



The City Stack

by Oliver J. Post

*A Morphology-Based City Analysis and Generation
Framework*

*Creating cities that **don't exist...**
...but look like they **could exist.***

Creating Cities?

2D



Source data from OpenStreetMap
Contributors (2017)

3D

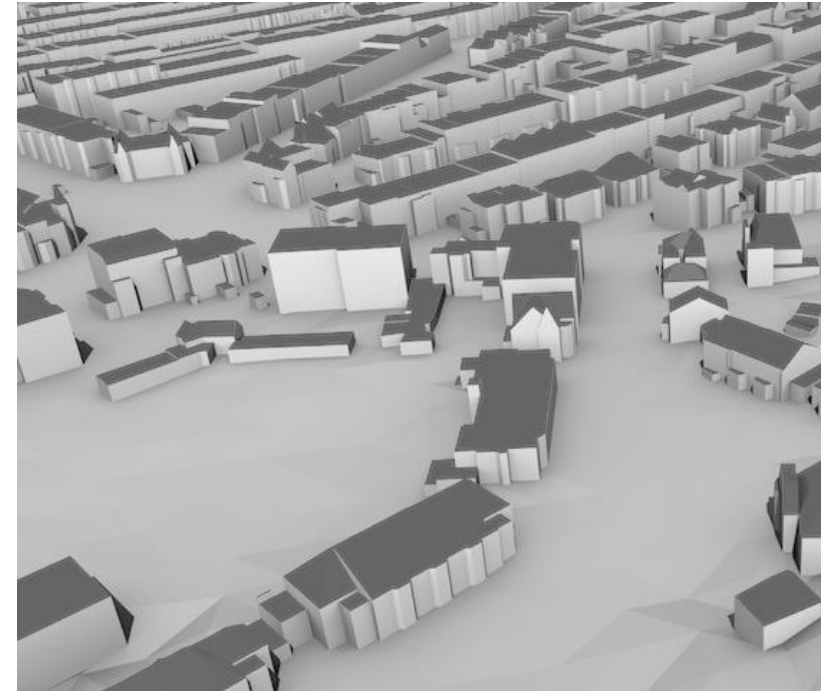
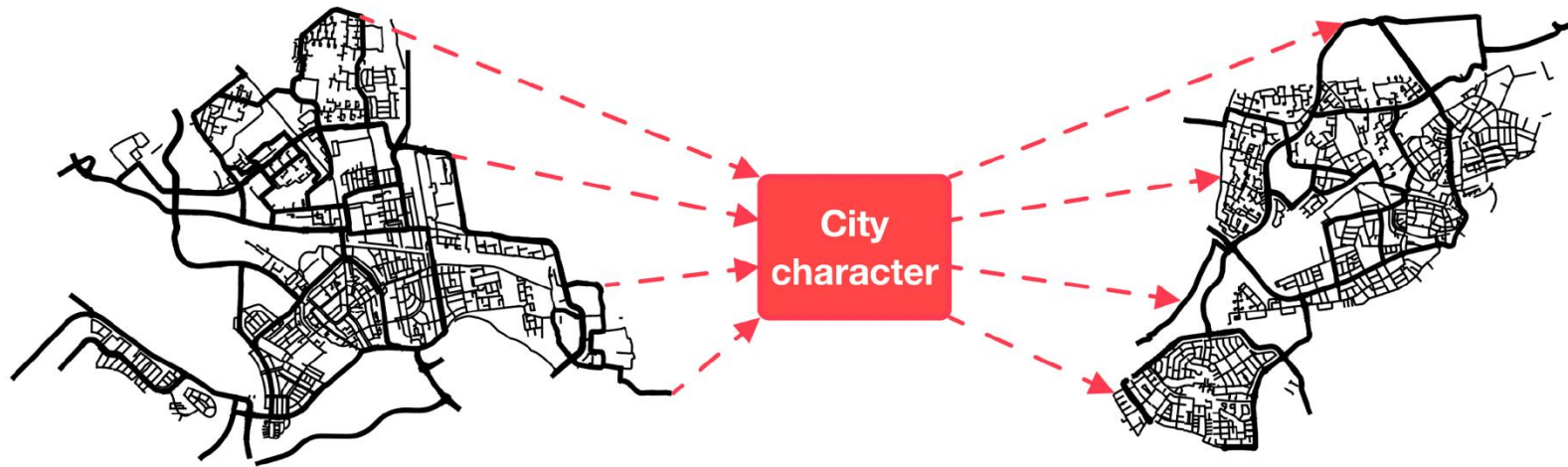


Image from CityJSON.org (n.d.)

Research Question

How can a digital city model be procedurally generated to resemble the character of a real-life city?

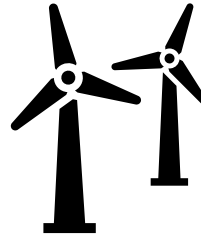


Source data from
OpenStreetMap
Contributors (2017)

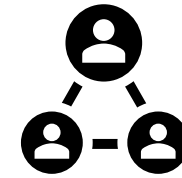
Use cases for Procedural Cities



Test files for **algorithms**,
file formats, and software



Input for Computational
Fluid Dynamics studies, like
wind simulations



Urban and social
simulations



Training data
for **Artificial Intelligence**



Virtual reality (**VR**) &
video **games**



As context for urban and
architectural design **prototyping**

Related Work

City Generation

Procedural City Generation

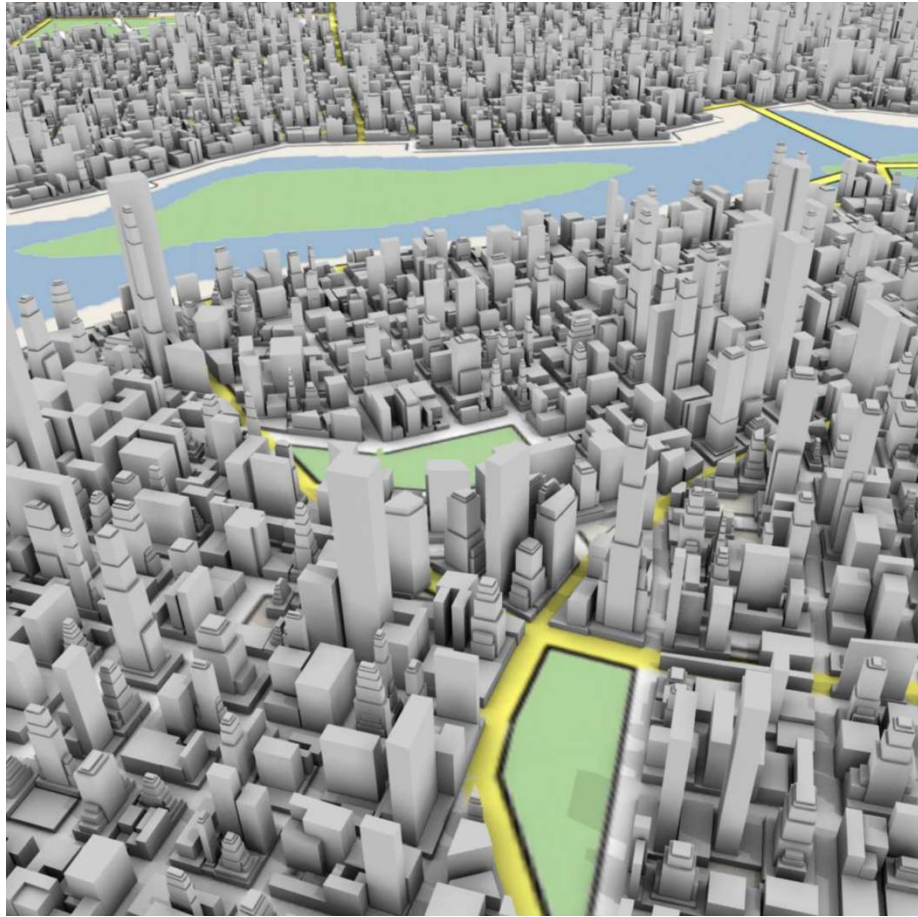


Image from Chen et al. (2008)

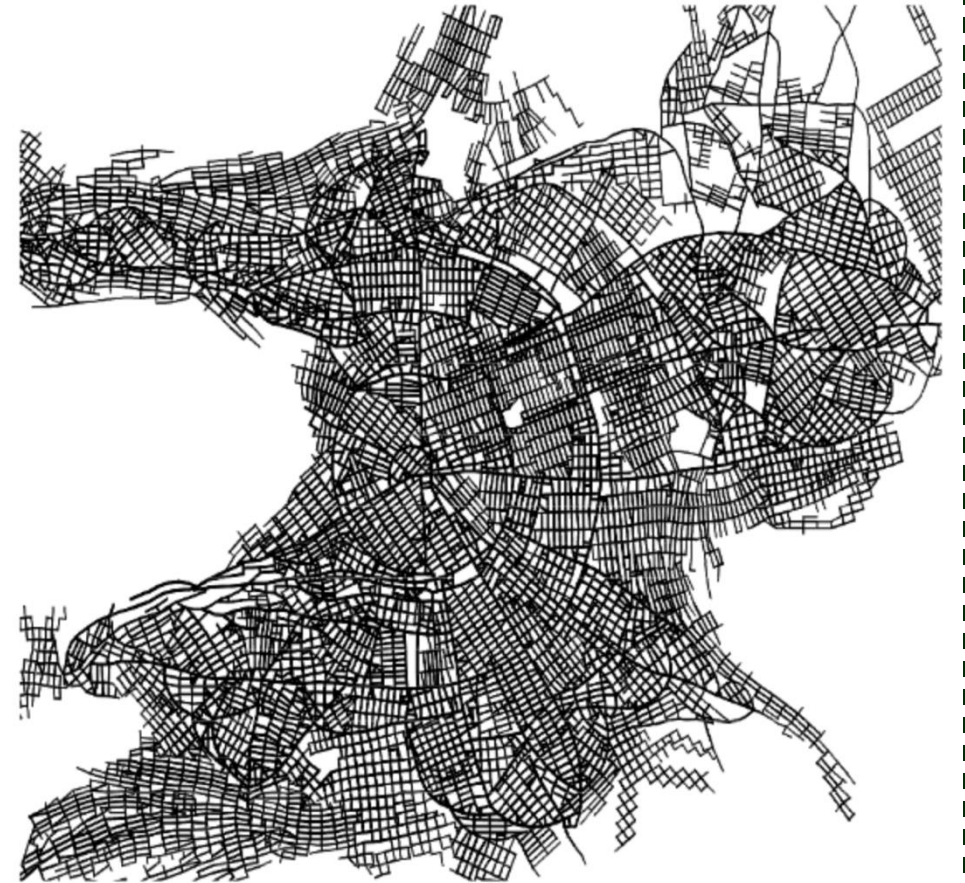
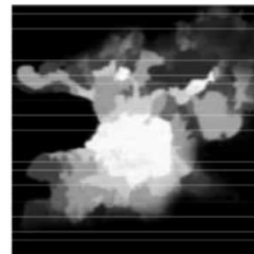
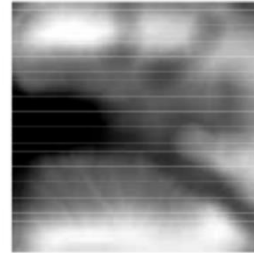
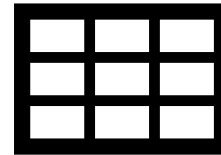


Image from Parish & Müller (2001)

Challenge: Not made to resemble the *complexity of real cities* worldwide



Based on generalized rules



Grid, organic, or radial
pattern

Possible, but...



Image from Chen et al. (2008)

Challenge: Depends on arbitrary user input

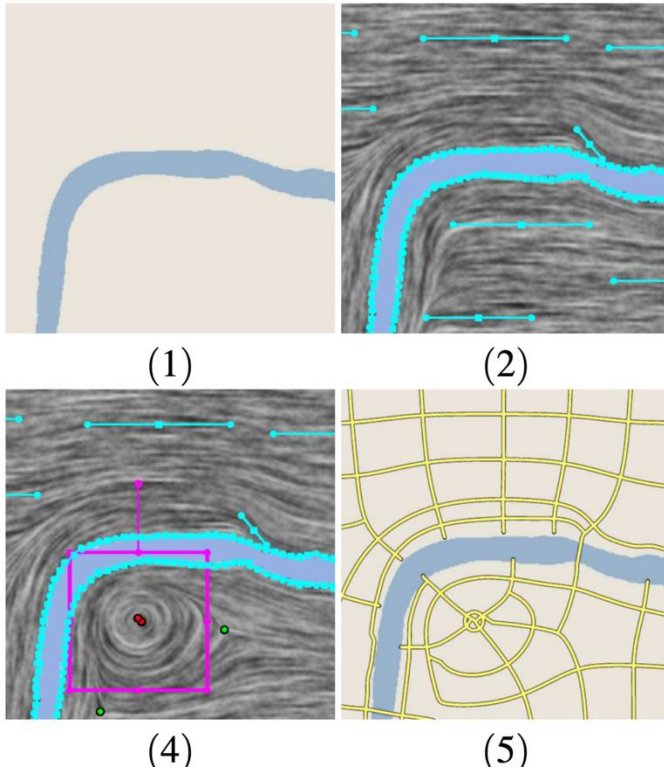


Image from Chen et al. (2008)

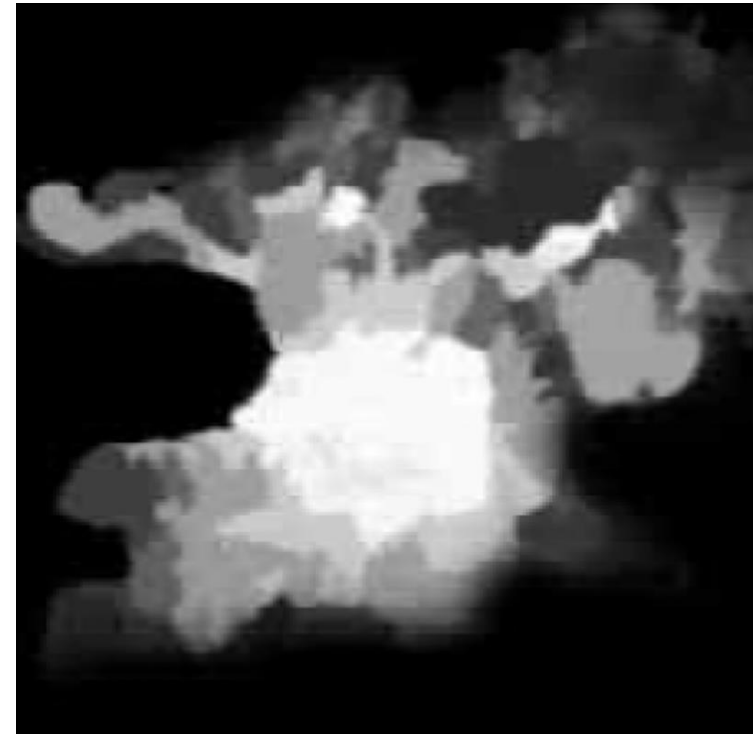


Image from Parish & Müller (2001)

Land Use Simulations

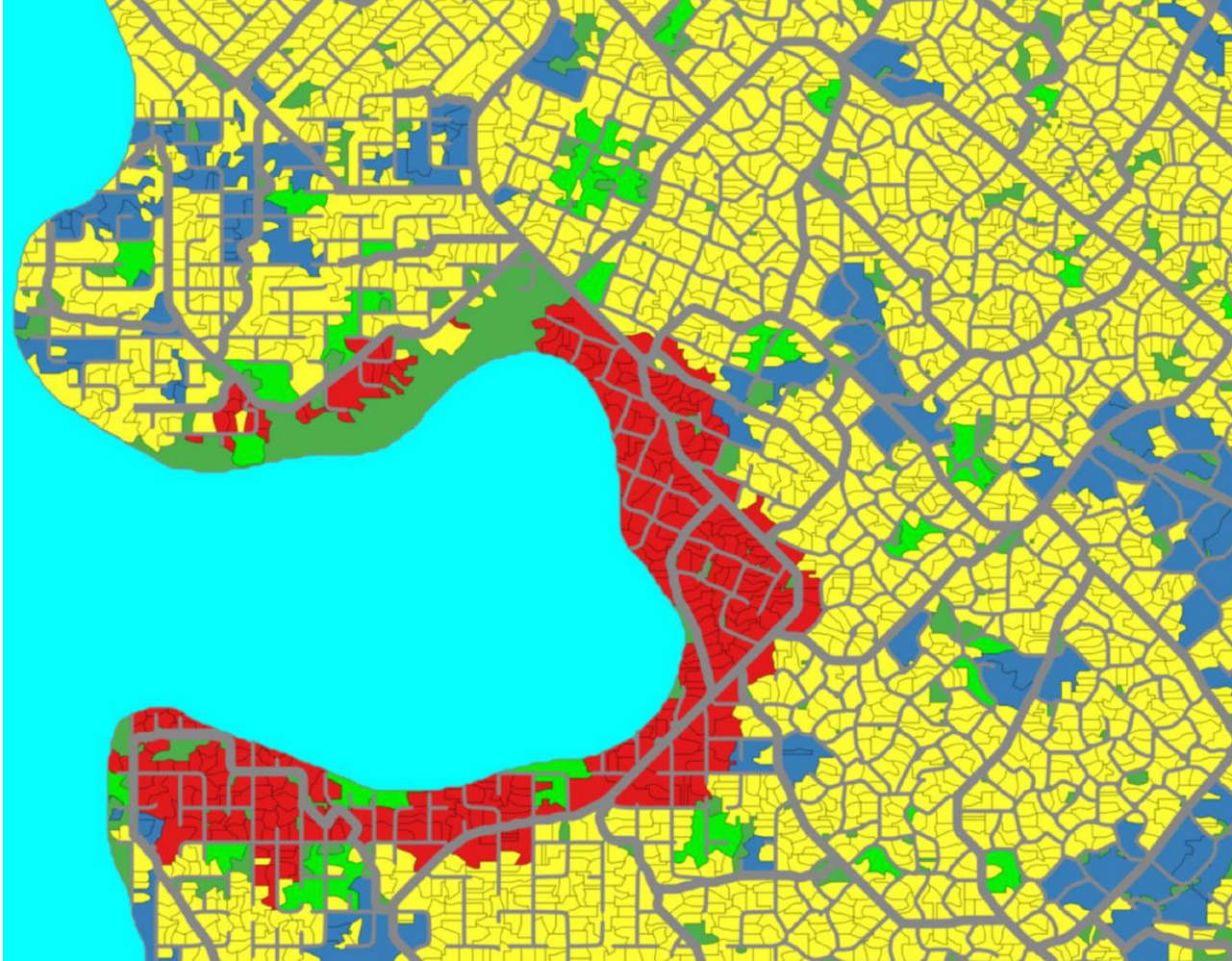


Image from Lechner et al. (2006)

Related Work

Morphology

Urban Morphology: Urban Tissue



Image from Araújo De Oliveira (2022)

Urban Morphology: Urban Tissue



Image from Araújo De Oliveira (2022)

Morphological Clustering

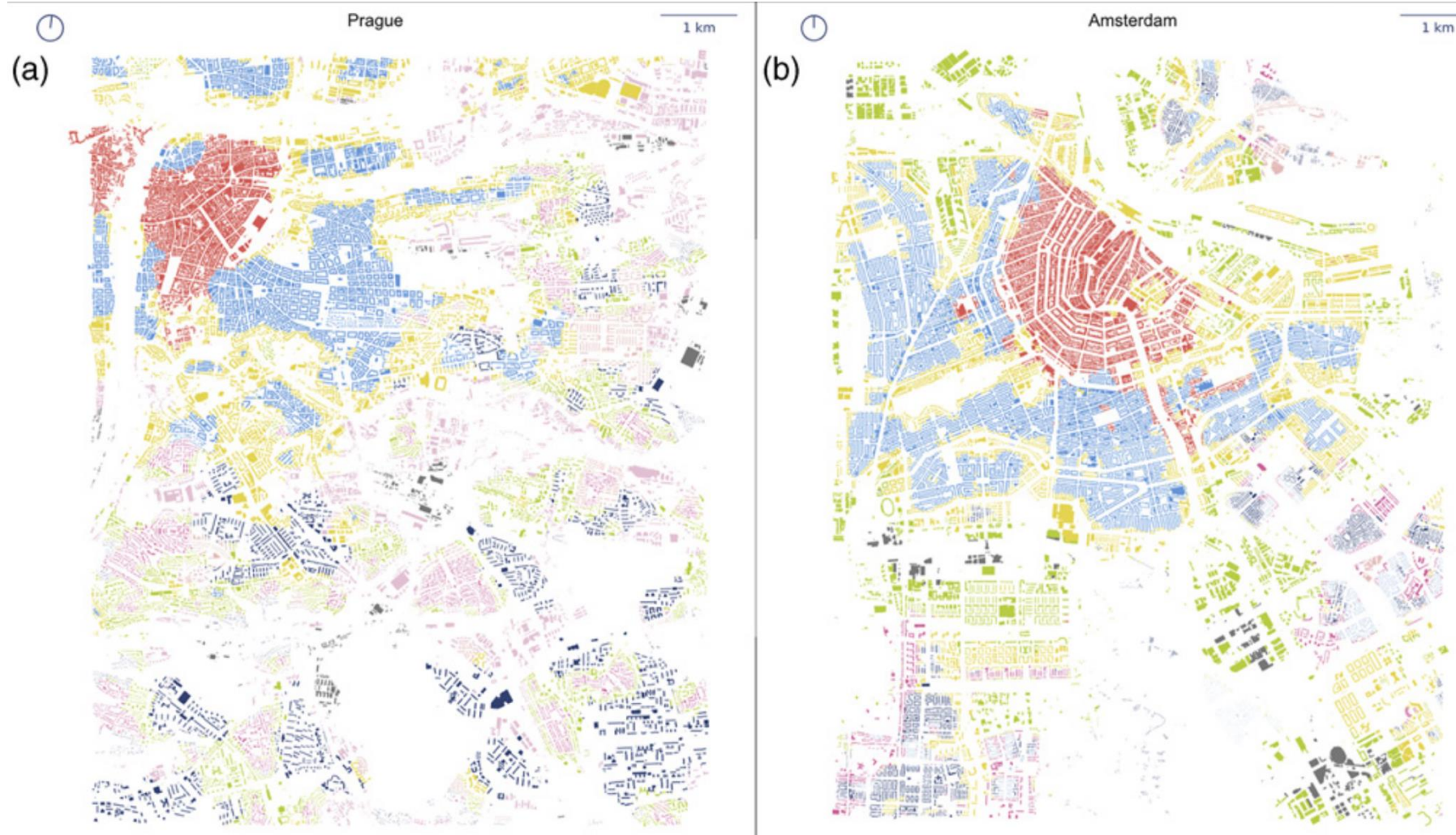


Image from
Fleischmann
et al. (2022)

Morphological Clustering

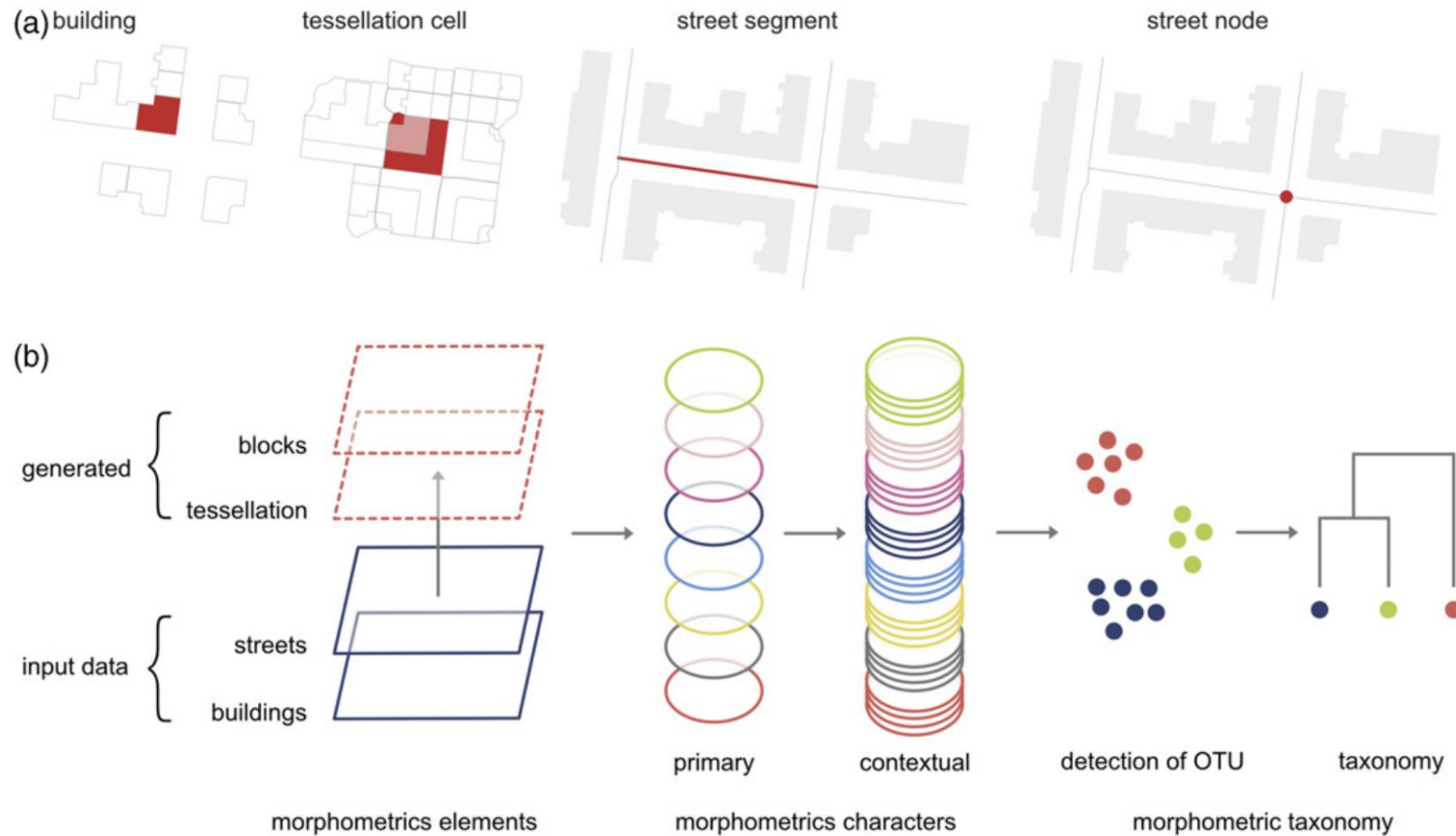


Image from Fleischmann et al. (2022)

Structure

Step 1: Analyze

How can the urban form of real-world cities be captured using publicly available geospatial data?

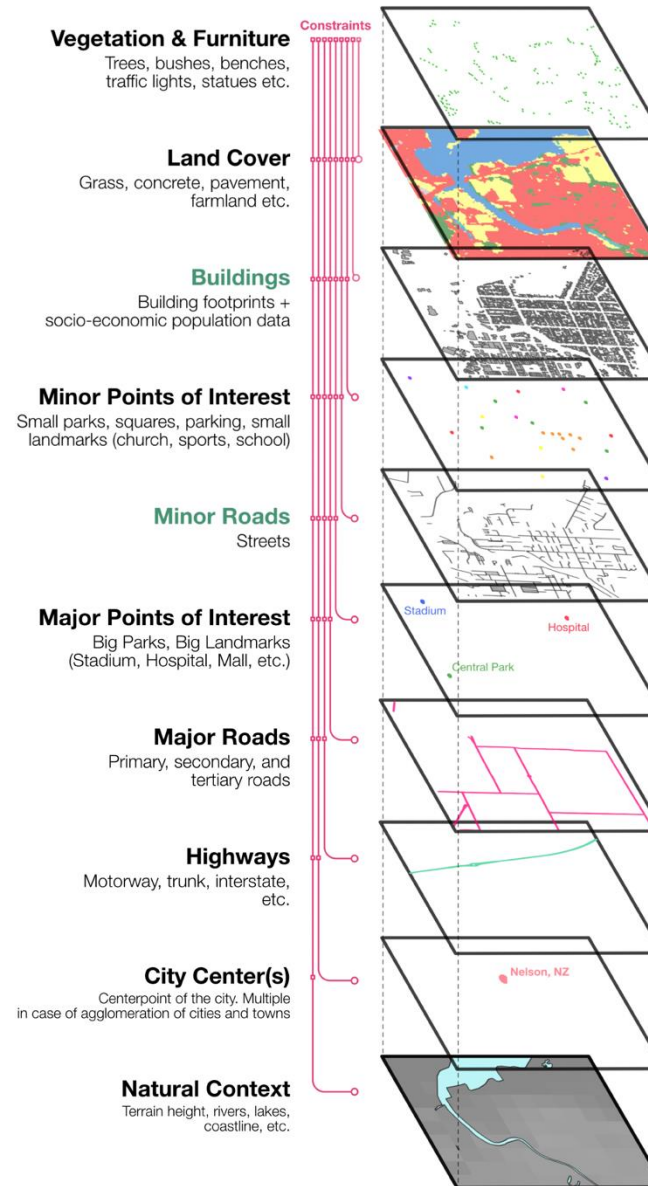
Step 2: **Encode**

*How can the captured urban form be **encoded** in a way that allows for the **comparison** of different cities and the **generation** of new cities with similar character?*

Step 3: **Generate**

*How can this encoded data be utilized to procedurally **generate** a digital city model that **resembles the form** of the encoded real-life city?*

The City Stack



Major Points of Interest

Big Parks, Big Landmarks
(Stadium, Hospital, Mall, etc.)

Major Roads

Primary, secondary, and
tertiary roads

Highways

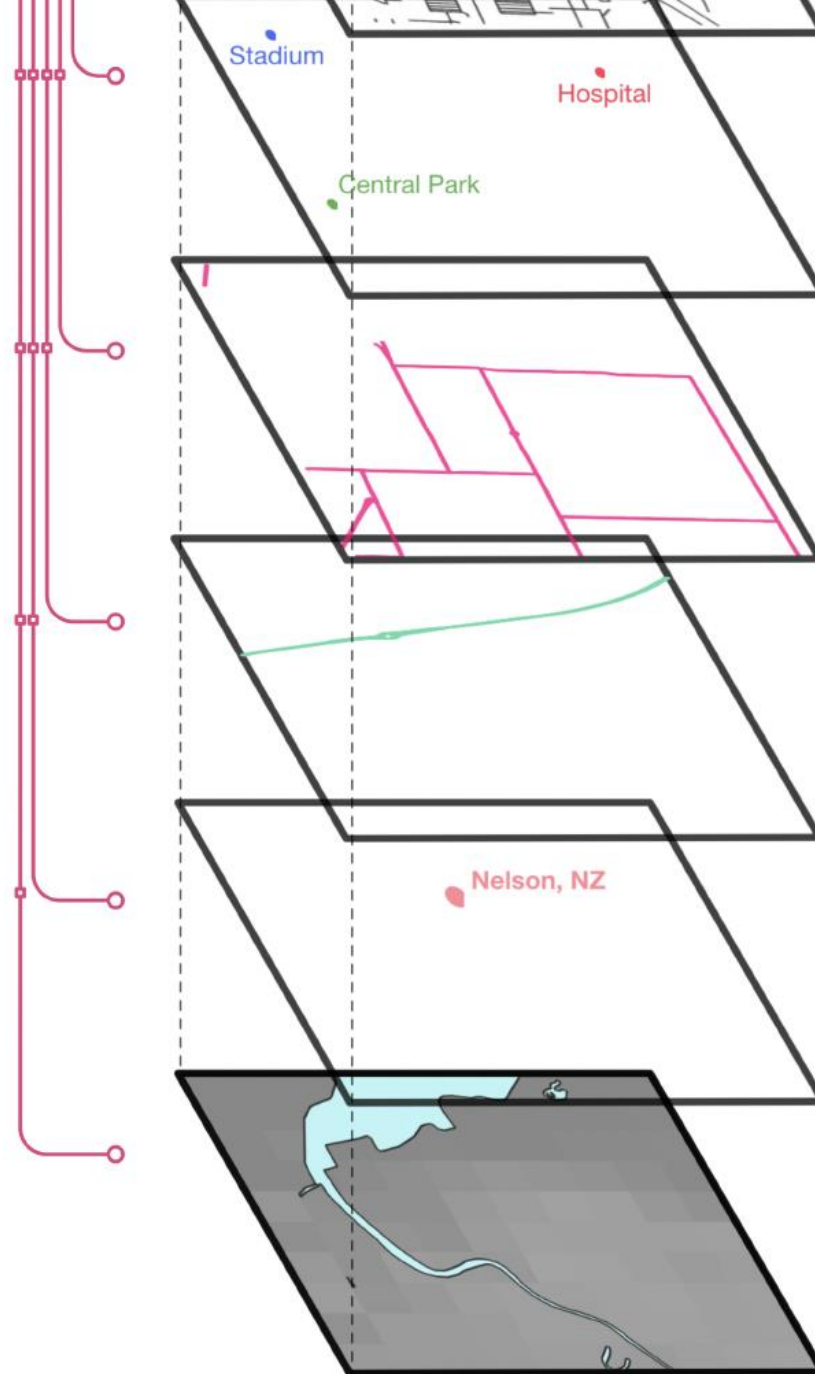
Motorway, trunk, interstate,
etc.

City Center(s)

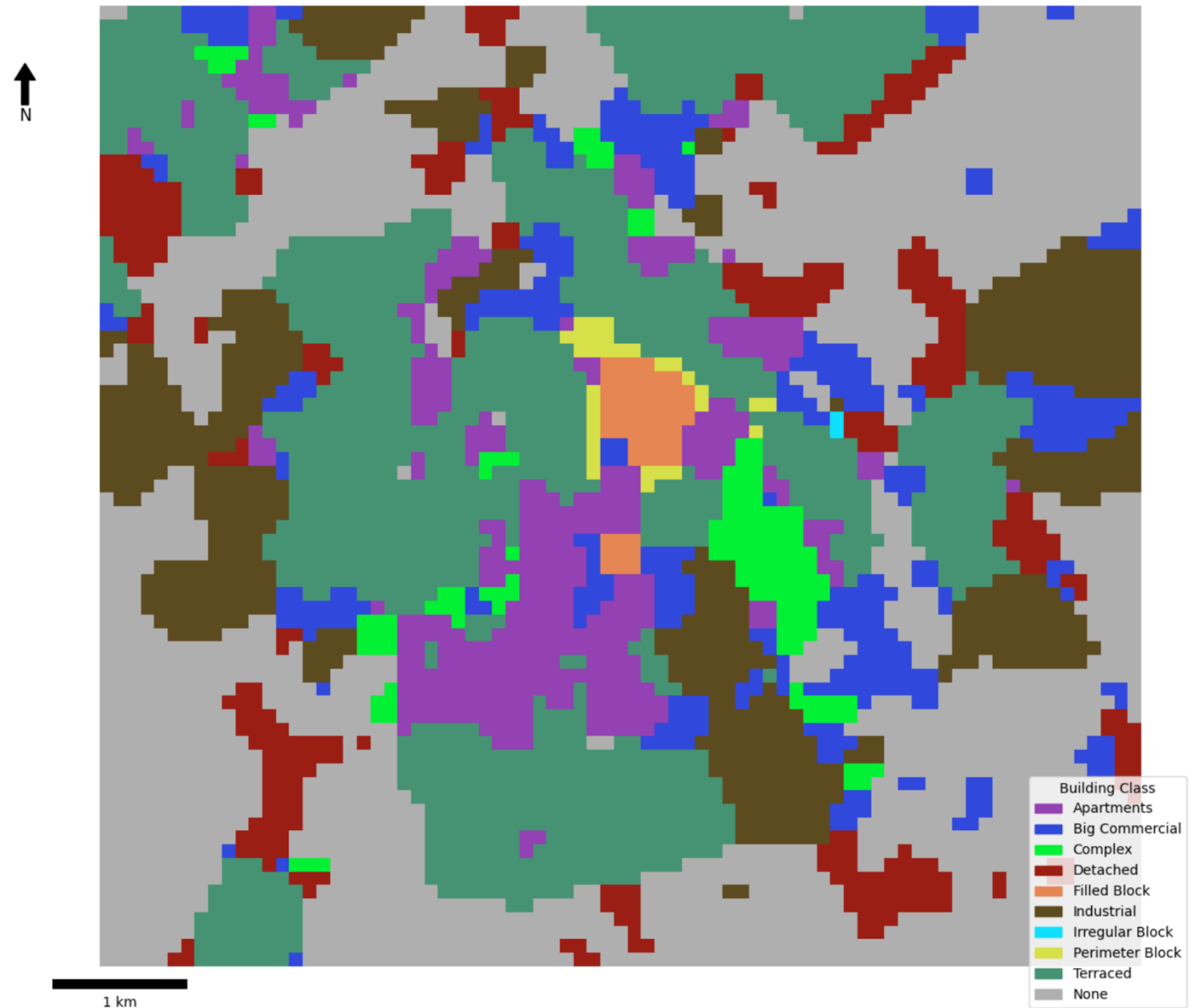
Centerpoint of the city. Multiple
in case of agglomeration of cities and towns

Natural Context

Terrain height, rivers, lakes,
coastline, etc.



The Typology Grid



Steps

1

Analyze the
City Stacks
of real cities

2

Encode using the
Typology Grid

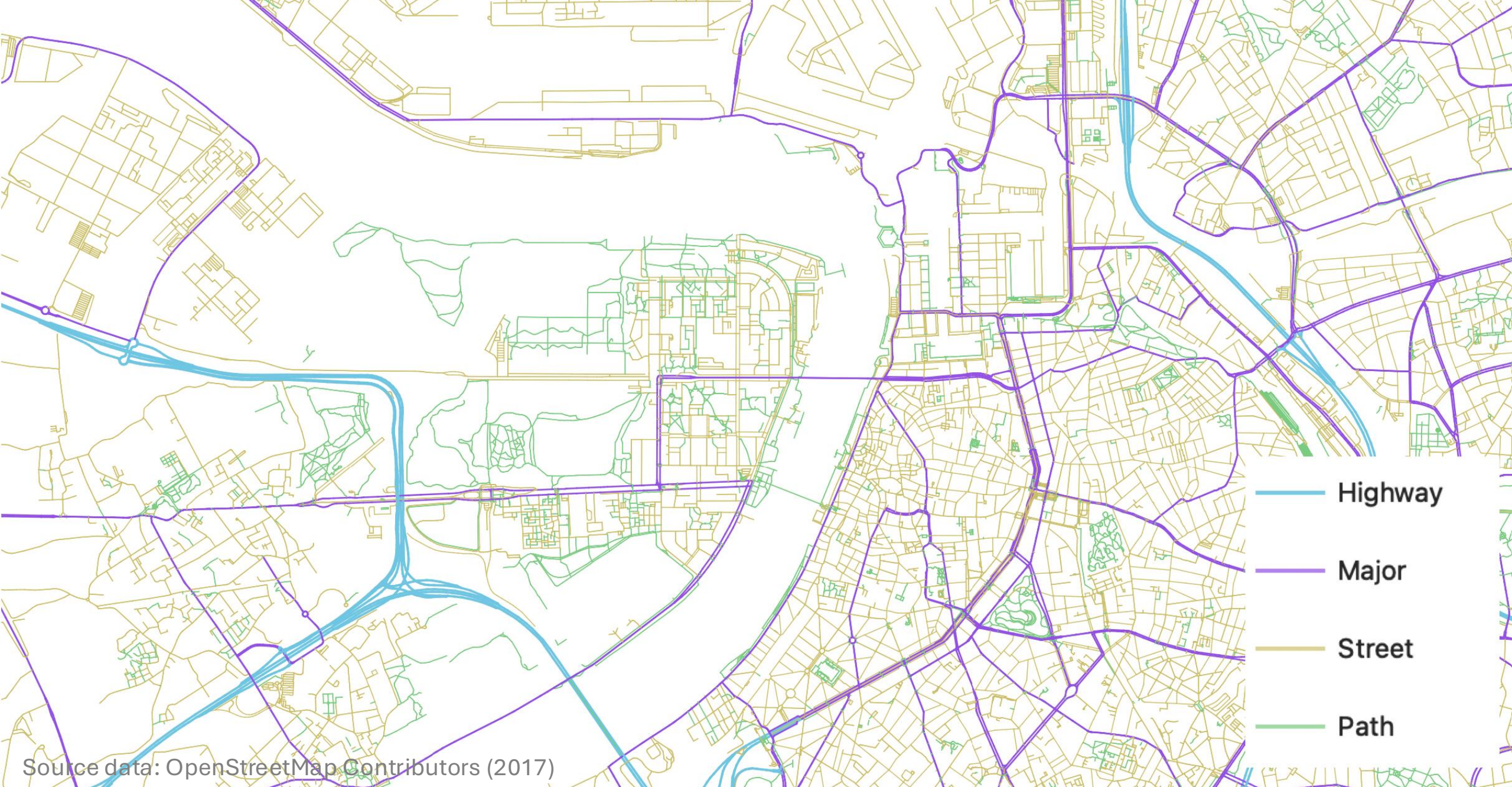
3

Generate similar
new City Stacks

Methodology

Step 1: Analyze





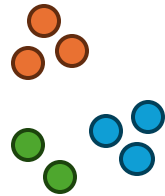


Source data: OpenStreetMap Contributors (2017)

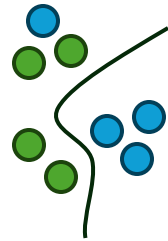


Source data: OpenStreetMap Contributors (2017)

Determining the Typologies

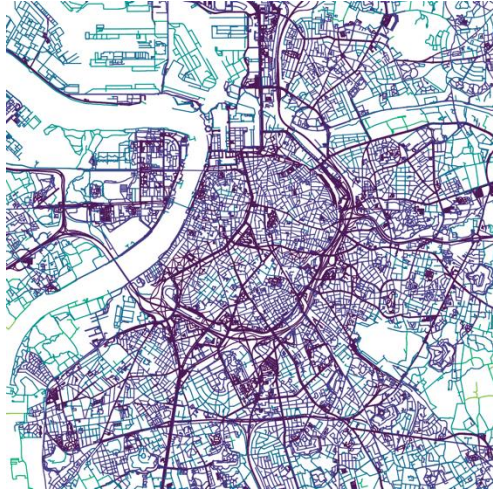


Clustering



Classification

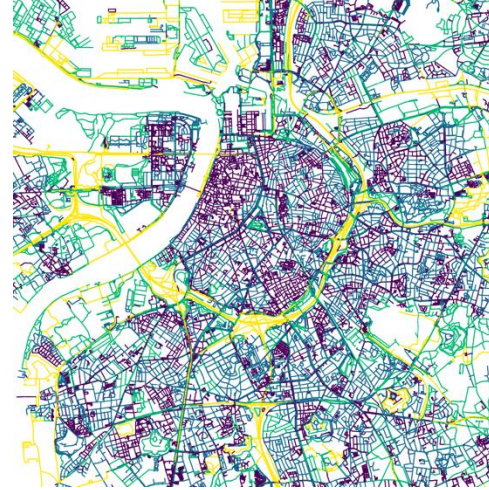
Clustering Roads



Neighbor Distance



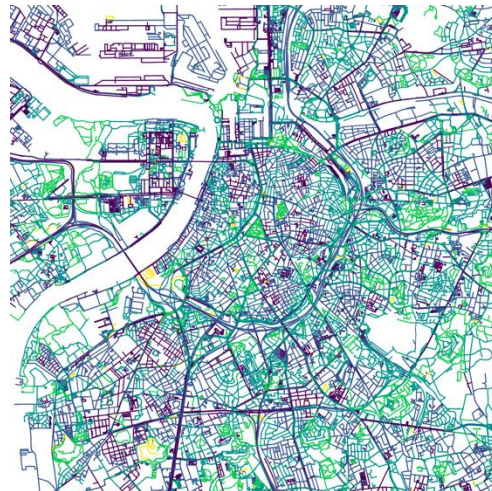
Neighbor Angle Difference



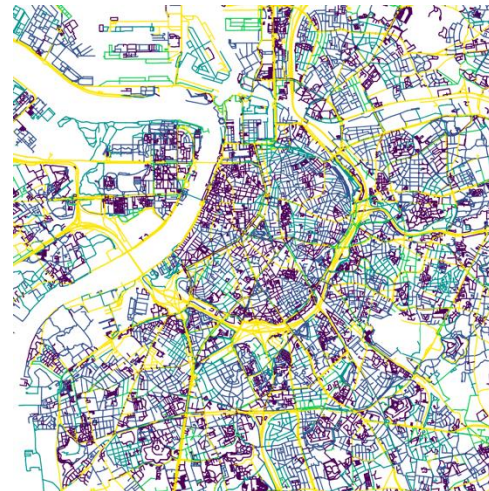
Length Distribution



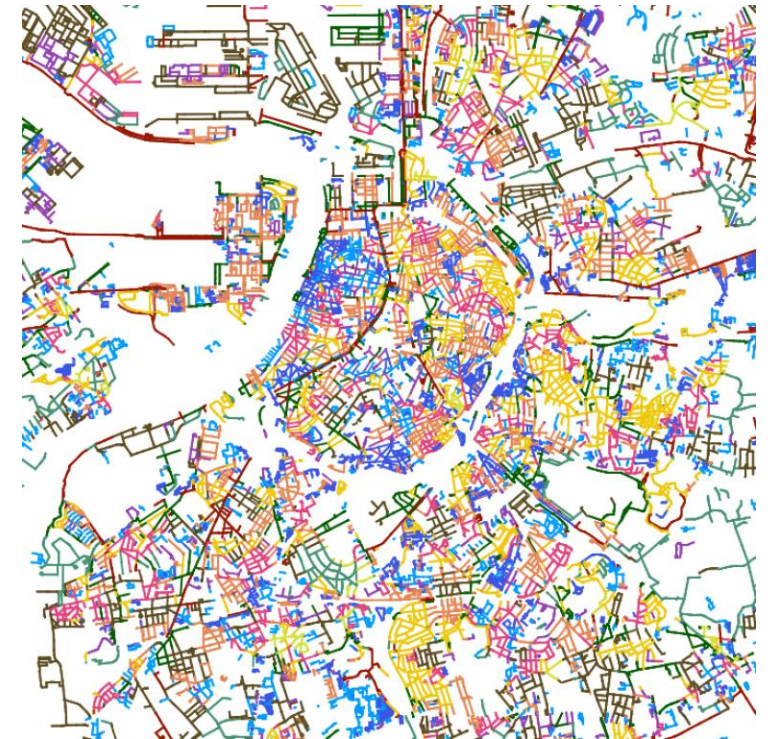
Angle Entropy



Curvilinearity



Continuity



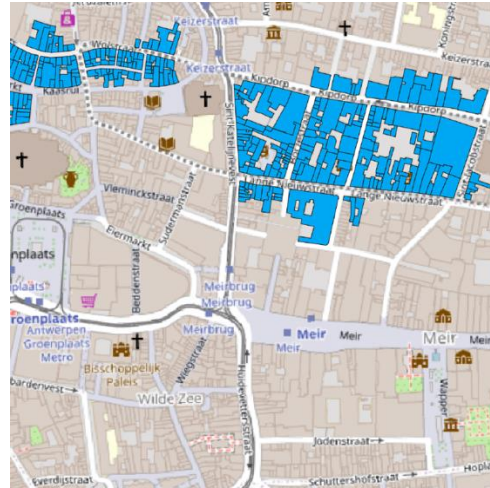
Gaussian Mixture Model Clustering

Source data: OpenStreetMap
Contributors (2017)

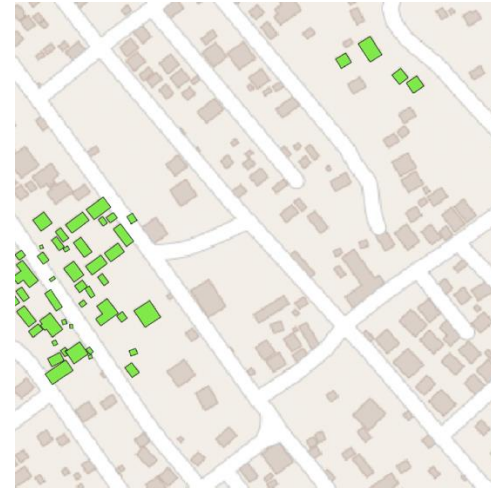
Classifying Buildings



Apartments



Filled Block



Detached



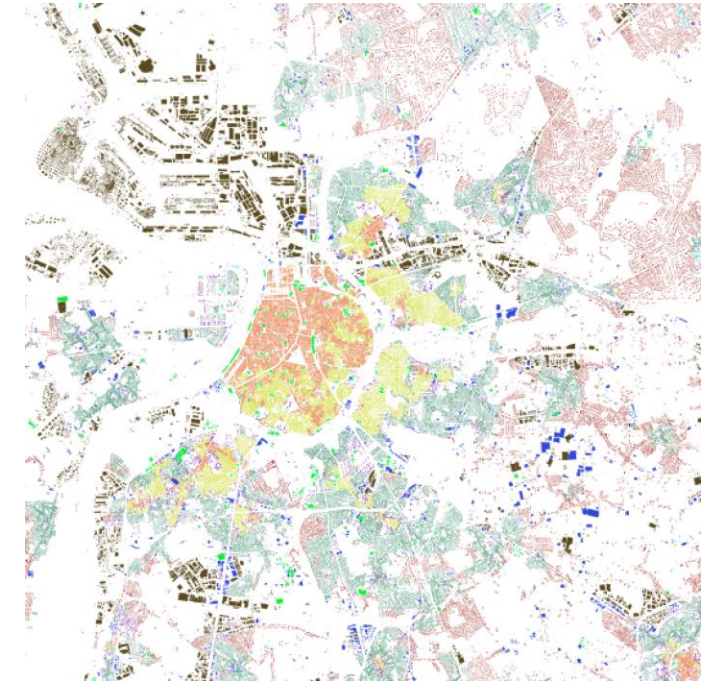
Perimeter Block



Irregular Block



Big Commercial



Gradient Boosting Classification

Source data: OpenStreetMap
Contributors (2017)

Named Urban Tissue Areas



Source data: OpenStreetMap Contributors (2017)

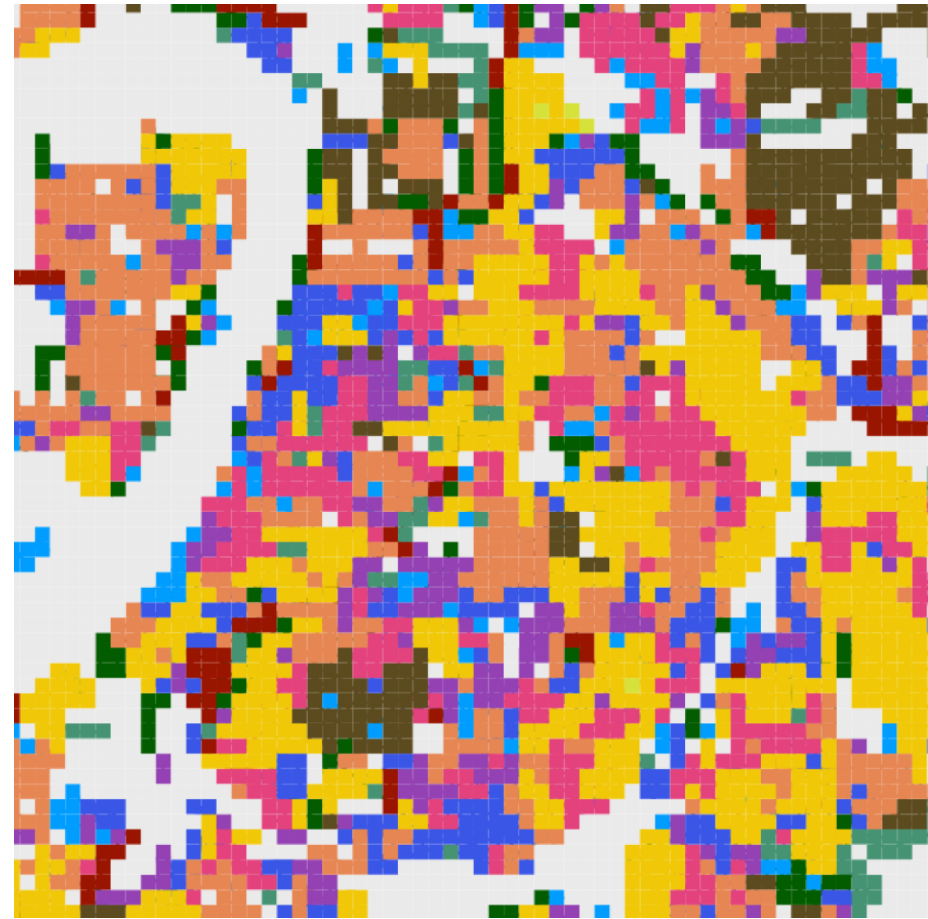
Perimeter Block

Step 2: Encode

Encoding Typologies



Clustered Road Segments



Road Typology Grid

Source data: OpenStreetMap Contributors (2017)

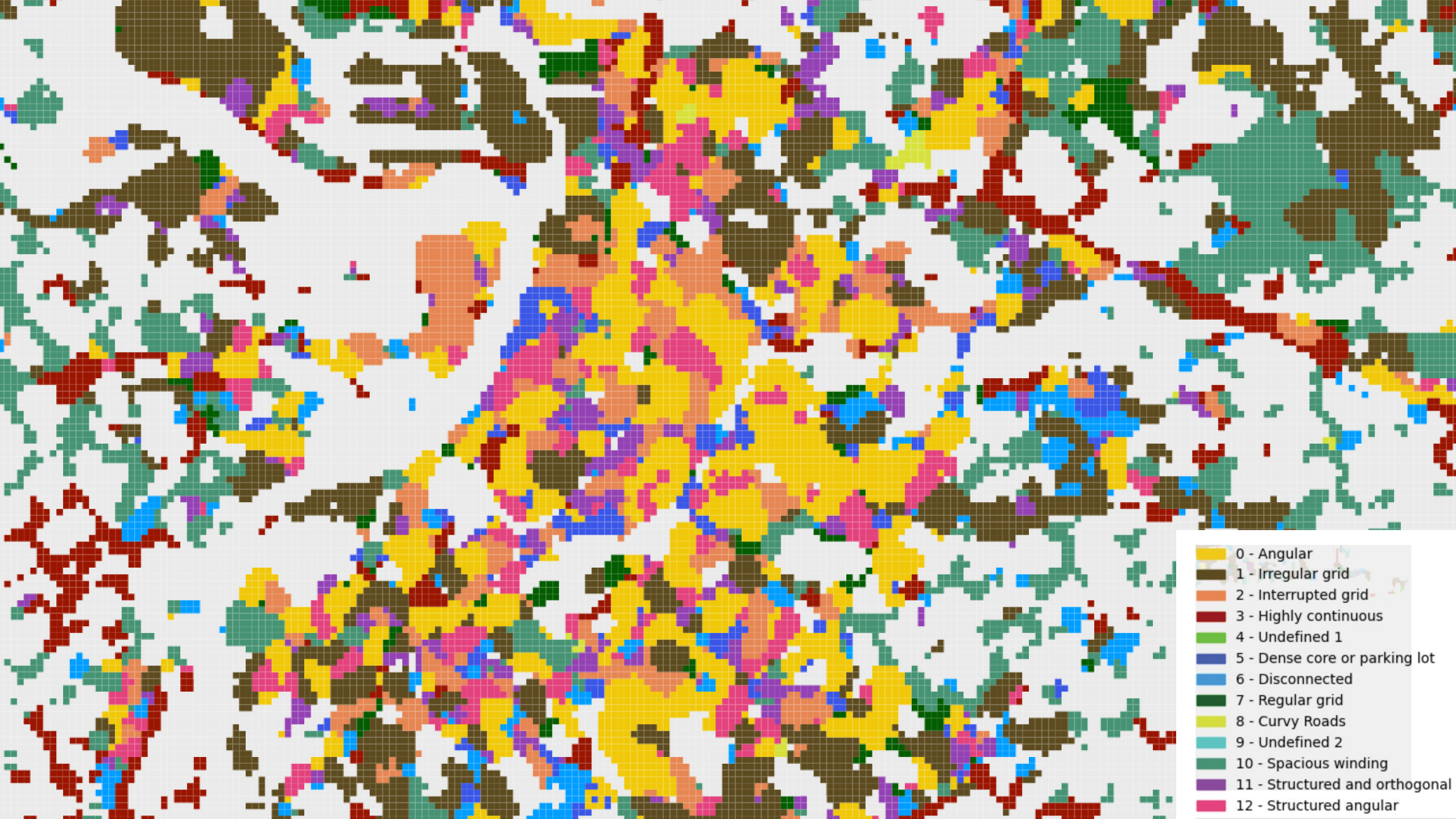
Typology Grid Smoothing



Before filter



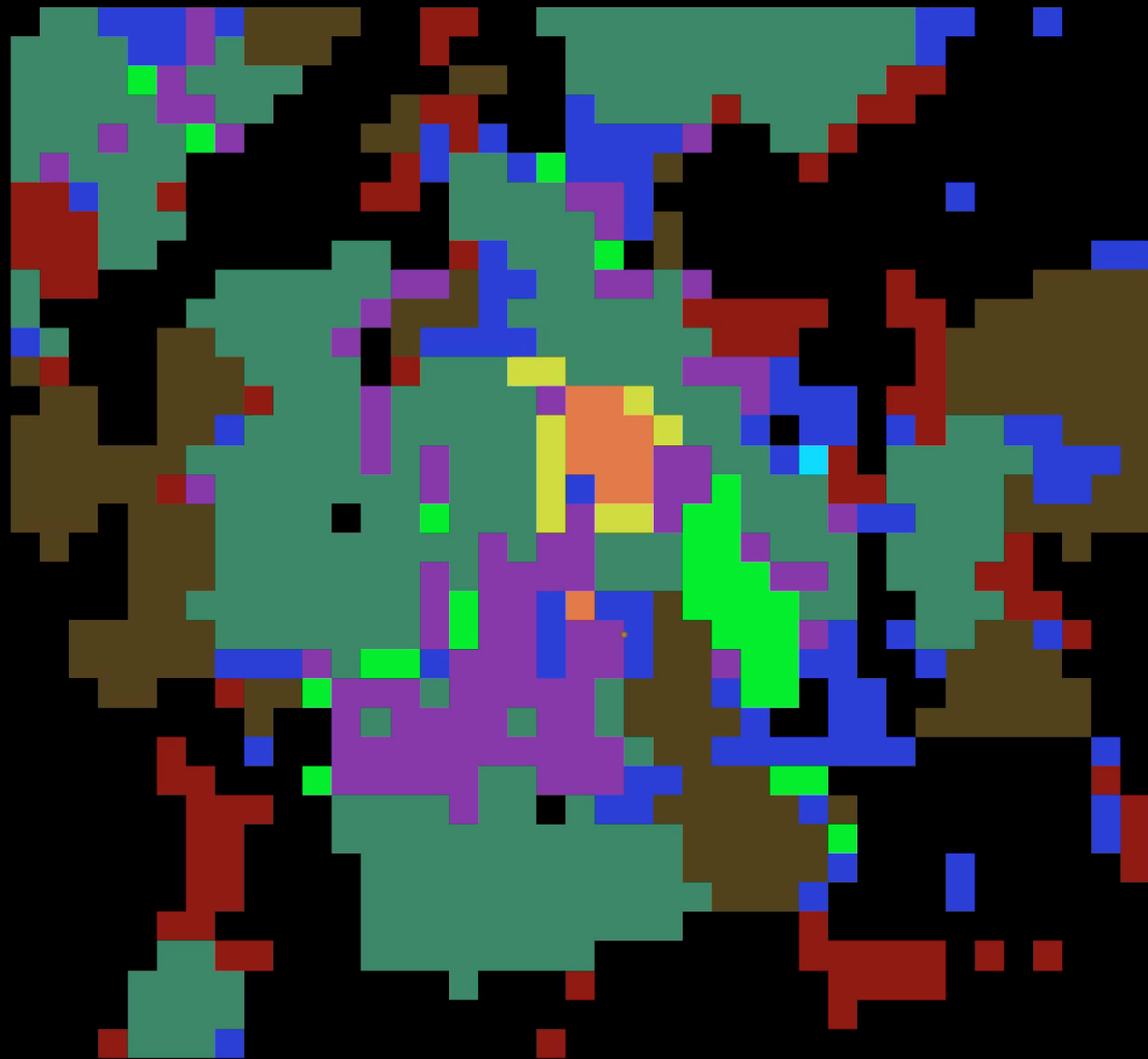
After 3×3 mode filter

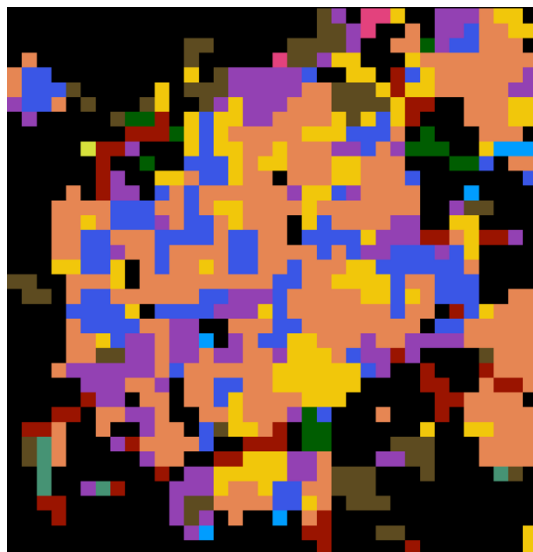


- 0 - Angular
- 1 - Irregular grid
- 2 - Interrupted grid
- 3 - Highly continuous
- 4 - Undefined 1
- 5 - Dense core or parking lot
- 6 - Disconnected
- 7 - Regular grid
- 8 - Curvy Roads
- 9 - Undefined 2
- 10 - Spacious winding
- 11 - Structured and orthogonal
- 12 - Structured angular

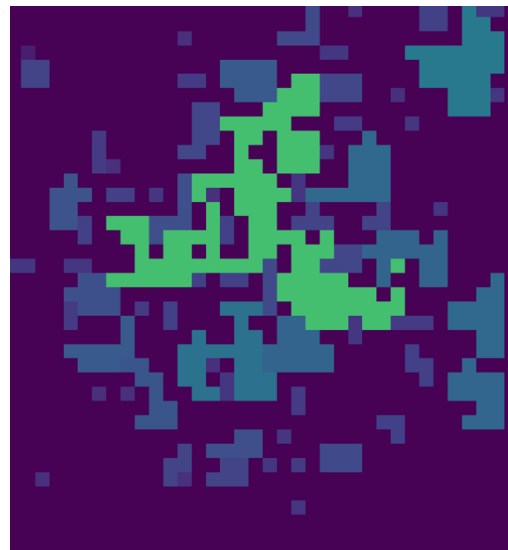
Step 3: Generate

Simulated Annealing

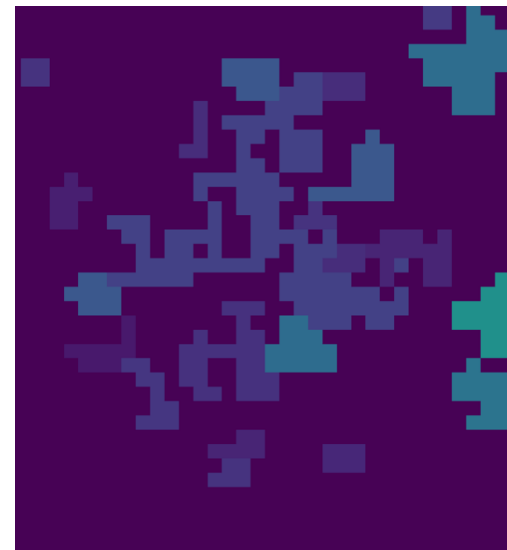




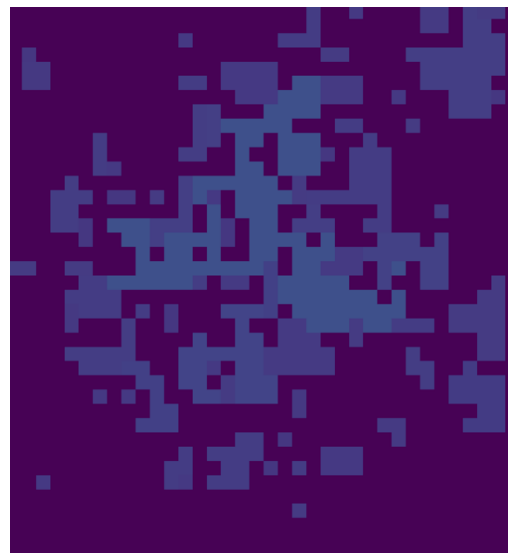
Typology Grid State



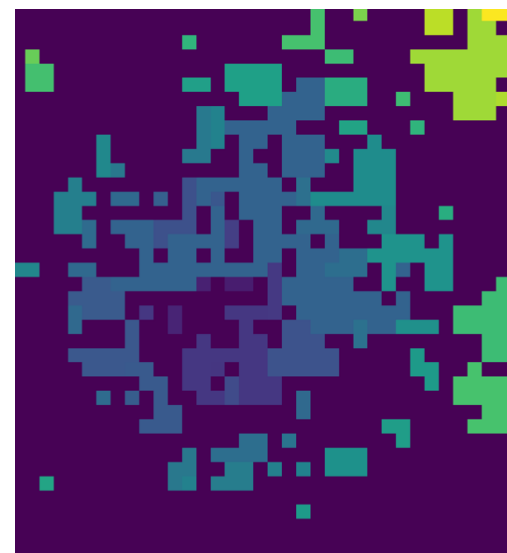
Area



Core Area Index

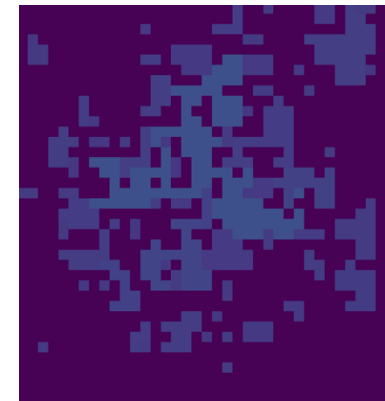
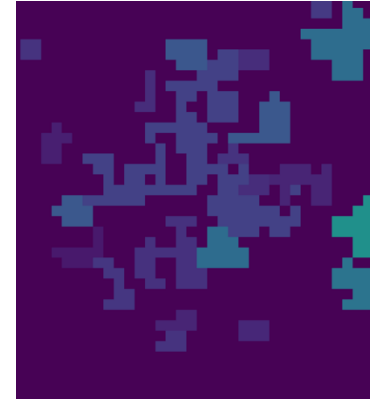
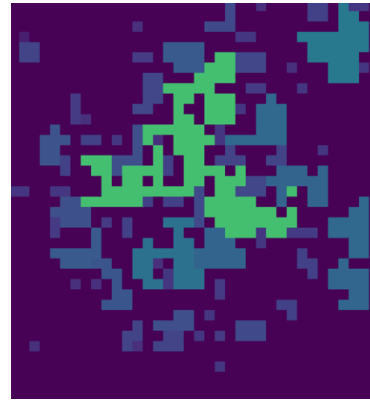
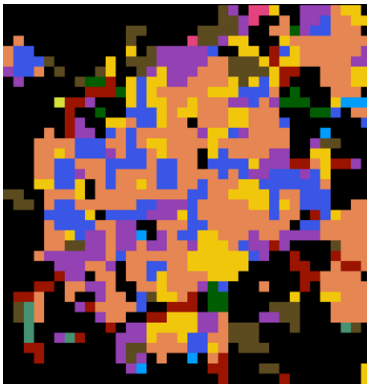


Shape Index



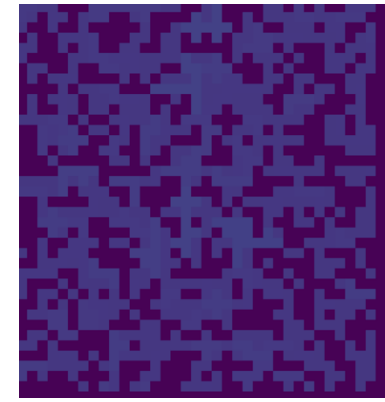
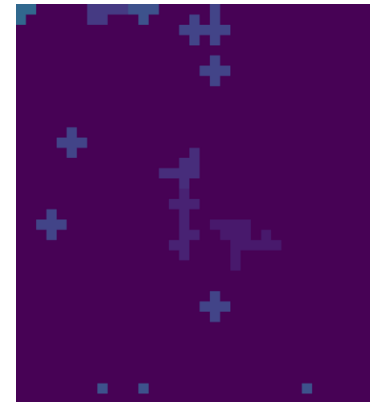
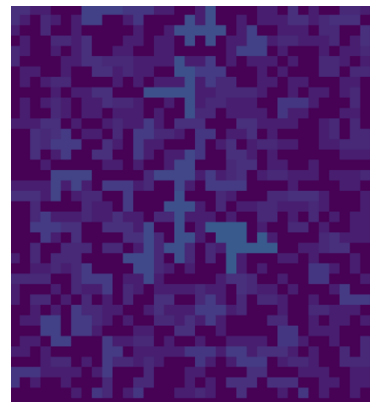
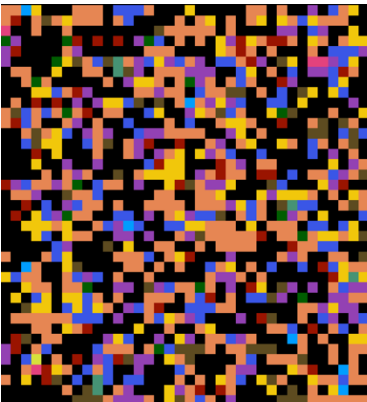
Distance to City Center

Real City

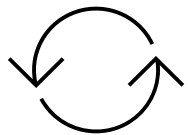


100%

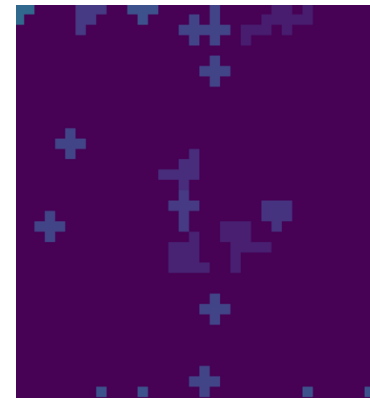
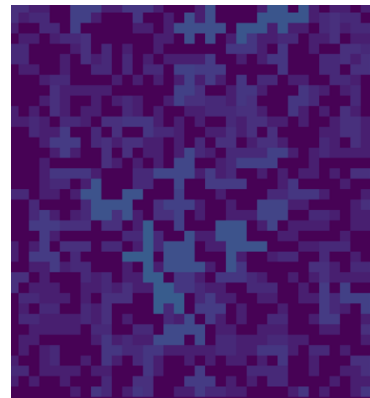
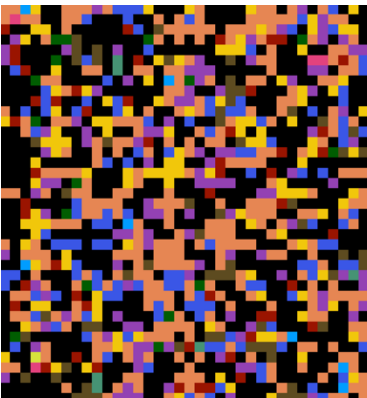
Current
State



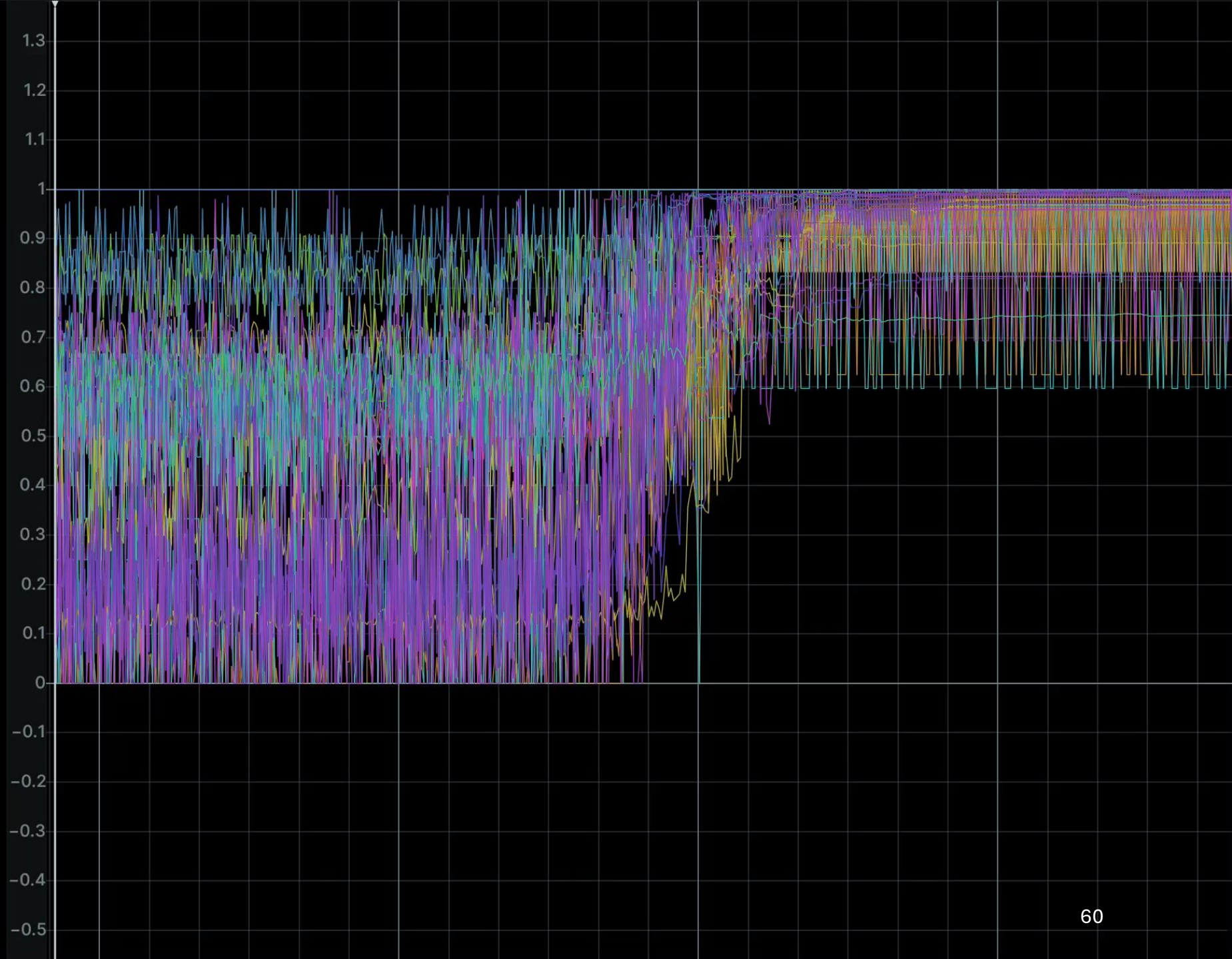
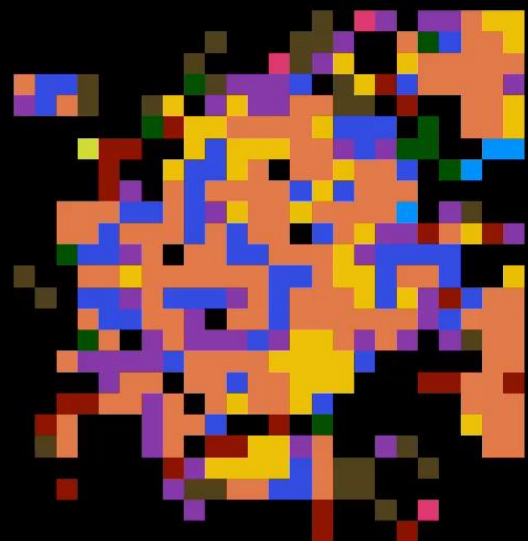
56.1%



New
State

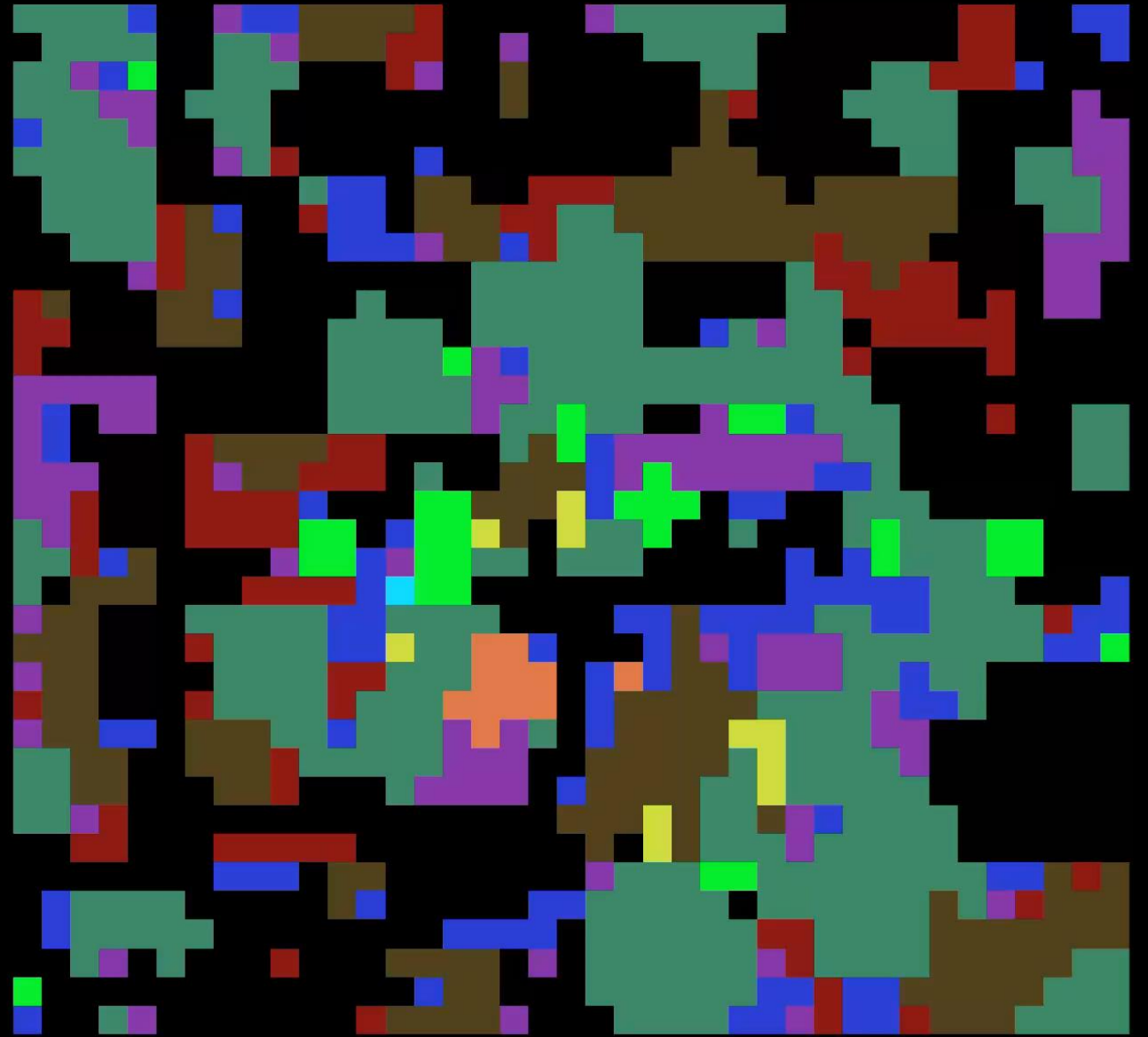


56.4%

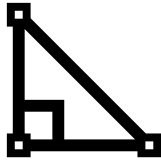


Inverse Procedural Modeling

*Based on Parish & Müller
road generation system*



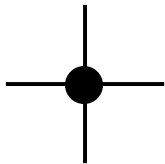
Typology Template



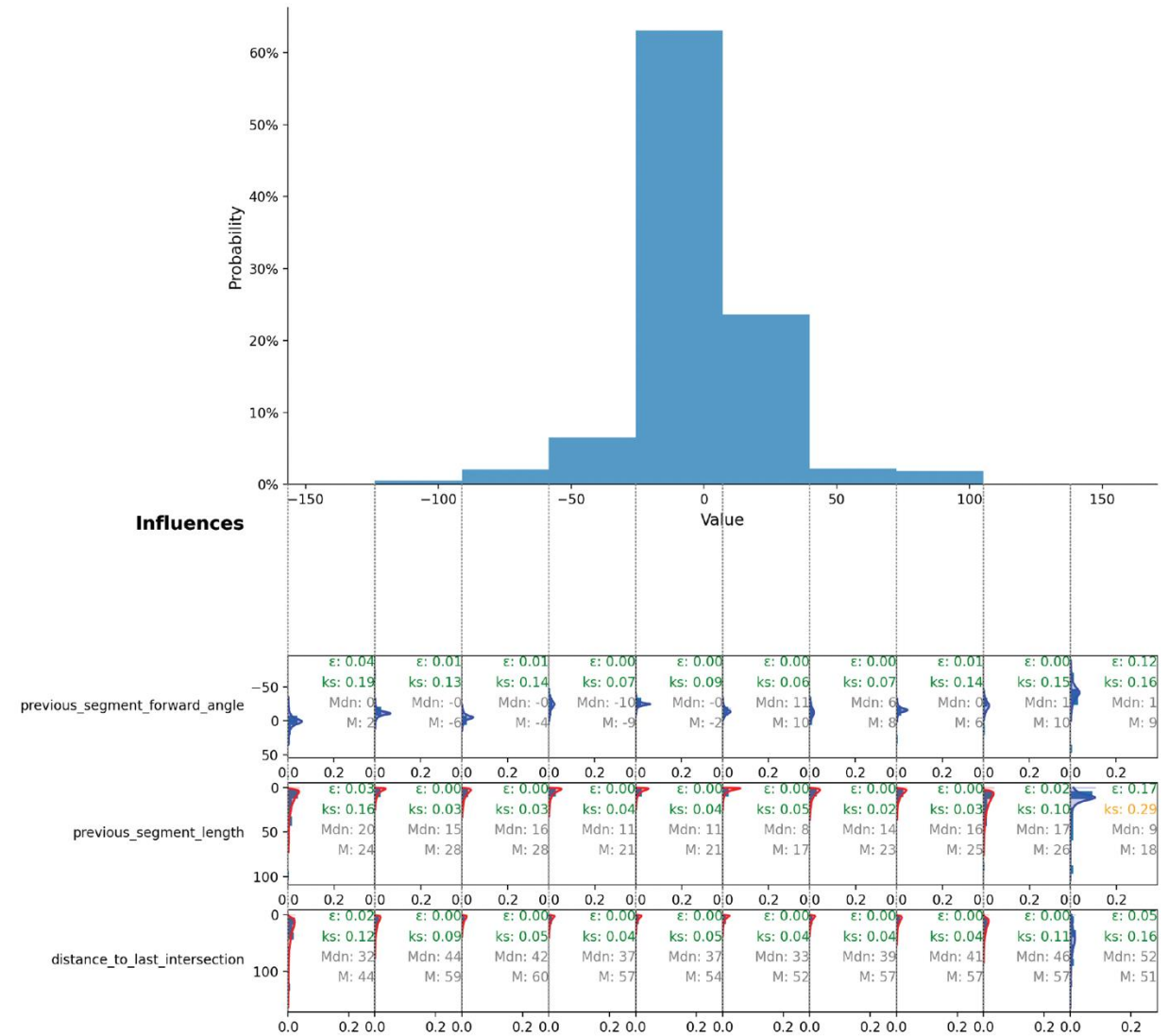
Forward Angle



Segment Length



Intersection degree



Better results from influences



Without influences



With influences

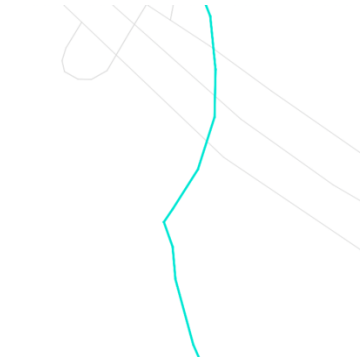
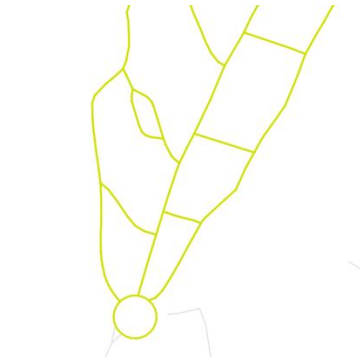
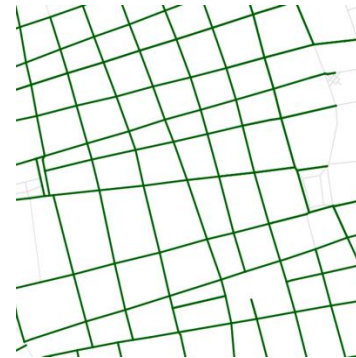
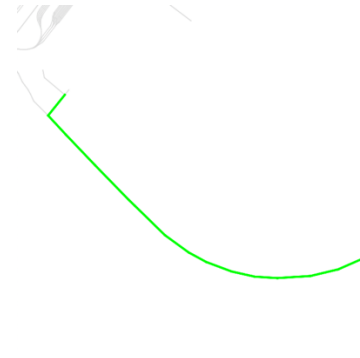


Image from OpenStreetMap
Contributors (2017)

Results

Analyze

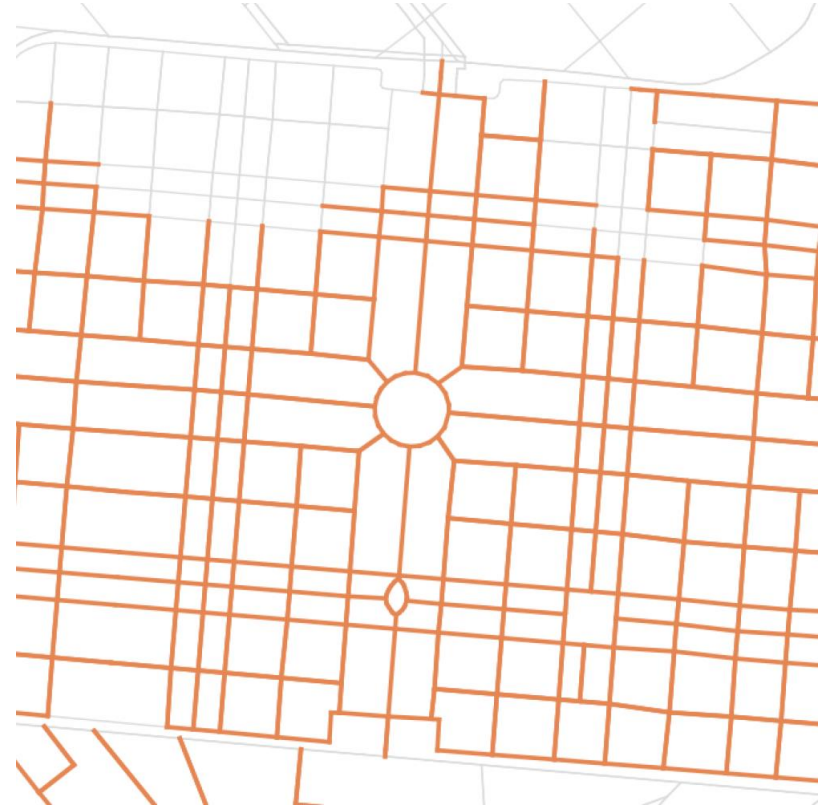
Roads



13 Clusters

Source data:
OpenStreetMap
Contributors
(2017)

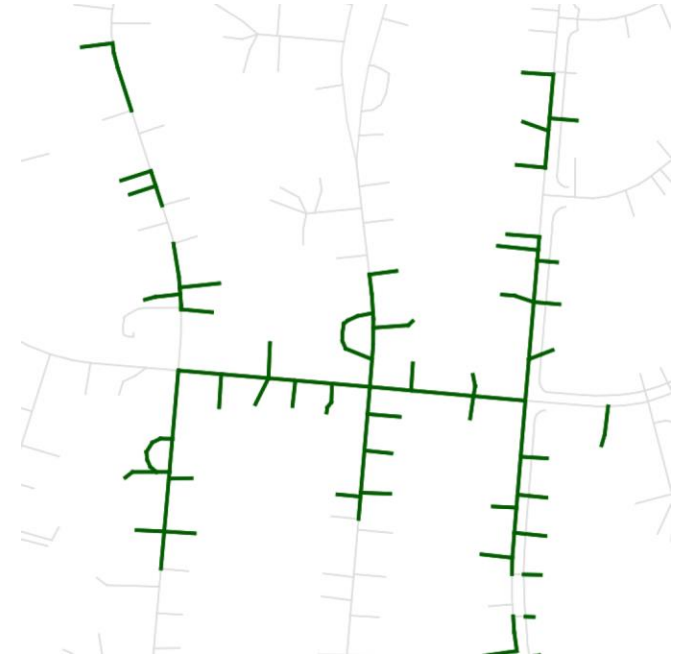
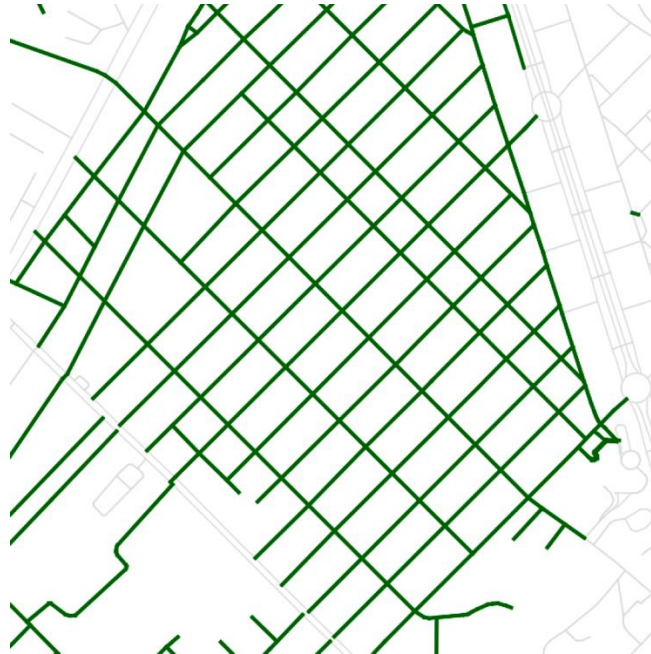
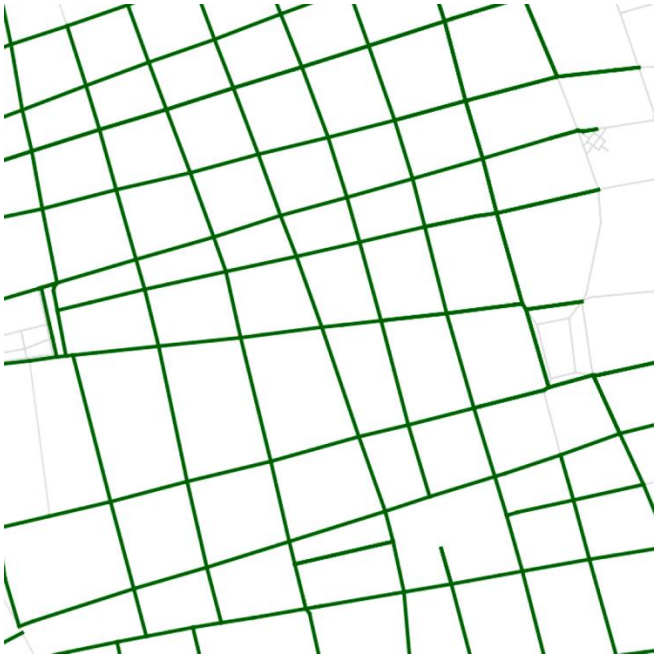
Consistent



Cluster 2: Interrupted Grid

Source data: OpenStreetMap Contributors (2017)

Outliers



Cluster 7: Regular Grid

Source data: OpenStreetMap Contributors (2017)

Interesting Groupings



Cluster 5: Dense Core or Parking Lot

Source data: OpenStreetMap Contributors (2017)

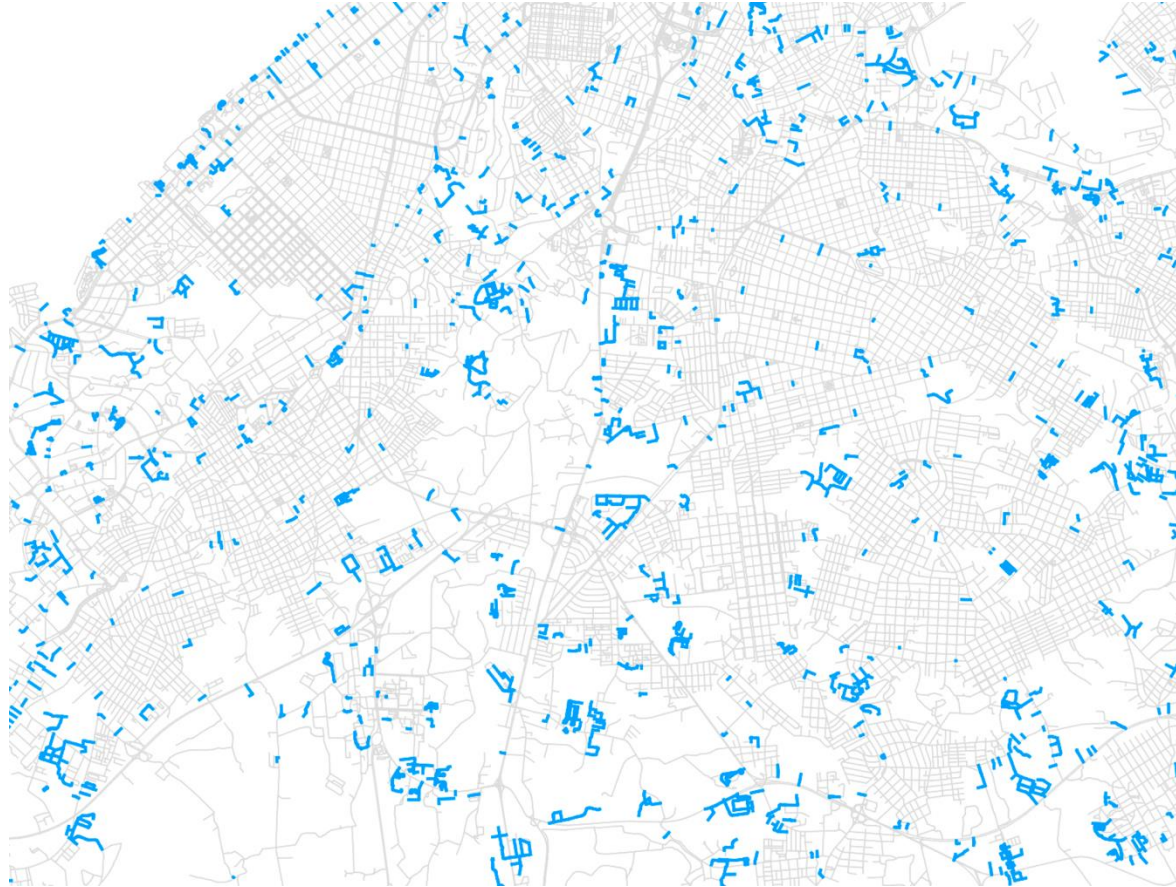
Inconsistent



Cluster 3: Highly Continuous

Source data: OpenStreetMap Contributors (2017)

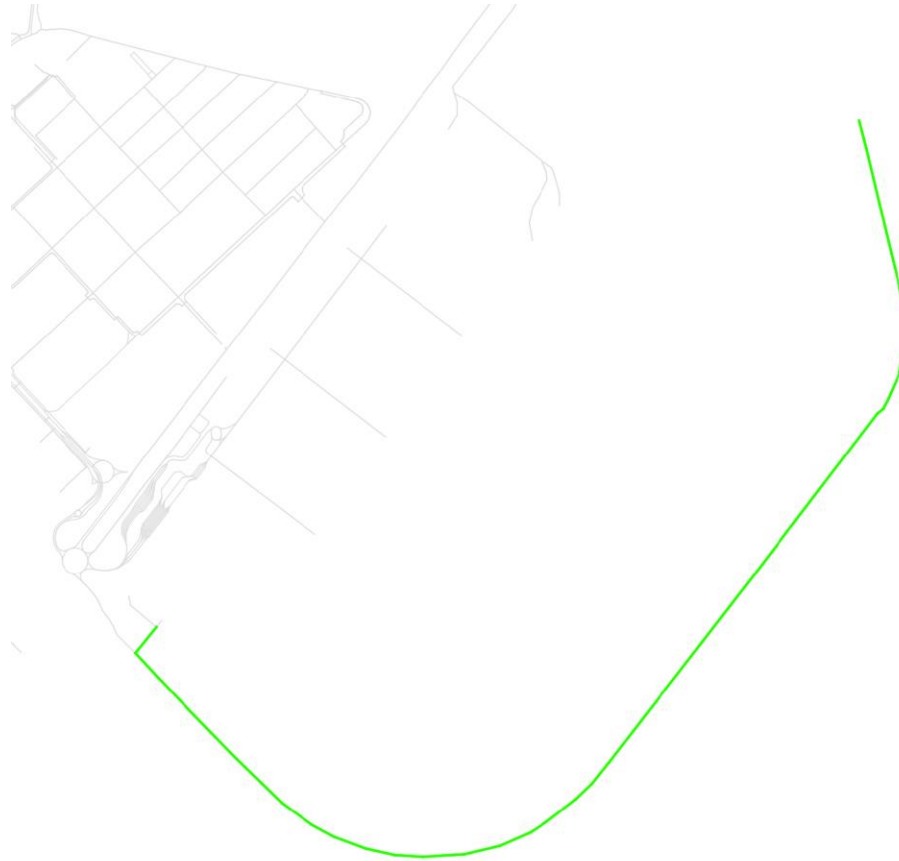
Scattered



Cluster 6: Disconnected

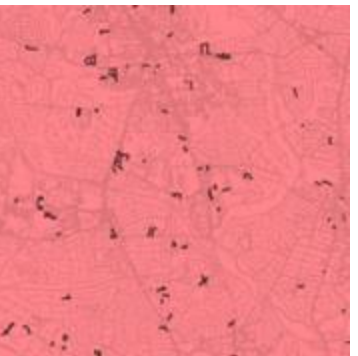
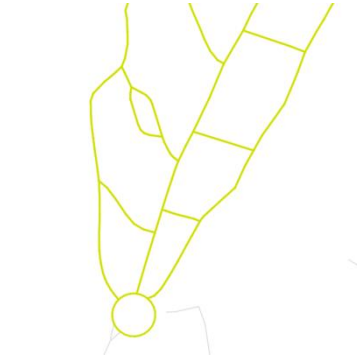
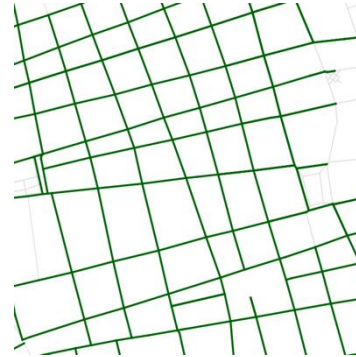
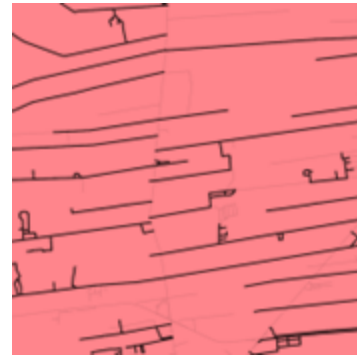
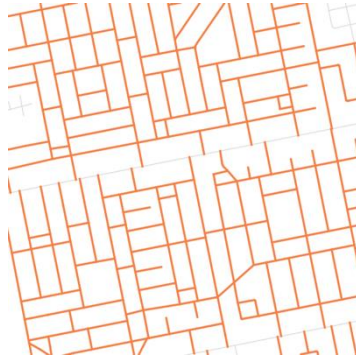
Source data: OpenStreetMap Contributors (2017)

Rare



Source data: OpenStreetMap Contributors (2017)

Cluster 4: Undefined 1 (0.02%)



Invalid Clusters

Source data: OpenStreetMap Contributors (2017)

Analyze

Buildings

Similarity with morphological clustering

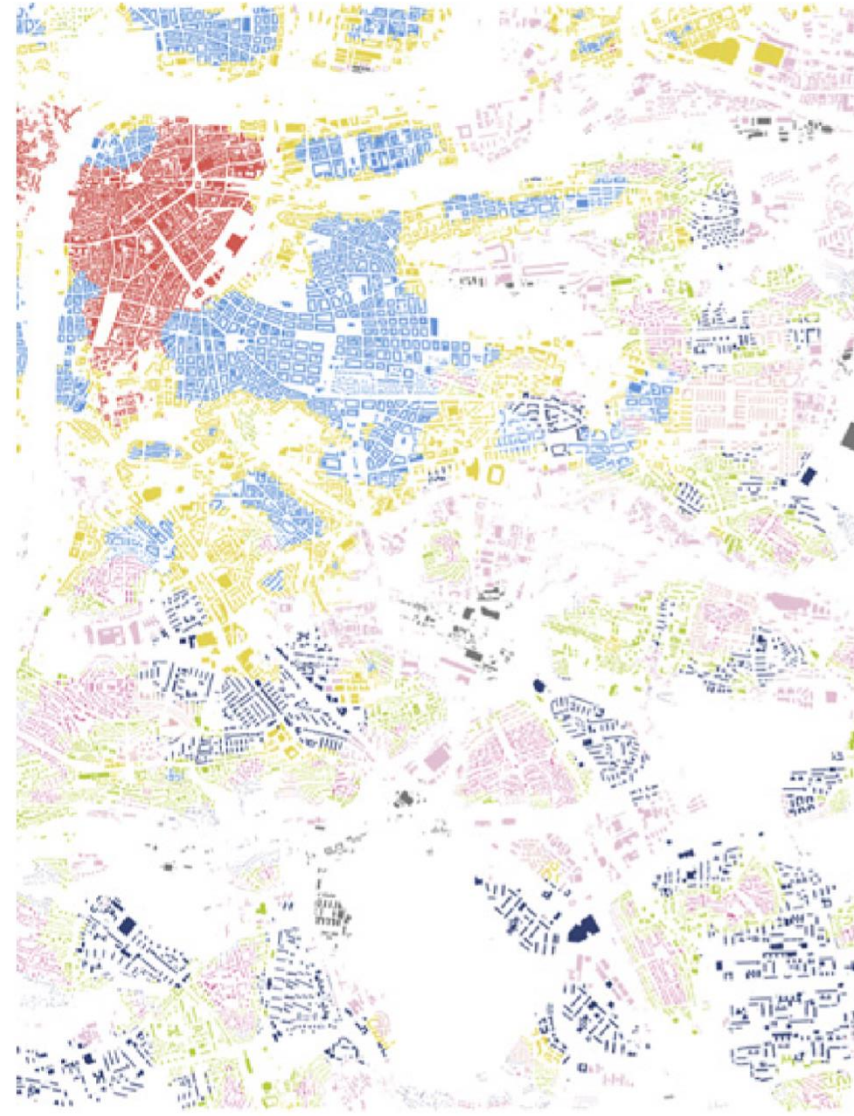
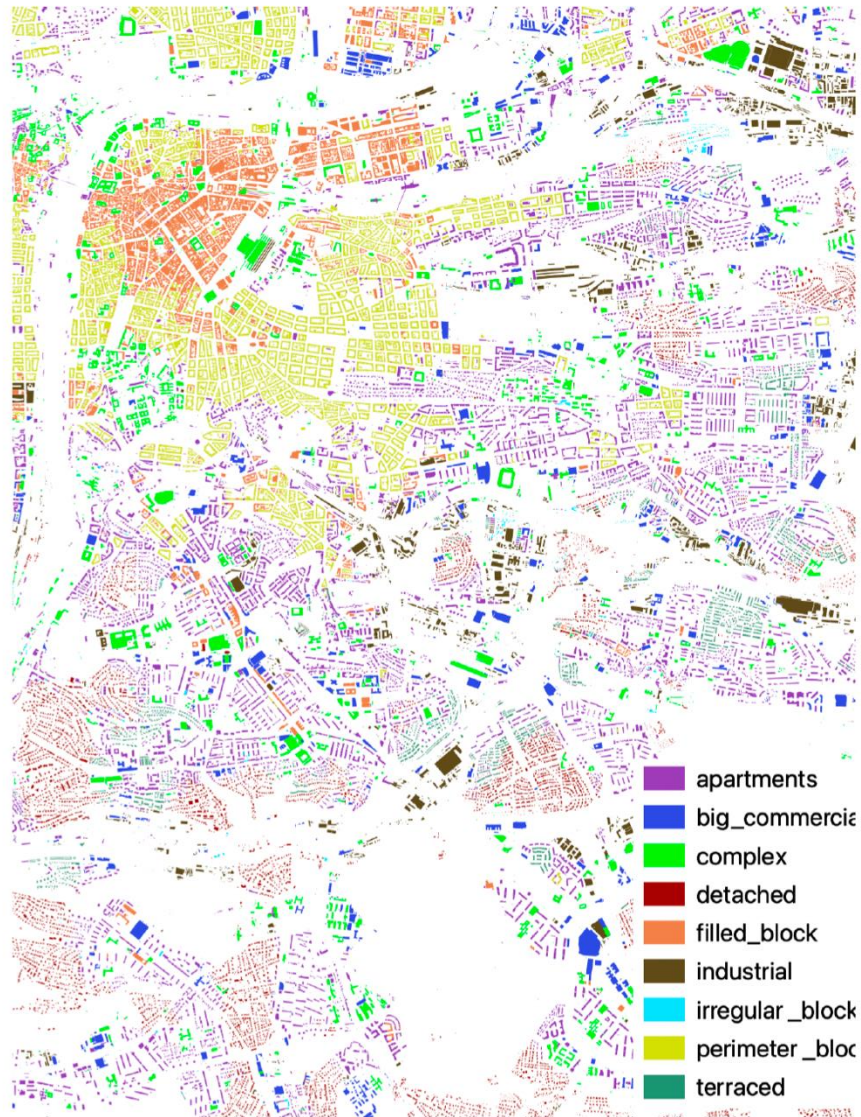


Image from
Fleischmann et al.
(2022)

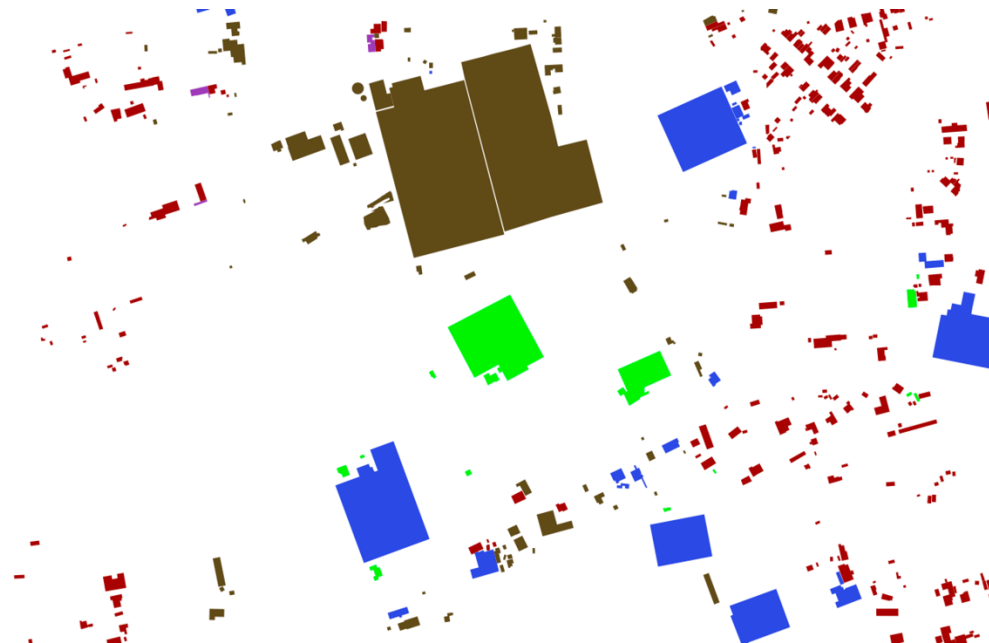


Source data: OpenStreetMap Contributors (2017)

Building-level accuracy



Local inconsistencies

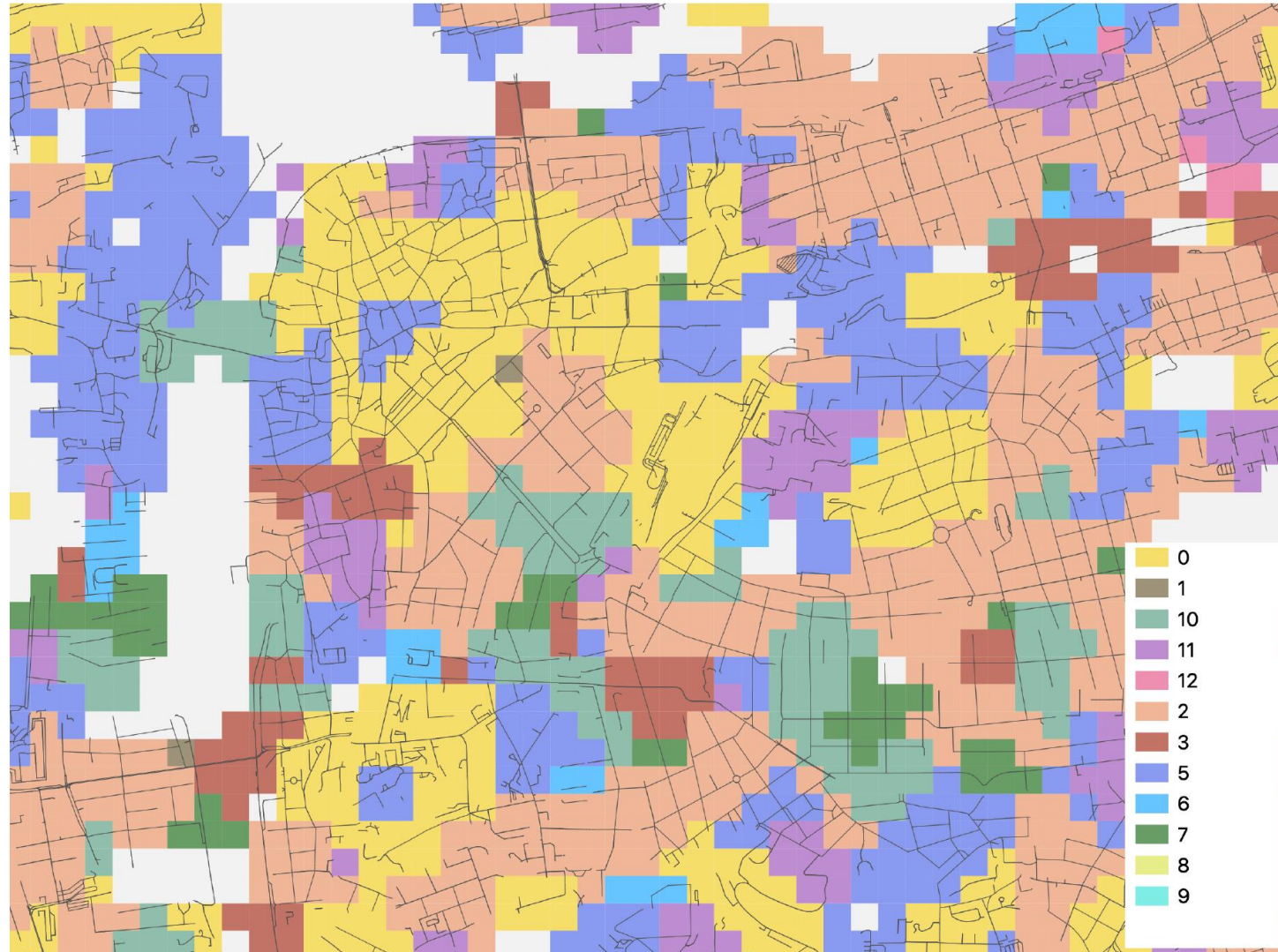


Typology ambiguousness

Source data: OpenStreetMap Contributors (2017)

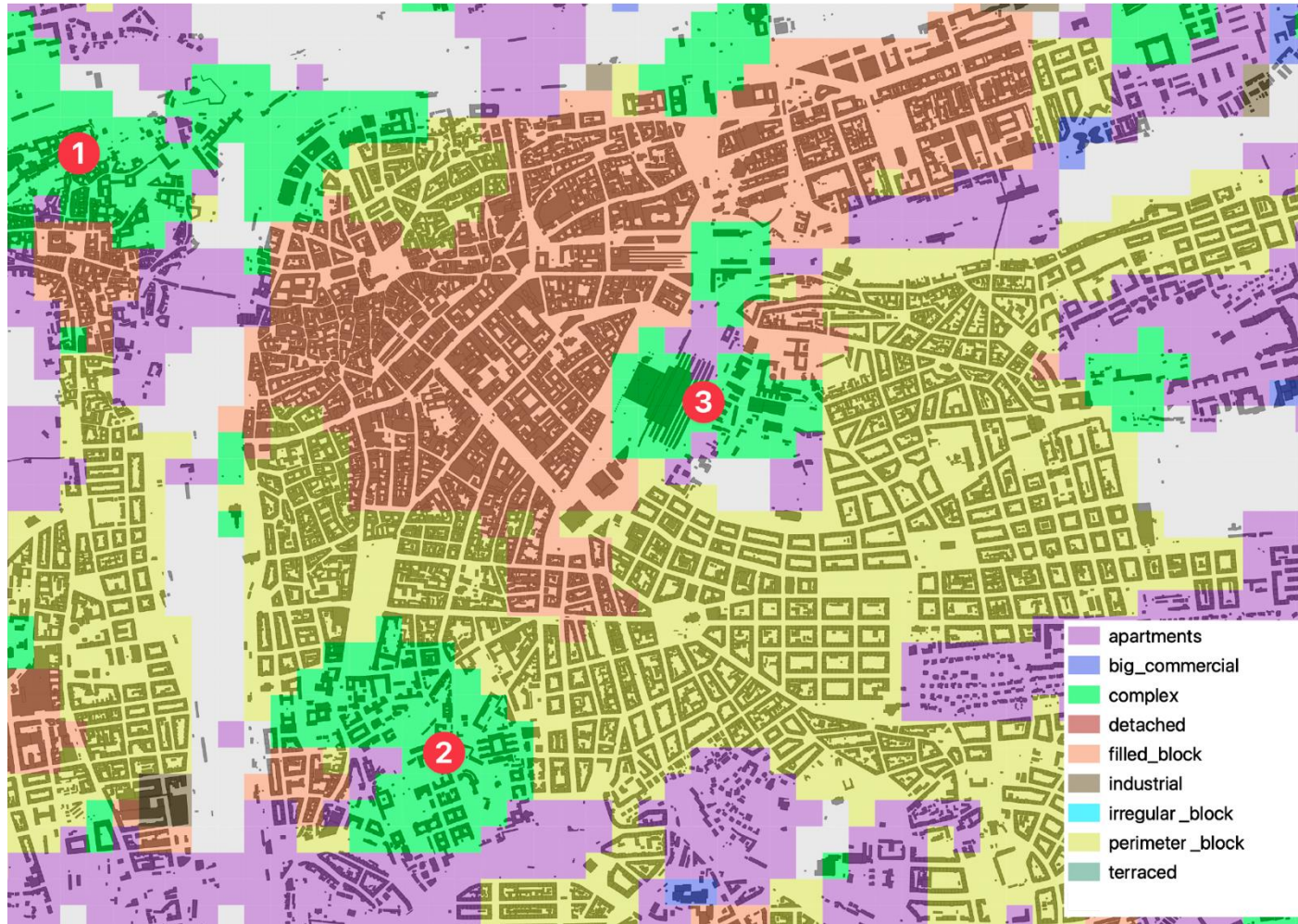
Encode

Road Typology Grid



Source data: OpenStreetMap
Contributors (2017)

Building Typology Grid

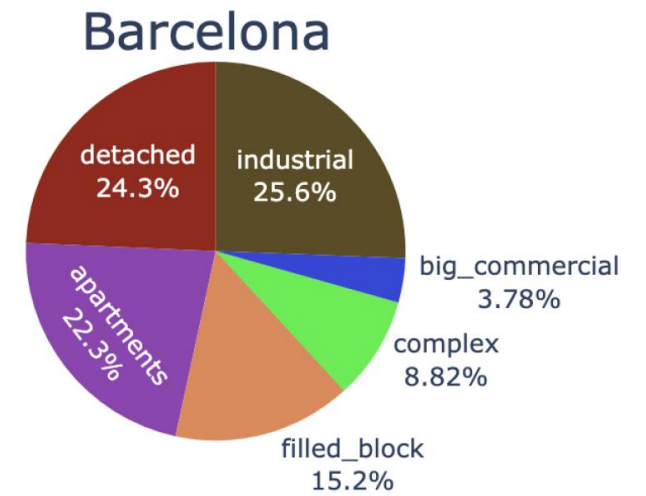
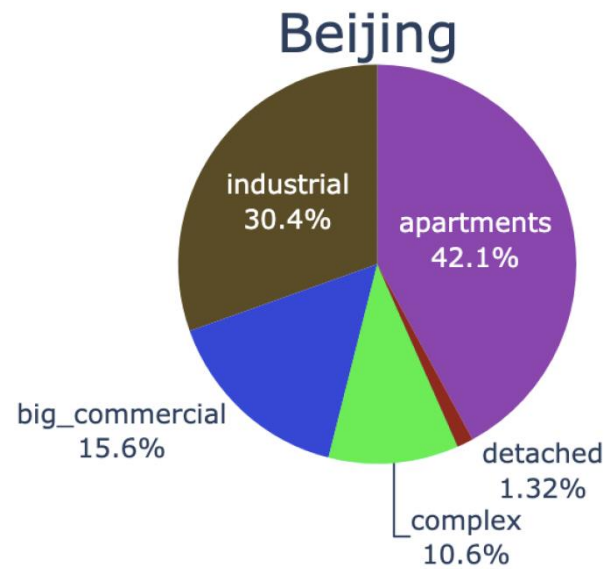
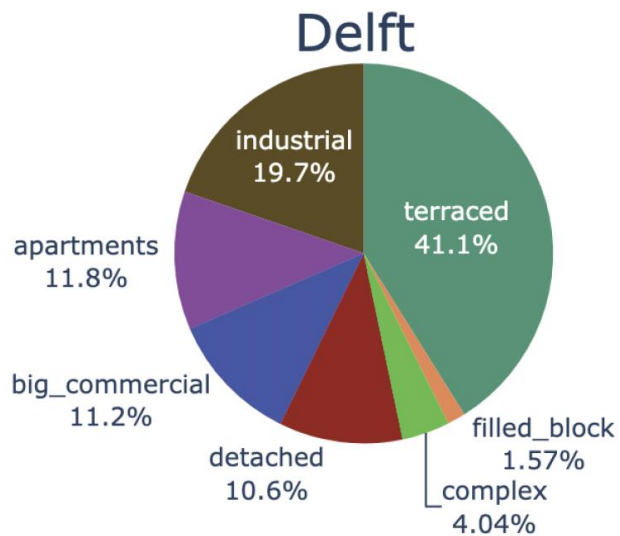


Complex Class

- 1 - Prague Castle
- 2 - Prague University
- 3 - Central Station

Source data: OpenStreetMap Contributors (2017)

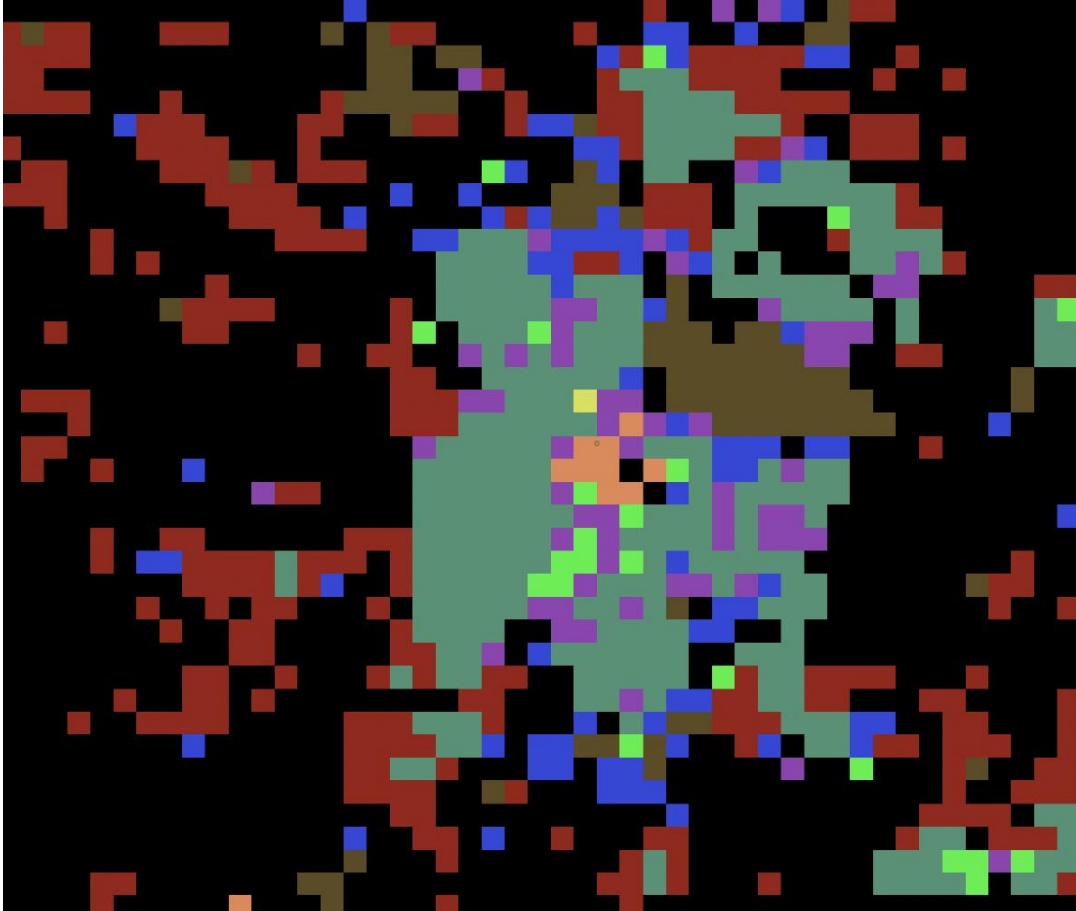
Comparing Typology Grids



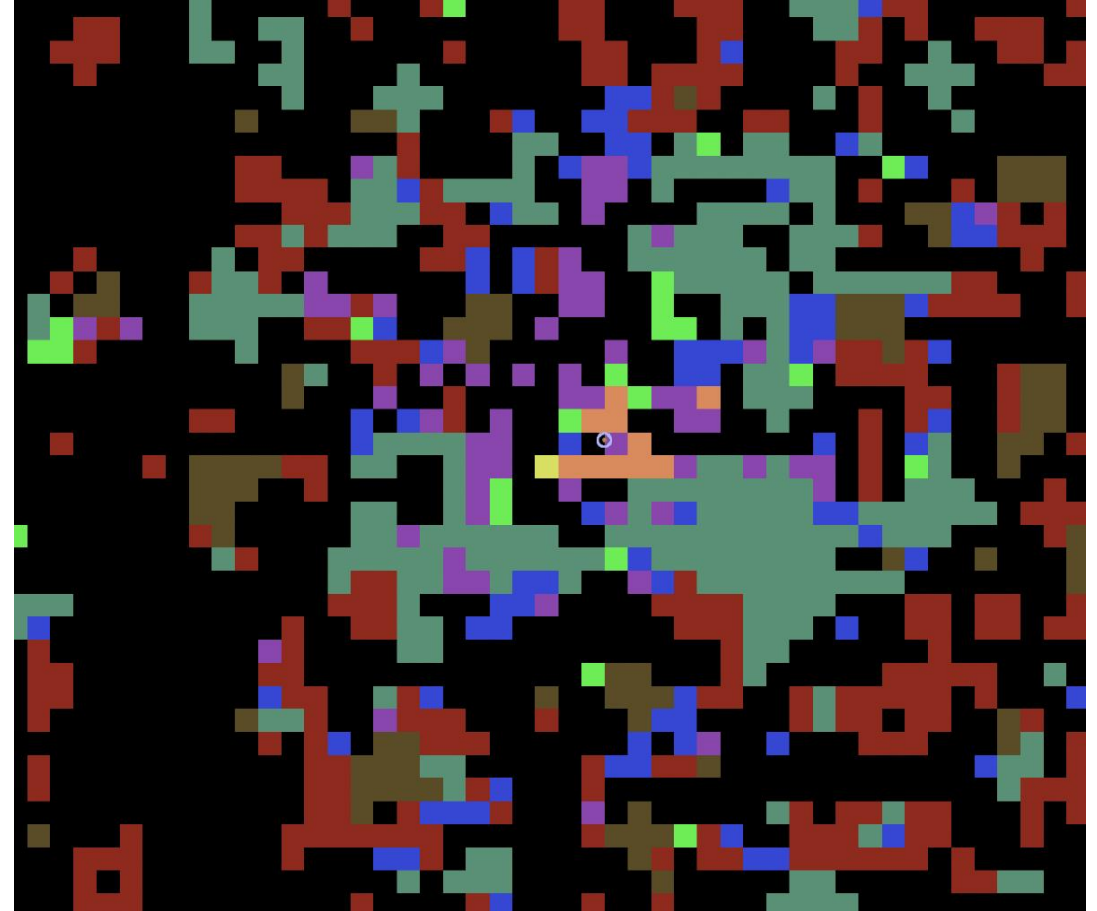
Generate

Typology Grid

Simulated Annealing Results

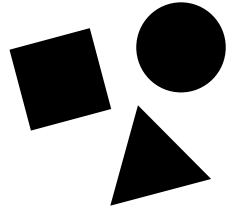


Original City

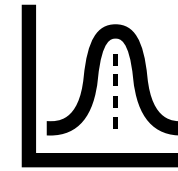


After 2.5 million iterations

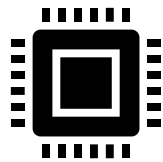
Simulated Annealing Results



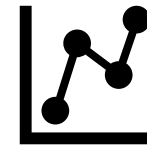
Visual Similarity
From 3 Shape Metrics



Encode Many
Metric Relationships



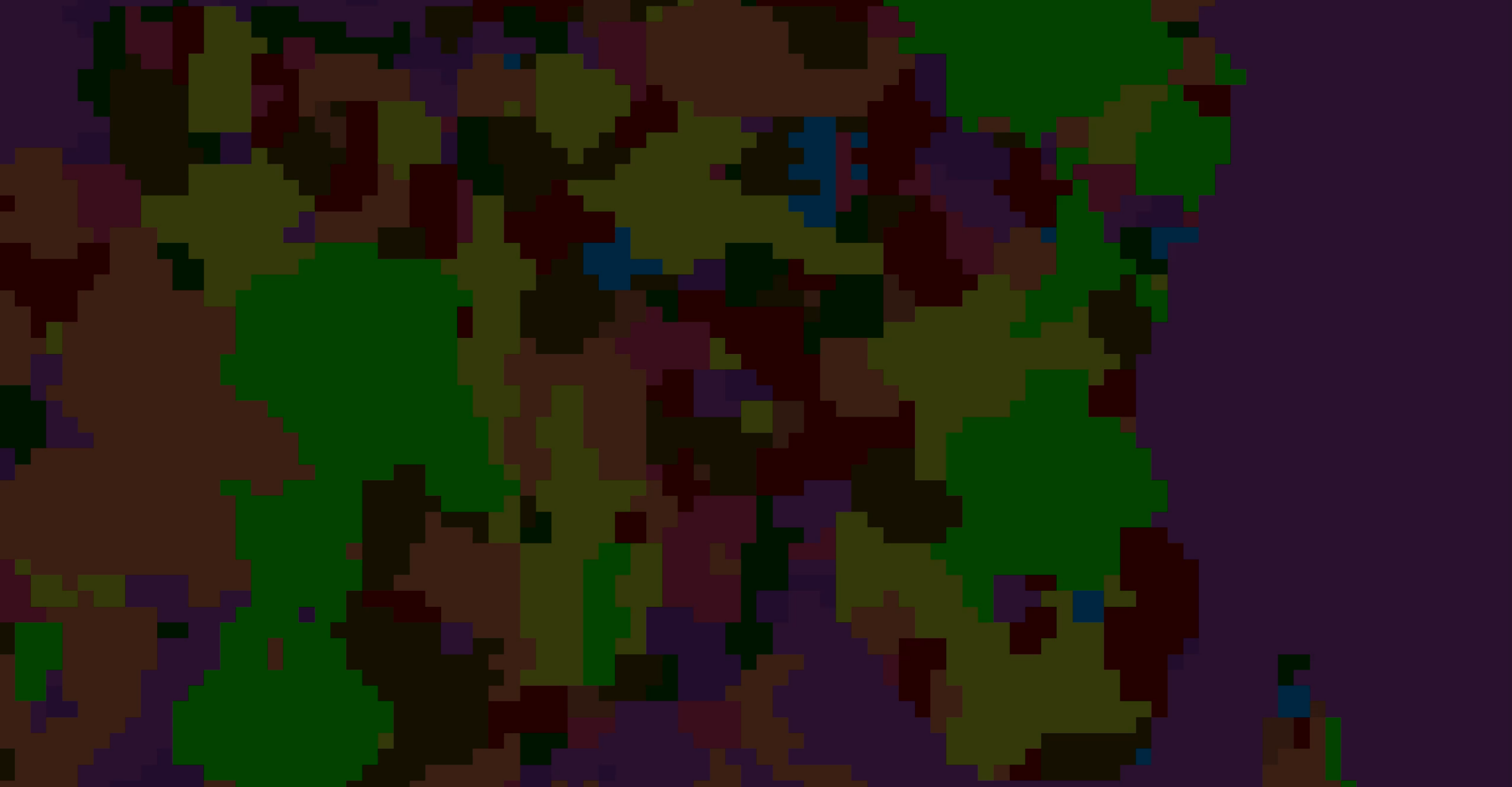
Computationally expensive



Sensitive to input parameters

Generate

Roads



Thessaloniki



Montevideo



Havana



5: Dense Core or
Parking lot



7: Regular Grid



Transitions between typologies



Unrealistic patterns



Grid consistency

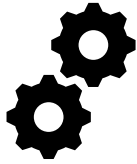
Generate

Buildings

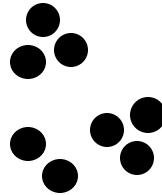


Future Research

Analyze - Roads



Feature Engineering



Other Clustering
Methods

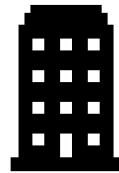


Classification
from Experts

Analyze - Buildings



Robust Validation

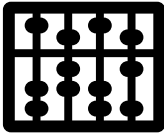


Improved Dataset

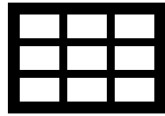


Feature Engineering

Generate – Typology Grid



Advanced Objective
Function



Typology Grid
Parameters

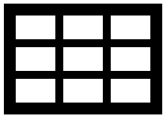


Improved Annealing

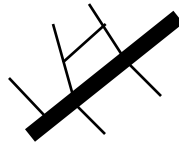


AI-Based
Grid Generation

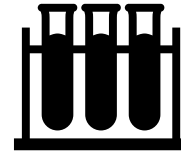
Generate – Roads



Typology Grid
Parameters



Road Hierarchy

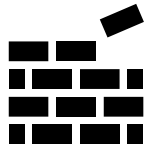


Other Generation
Methods

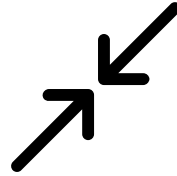


Inverse Procedural
Modelling using AI

Generate – Buildings



Advanced Building
Generation



Typology transitions



AI-Based
Footprint Generation

Conclusions

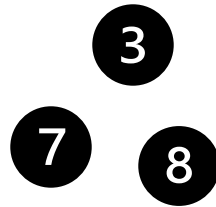
Analyze

How can the urban form of real-world cities be captured using publicly available geospatial data?

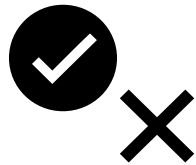
Clustering



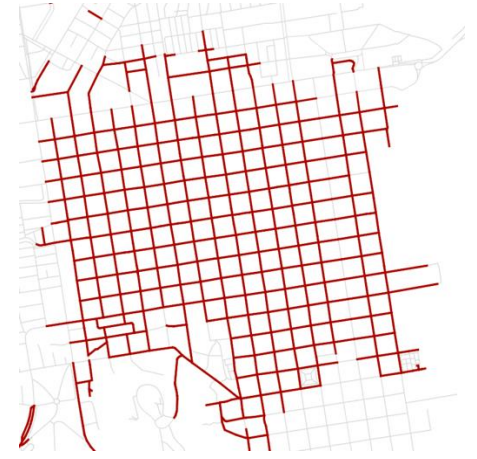
Globally Applicable
and Scalable



Mixed Validity of Clusters



Assigned correctly
vs Noisy Pattern



Source data: OpenStreetMap Contributors (2017)

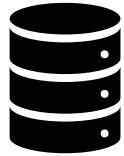
Classification



Globally Applicable
and Scalable



Accurate Results



Depends on Data
Quality & Availability

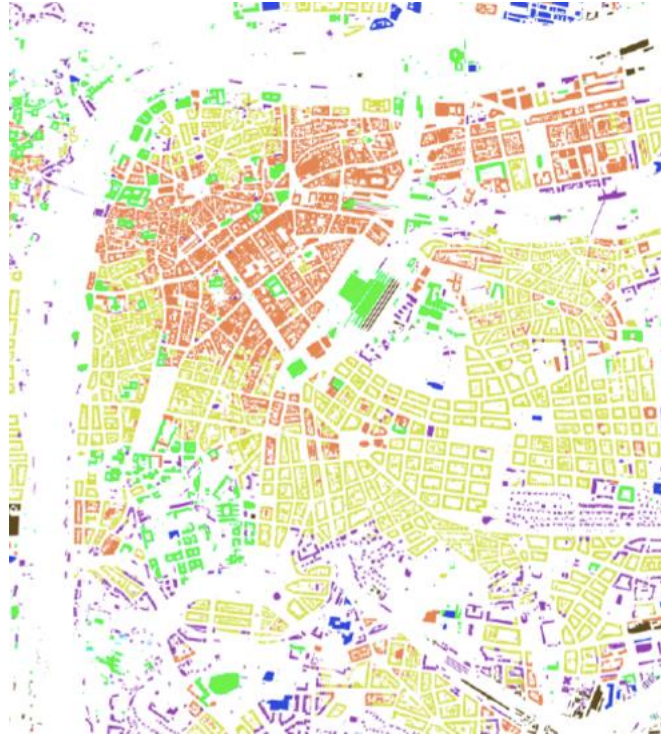
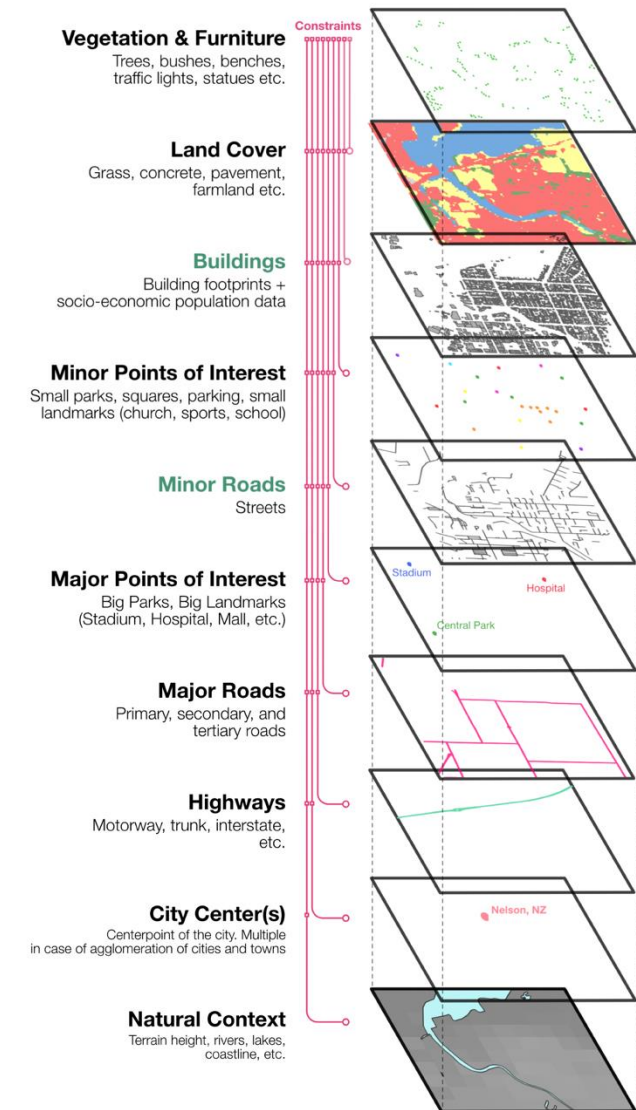


Image from Fleischmann
et al. (2022)



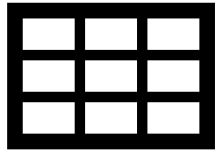
Extra value from individual layer
analysis using city stack



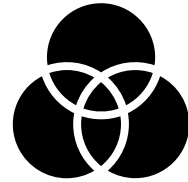
Encode

How can the captured urban form be encoded in a way that allows for the comparison of different cities and generation of new cities with a similar character?

Typology Grid



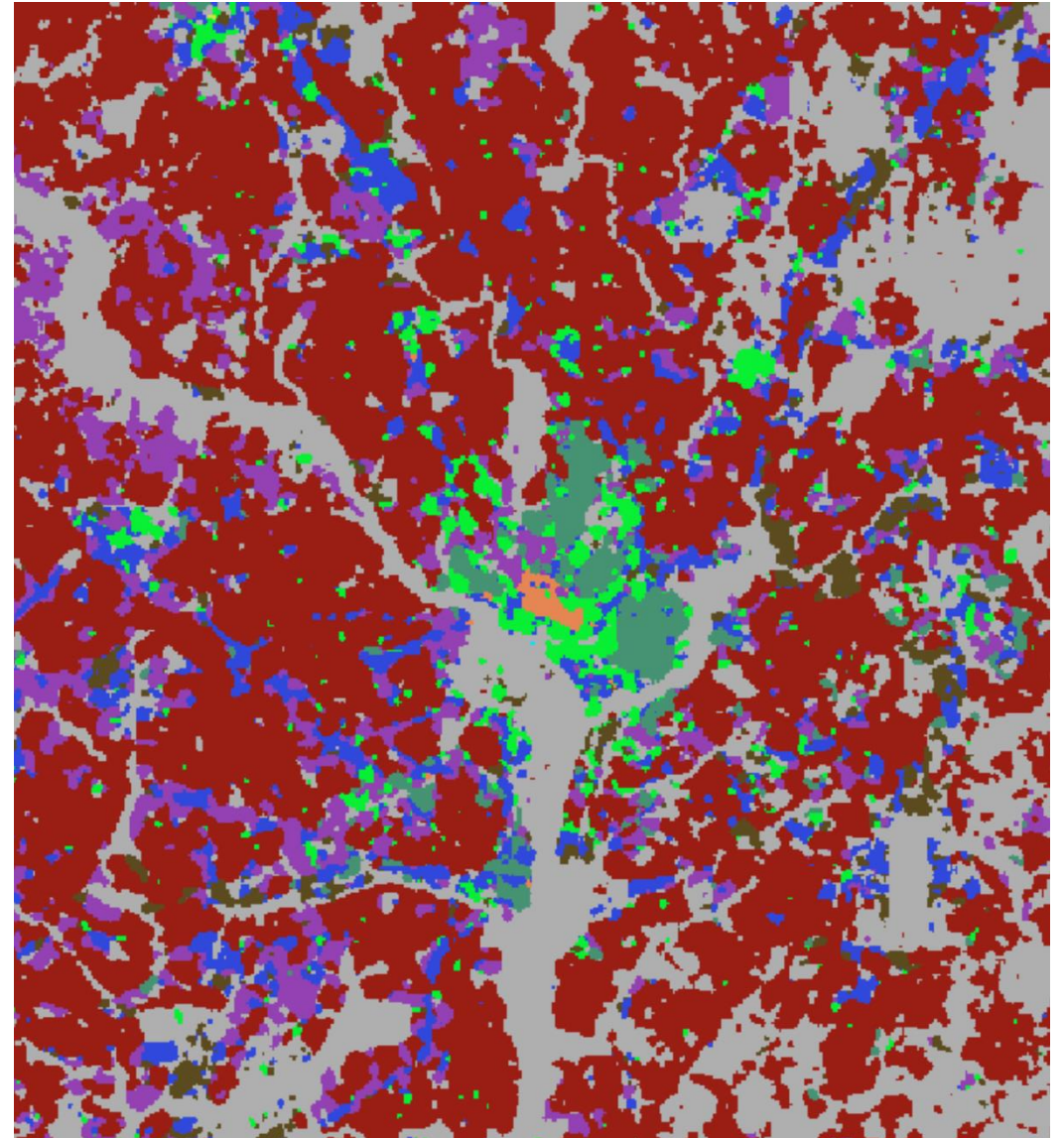
Comprehensible
Complexity



High
Comparability



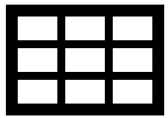
(Over) Simplification



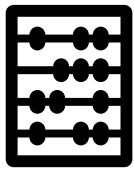
Generate

How can this encoded data be utilized to procedurally generate a digital city model that resembles the form of the encoded real-life city?

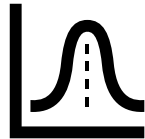
Simulated Annealing



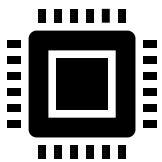
Plausible
Results



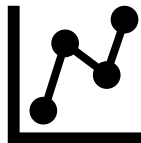
High Control



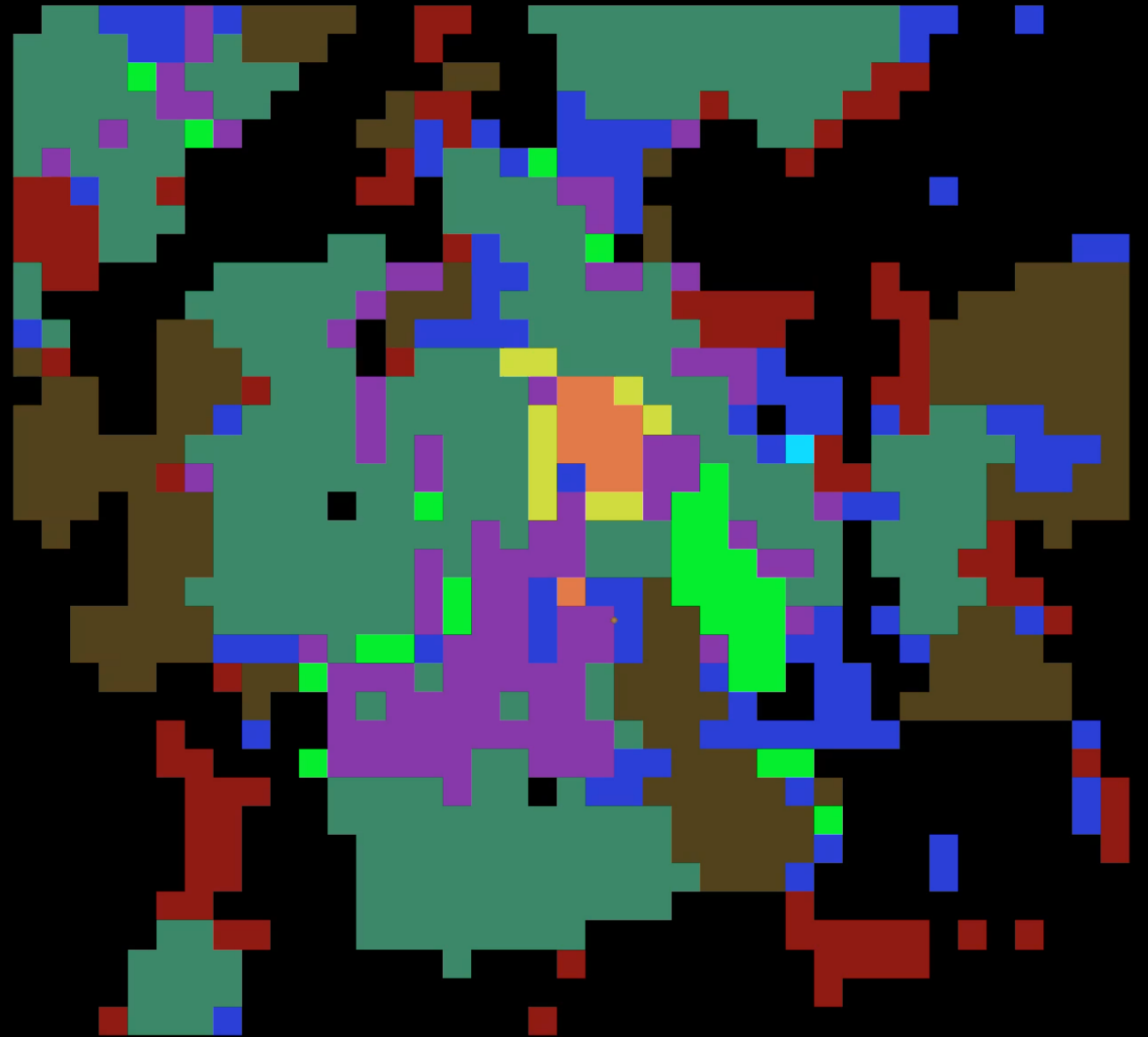
Complex
Relationships



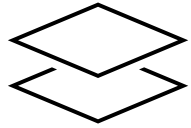
Computationally
Expensive



Sensitive to Input
Parameters



Inverse Procedural Modelling



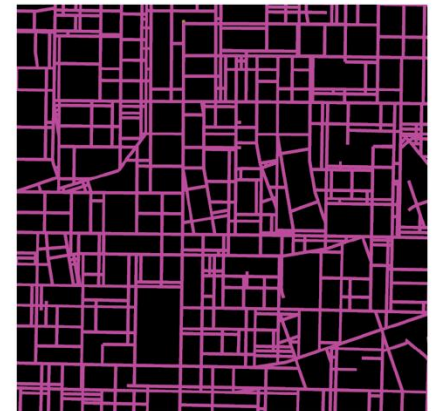
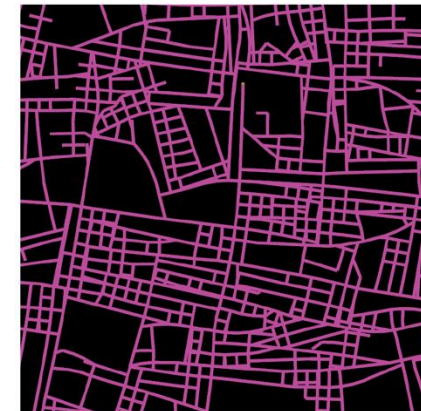
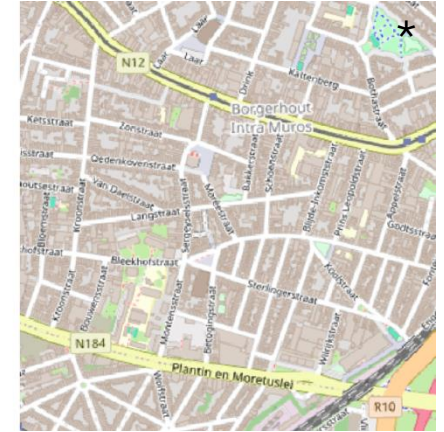
Extra Dimension
to Existing Methods



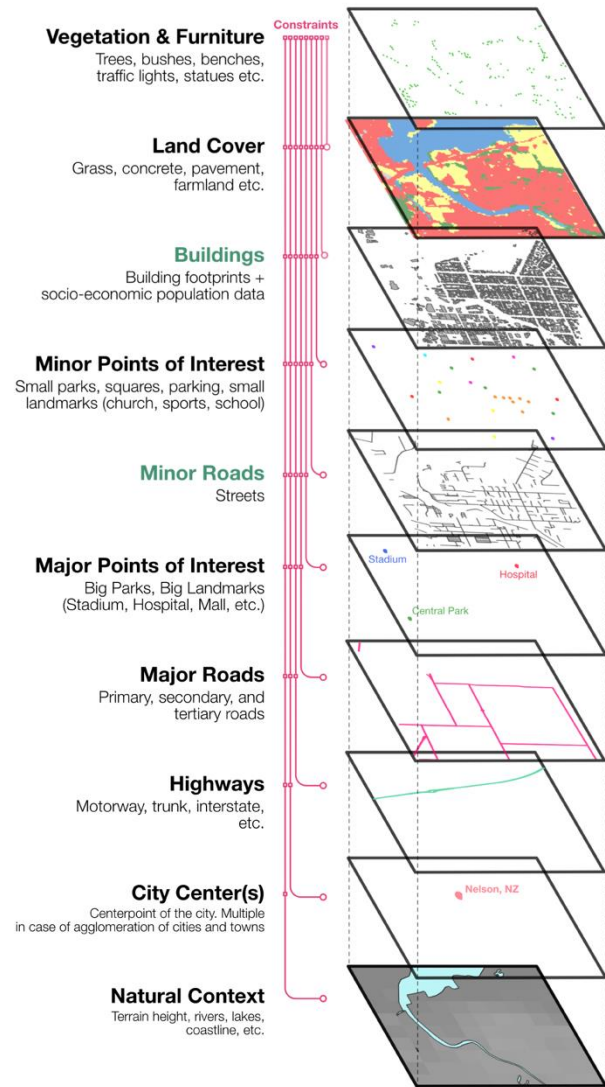
Worldwide
City Variations



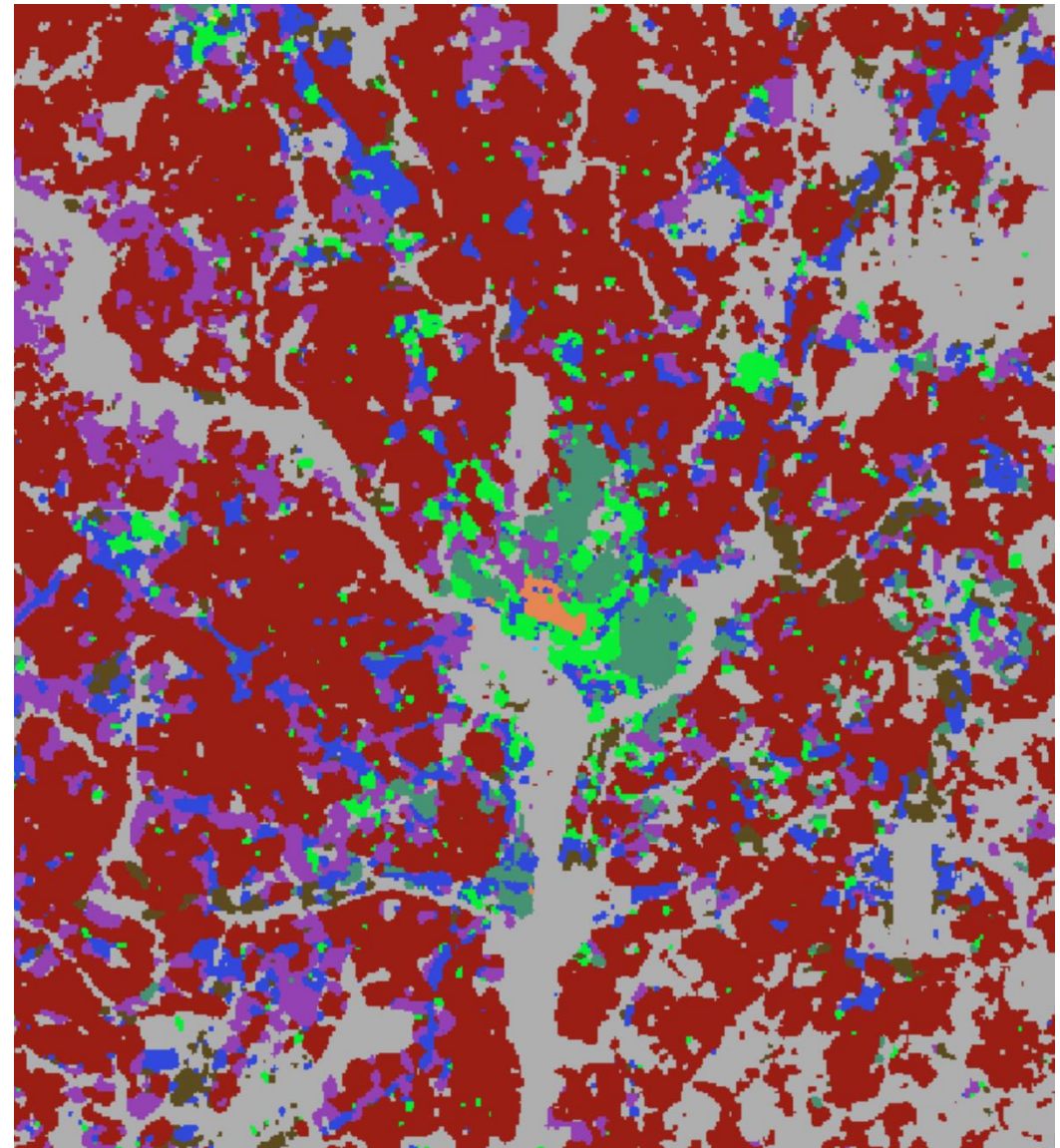
Lacking True
Realism



* Image from OpenStreetMap Contributors (2017)



City Stack



Typology Grid

Thank you for your attention!

Sources

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