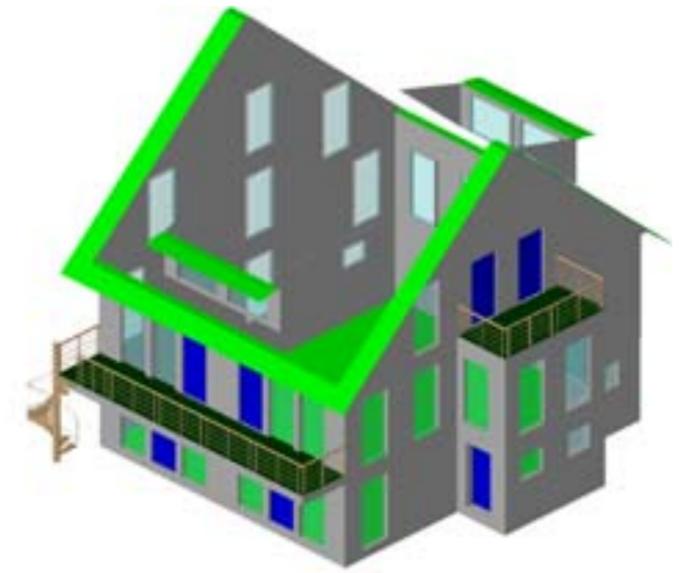
(a) input IFC



(b) IFC without roof

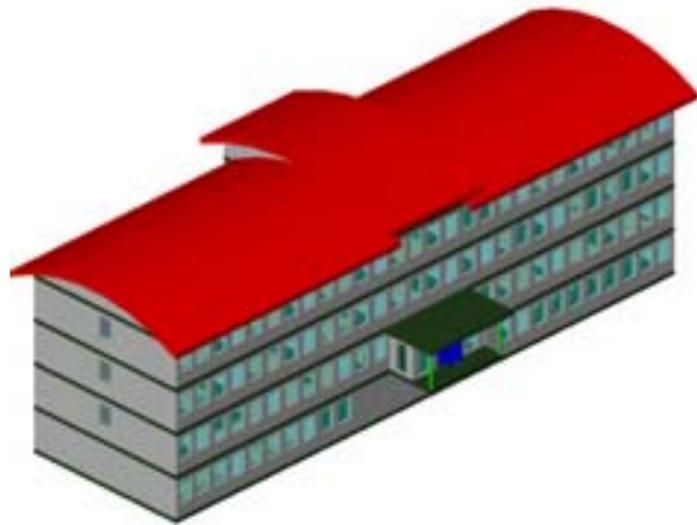


(c) output CityGML

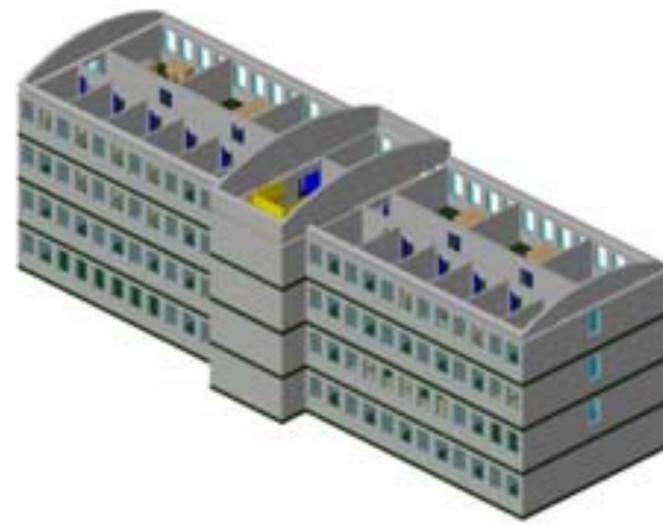


(d) CityGML without roof

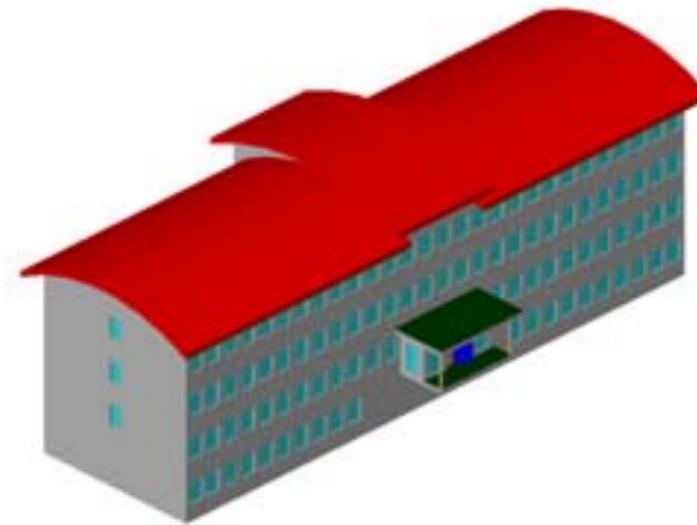
# Results



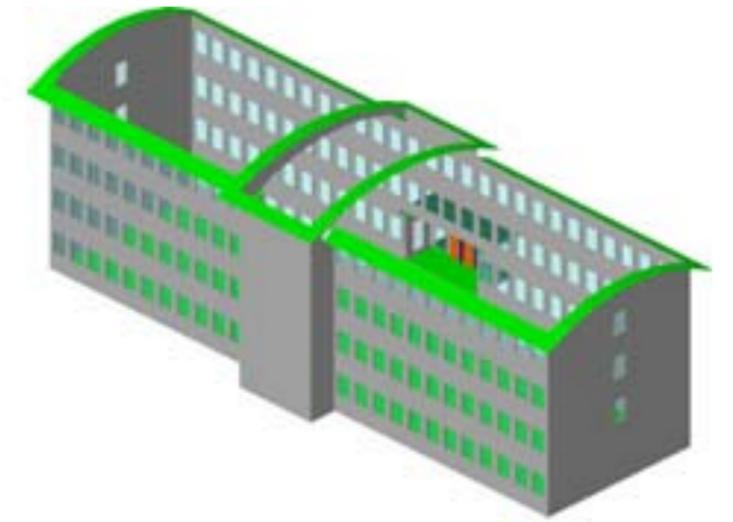
(a) input IFC



(b) IFC without roof

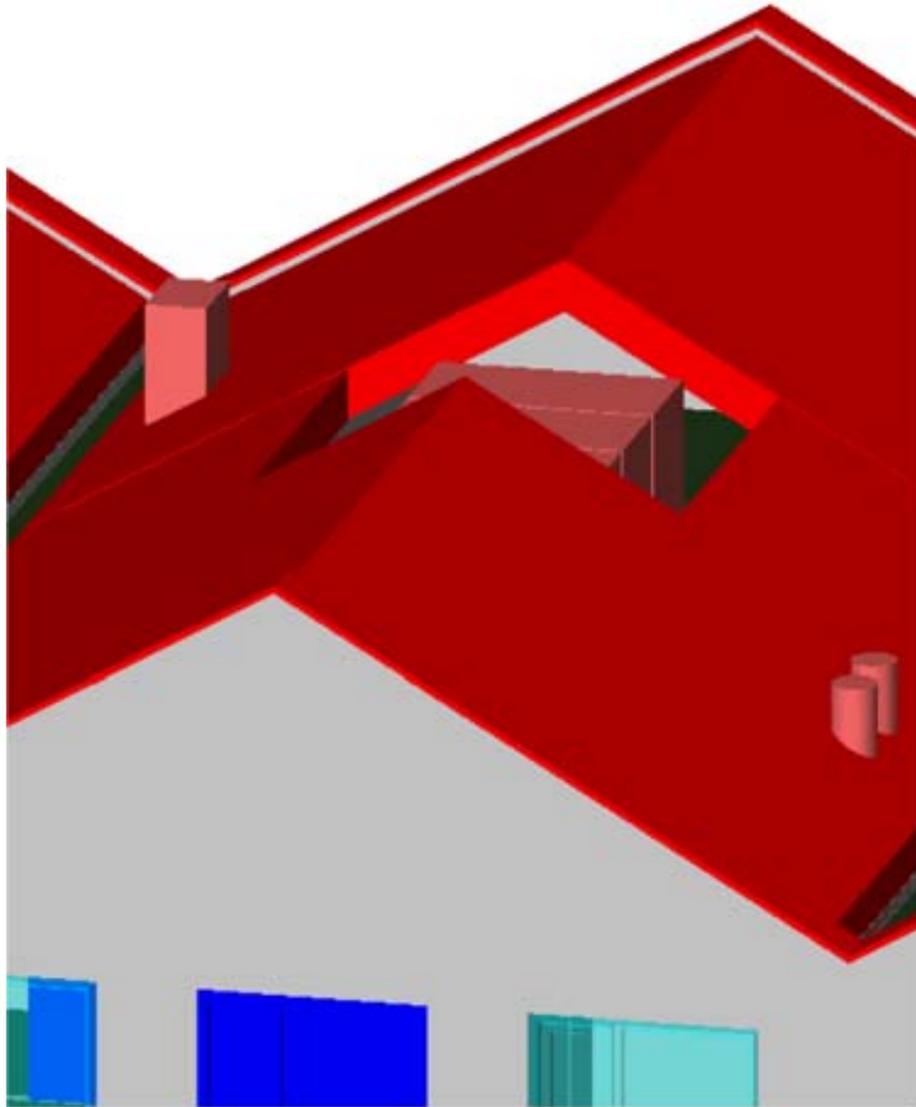


(c) output CityGML

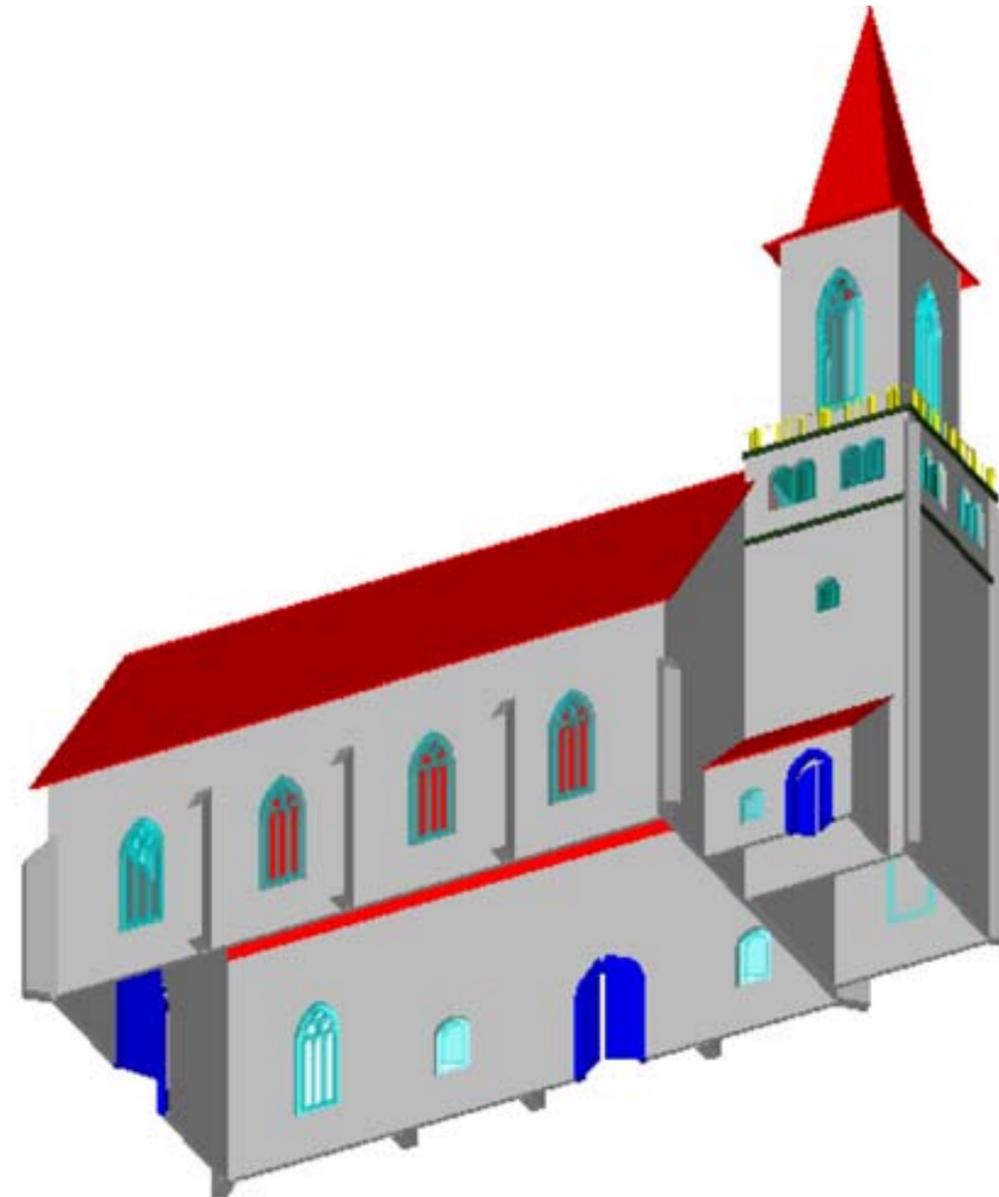


(d) CityGML without roof

# Issues



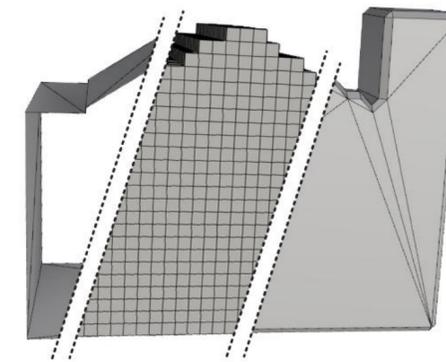
(a) Building where part of the roof is missing



(b) A church missing a base slab

- Motivation: repair 3D models so that they can be used in applications
- Voxelisation
- Reconstruction of mesh
- Obtain semantics and export

AUTOMATIC REPAIR OF 3D CITY BUILDING MODELS USING A  
VOXEL-BASED REPAIR METHOD



A thesis submitted to the Delft University of Technology in partial fulfillment  
of the requirements for the degree of

Master of Science in Geomatics

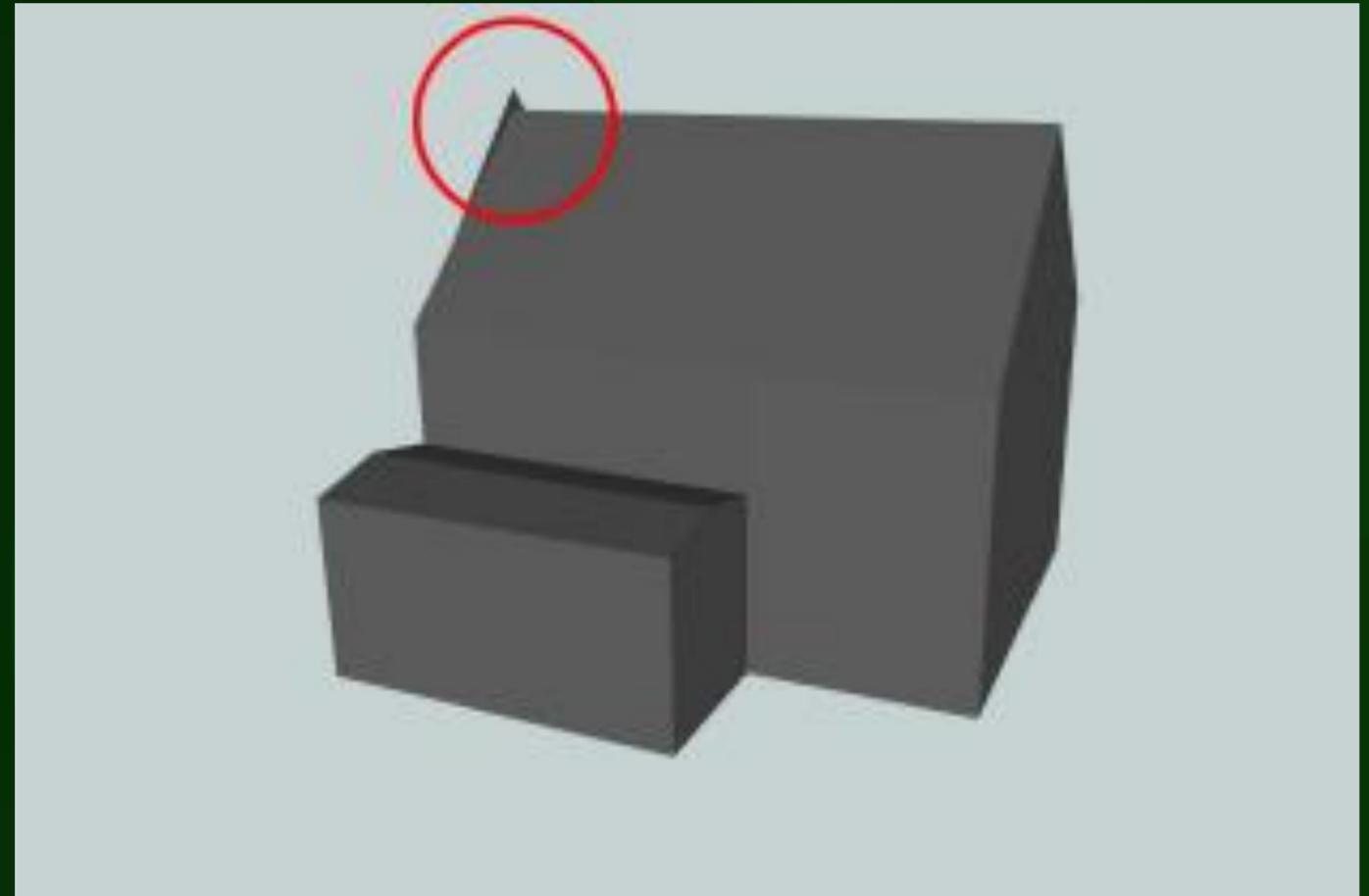
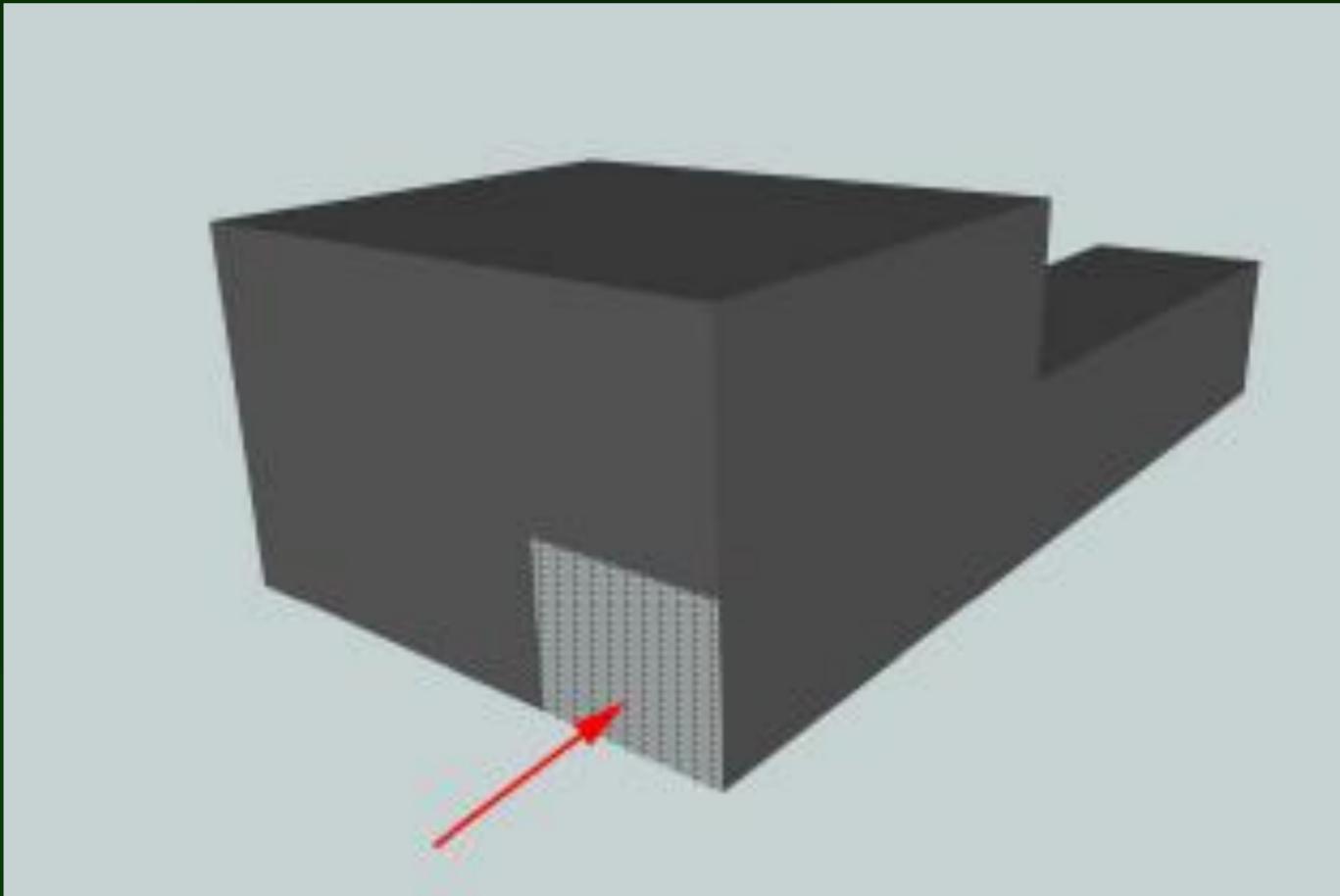
by

Damien Mulder

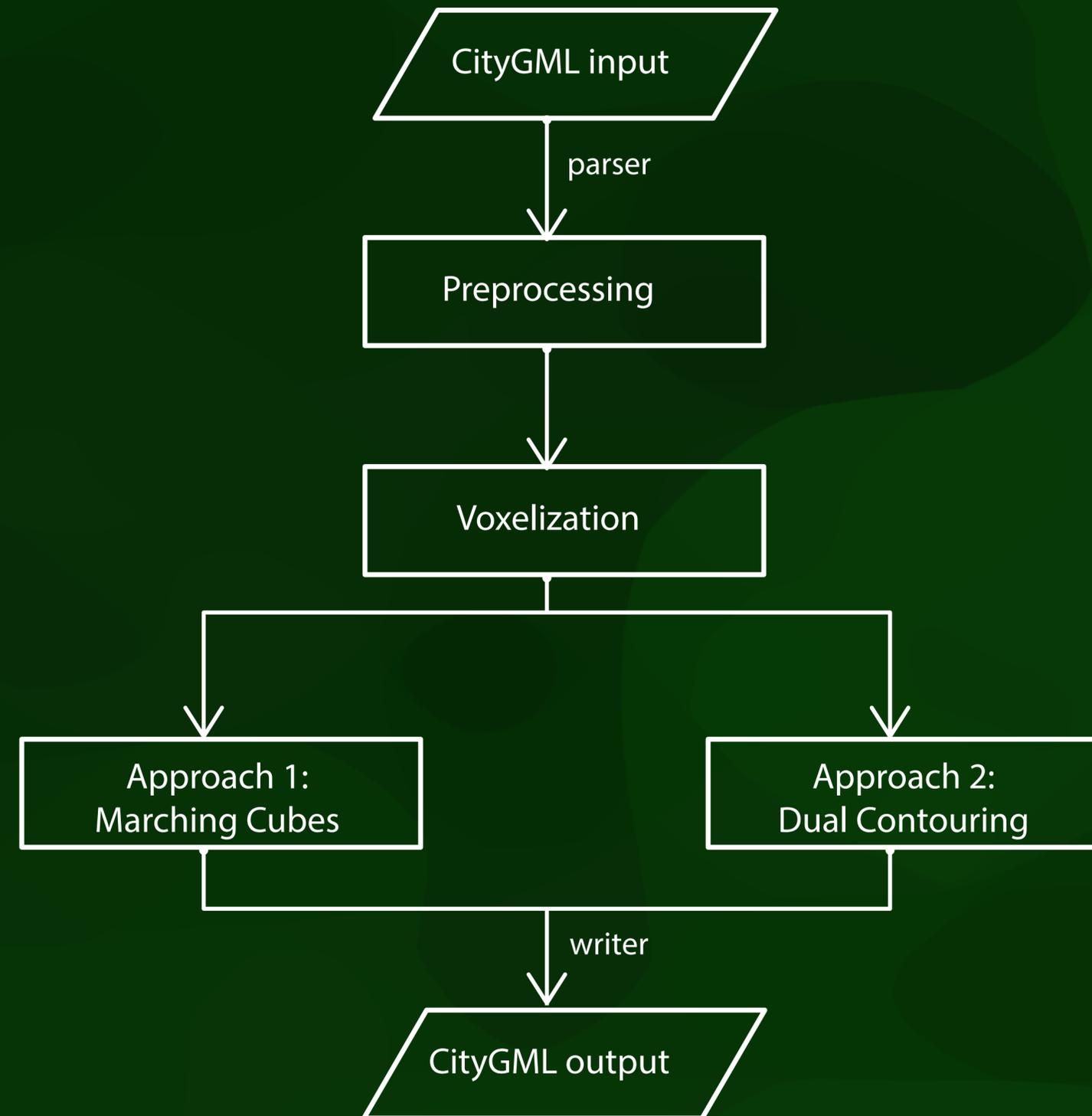
M.Sc Geomatics Thesis

June 2015

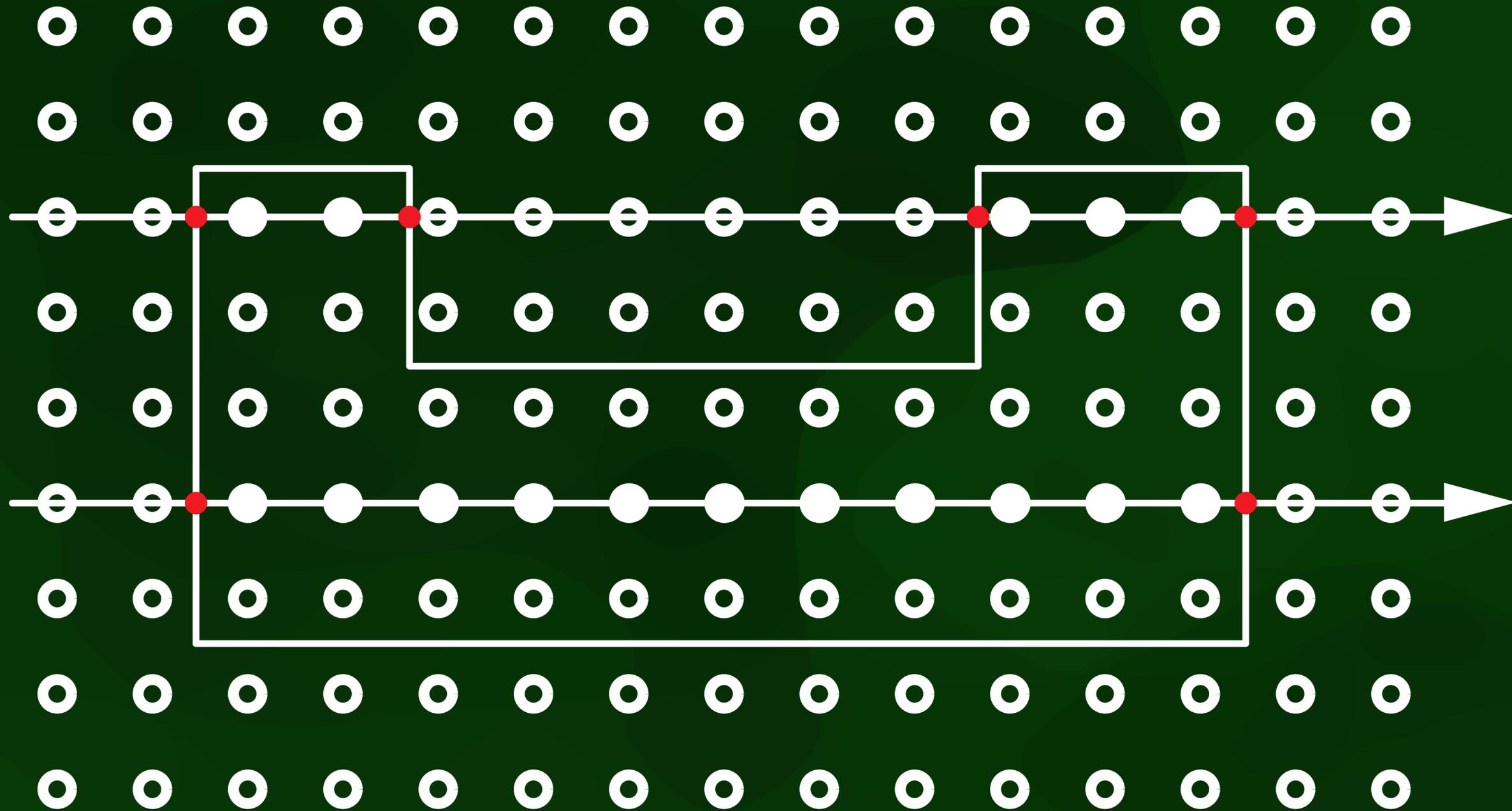
# Fixing 3D models



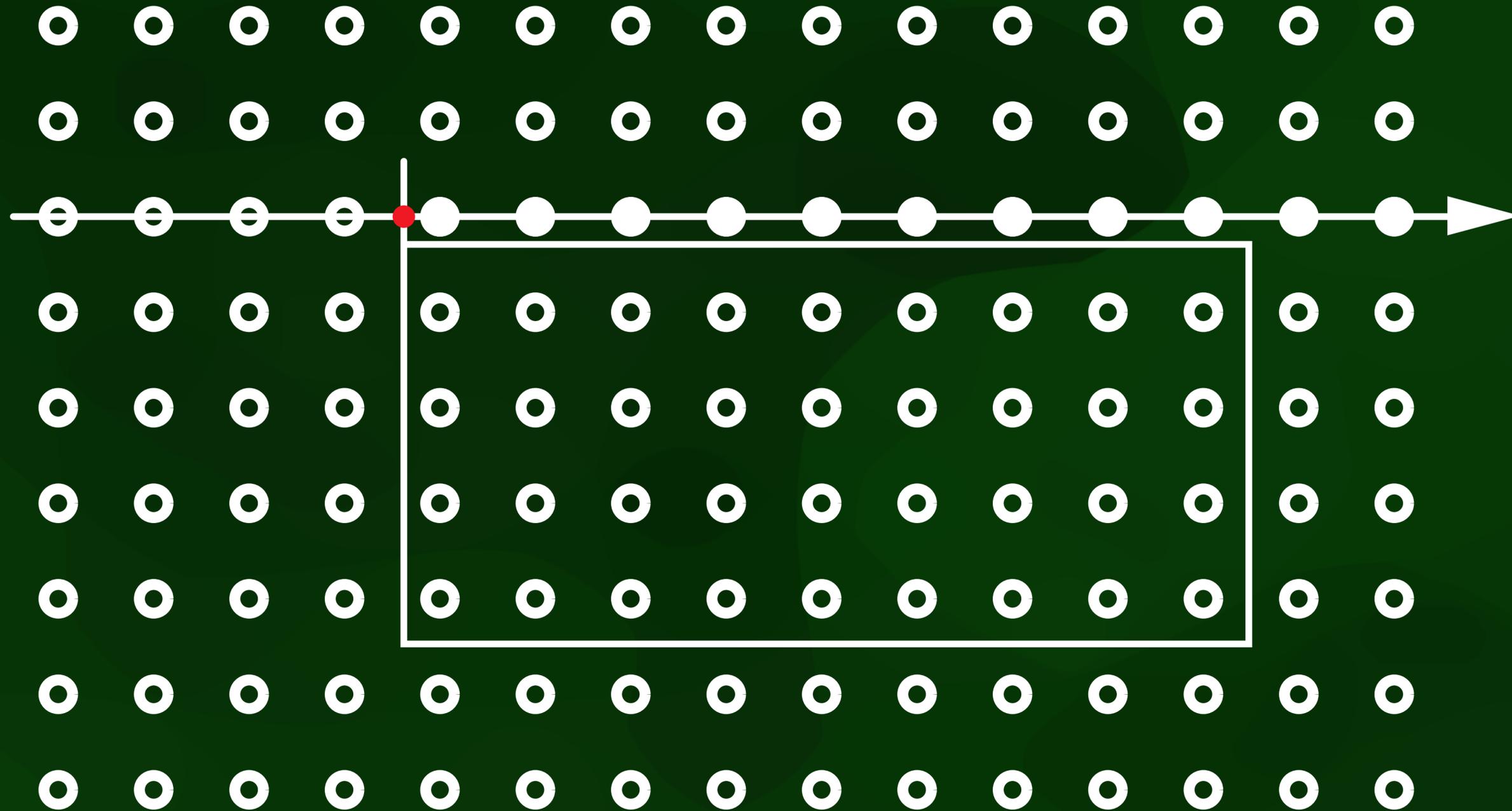
# Methodology



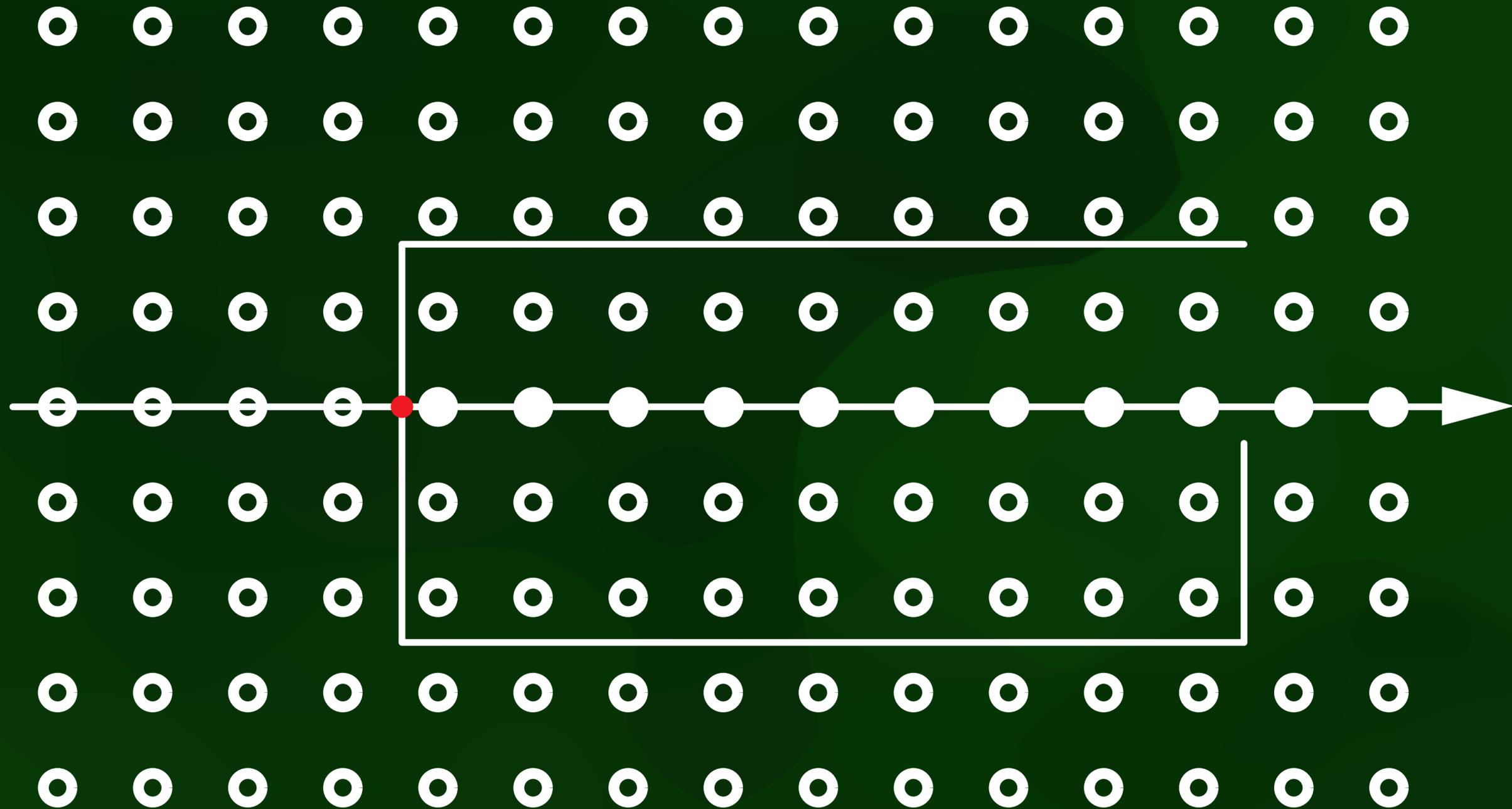
# Voxelisation



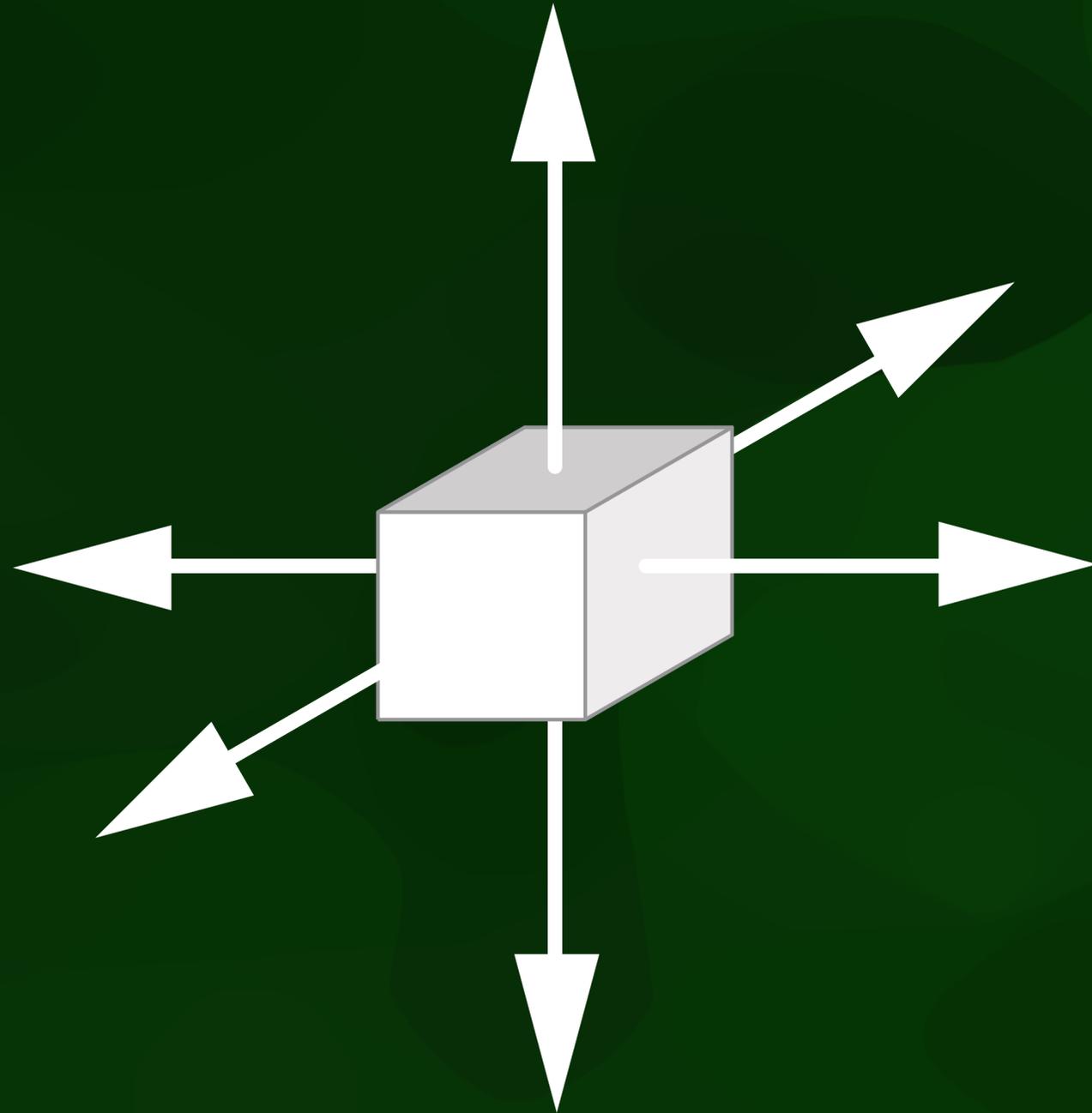
# Voxelisation: overshoot



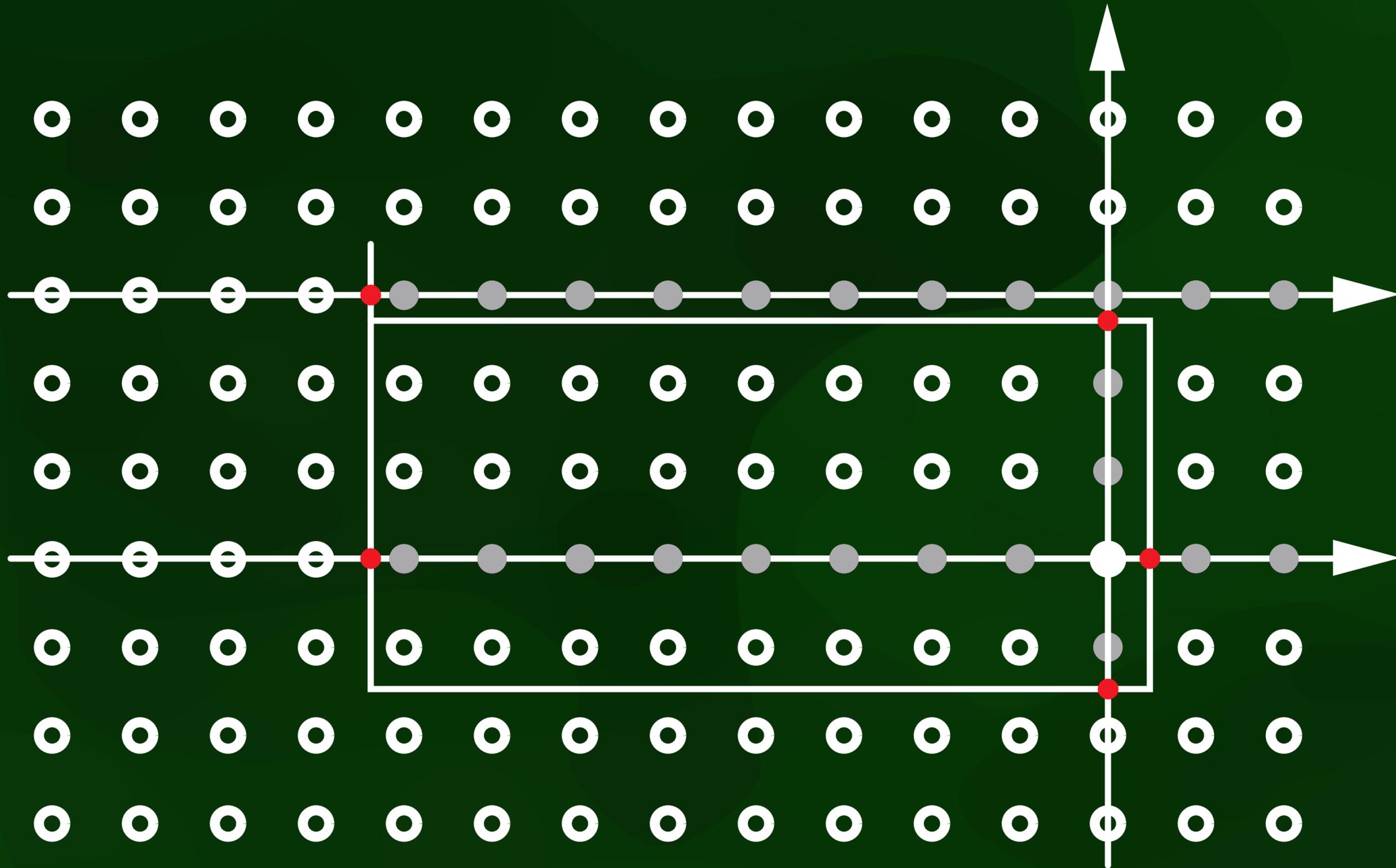
# Voxelisation: gap



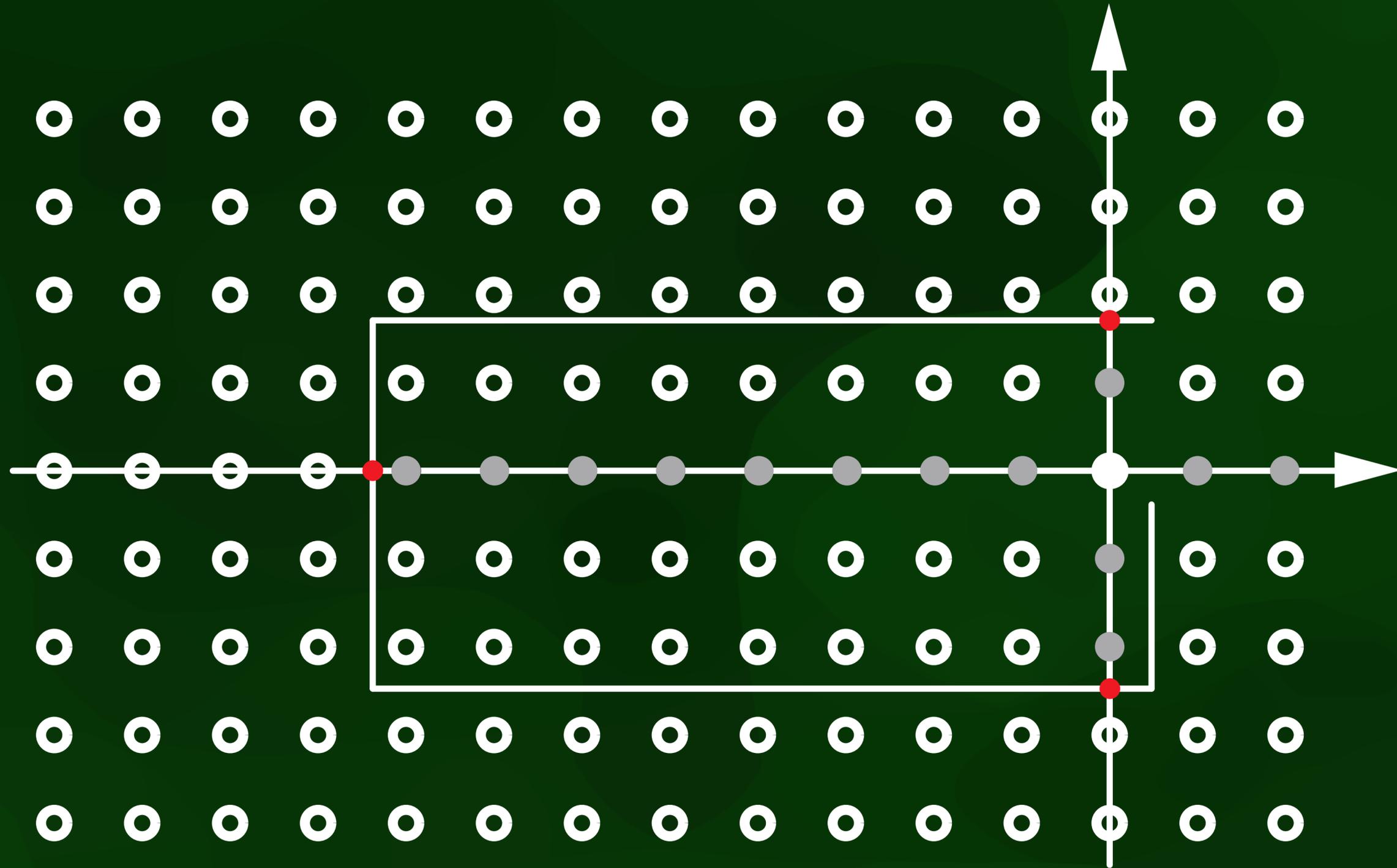
# Voxelisation: shooting rays



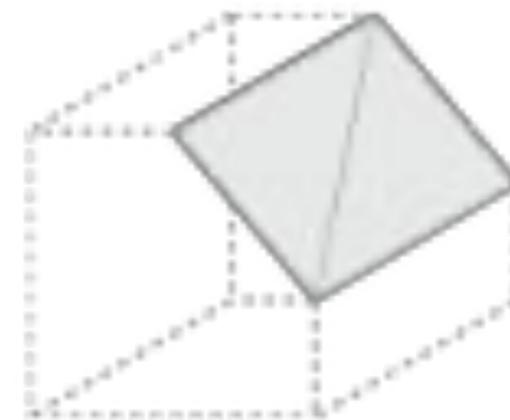
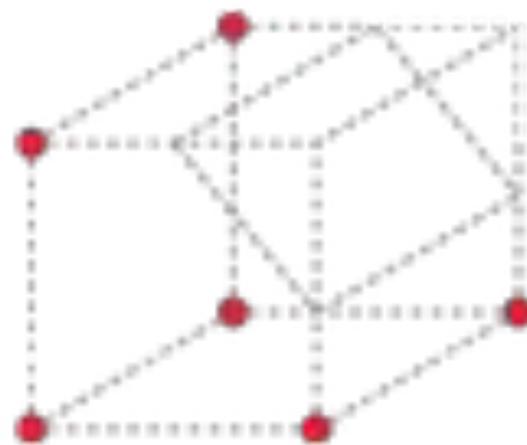
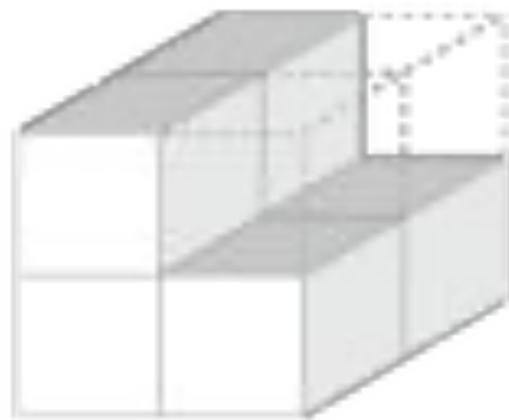
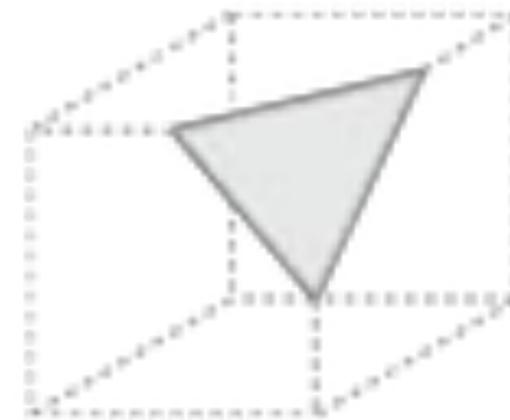
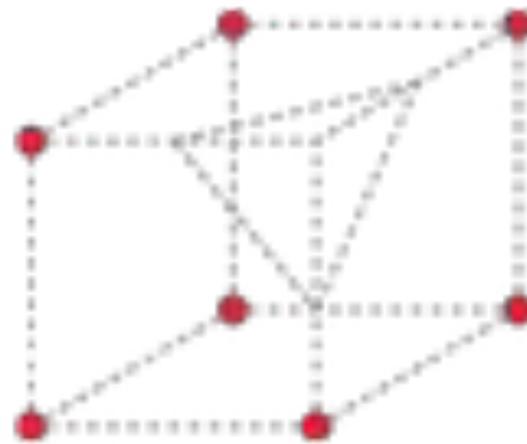
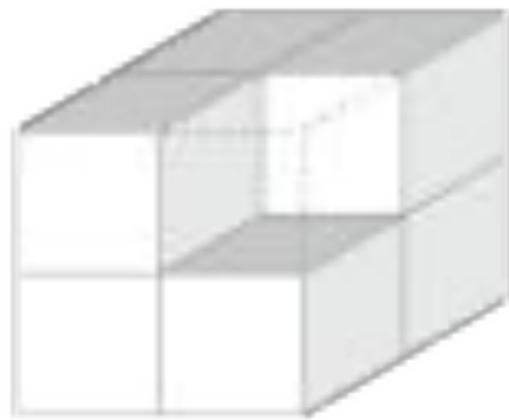
# Majority counting: overshoot



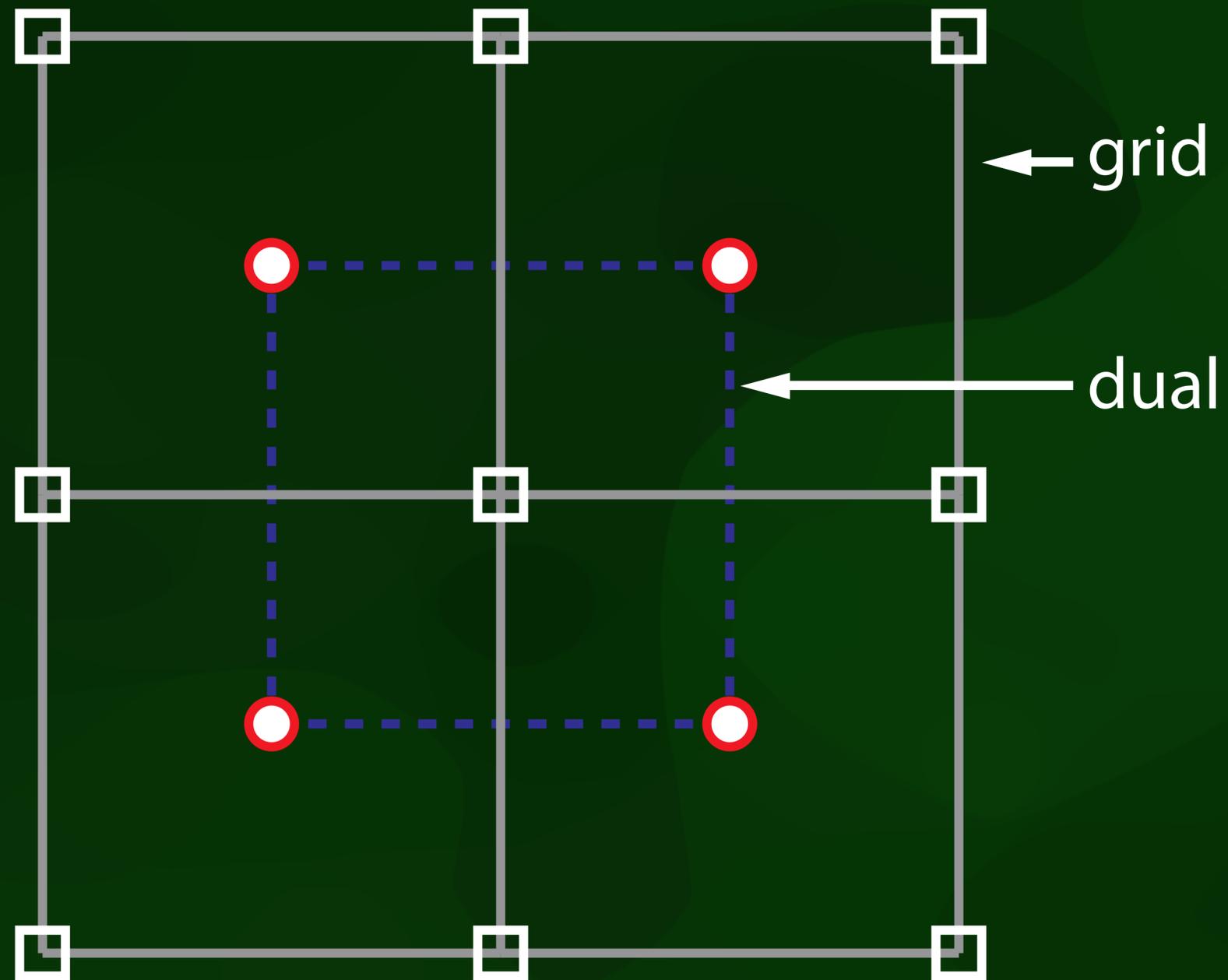
# Majority counting: gap



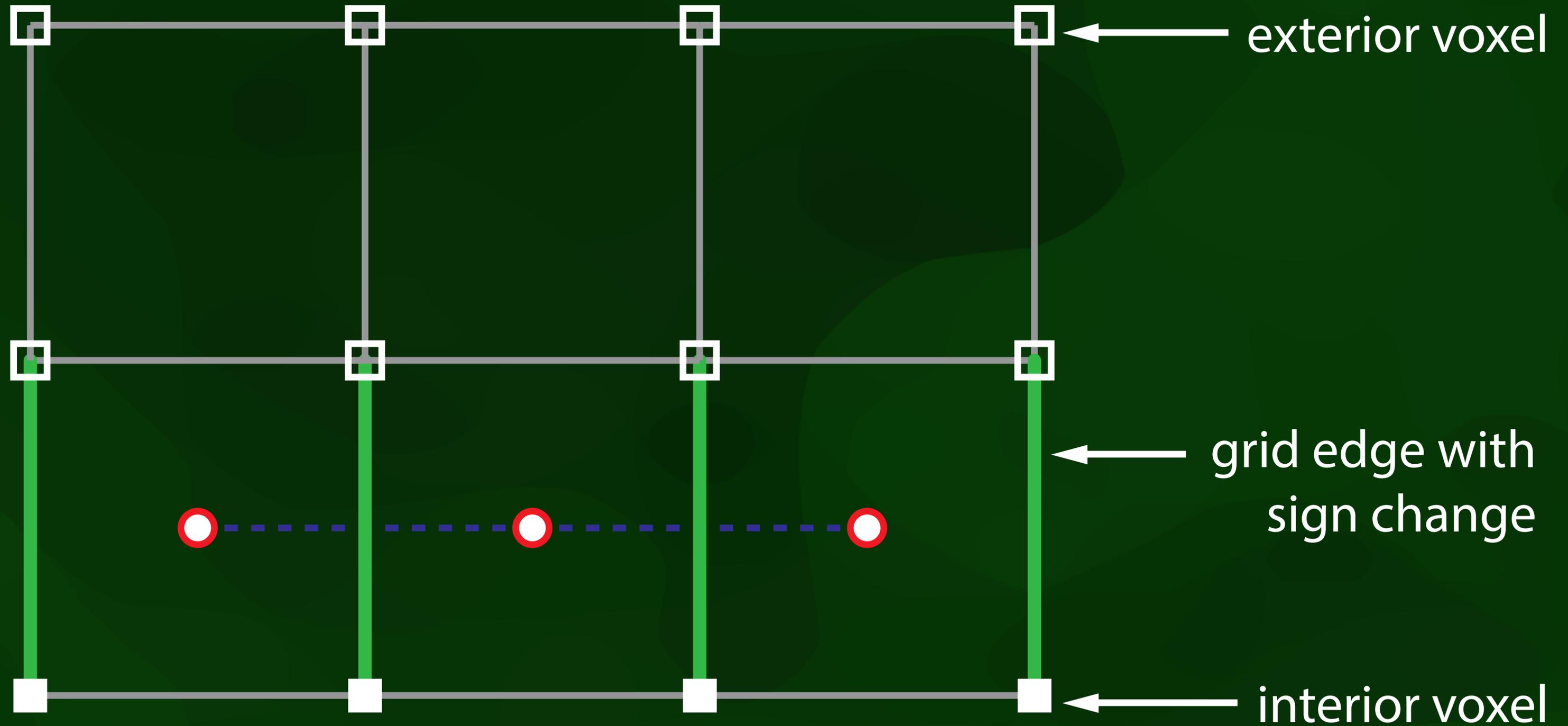
# Marching cubes



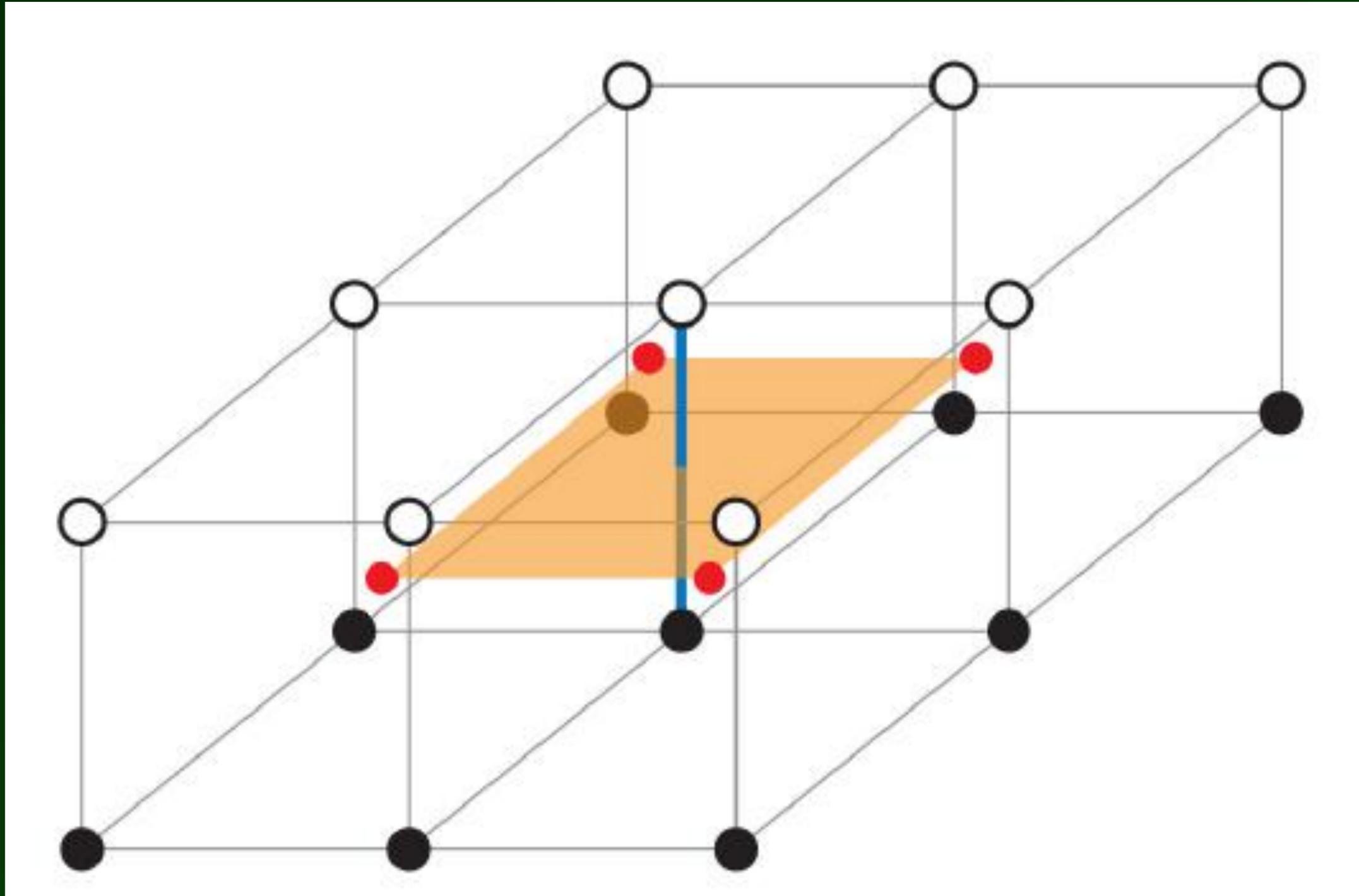
# Dual contouring



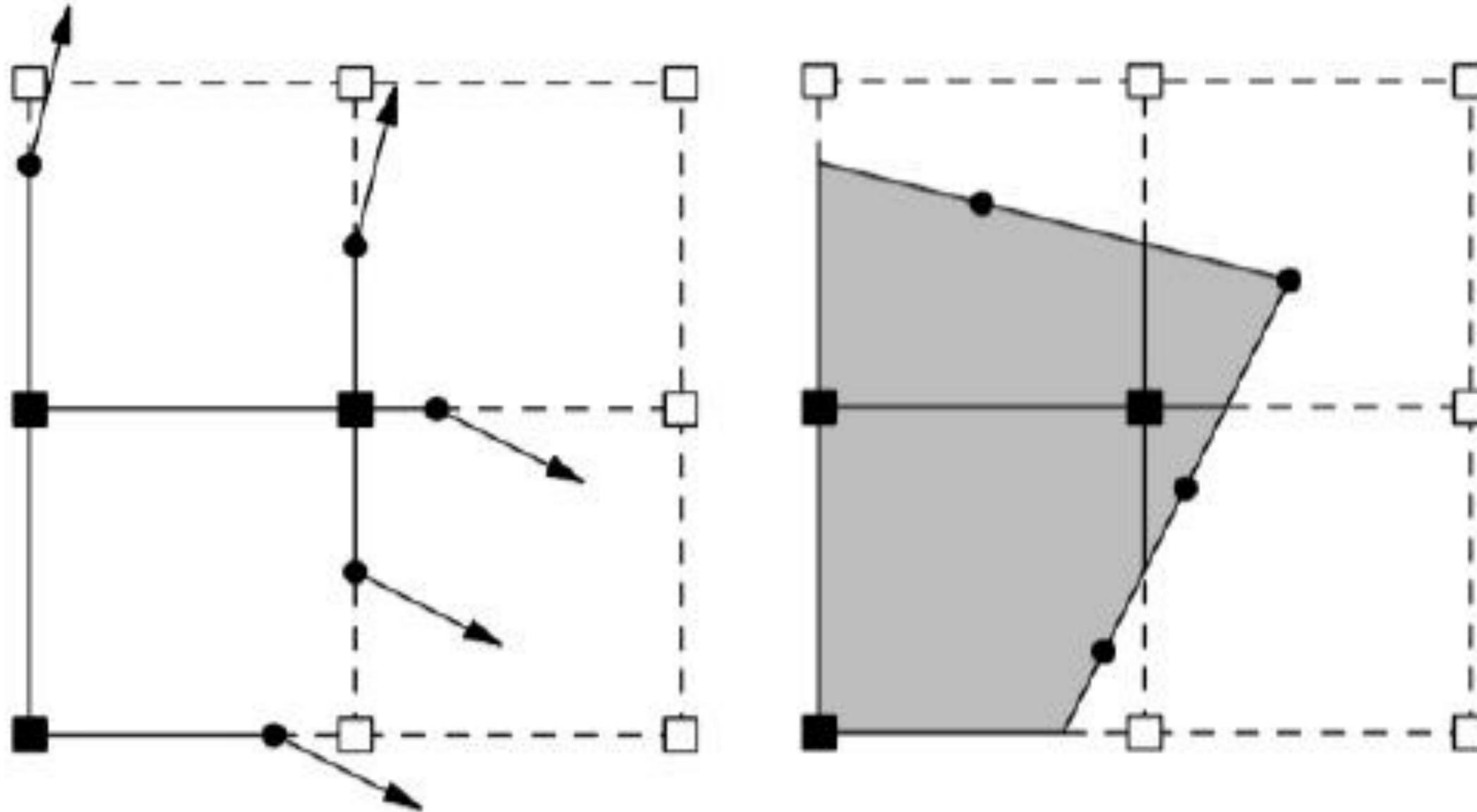
# Dual contouring



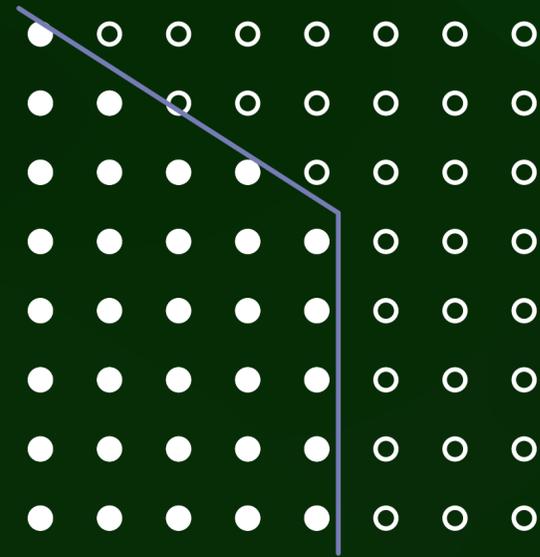
# Dual contouring



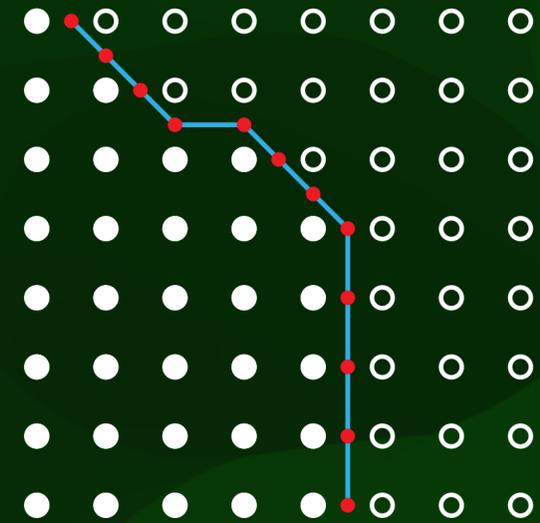
# Dual contouring



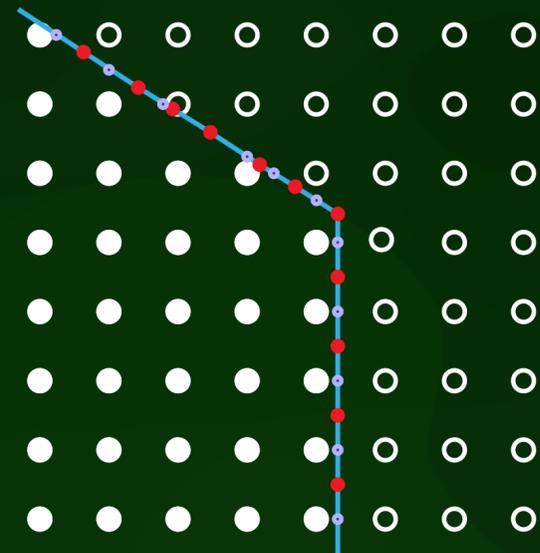
# Full process



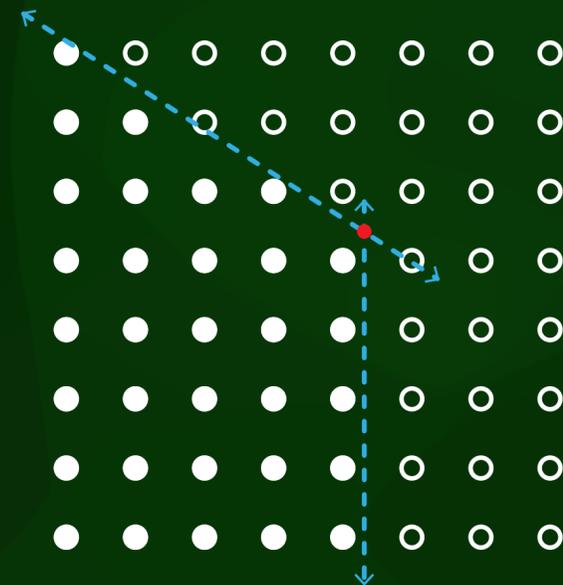
(a) The original polygonal model



(b) Marching Cubes result

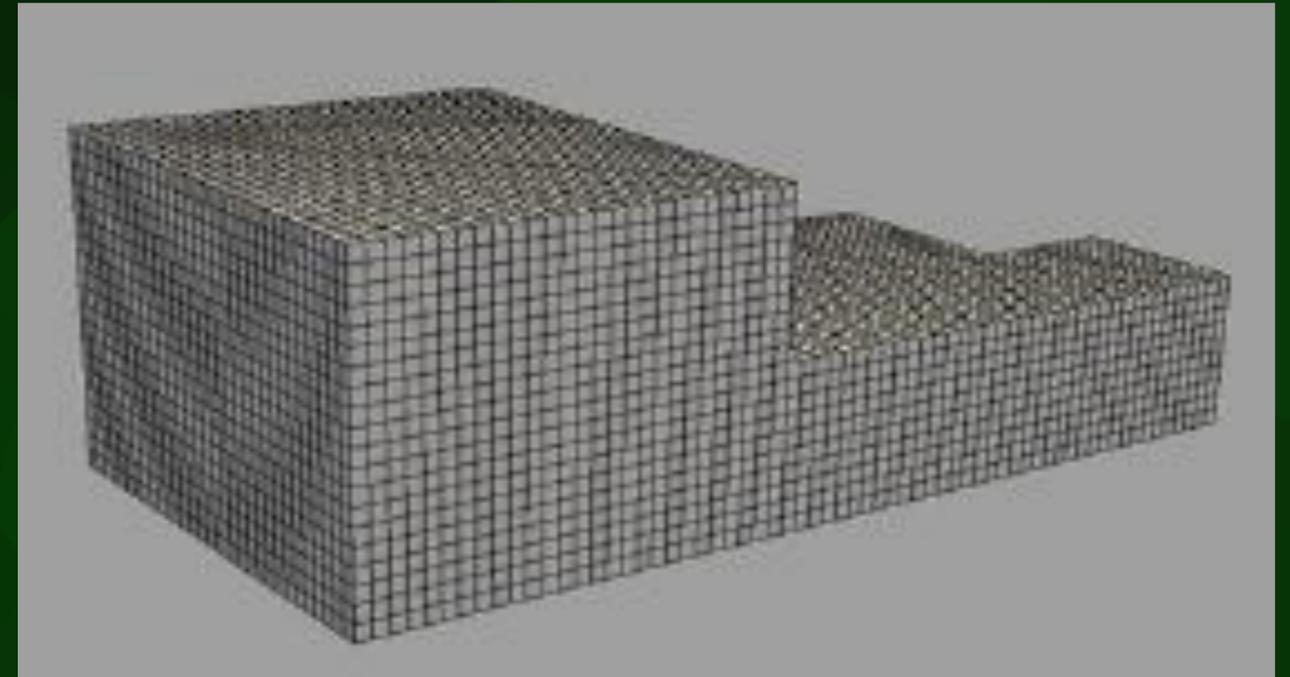
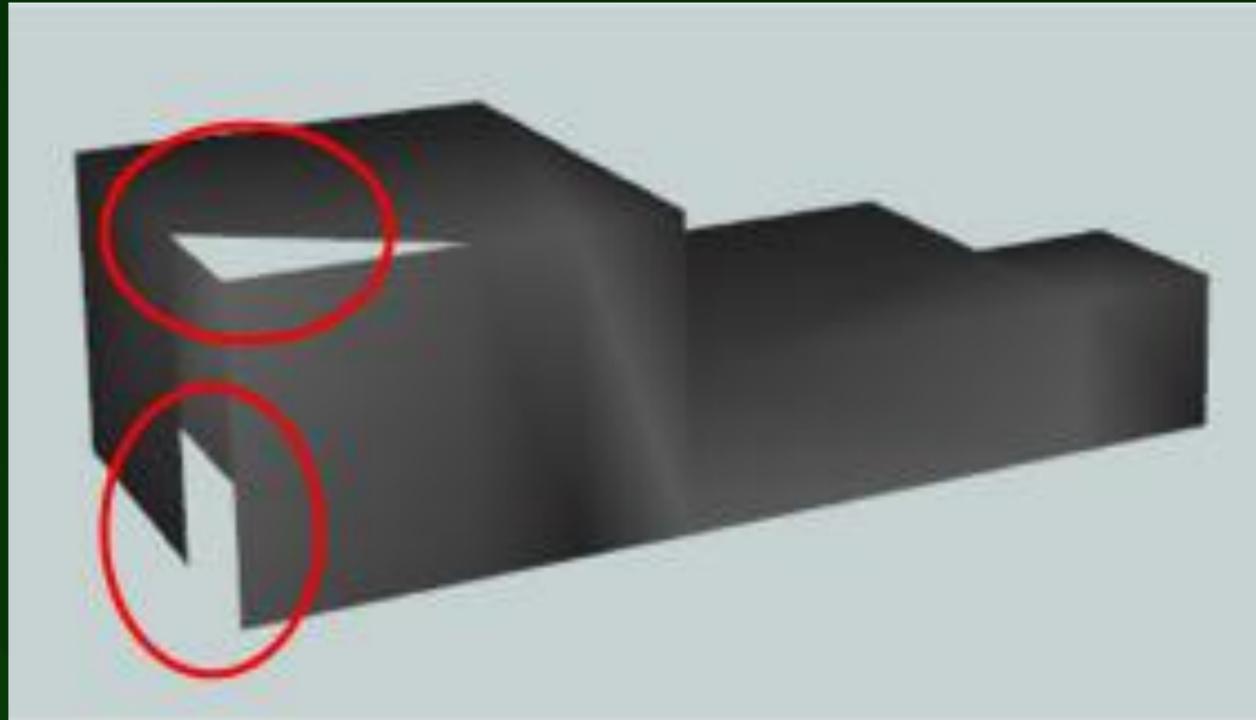


(c) Dual Contouring result

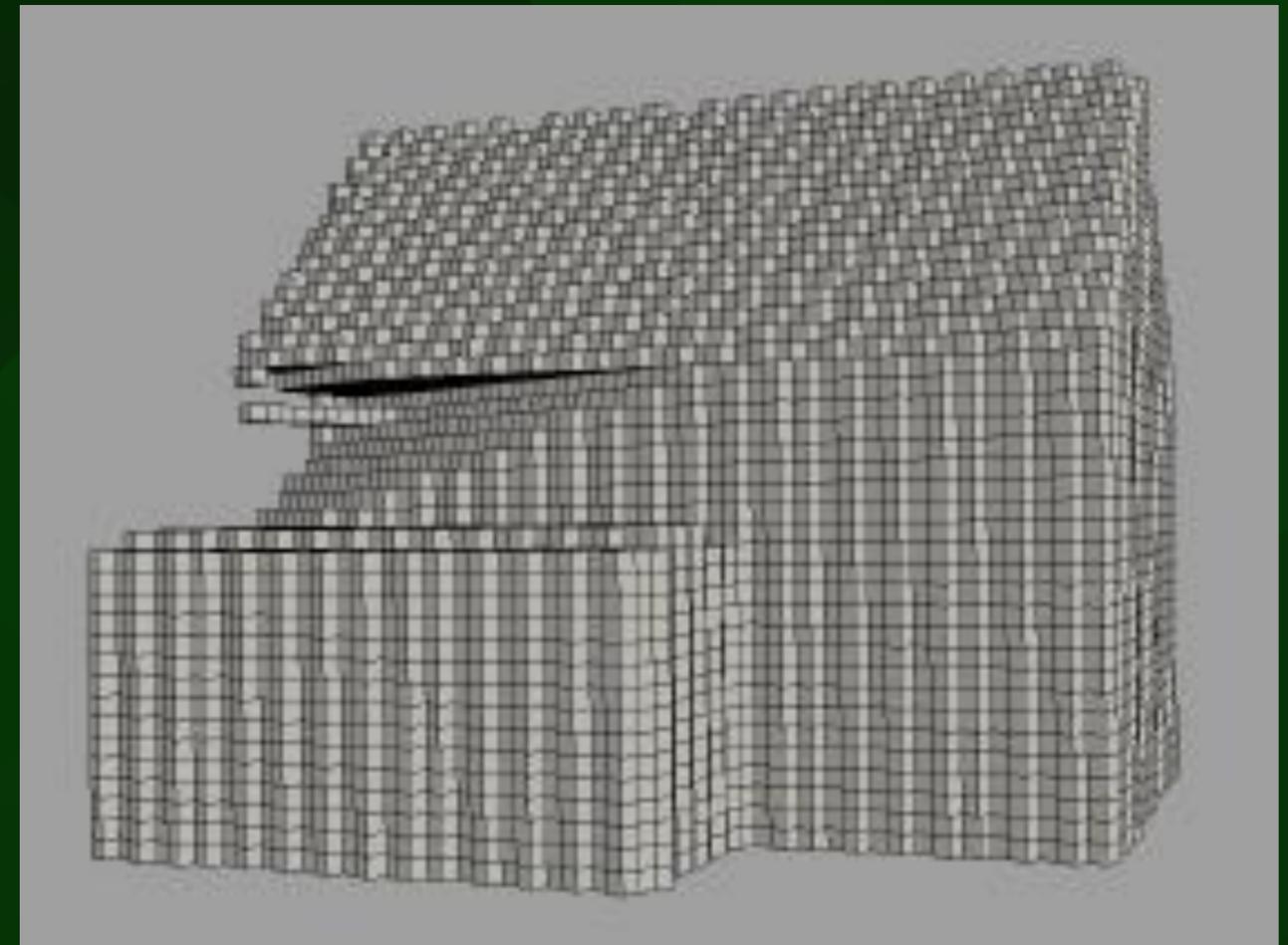
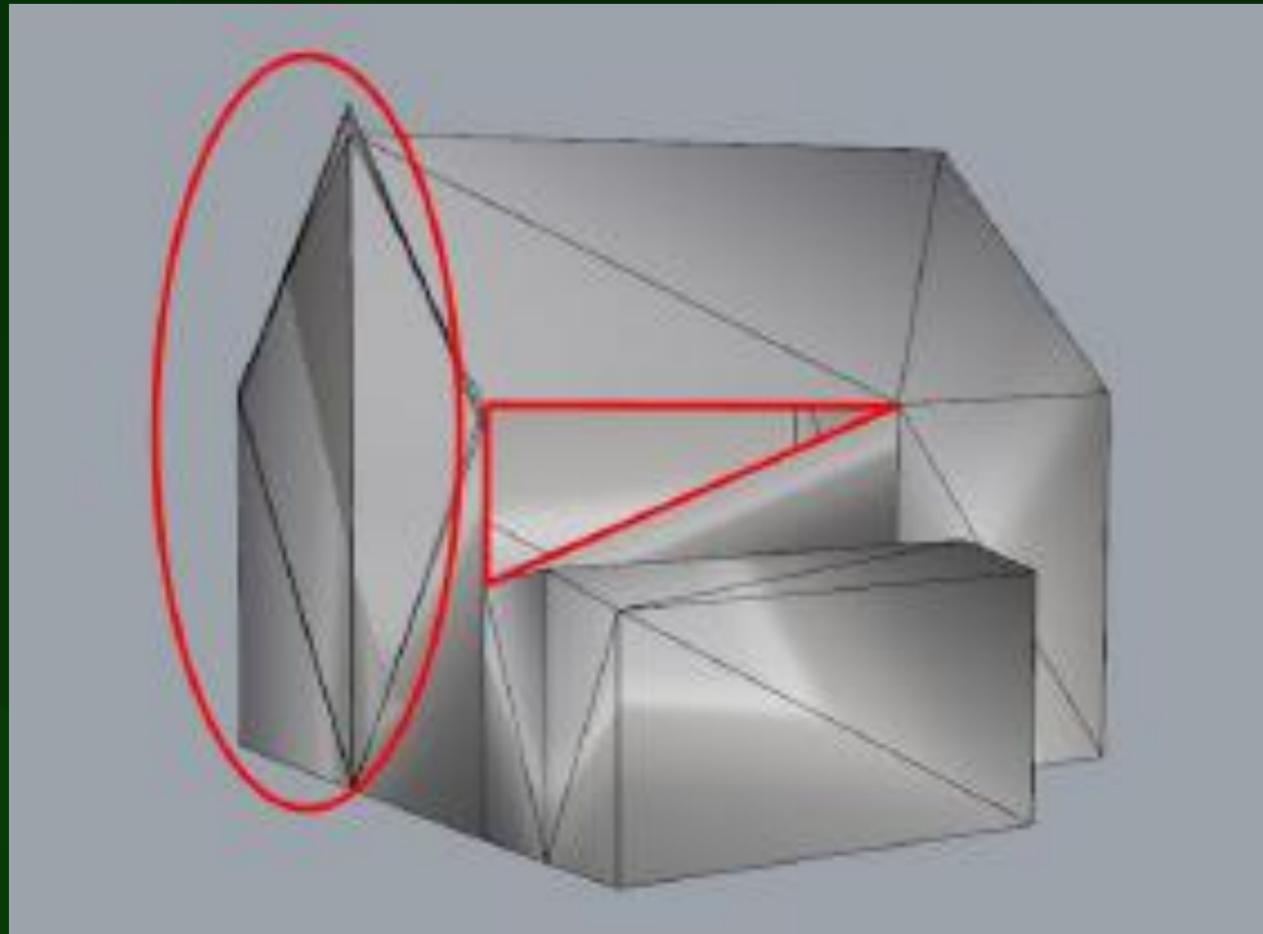


(d) Pressing result

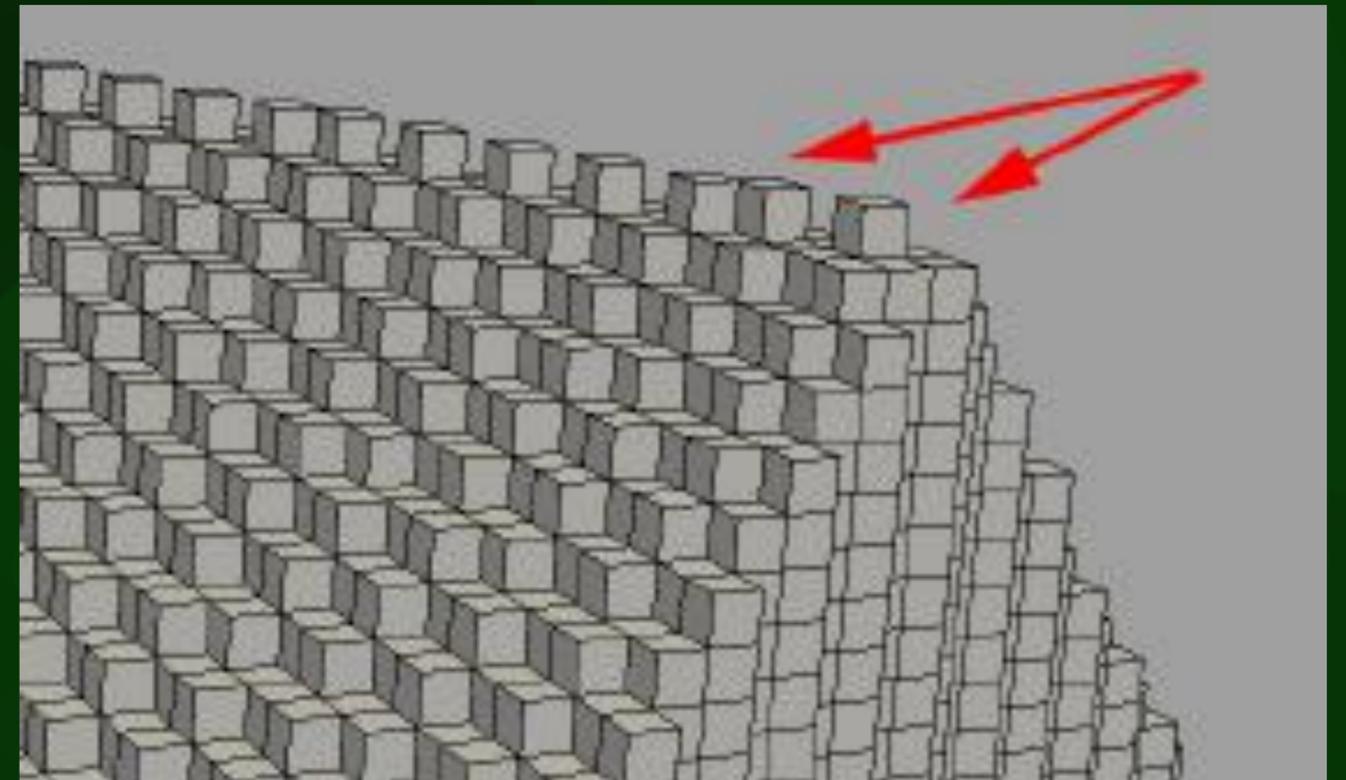
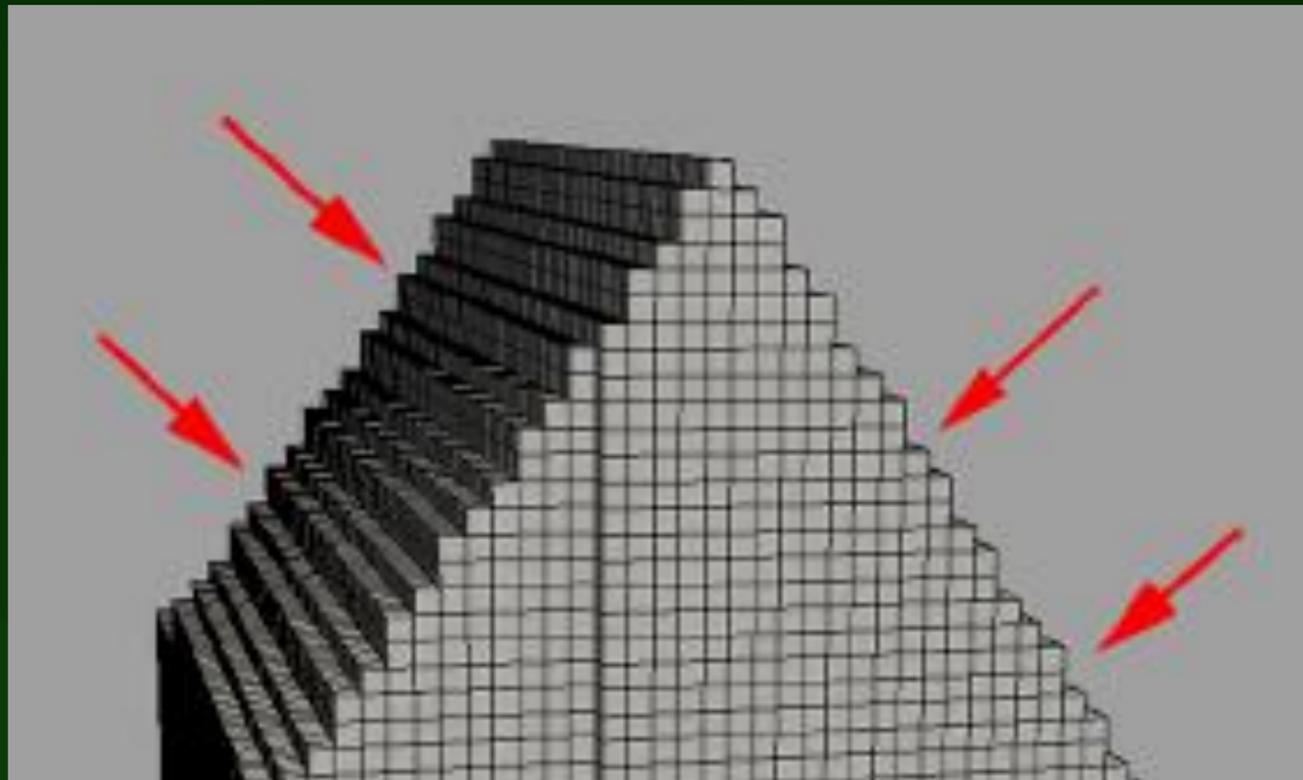
# Results



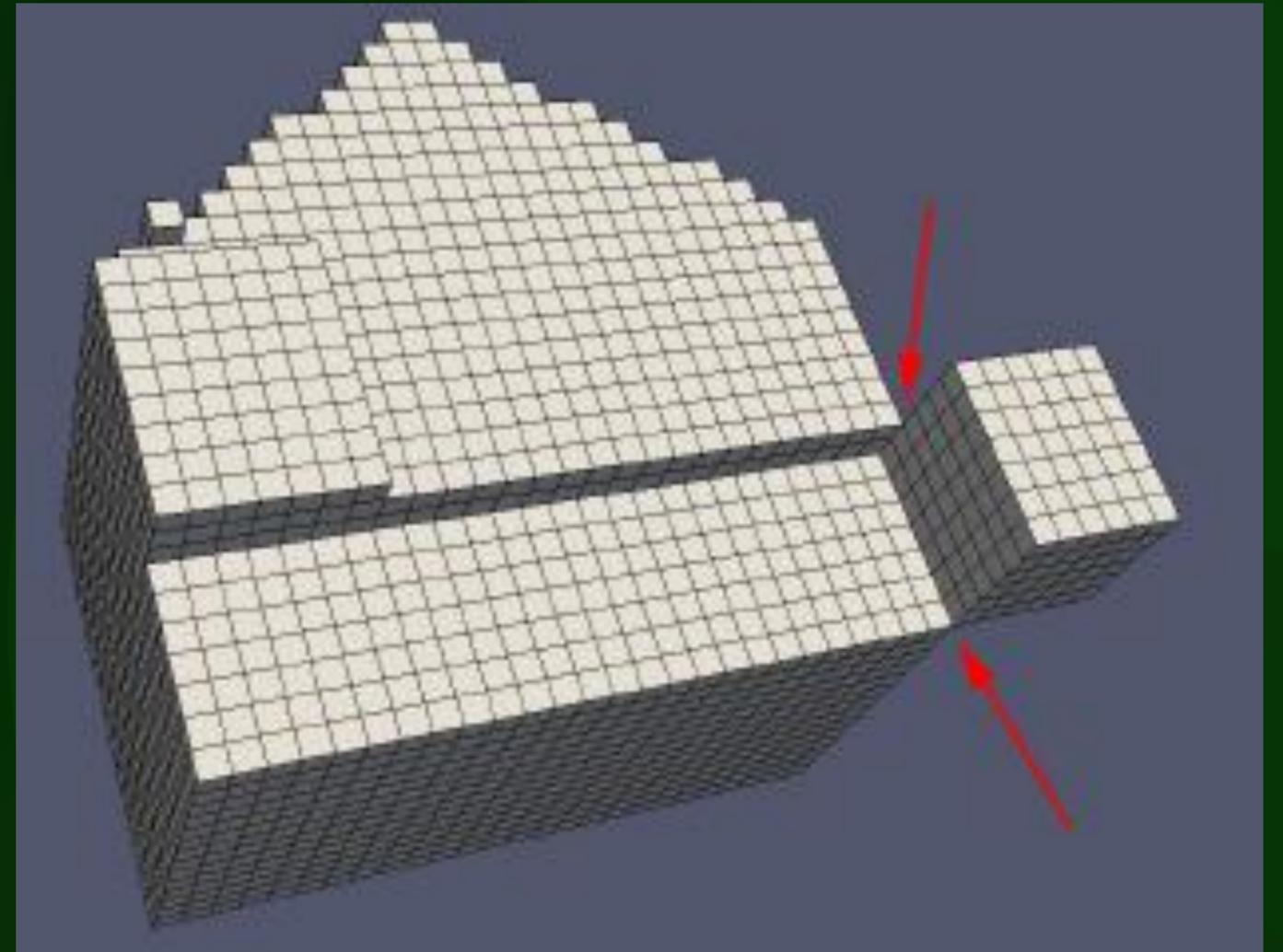
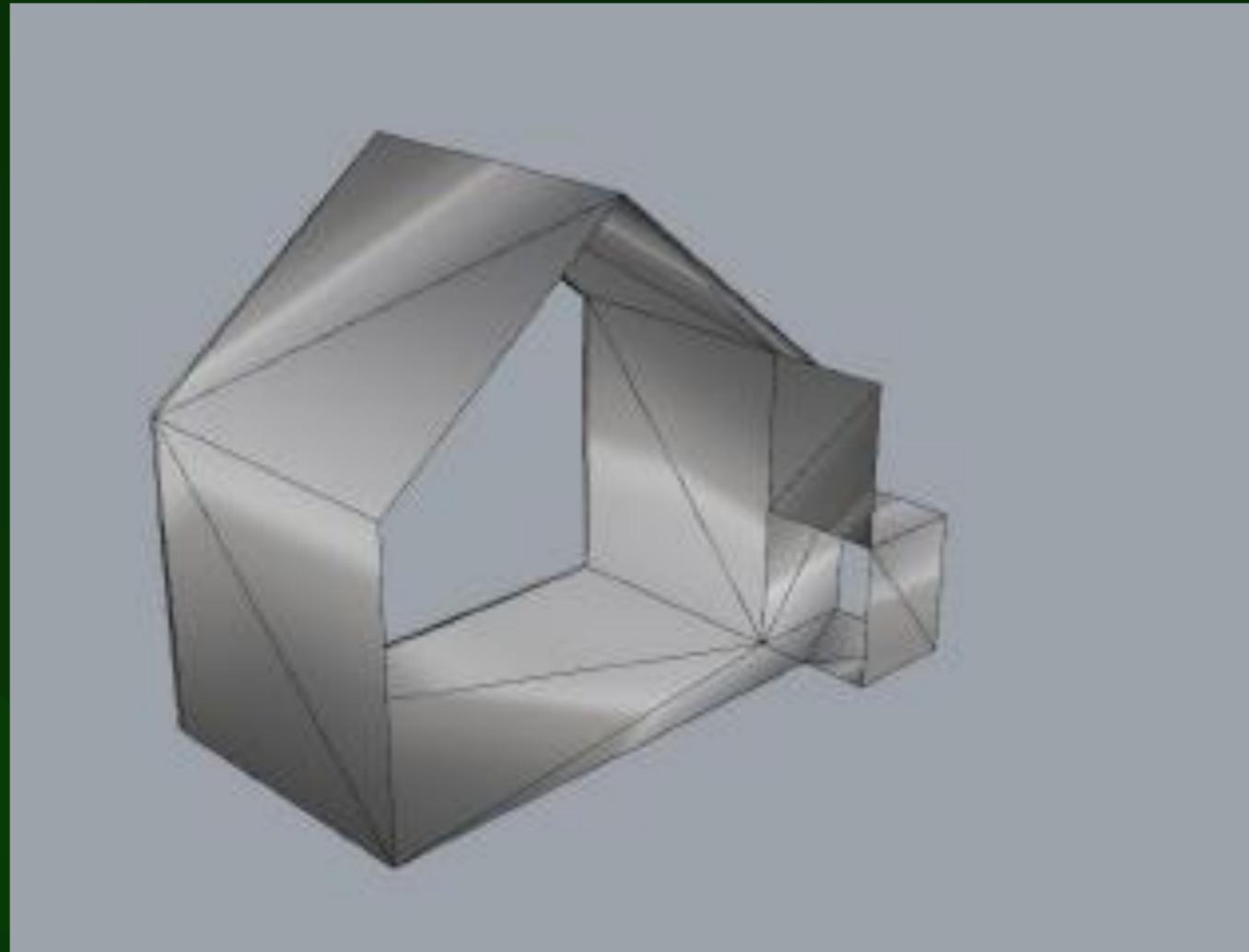
# Results



# Artefacts

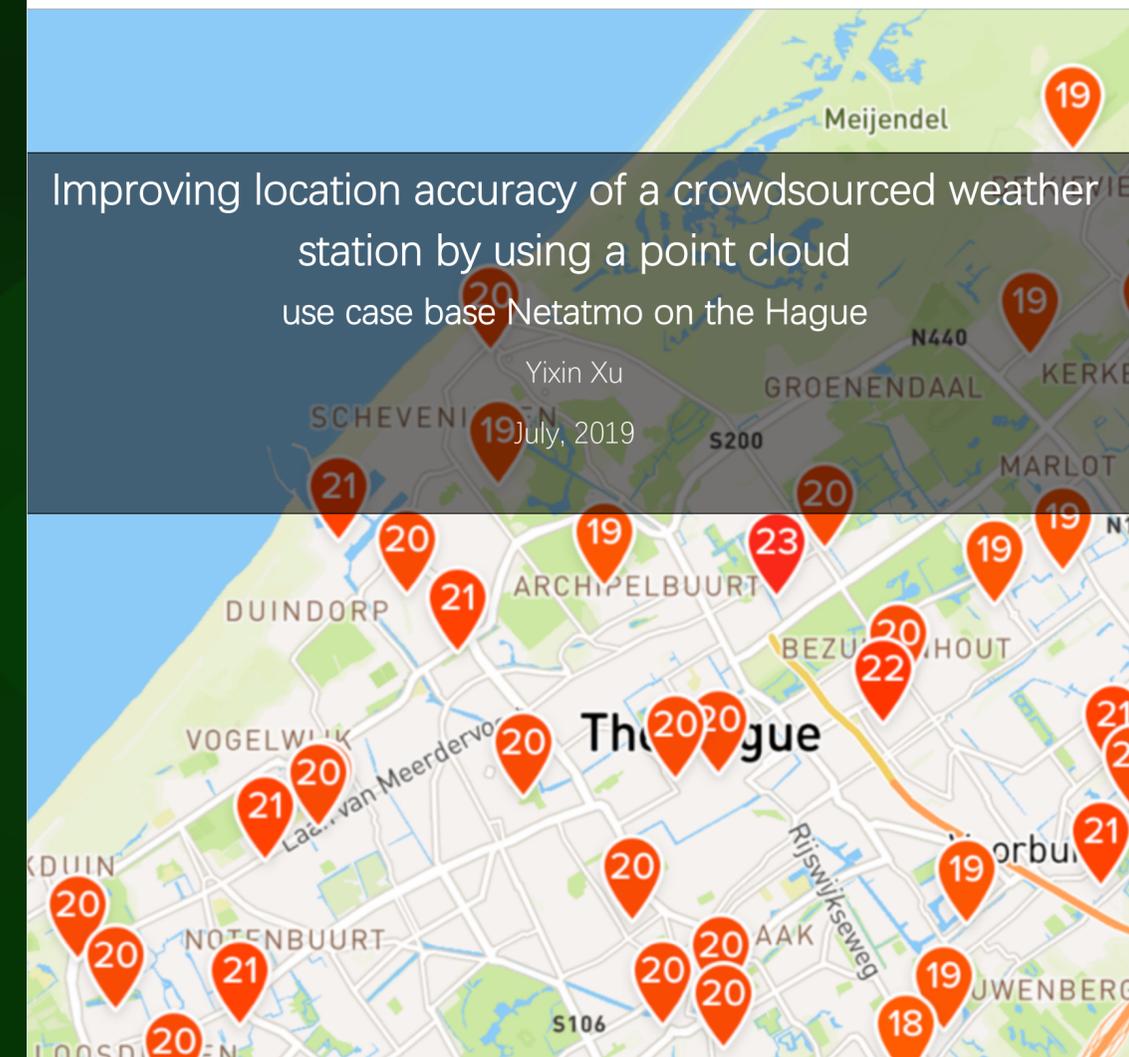


# Results

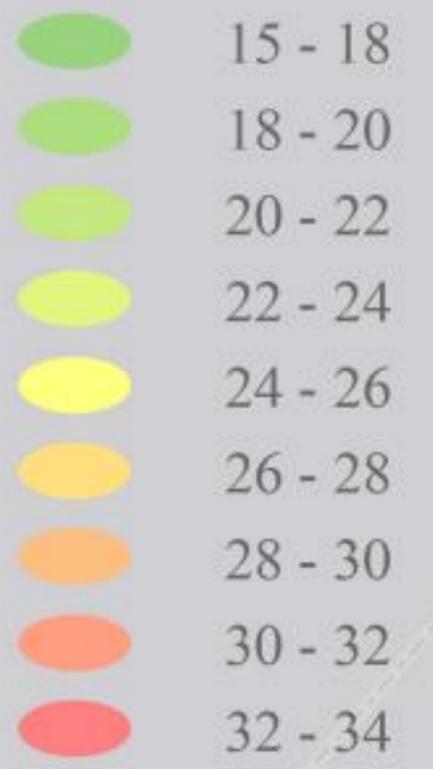


- Motivation: improving the accuracy of the location of personal weather stations for urban heat island research
- Generate potential locations
- Evaluate them through skyview + solar modelling

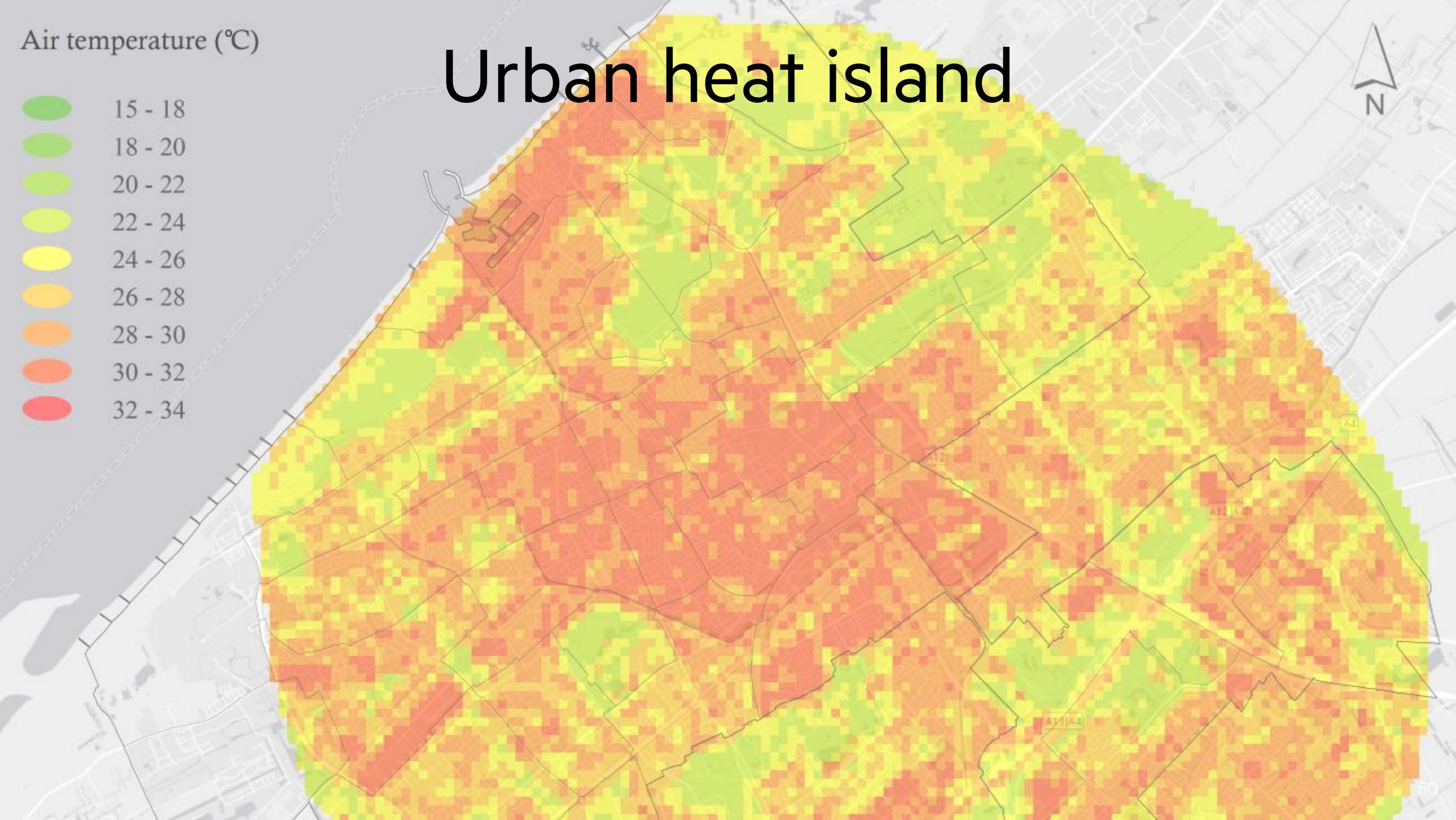
Improving location accuracy of a crowdsourced weather station by using a point cloud  
use case base Netatmo on the Hague



Air temperature (°C)



# Urban heat island



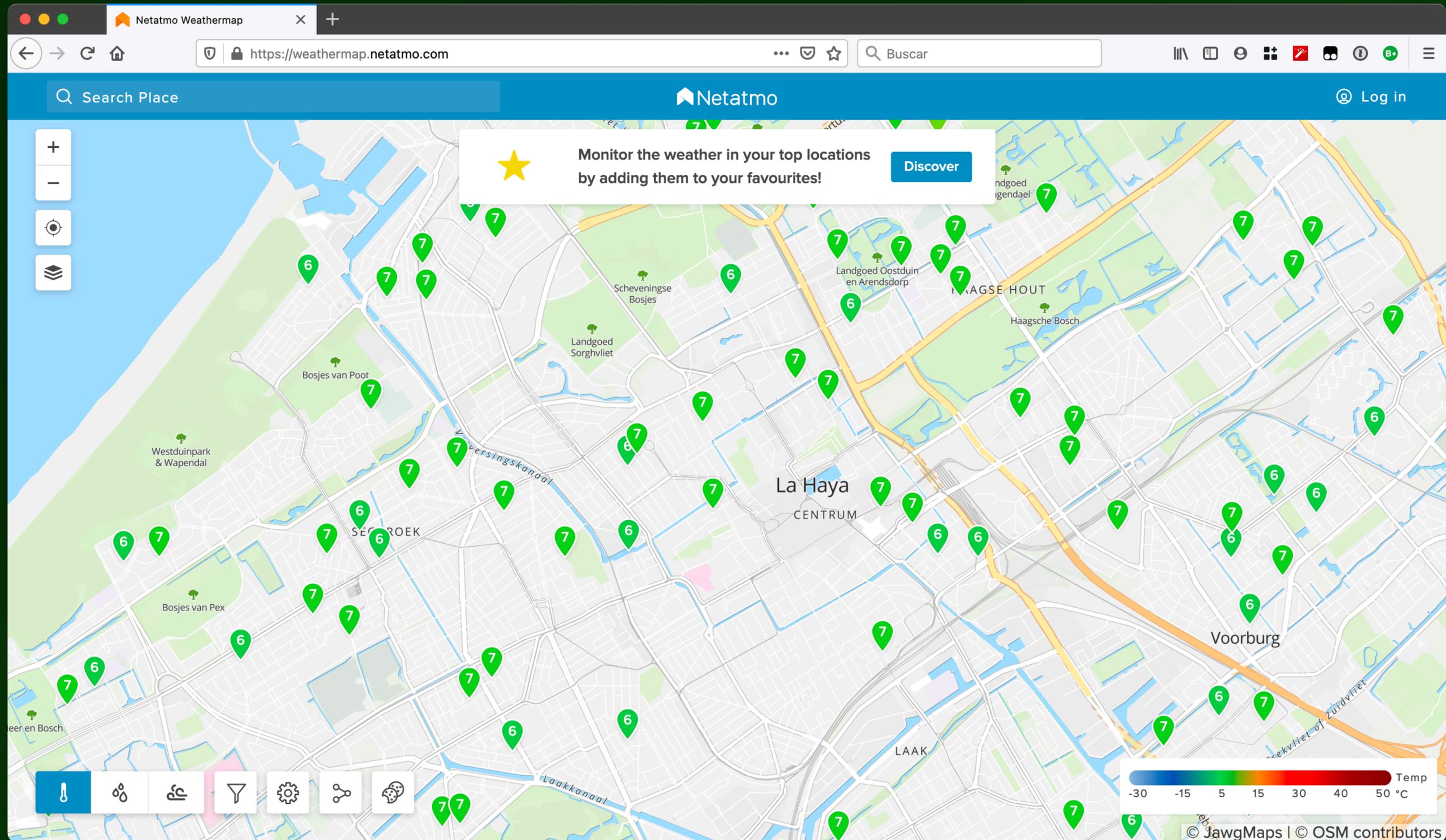
# Traditional weather stations



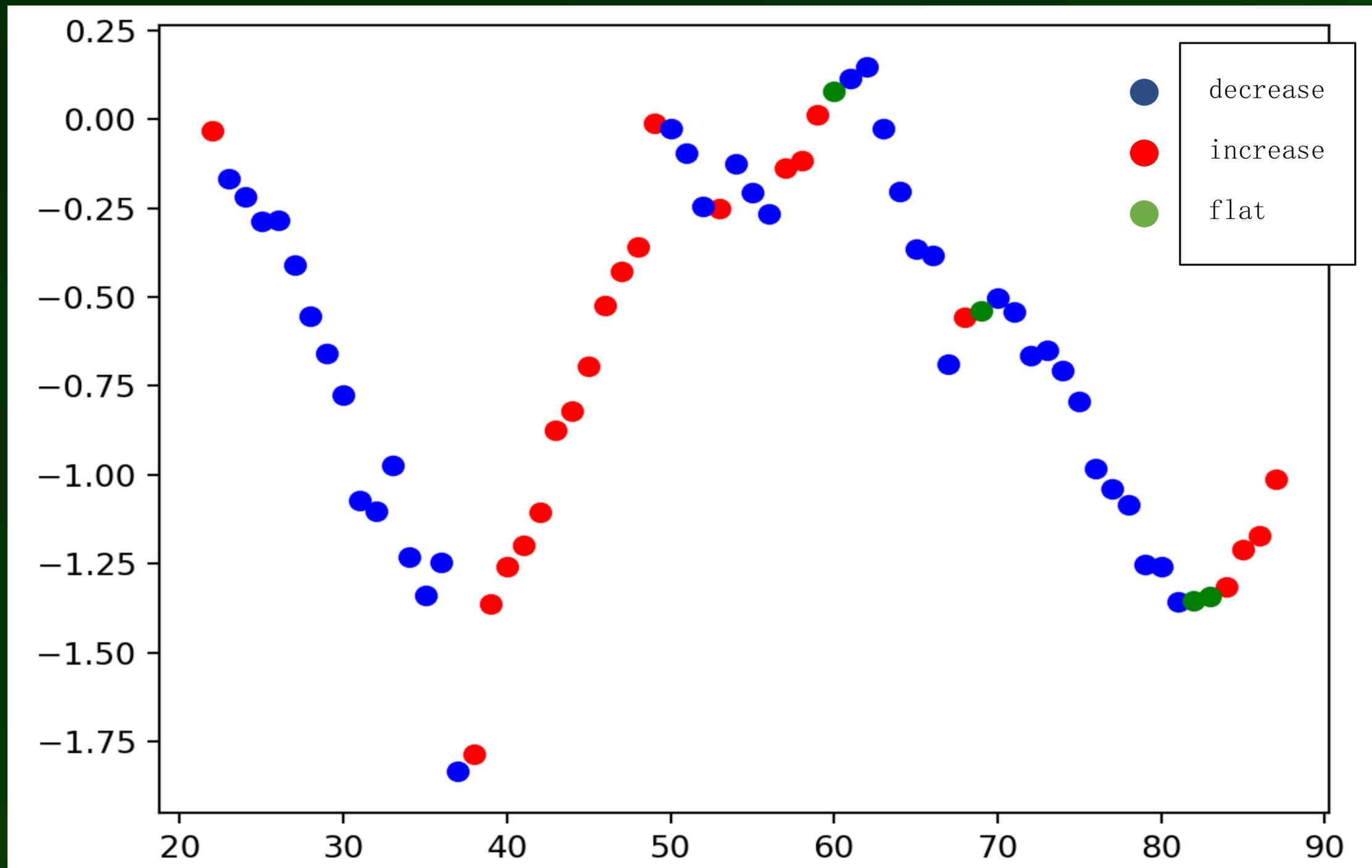
# Personal weather stations



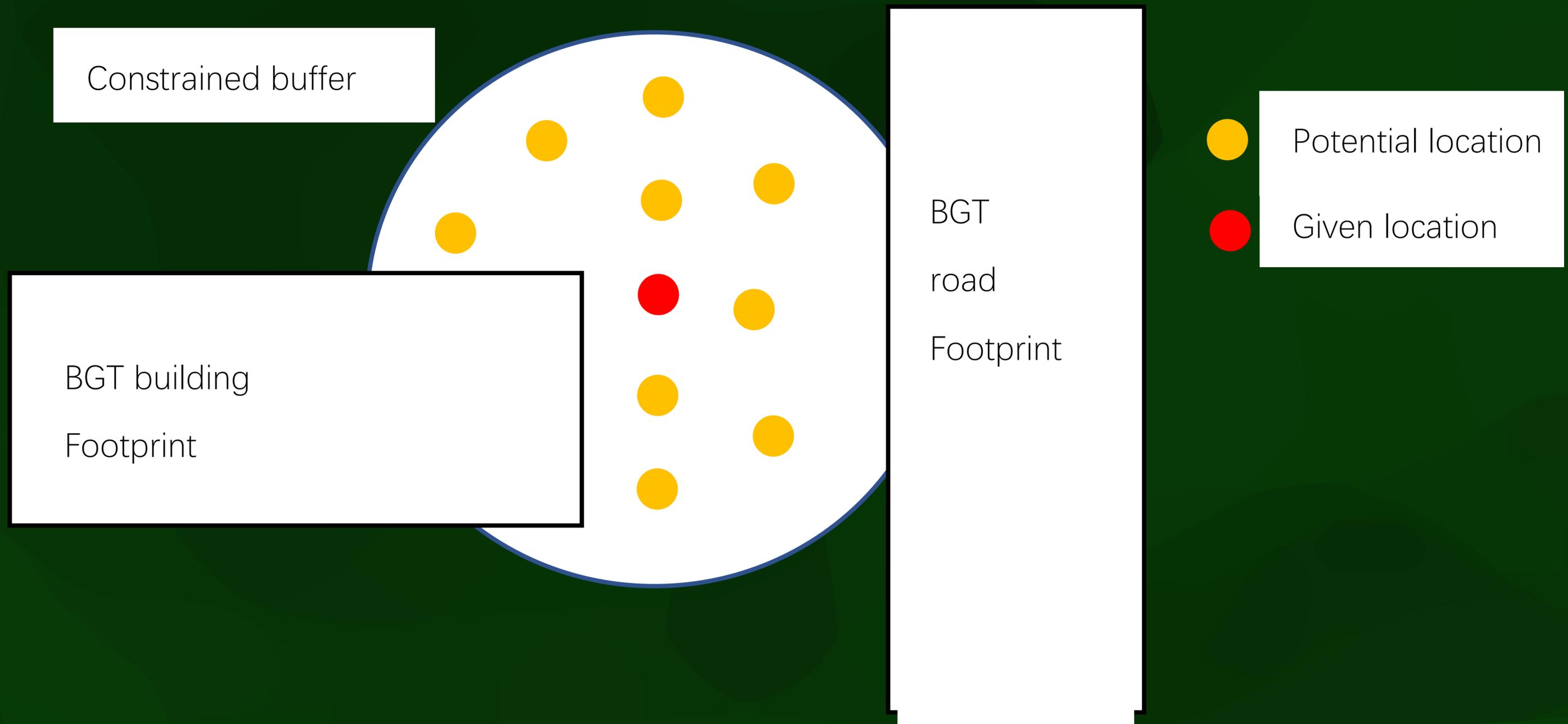
# Crowdsourced weather data



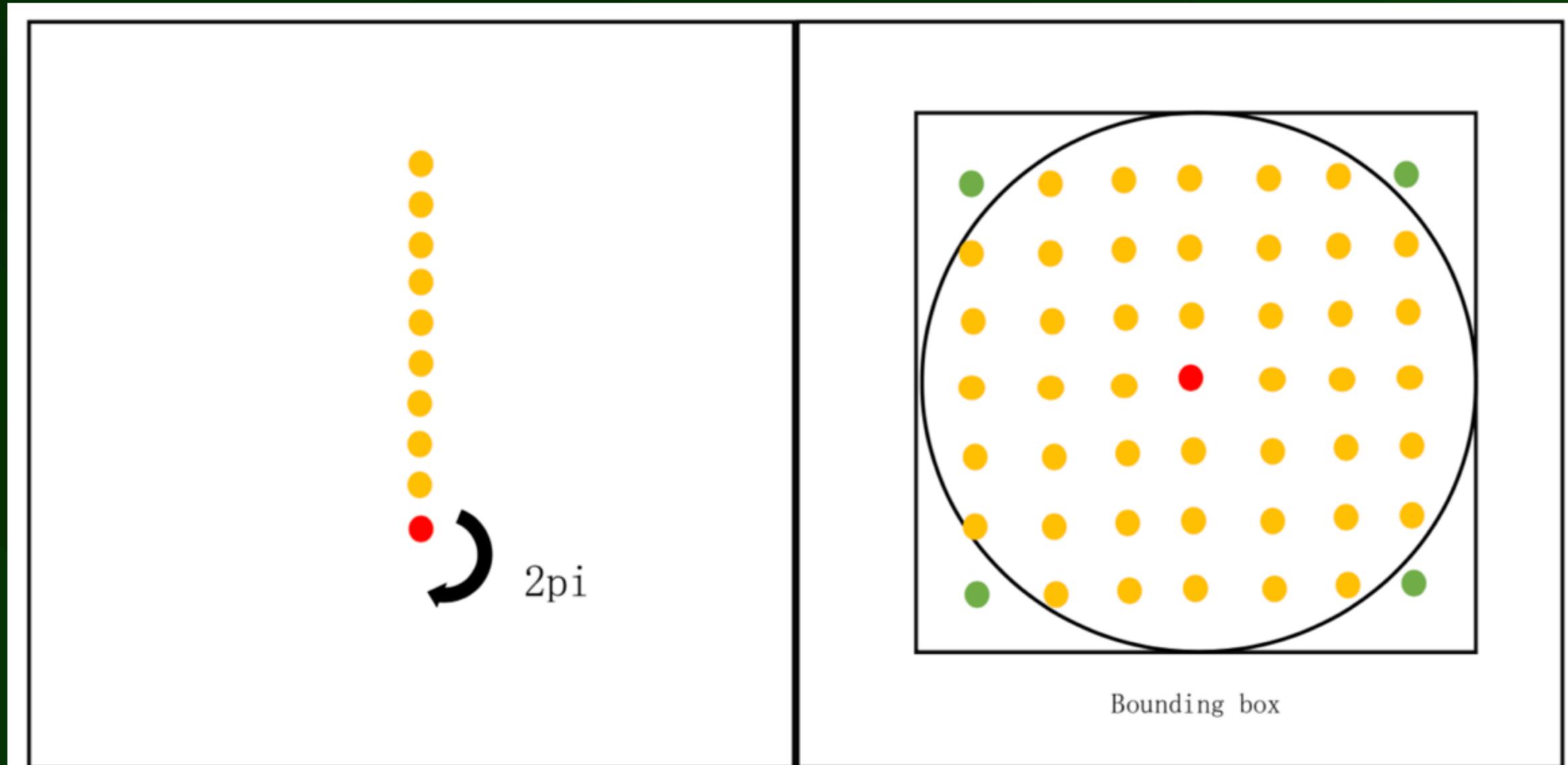
# Behaviour



# Potential locations

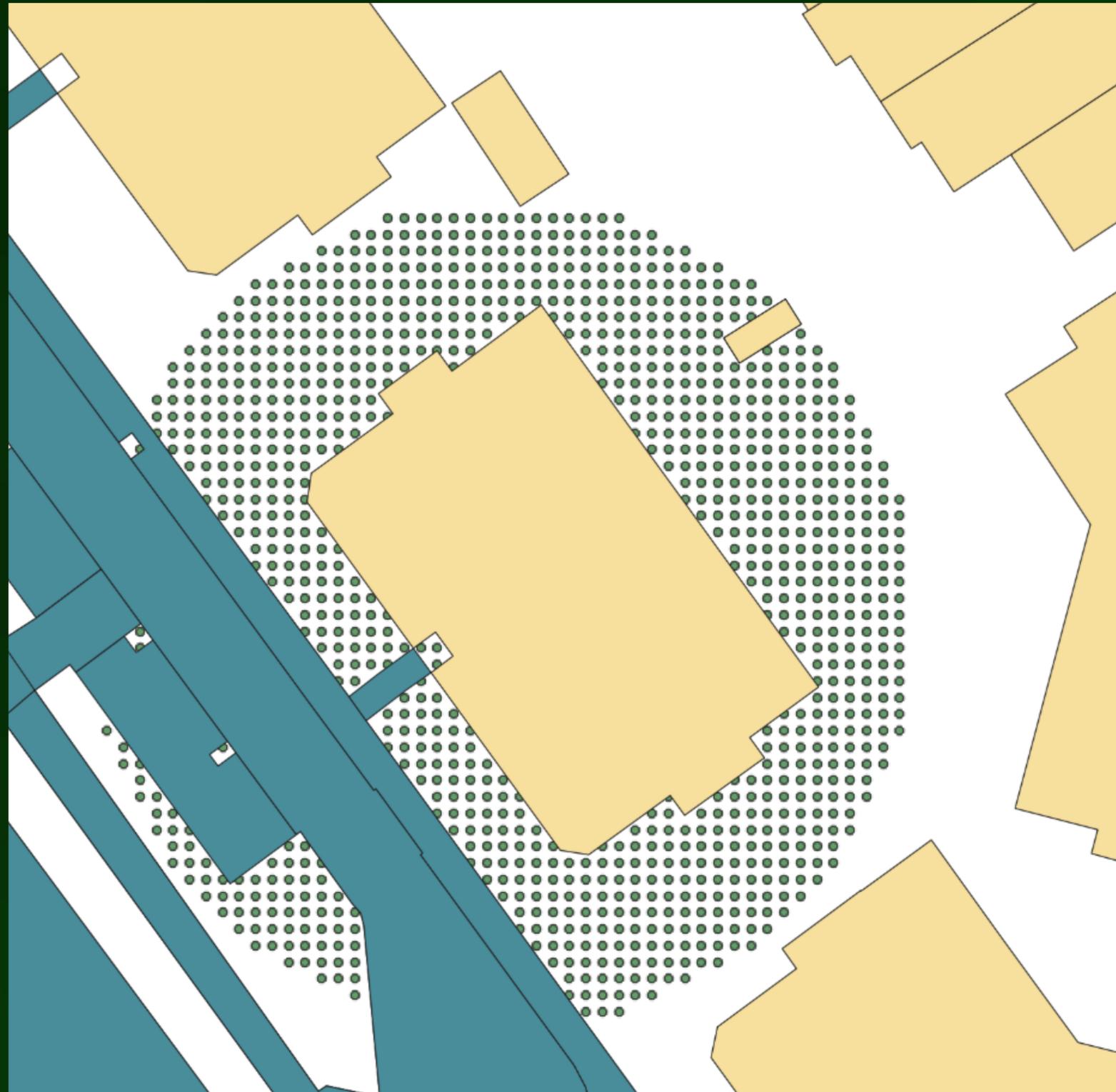


# Potential locations

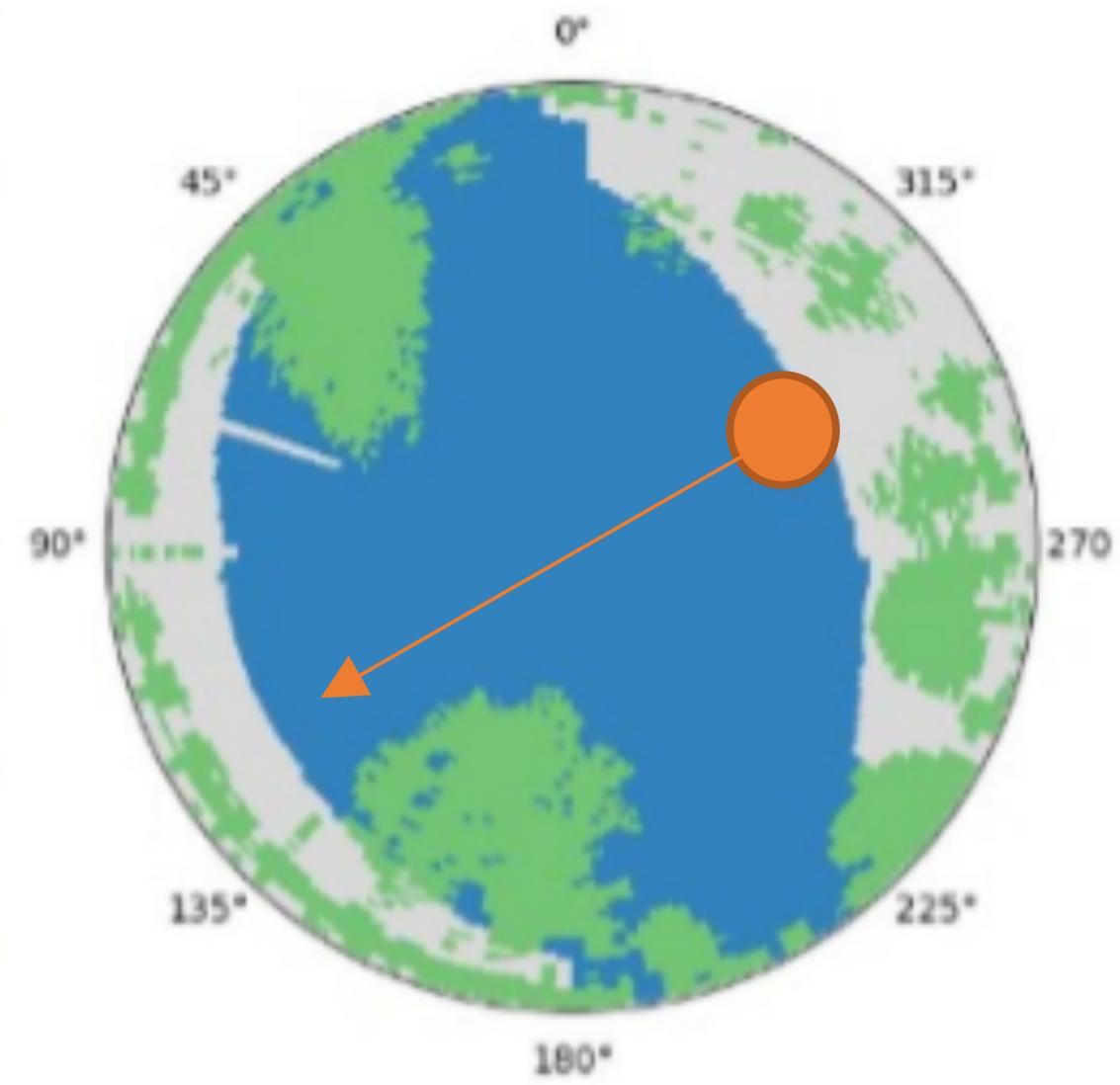
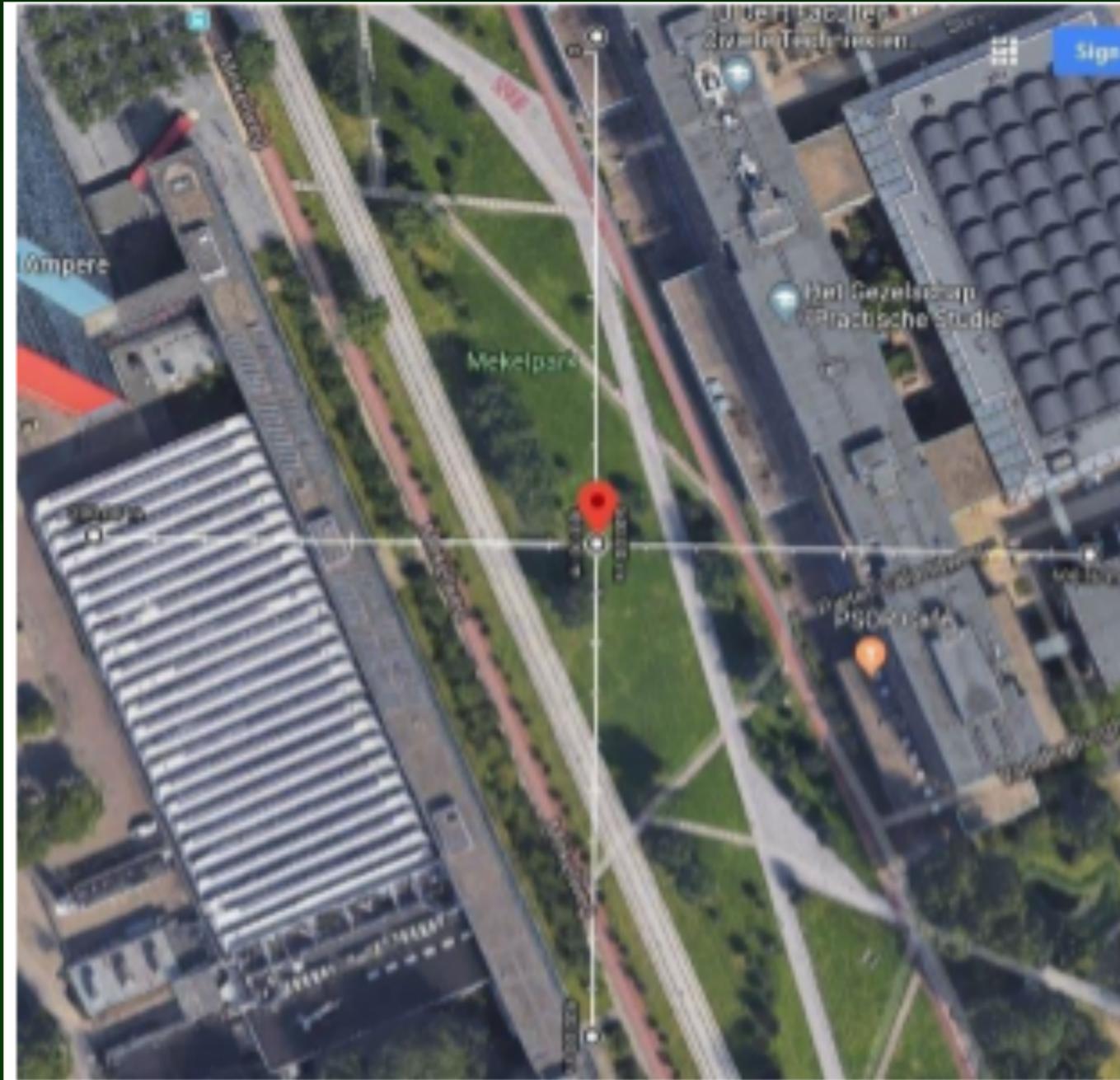


- Clipped point
- Generating point
- Initial point

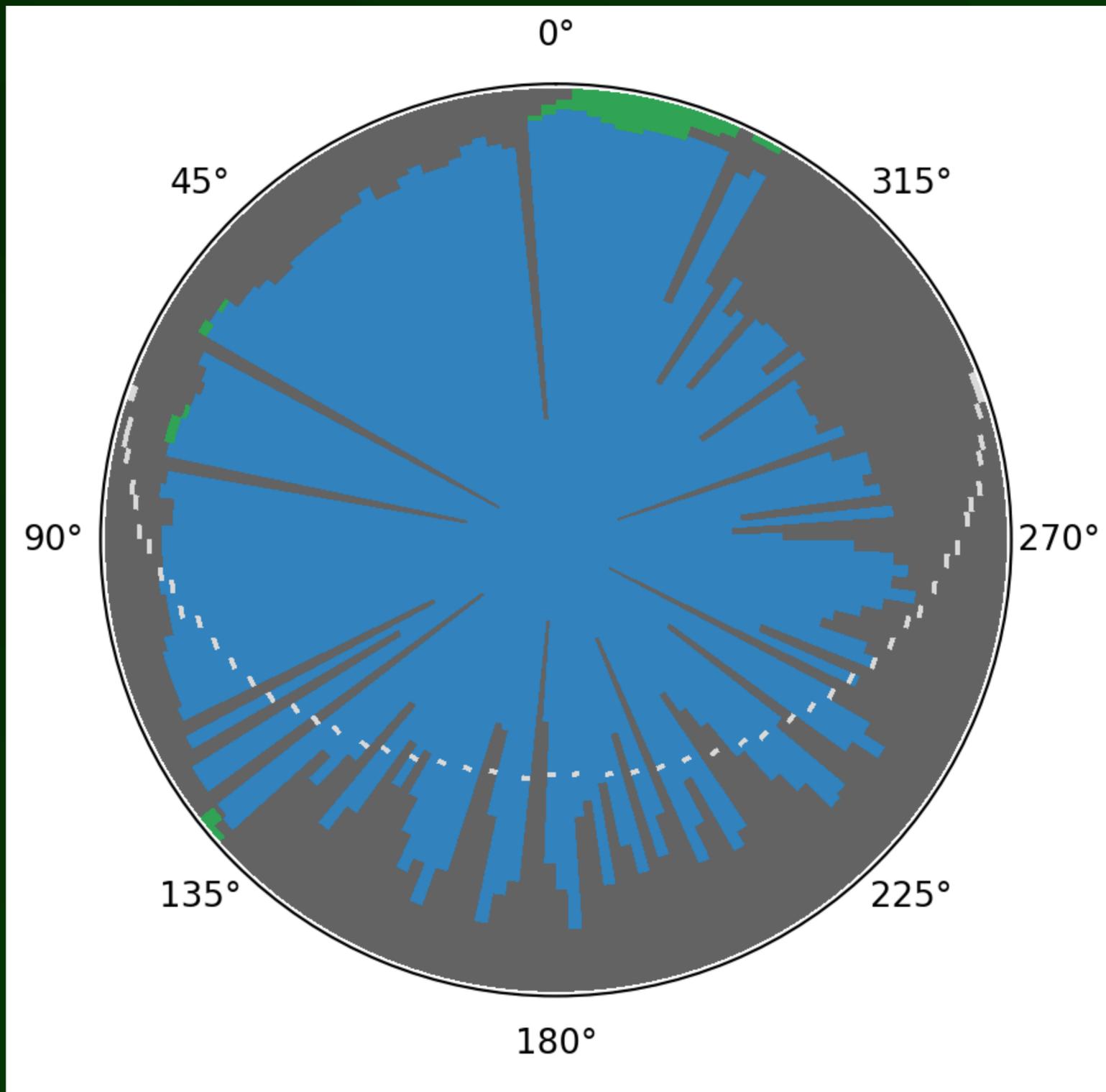
# Potential locations



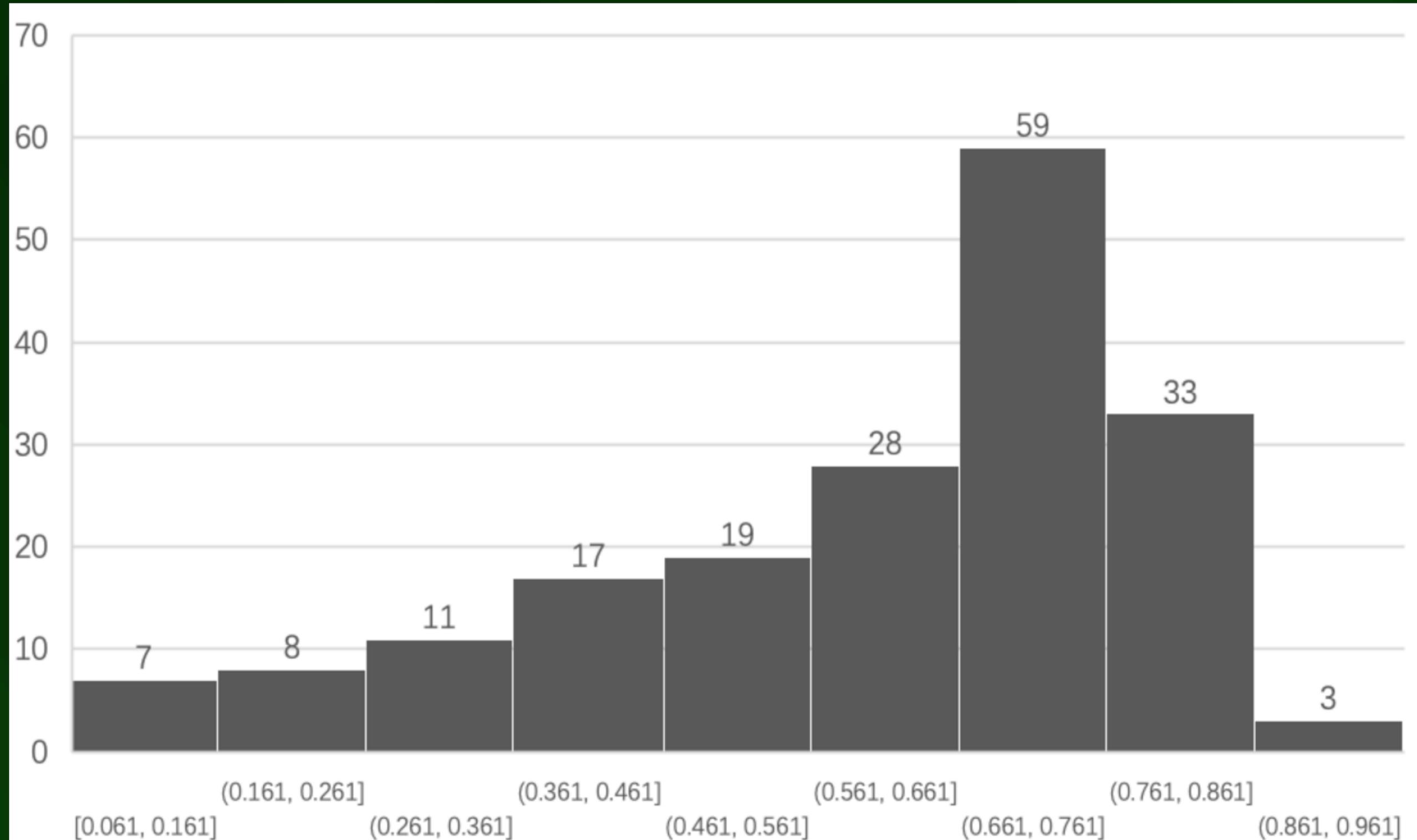
# Skyview computation



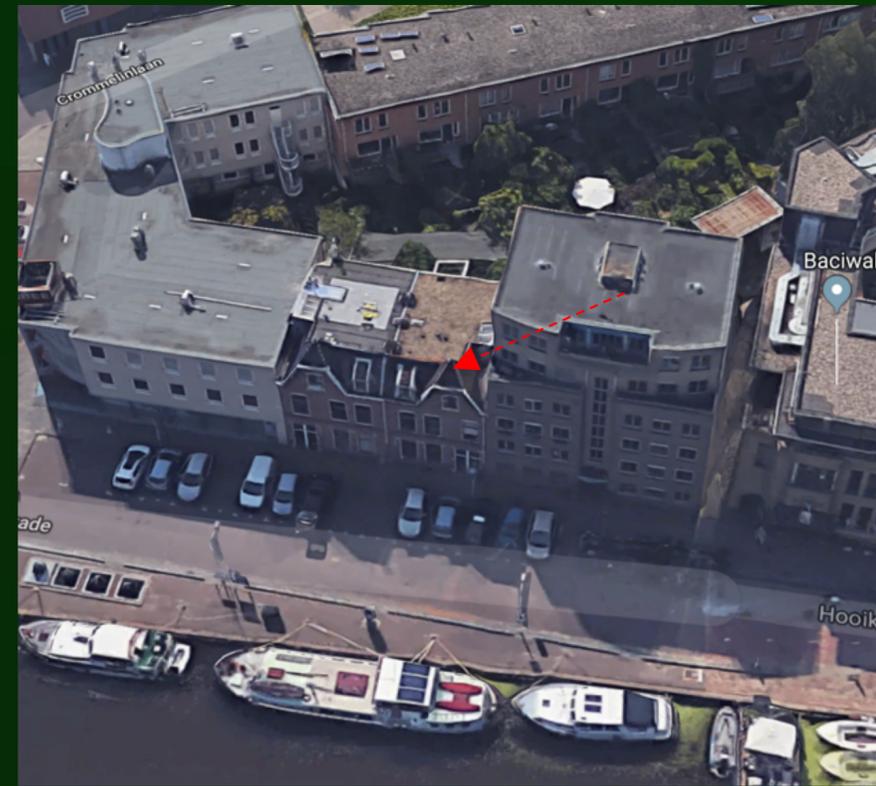
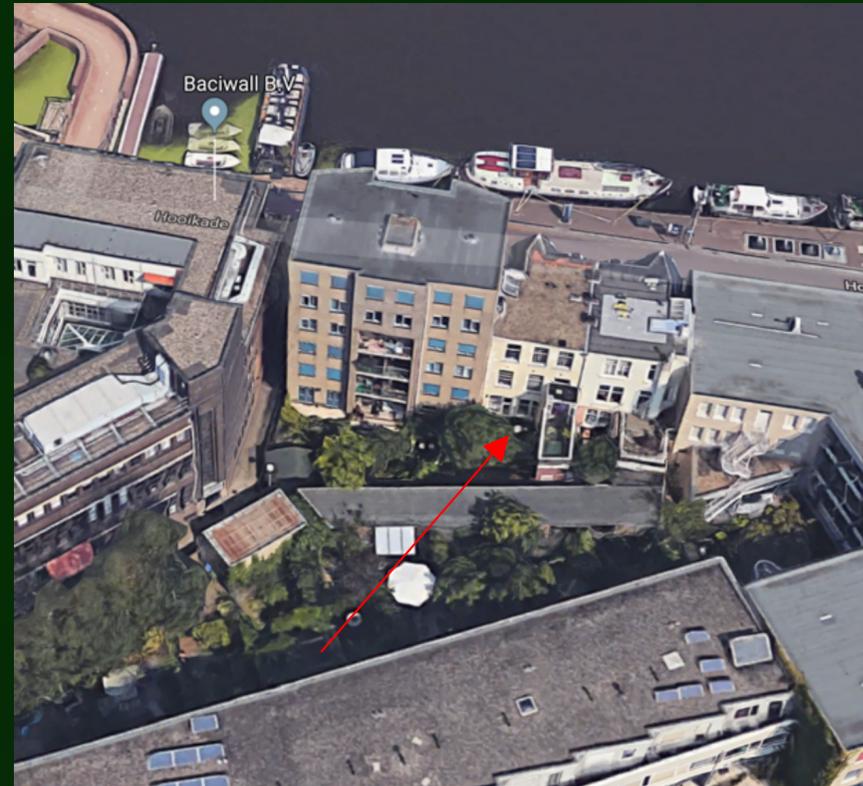
# Analysis



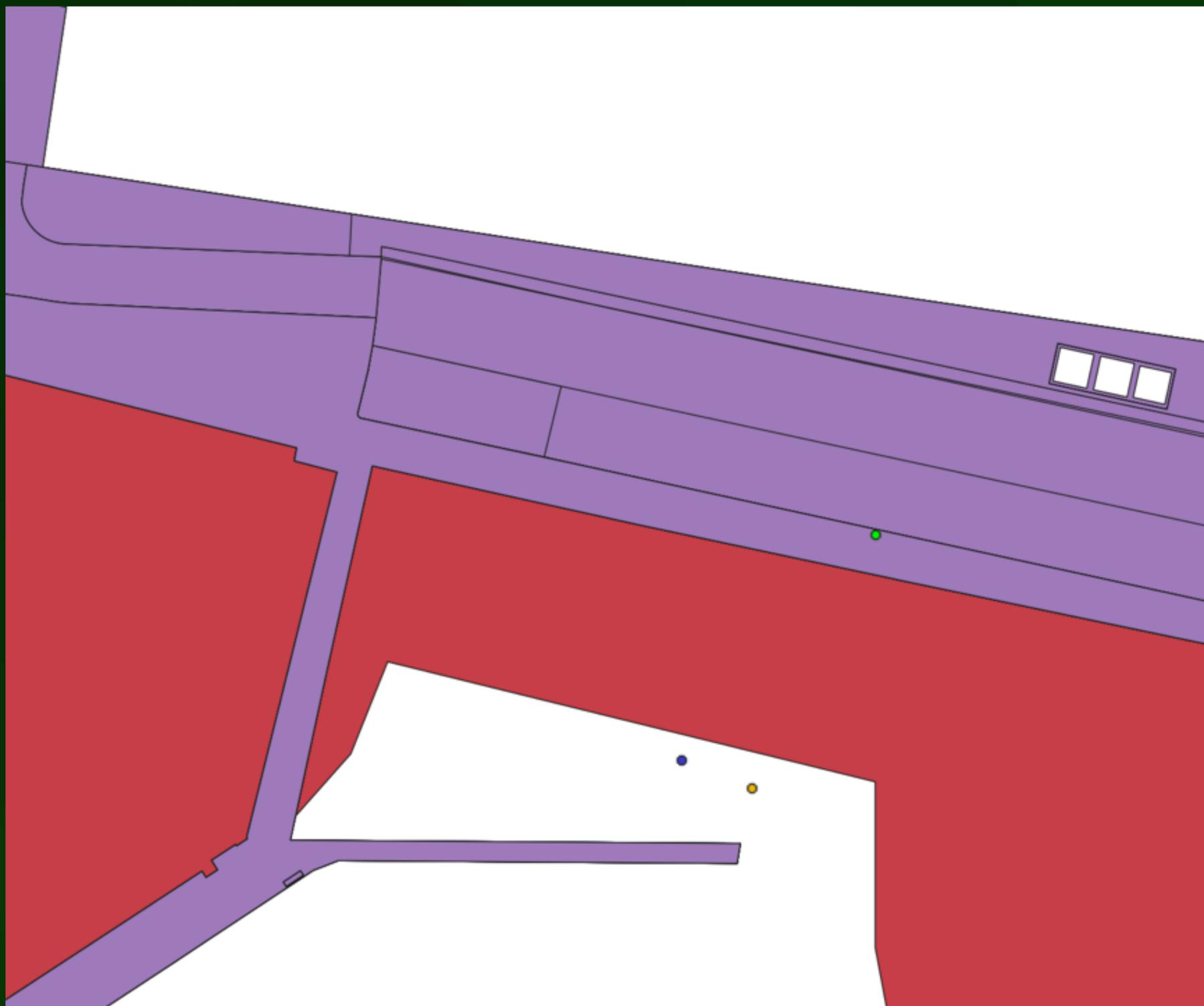
# Results



# Experiment



# Experiment



- Motivation: automate some (simple) building permit checks using a 3DCM
- Formalisation of regulations
- Store necessary data in CityJSON extension
- Automate some checks (car + bicycle parking)

MSc thesis in Geomatics

## Automatic building permits checks by means of 3D city models

Jialun Wu  
2021



# Formalisation of regulations

For residential buildings:

BUH40 = Count BU (function. "home")

AND (A(BU) 40 m2)

BUH40-65 = Count BU (function. "home")

AND (40 A(BU) 65 m2)

BUH65-85 = Count BU (function. "home")

AND (65 A(BU) 85 m2)

BUH85 = Count BU (function. "home")

AND (85 m2 A(BU))

Rules (must be true)

IF BU(function) = "home" THEN

MinNPP = (BUH40\*2) + (BUH40-65\*3)

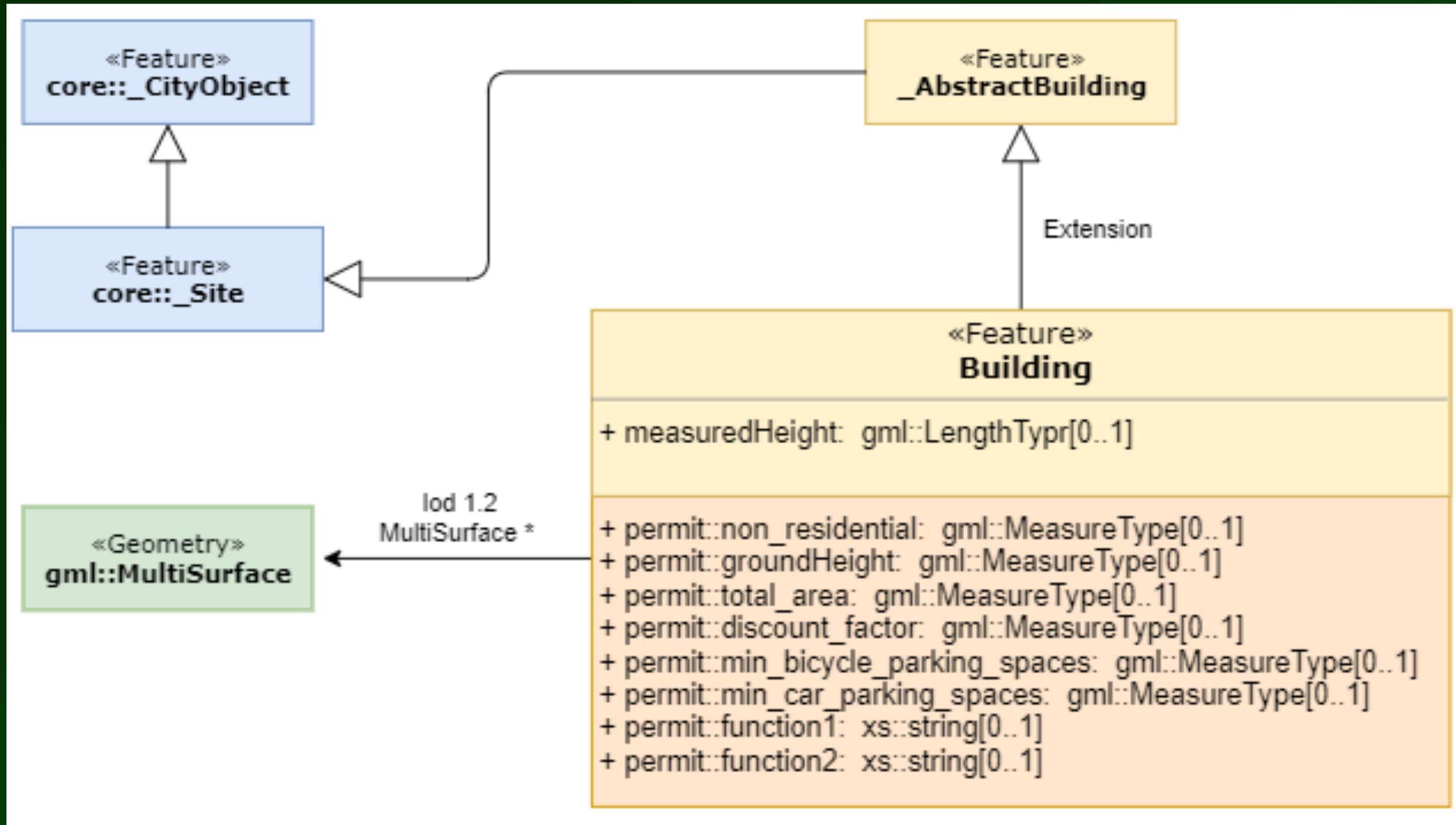
+ (BUH65-85\*4) + (BUH85\*5)

NewParkings  $\geq$  sum(MinNPP) + sum((MinMQPP / parkingArea))

# New attributes to store

	Information	Explanation	Sources	name in sources
7*Attributes	id	Bag id of building	BAG	identificatie
	+function	Function of buildings included in codelist	BAG	NR_XXX (different functions)
	+groundHeight	Elevation above sea level at the ground level	3D BAG	ground-0.00
	measuredHeight	Elevation above sea level at rooflevel	3D BAG	roof-0.75
	+zone	Zone where the building is located	Digital map	zone
	+height_valid	Indicate the height is valid	3D BAG	height_valid
	+total_area	Gross floor area (GFA) of building	BAG	Calculation results on different attributs
2*Geometry	type	geometry type of buildings	BAG	type
	coordinates	a lists contain [x,y,z] 3D coordinates	BAG	coordinates

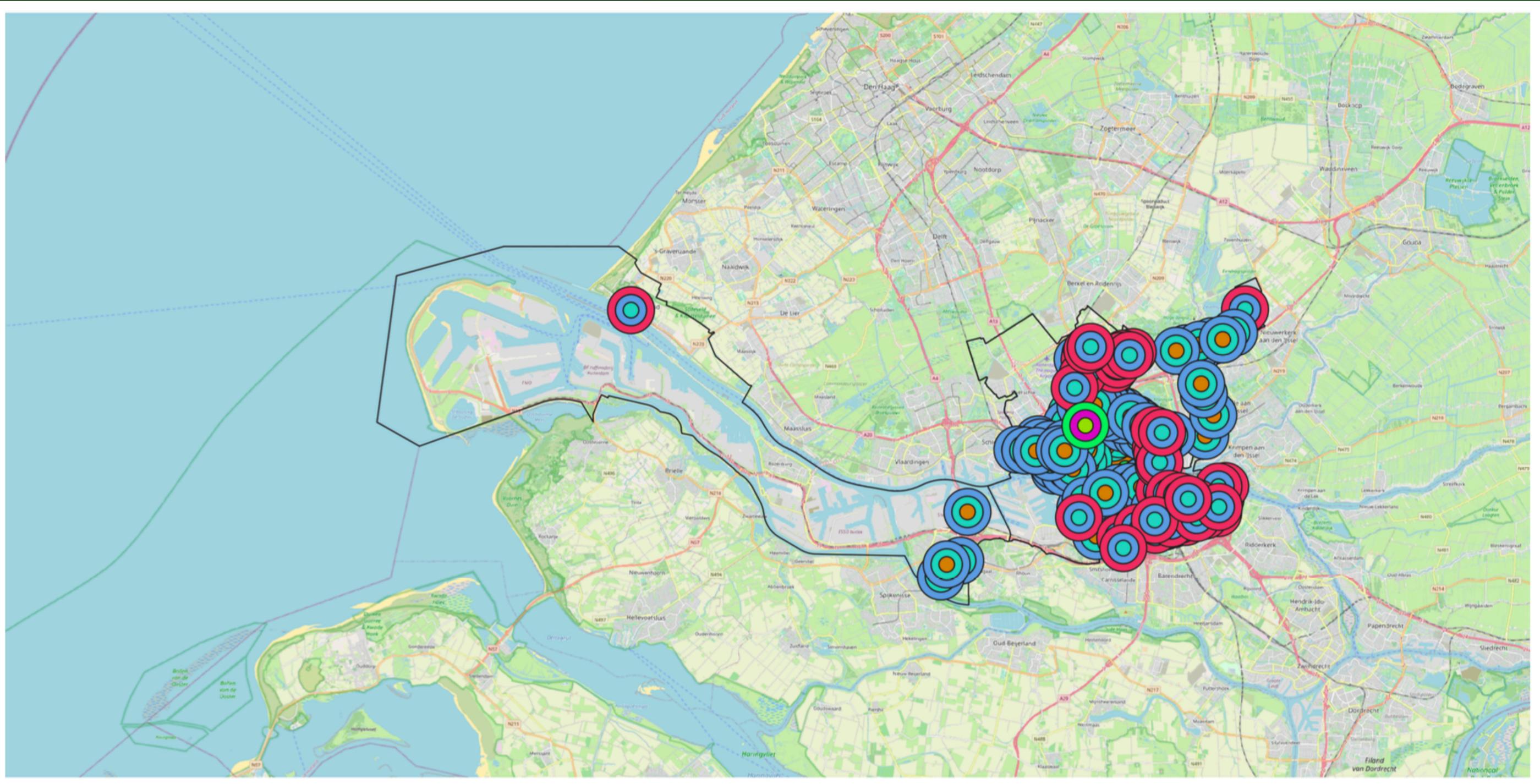
# CityJSON extension



# CityJSON extension

```
"68": {  
  "type": "Building",  
  "toplevel": true,  
  "attributes": {  
    "+height_valid": 1,  
    "+non_residential": 1,  
    "+groundHeight": 0,  
    "measuredHeight": 28.0,  
    "+total_area": 1371.56879999999998,  
    "+discount_factor": 0.95,  
    "+min_bicycle_parking_spaces": 117,  
    "+min_car_parking_spaces": 78,  
    "+function": "catering I"  
  }  
}
```

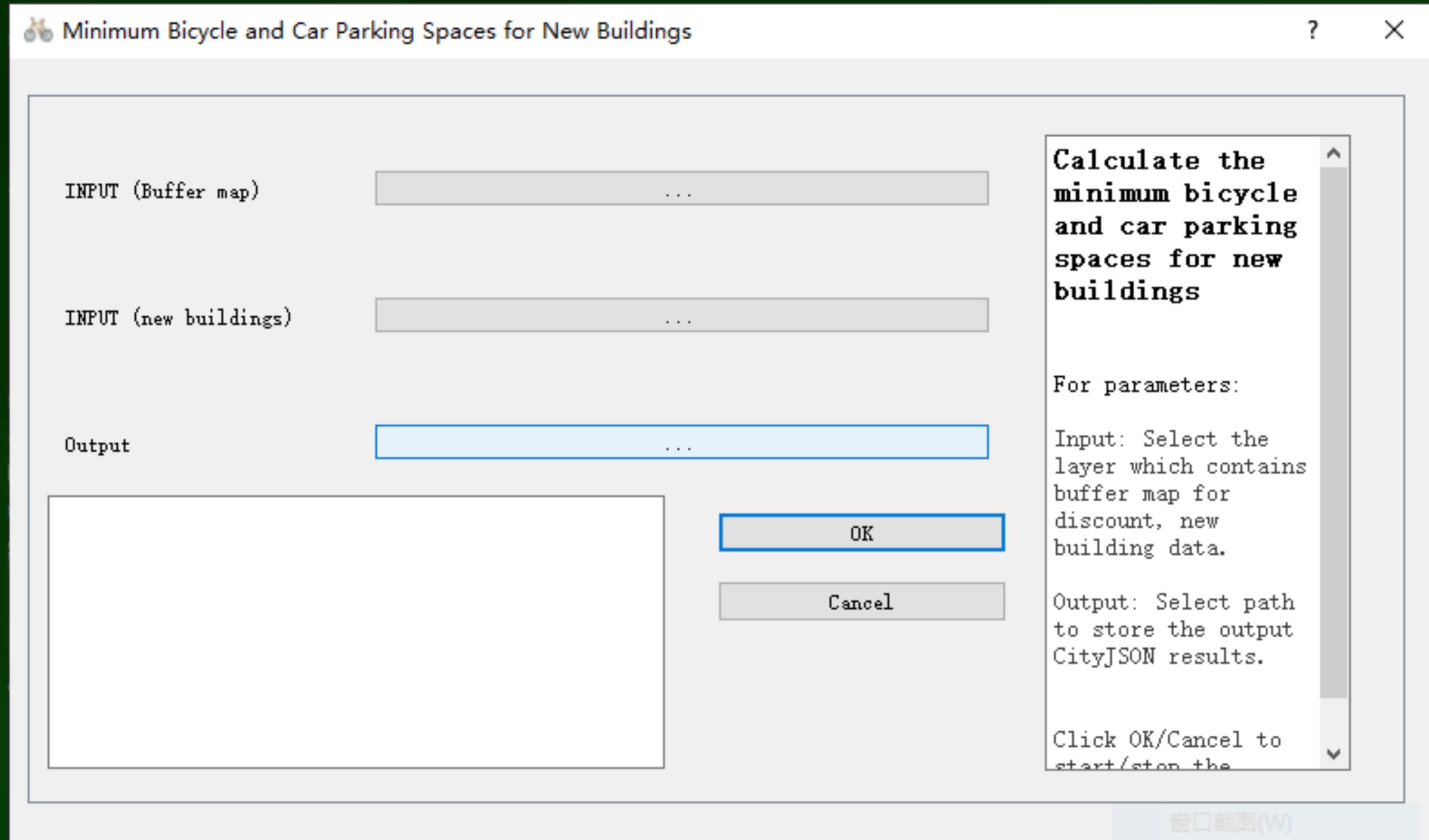
# Generating required info



# Programming checks

```
N_40 = int(f['properties']['N_40'])
N_40_65 = int(f['properties']['N_40_65'])
N_65_85 = int(f['properties']['N_65_85'])
N_85_120 = int(f['properties']['N_85_120'])
N_120 = int(f['properties']['N_120'])
if f['properties']['zone'] == 'A':
    oneb['attributes']['+min_car_parking_spaces'] = int(
        N_40 * 0.1 + N_40_65 * 0.4 + N_65_85 * 0.6 + N_85_120 * 1 +
        N_120 * 1.2)
if f['properties']['zone'] == 'B':
    oneb['attributes']['+min_car_parking_spaces'] = int(
        N_40 * 0.1 + N_40_65 * 0.5 + N_65_85 * 0.8 + N_85_120 * 1 +
        N_120 * 1.2)
if f['properties']['zone'] == 'C':
    oneb['attributes']['+min_car_parking_spaces'] = int(
        N_40 * 0.1 + N_40_65 * 0.6 + N_65_85 * 1.4 + N_85_120 * 1.6
        + N_120 * 1.8)
```

# Results: tool

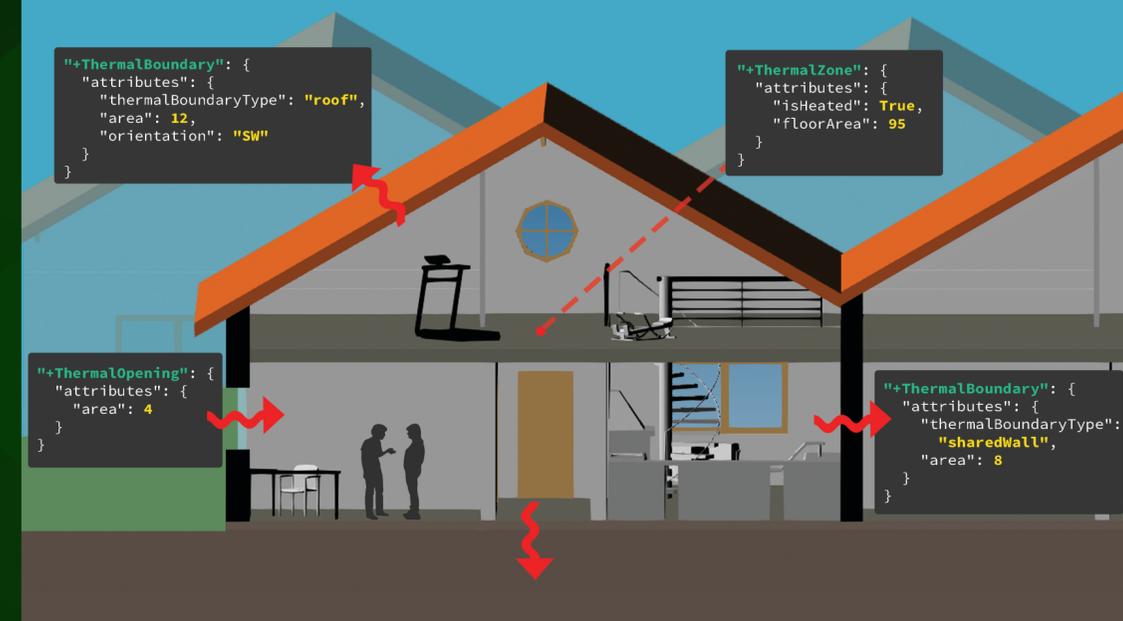


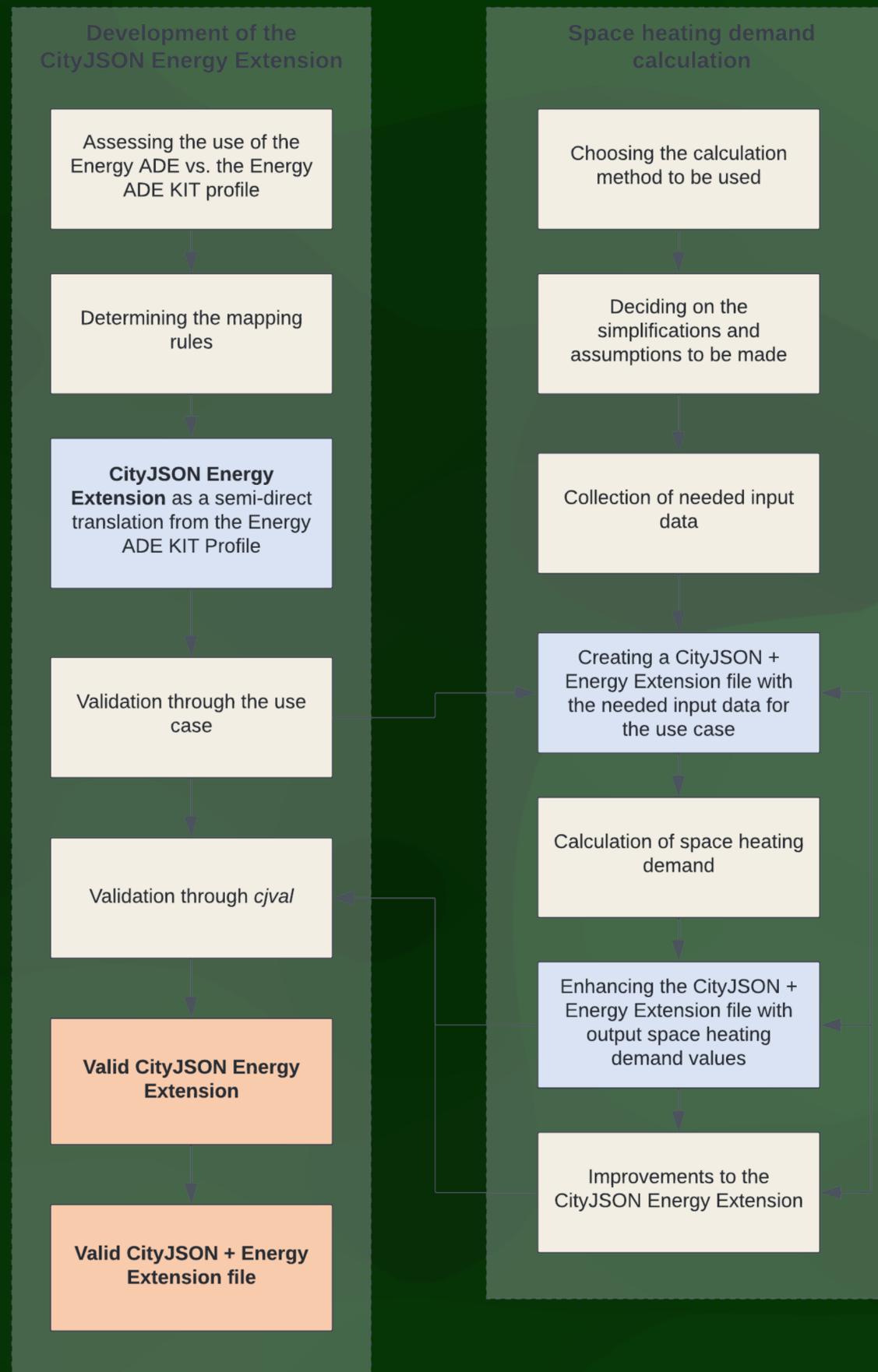
- Motivation: use 3DCM for space heating demand calculations
- Develop CityJSON extension with all required information
- Implement space heating models
- Use implementation to improve extension design

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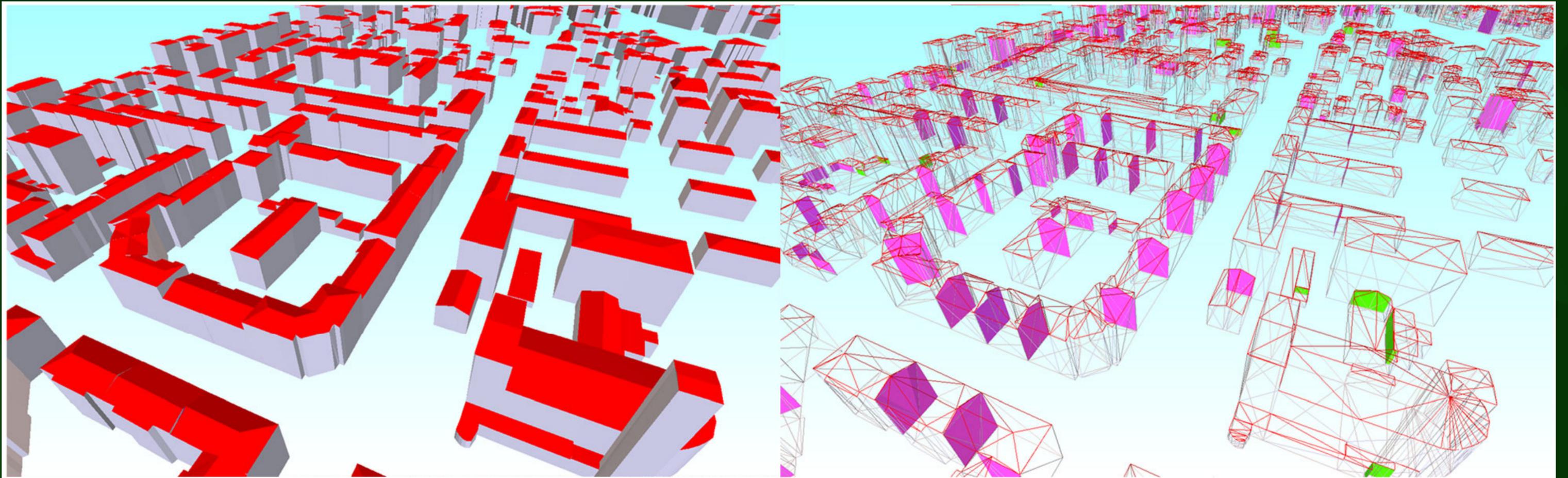
## Development and Testing of the CityJSON Energy Extension for Space Heating Demand Calculation

Özge Tufan | 2022





# Storing new (complex) geometries



# New attributes

Net internal area	Excludes internal structural elements
Class	Type of use of the building, e.g. residential, mixed-use
Function*	Further description of the class, e.g., health, business
Usage	Whether the building is still in use
Measured height	Height of the building, in <i>m</i>
Relative to terrain	Whether the building is (entirely) above or below the terrain
Roof type	E.g. slanted, single/multiple horizontal
Year of construction	Construction year of the building
Footprint area*	Footprint area, calculated from the <i>LoD0</i> geometry, in <i>m</i> <sup>2</sup>
Storeys above ground*	Number of storeys situated above ground level
Storeys below ground*	Number of storeys situated below ground level
Building name*	Unique name of the building
Is single part	Boolean value to show whether the building has <i>BuildingParts</i>
# of adjacent buildings	Number of topologically adjacent buildings
LoD2 volume*	Building volume, calculated from the <i>LoD2</i> geometry, in <i>m</i> <sup>3</sup>
LoD max	Maximum <i>LoD</i> present for the building
Building (pand) ID	Unique ID of the building
List adjacent buildings	Building (pand) ID of topologically adjacent buildings
Surface ID	Unique ID of the <i>BoundarySurface</i>
Parent building ID	Building (pand) ID of the building that the surface belongs to
Surface name	Unique name of the <i>BoundarySurface</i>
Azimuth	Azimuth of the surface, in <i>degrees</i>
Inclination	Inclination of the surface, in <i>degrees</i>
Direction	Direction of the surface
LoD2 area	Surface area, calculated from the <i>LoD2</i> geometry, in <i>m</i> <sup>2</sup>
Surface normal	Normal vector of the surface

# New attributes

```
"extraAttributes": {  
  "Building": {  
    "+buildingType": {...},  
    "+constructionWeight": {...},  
    "+volume": {...},  
    "+floorArea": {...},  
    "+heightAboveGround": {...}  
  }  
}
```

```
"Build1": {  
  "type": "Building",  
  "geometry": [...],  
  "attributes": {  
    "+buildingType": "singleFamily",  
    "+constructionWeight": "heavy",  
  }  
}
```

# New City Objects

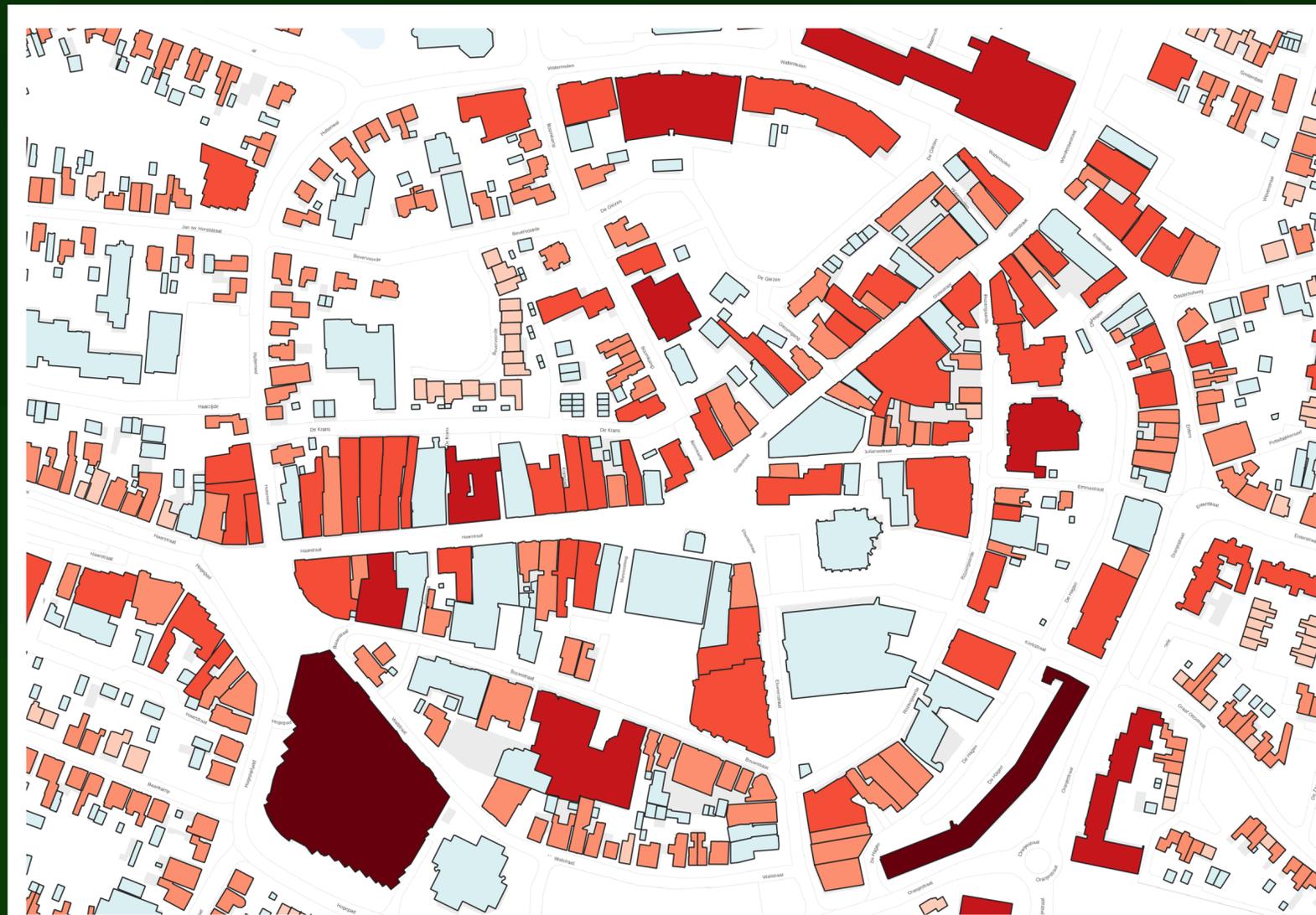
```
"extraCityObjects": {
  "+WeatherData": {
    "type": "object",
    "properties": {
      "type": {...},
      "attributes": {
        "type": "object",
        "properties": {
          "weatherDataType": {...},
          "values": {...},
          "position": {...}
        }
      }
    }
  }
  ...
}
```

```
"OutdoorTemperature": {
  "type": "+WeatherData",
  "attributes": {
    "weatherDataType": "airTemperature",
    "values": "RegularTimeSeries1",
    //ID of TimeSeries object
  }
},
"RegularTimeSeries1": {
  "type": "+RegularTimeSeries",
  "attributes": {
    "values": [2.61, 4.82, 5.91, 9.32,
              14.73, 16.12],
    ...
  }
}
```

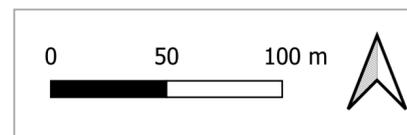
# Test data



# Results: heating energy demand



Monthly energy demand (kWh) in January



Monthly energy demand (kWh) in January



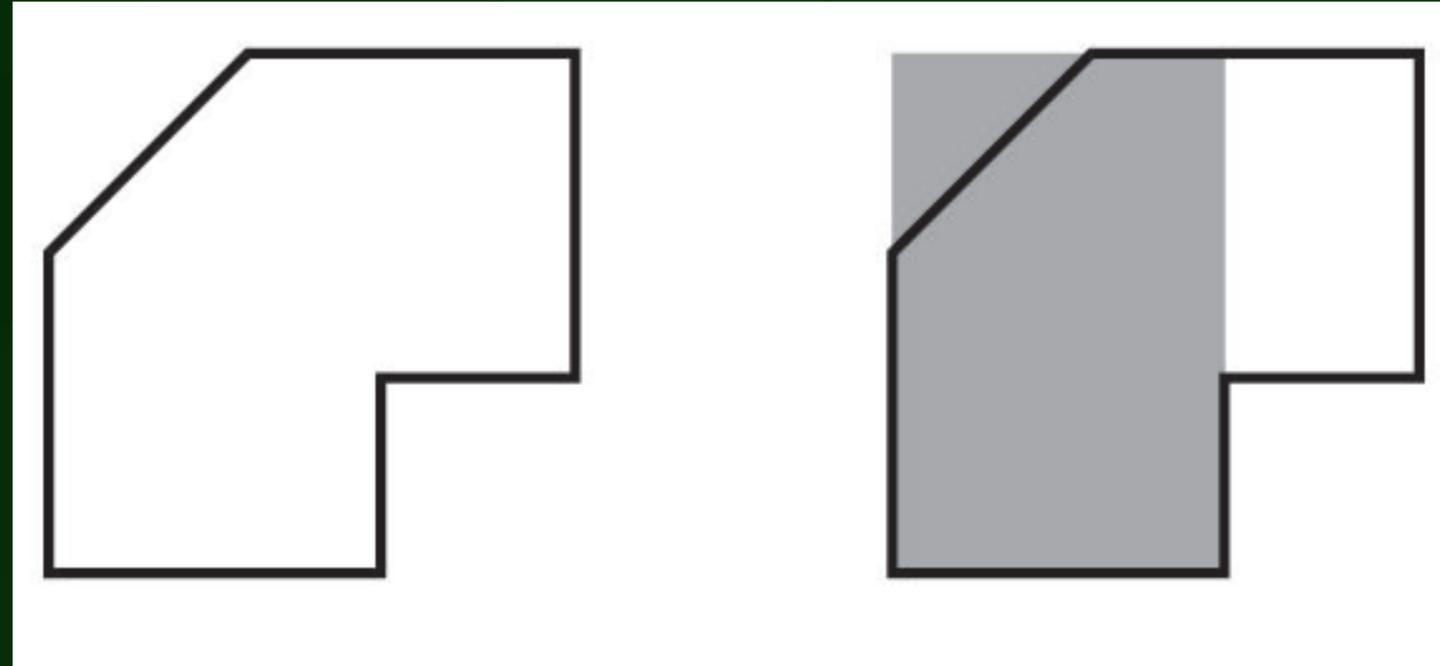
- Motivation: unreliable or non-existent information in IFC models
- Automatically create shapes of rooms, storeys and apartments
- Built on IfcOpenShell

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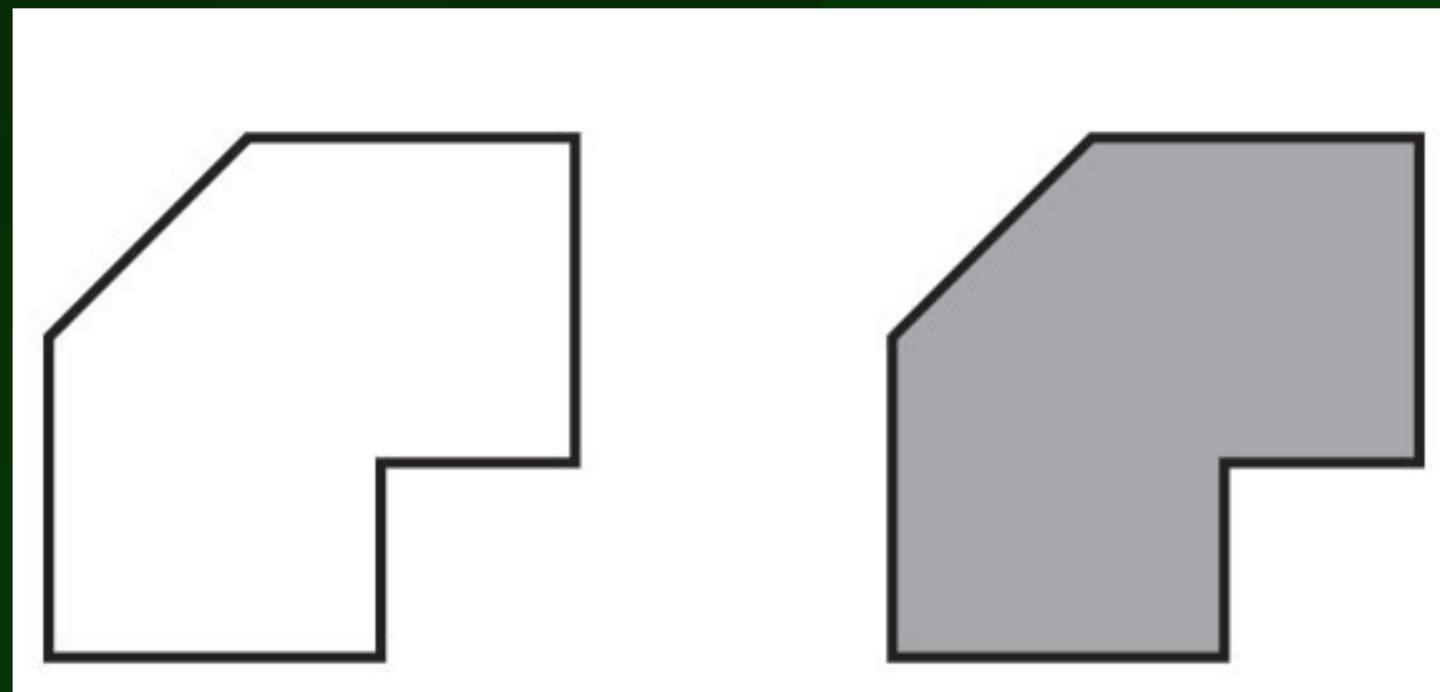
Automatic building feature  
detection and reconstruction  
in IFC models

Jasper van der Vaart  
2022

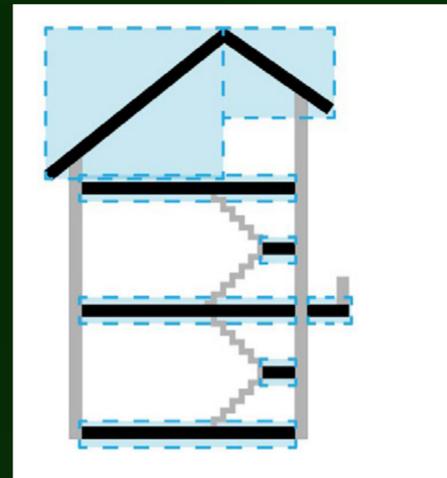
# Current IfcSpaces



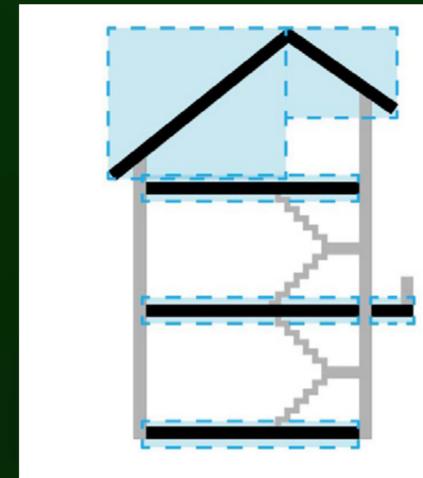
(a)



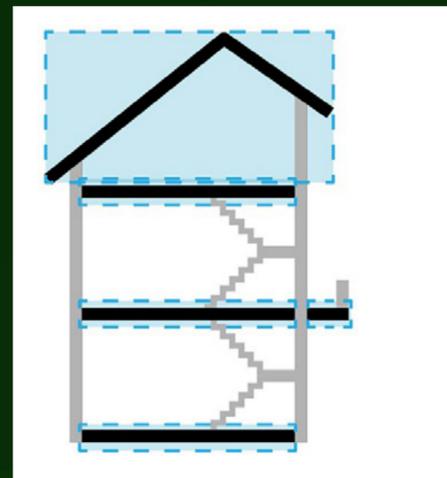
# Computing storeys



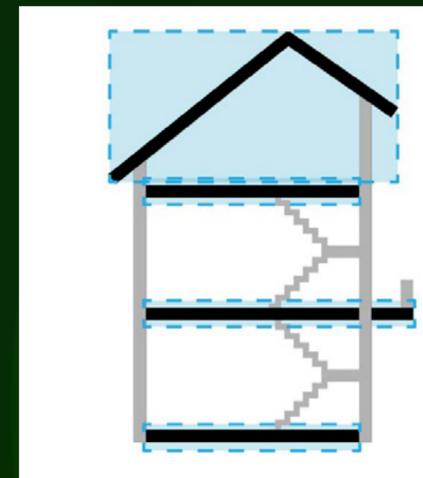
(a)



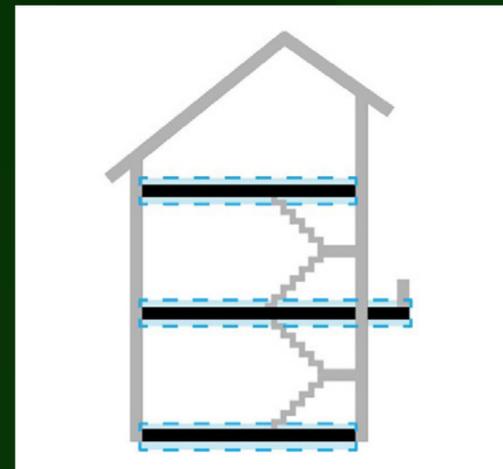
(b)



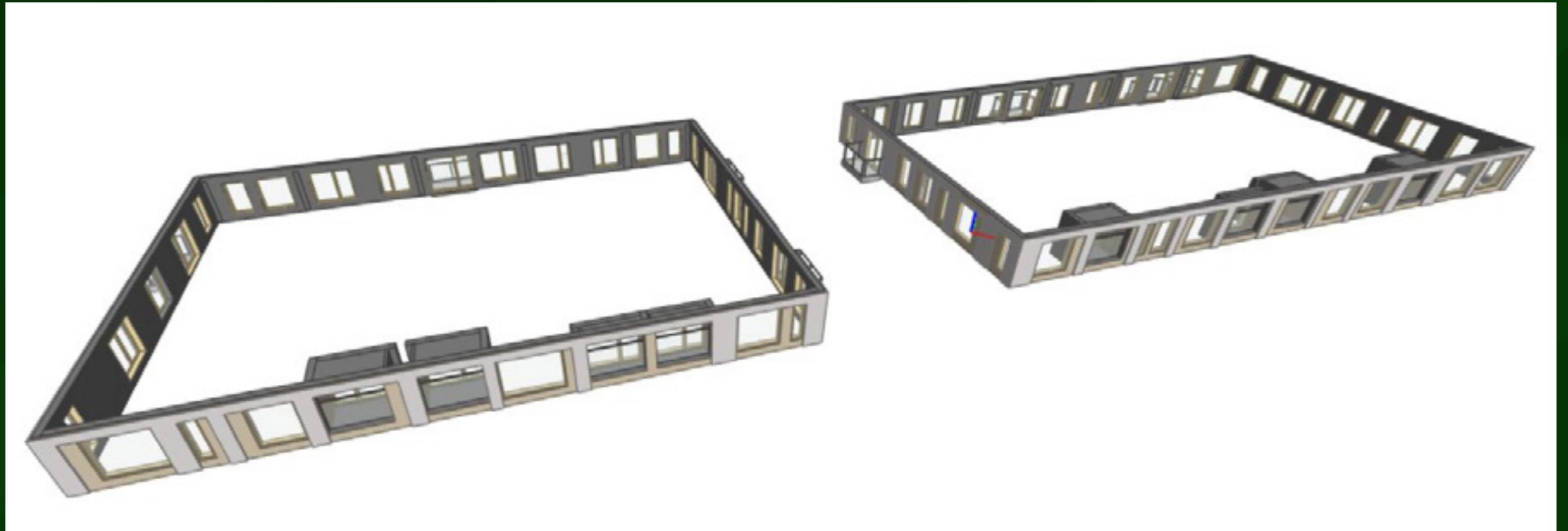
(c)



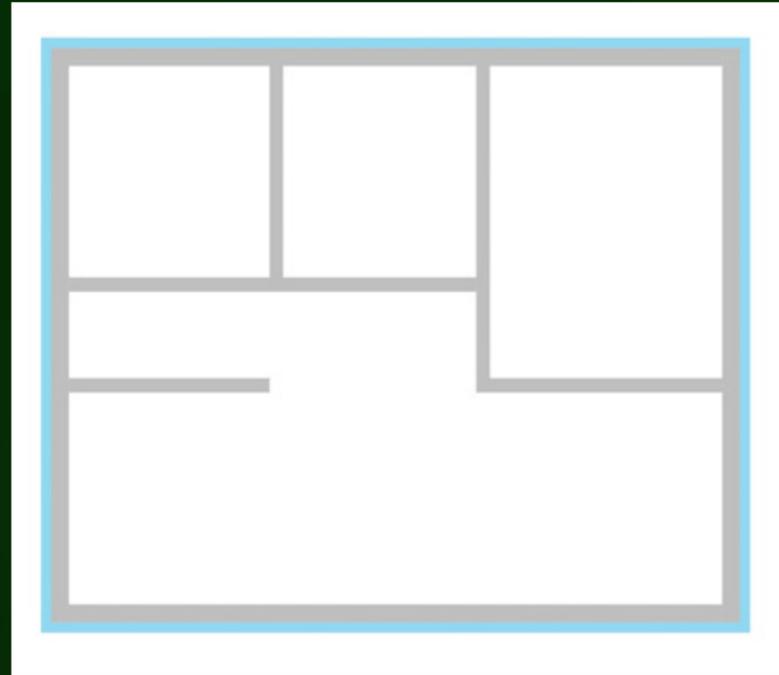
(d)



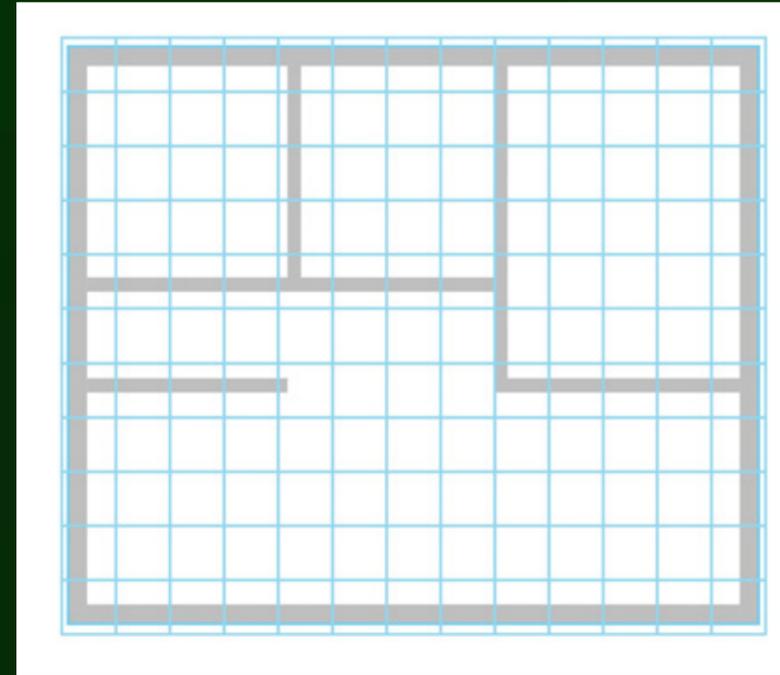
# Computing storeys



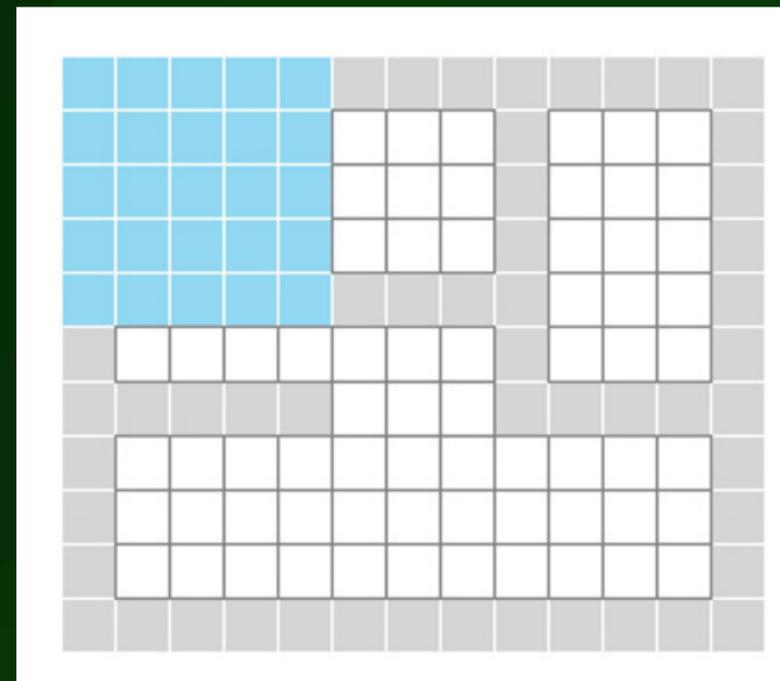
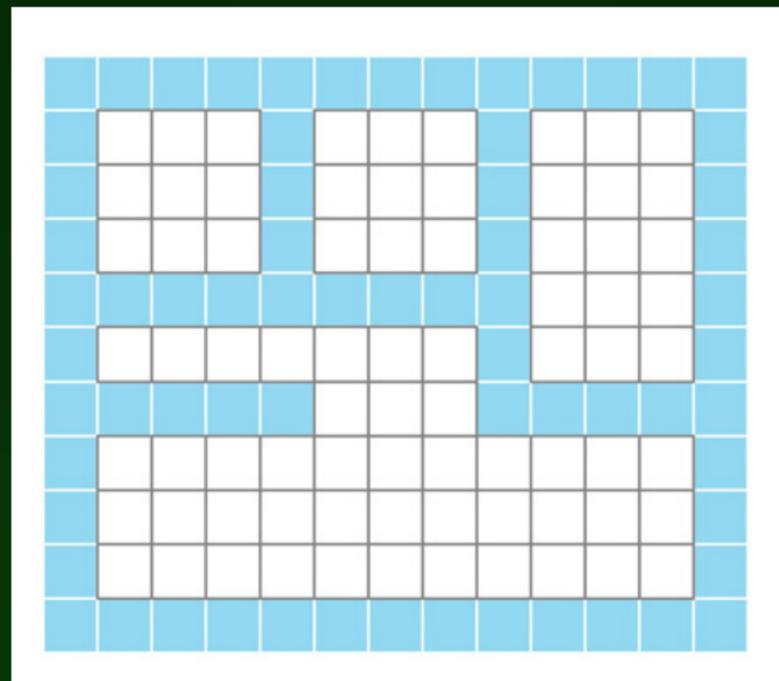
# Computing rooms



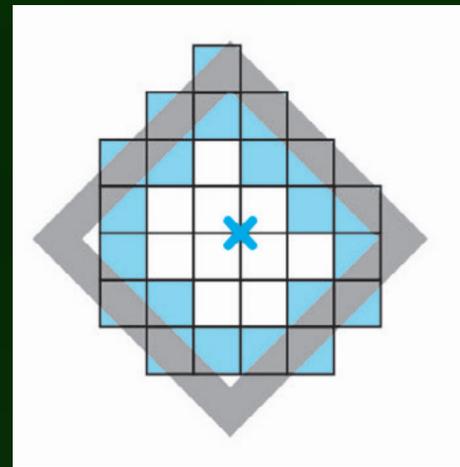
(c)



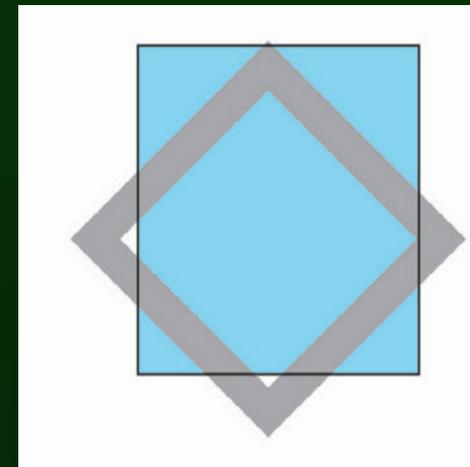
(d)



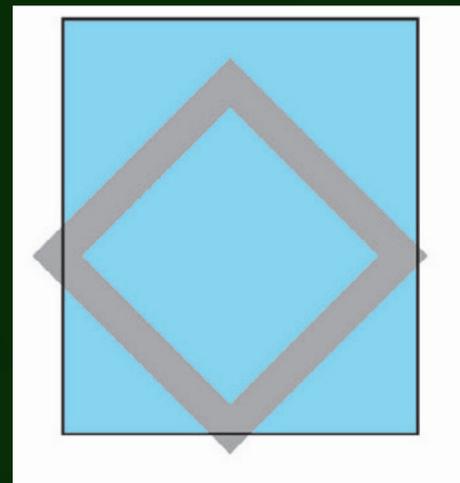
# Computing rooms



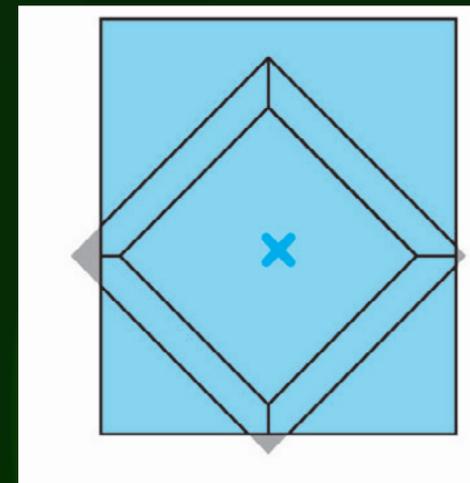
(a)



(b)



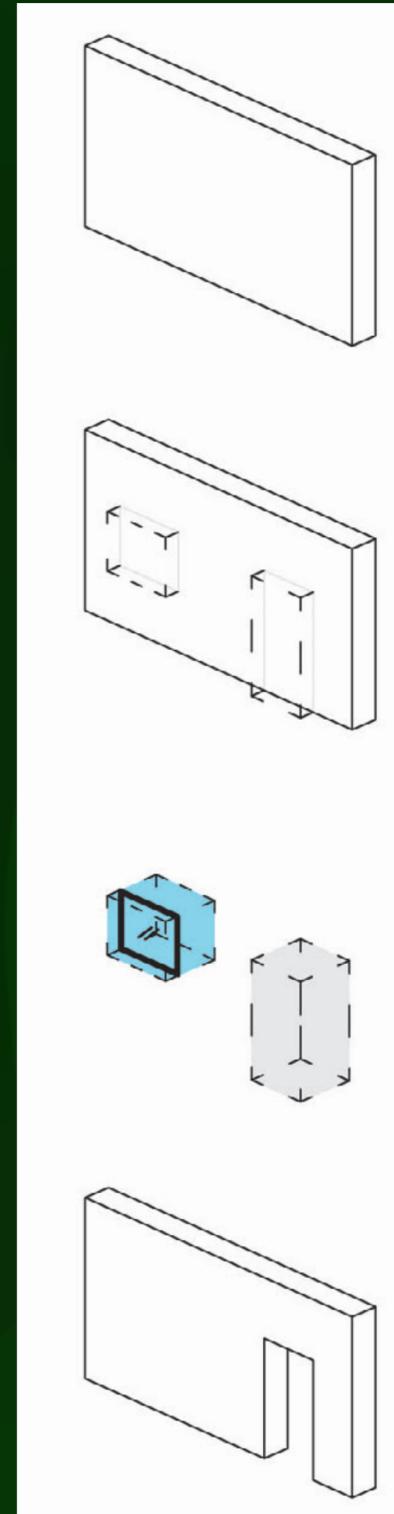
(c)



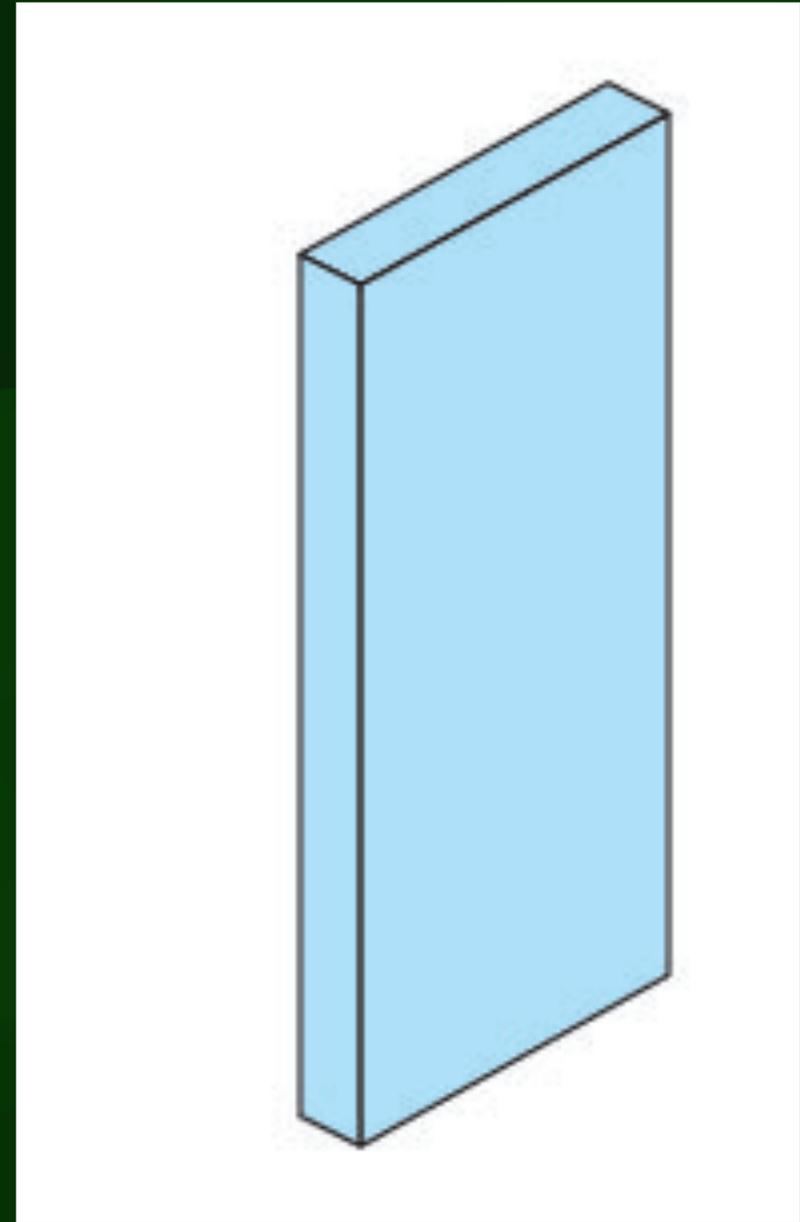
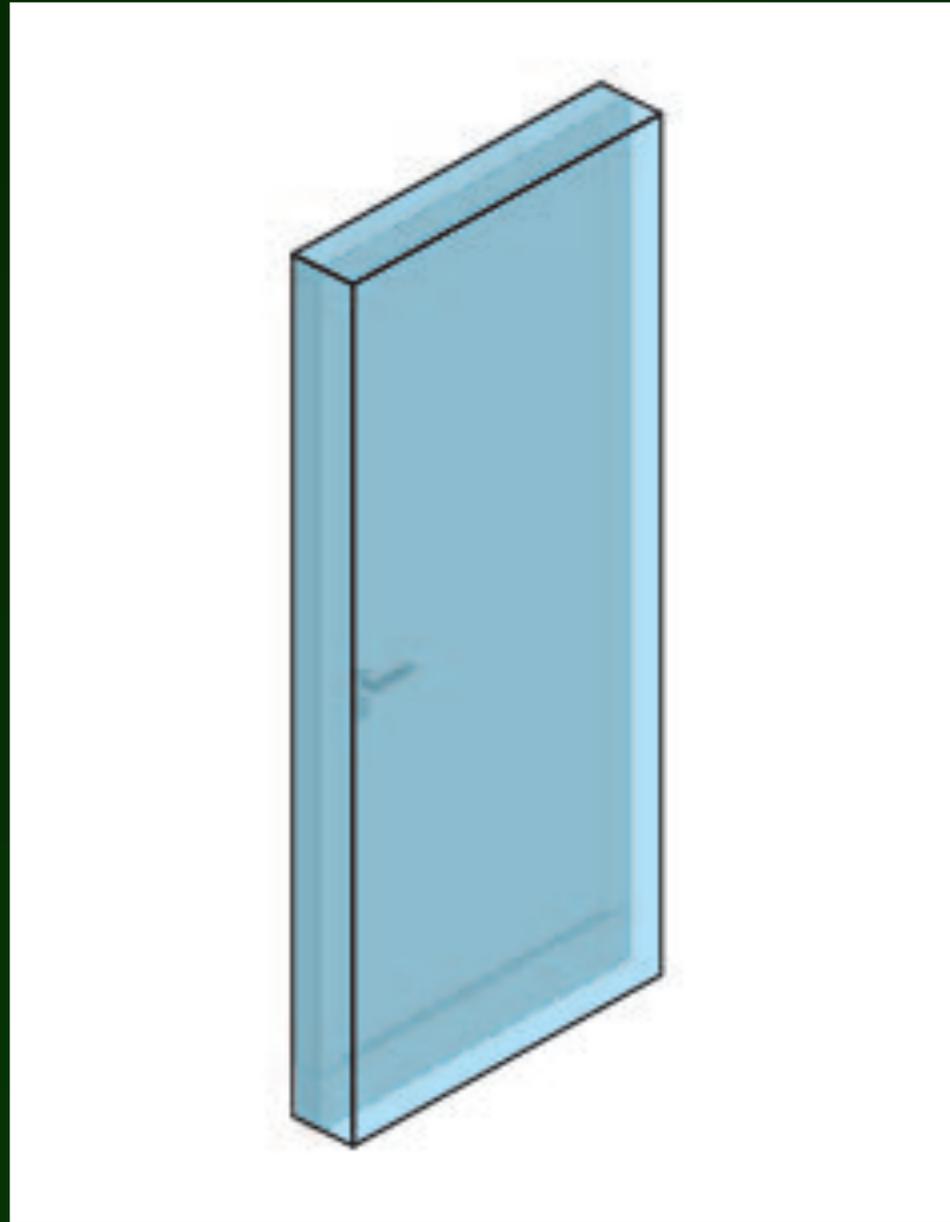
(d)



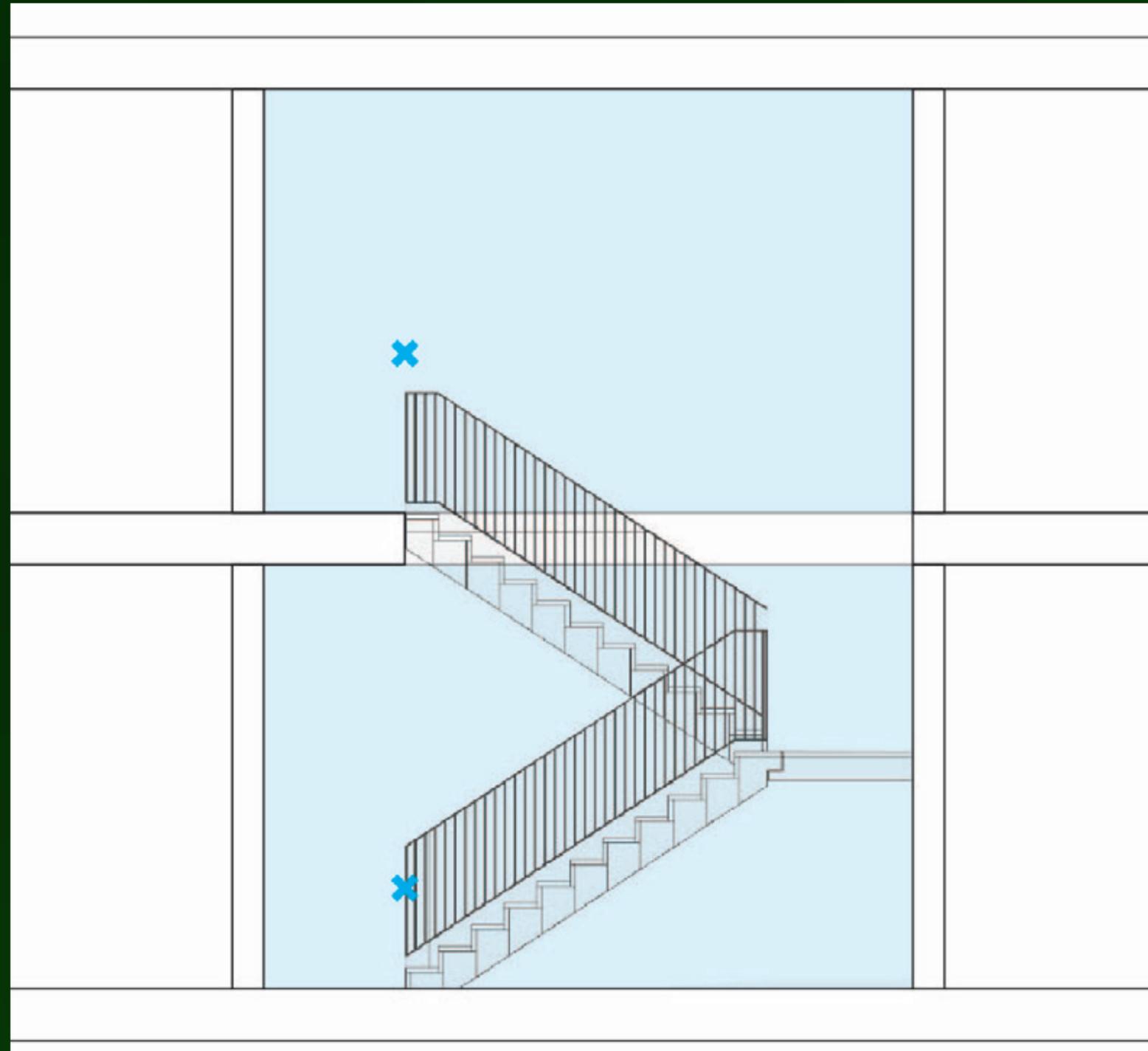
# Computing rooms



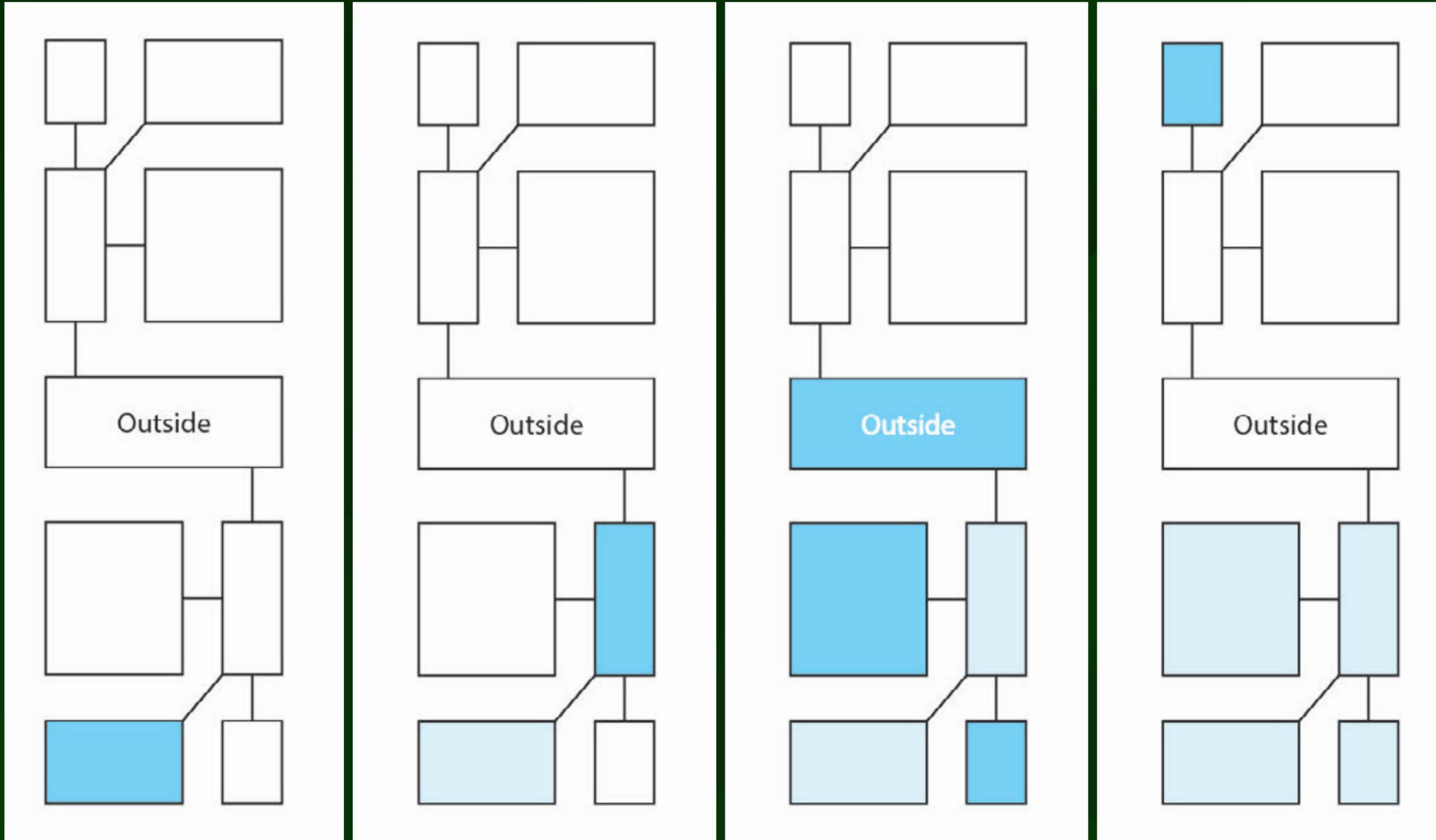
# Computing rooms



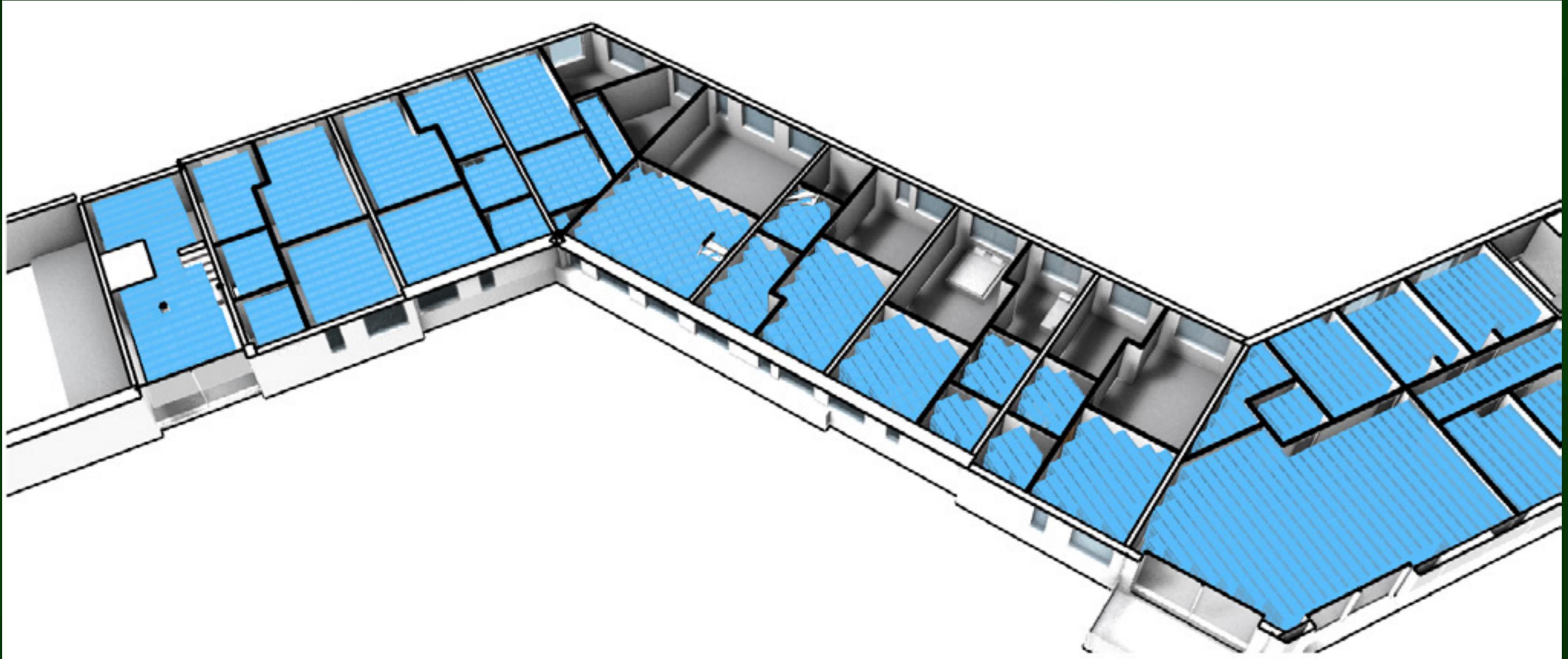
# Computing rooms



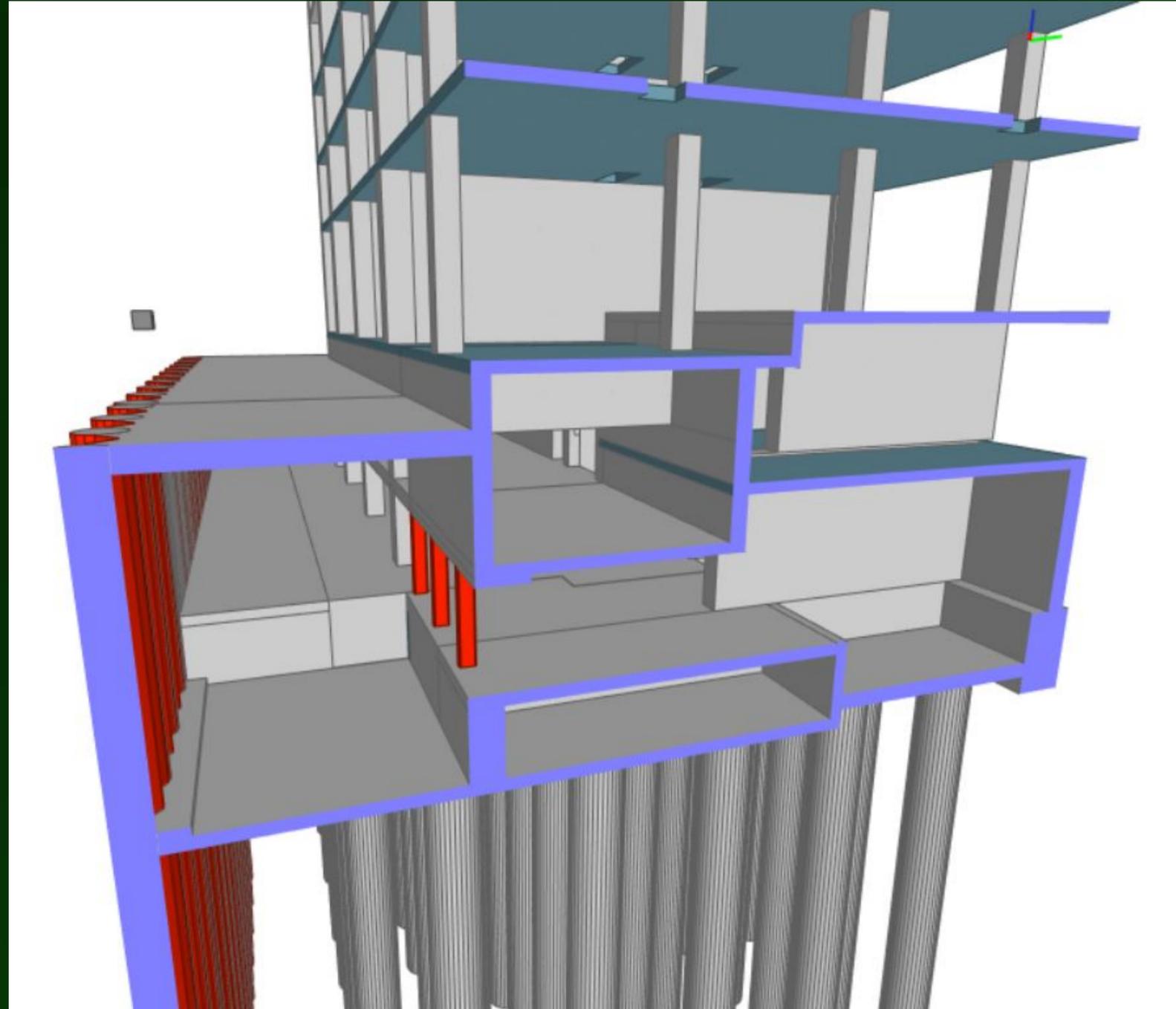
# Computing apartments



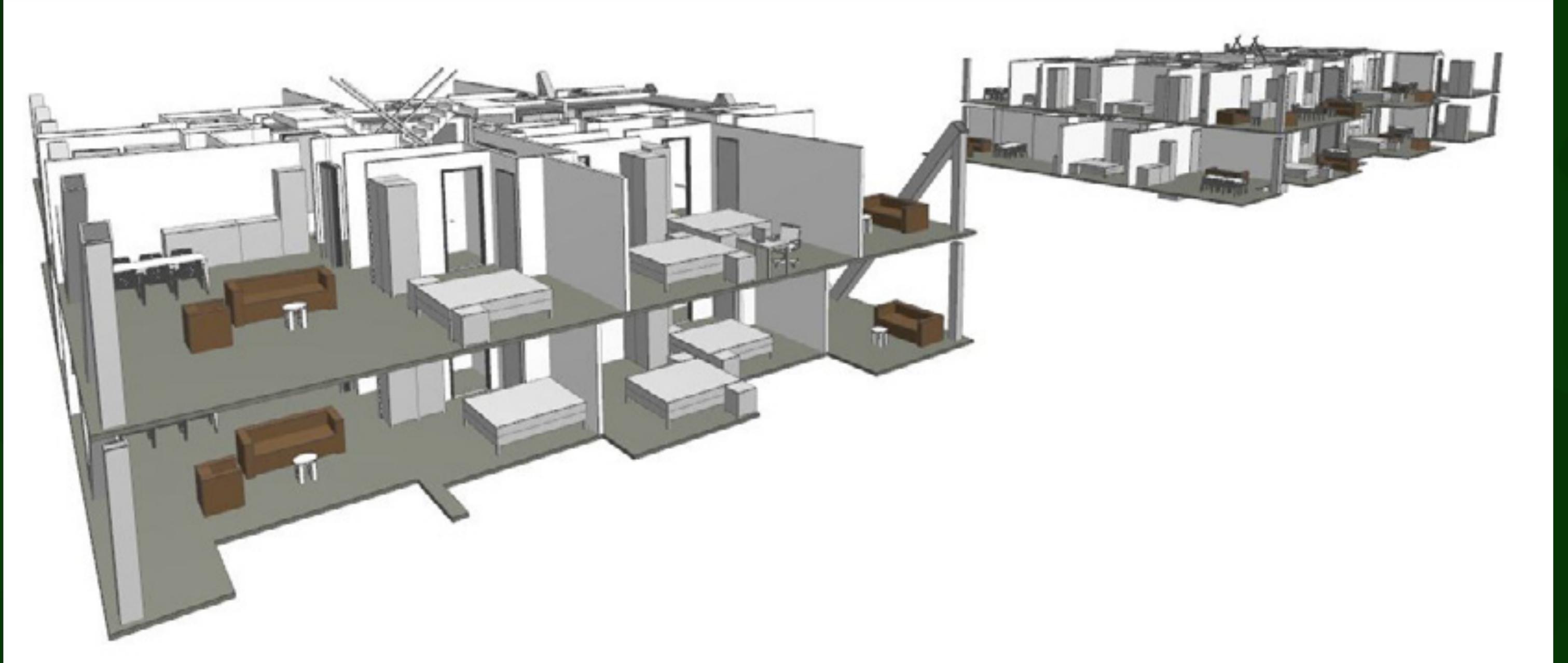
# Results



# Results



# Results



# Recommendations

- GEO5014: Geomatics as support for energy applications
- GEO5015: Modelling wind and dispersion in urban environments
- GEO5010: Research assignment
- Your own MSc thesis

# What's next?

- This Friday: last help session (10:45-12:30) and Homework 3 is due (13:45)
- Week 9: prepare for final exam, questions -> Discord
- Week 10:
  - Monday (23rd): Final exam 9:00-11:00 (see website for details)
  - Tuesday (24th): Marking + marks published in website by evening
  - Wed-Fri (25th-27th): Questions about your mark? Come to my office (BG.West.550) or ask on Discord

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



3D geoinformation

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

# Sources of images

- [2-6]: Filip Biljecki (paper on application of 3D city models and PhD thesis)
- [9-20]: Roeland Boeters (MSc thesis and related paper)
- [21-29]: Sjors Donker (MSc thesis)
- [30-48]: Damien Mulder (MSc thesis)
- [49, 51-62]: Yixin Xu (MSc thesis)

# Sources of images

- [50]: Anna-Maria Ntarladima (MSc thesis)
- [63-70]: Jialun Wu (MSc thesis)
- [71-78]: Özge Tufan (MSc thesis)
- [79-91]: Jasper van der Vaart (MSc thesis)