

# Modeling the Co-evolution of Urban Form and Transportation Networks

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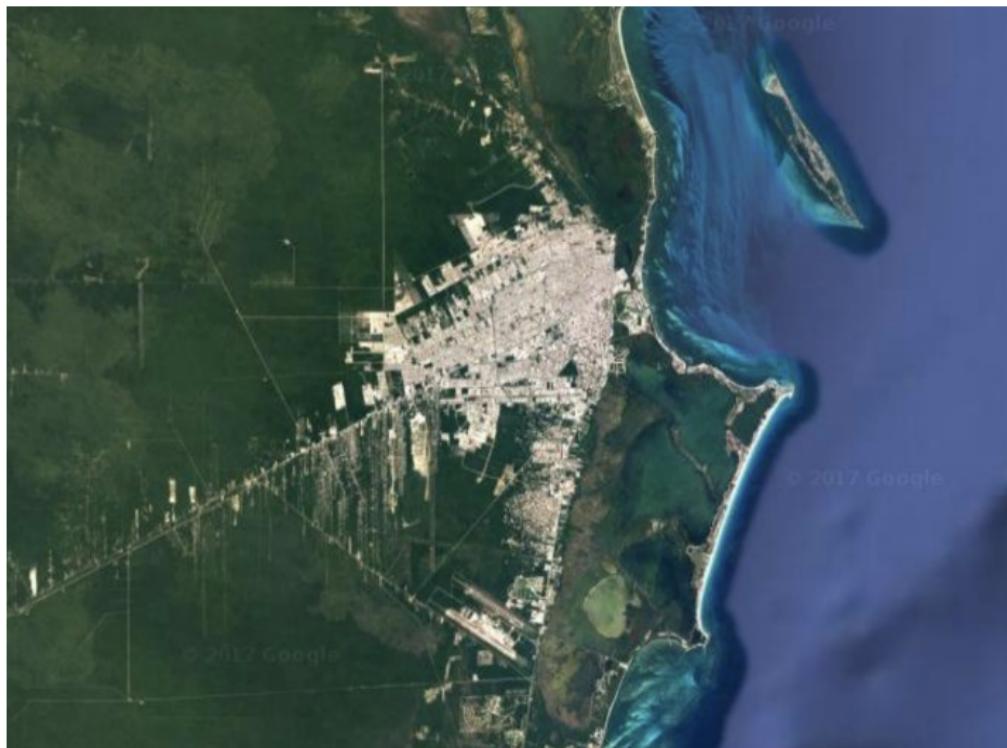
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# Complex processes of Urban Morphogenesis



*Source: Google maps*

# Modeling Urban Morphogenesis

## **Research Objective :**

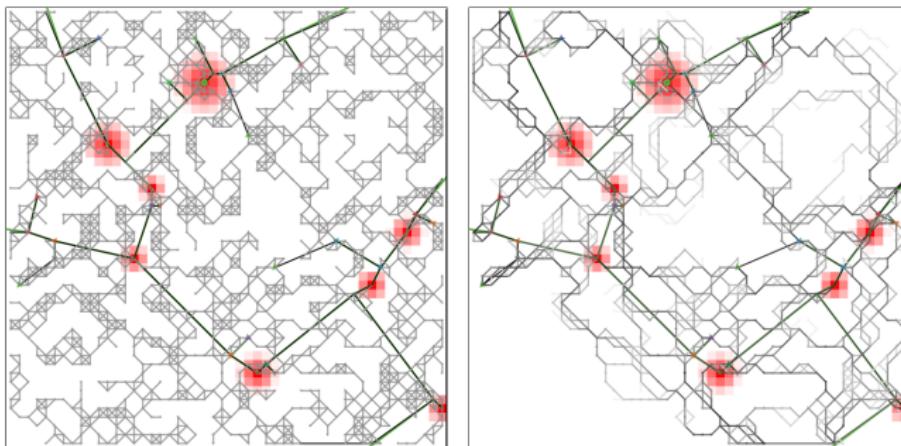
# Model : Rationale

# Model : Specification

model setup / stopping condition

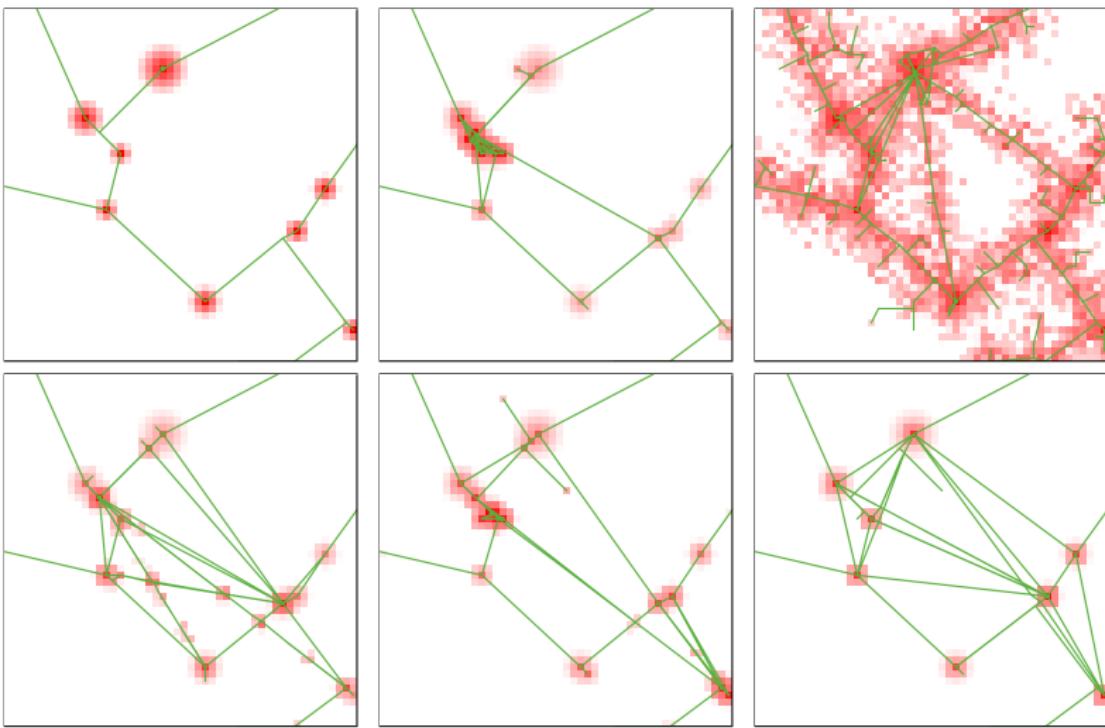
# Network Generation

- ① Fixed process for new nodes and connectivity
- ② Variable heuristic for new links, among: nothing, random, gravity-based deterministic breakdown, gravity-based random breakdown (from [S cost-benefits (from [Louf et al., 2013])], biological network generation (based on [Tero et al., 2010])

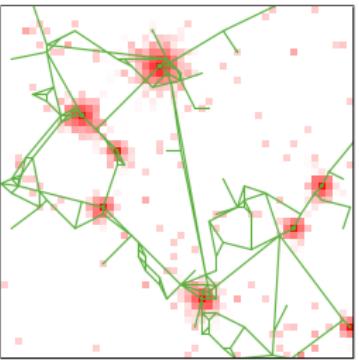
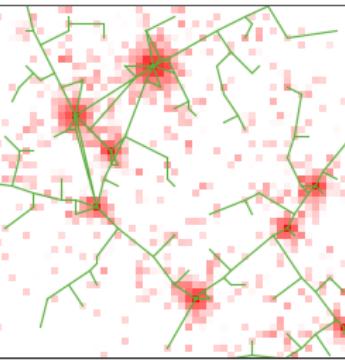
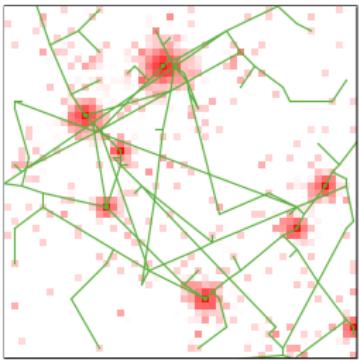
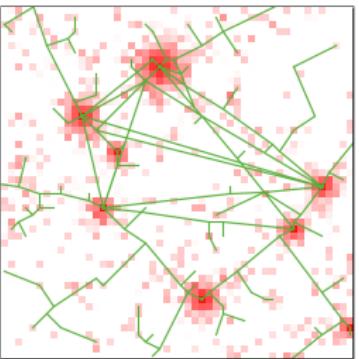
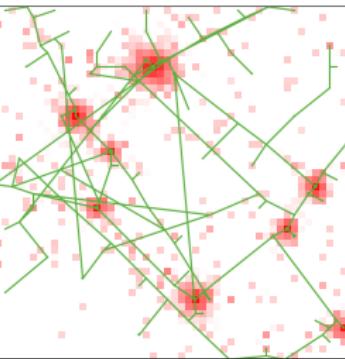
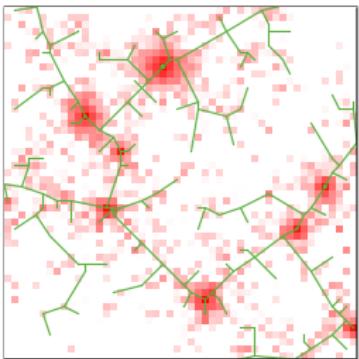


*Intermediate stage for biological network generation*

# Generated Urban Shapes: Urban Form

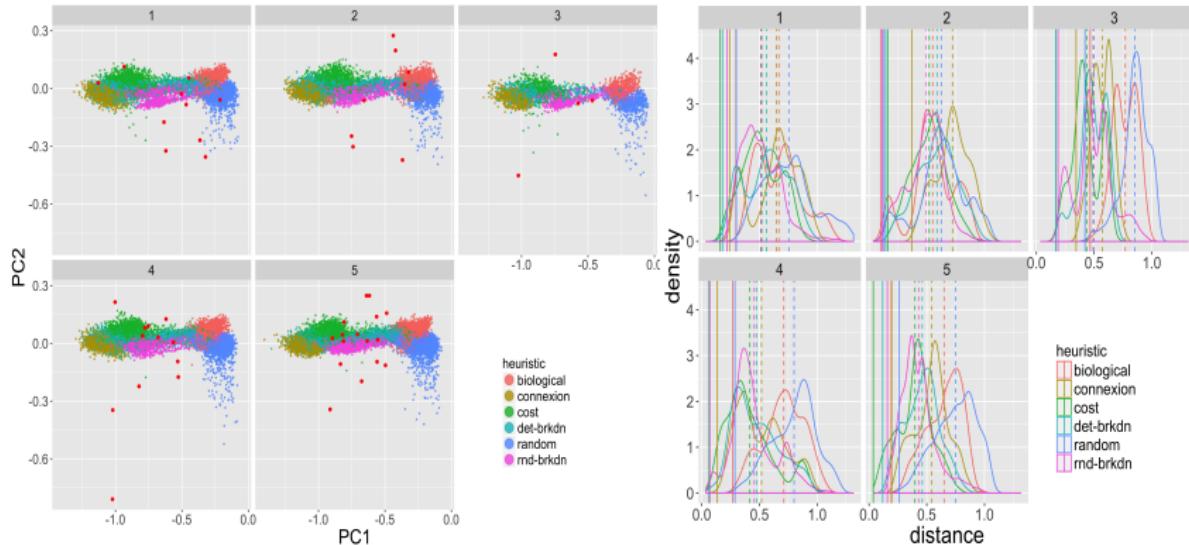


# Generated Urban Shapes: Network



# Results : Network Heuristics

*Comparison of feasible space for network indicators with fixed density*

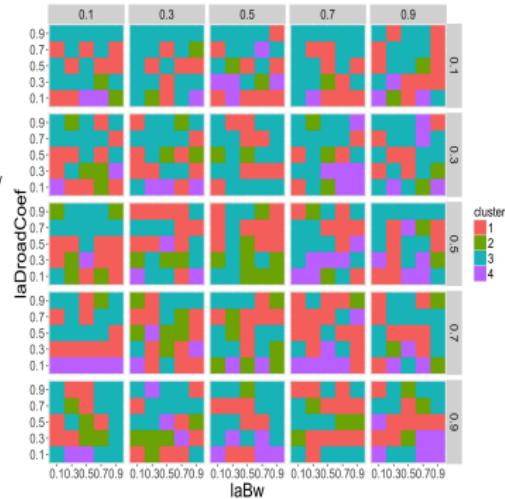
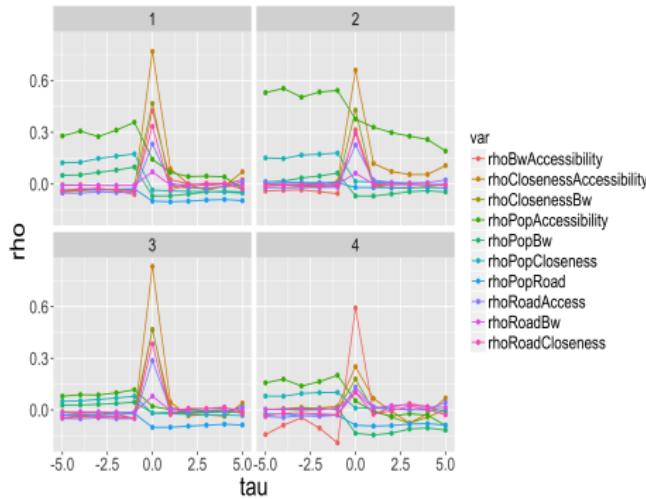


(Left) Feasible spaces by morphological class and network heuristic; (Right) Distribution of distances to topologies of real networks

# Results : Calibration

## Results : Causality Regimes

## *Unsupervised learning on lagged correlations between local variables unveils a diversity of causality regimes*



(Left) Lagged correlation profiles of cluster centers; (Right) Distribution of regimes across parameter space

# Discussion

## Implications

→

## Developments

→

# Conclusion



- Code et data available at  
<https://github.com/JusteRaimbault/CityNetwork>

# Reserve slides

## Reserve Slides

## Defining co-evolution

No clear definition of co-evolution in the literature : [Bretagnolle, 2009] distinguishes “reciprocal adaptation” where a sense of causality can clearly be identified, from co-evolutive regimes

[?] identifies multiple causality regimes in a simple strongly coupled growth model → to be put in perspective with a theoretical definition of co-evolution based on the conjunction of Morphogenesis and the Evolutive Urban Theory, summarised by [Raimbault, 2017]

# Data Processing

# Morphological Indicators

Urban morphology measured by:

- Spatial autocorrelation (Moran Index)
- Average distance
- Entropy
- Hierarchy (OLS slope for rank-size)

# Network Indicators

Network Topology measured by:

- Betweenness and Closeness centralities: average and hierarchy
- Accessibility (weighted closeness)
- Efficiency (network pace relative to euclidian)

# Model specification

Patch utility given by  $U_i = \sum_k w_k \cdot \tilde{x}_k$   
Gravity interaction

# Biological Network generation

Adding new links with biological heuristic:

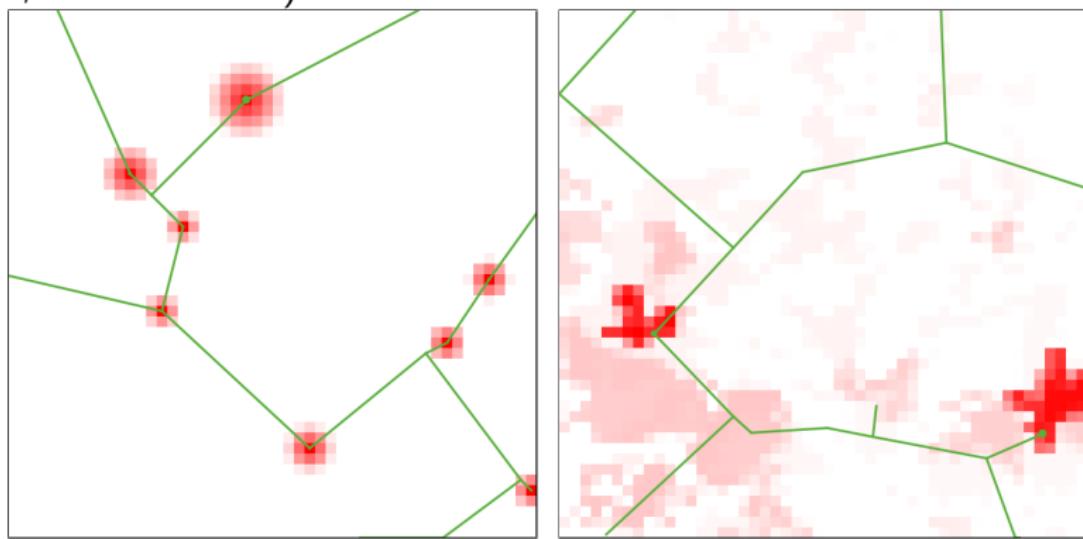
- ① Create network of potential new links, with existing network and randomly sampled diagonal lattice
- ② Iterate for  $k$  increasing ( $k \in \{1, 2, 4\}$  in practice) :
  - Using population distribution, iterate  $k \cdot n_b$  times the slime mould model to compute new link capacities
  - Delete links with capacity under  $\theta_d$
  - Keep the largest connected component
- ③ Planarize and simplify final network

# Model parameters

## Model setup

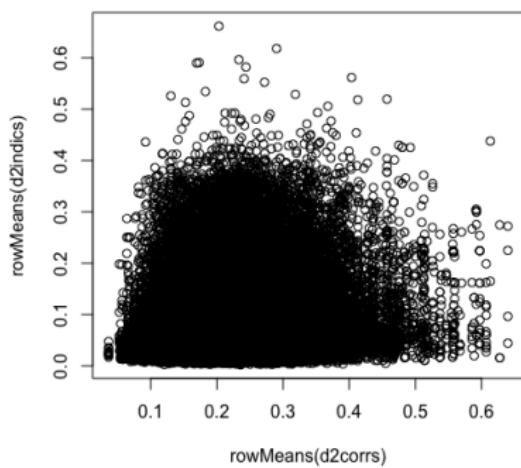
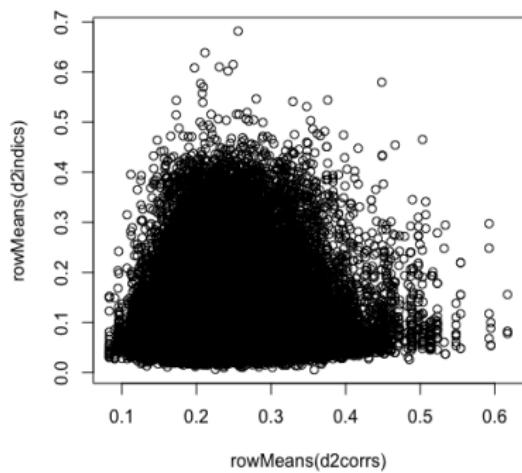
**Synthetic setup:** rank-sized monocentric cities, simple connection with bord nodes to avoid bord effects

**Real setup:** Population density raster at 500m resolution (European Union, from Eurostat)

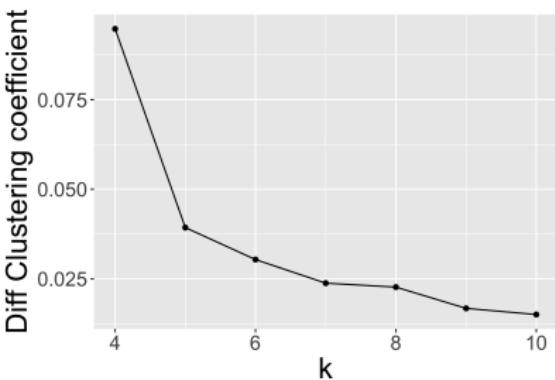
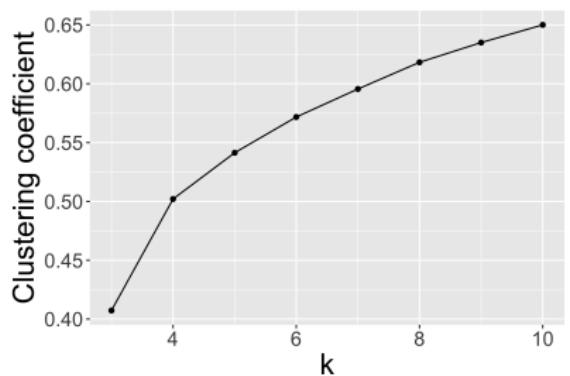


# Calibration Method

# Calibration : optimal points



## Calibration : optimal points



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