Generating urban morphologies at large scales

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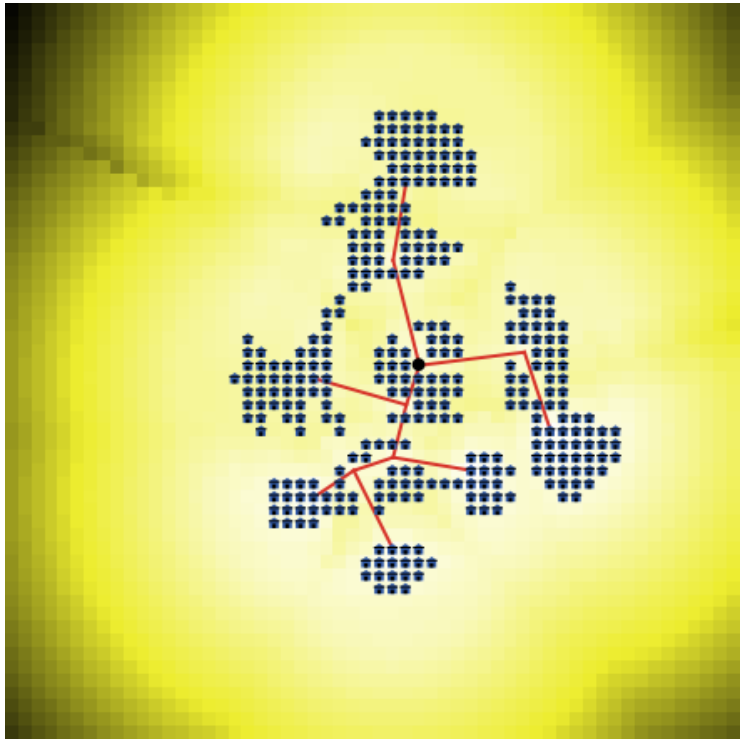
Morphogenesis of Urban Systems

"*new innovation community, sustainable urban development, flourishing city, urban regeneration*"

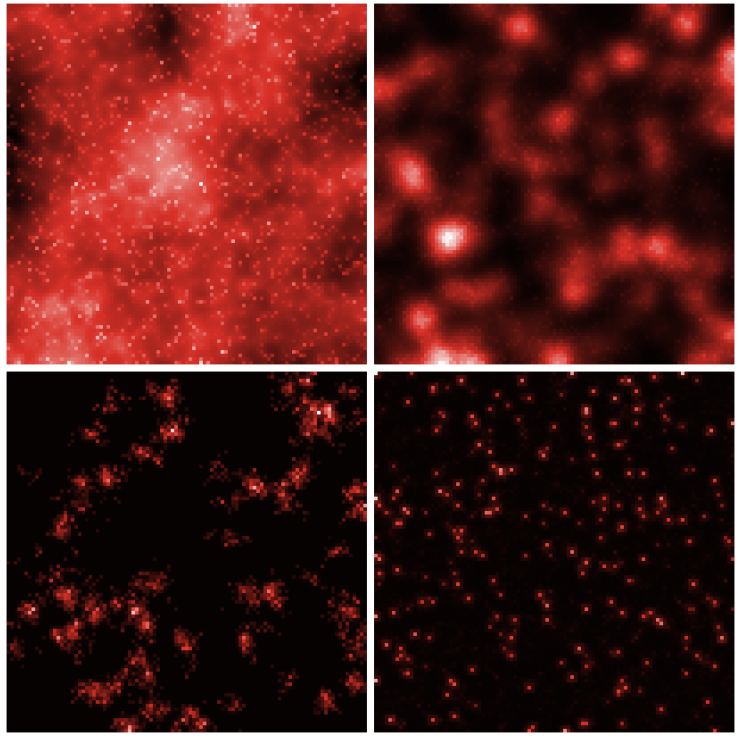
$\rightarrow$ Are cities alive? Which morphogenetic processes?

Urban Systems and Artificial Life



Hybrid urban morphogenesis with simple rules for urban sprawl and road network evolution

Raimbault, J., Banos, A., Doursat, R. (2014). A Hybrid Network/Grid Model of Urban Morphogenesis and Optimization. In 4th International Conference on Complex Systems and Applications (pp. 51-60).

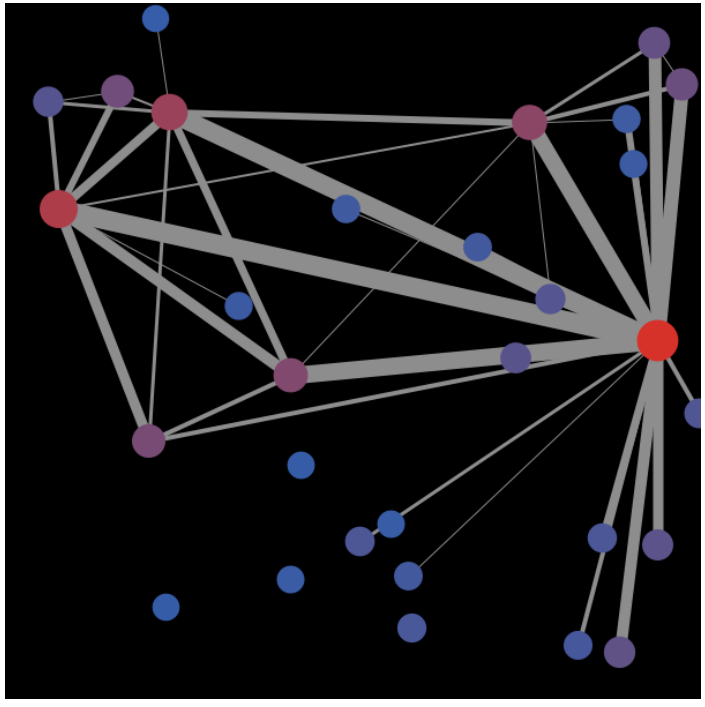


Reaction-diffusion processes to reproduce territorial settlements at an intermediate scale

Raimbault, J. (2018). Calibration of a density-based model of urban morphogenesis. PloS one, 13(9), e0203516.

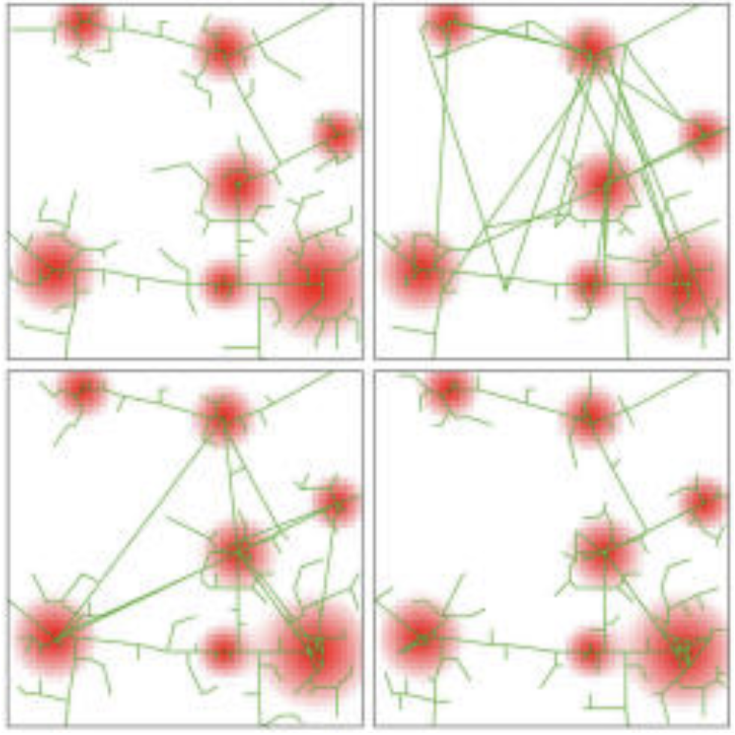
Raimbault, J. (2019). An urban morphogenesis model capturing interactions between networks and territories. In The Mathematics of Urban Morphology (pp. 383-409). Birkhäuser, Cham.

Urban Systems and Artificial Life



Cities-network co-evolution model explored on synthetic systems of cities

Raimbault, J. (2019). Modeling the co-evolution of cities and networks. Forthcoming in Handbook of Cities and Networks, Rozenblat C., Niel Z., eds.



Complementary heuristics to reproduce topological properties of transportation networks

Raimbault, J. (2018). Multi-modeling the morphogenesis of transportation networks. In Artificial Life 2018 Conference Proceedings (pp. 382-383).

Urban form from the bottom up

→ Emergence of the urban form from local processes

→ Particularity of large geographical scales (building layout morphogenesis)

→ Quantitative indicators to measure urban form

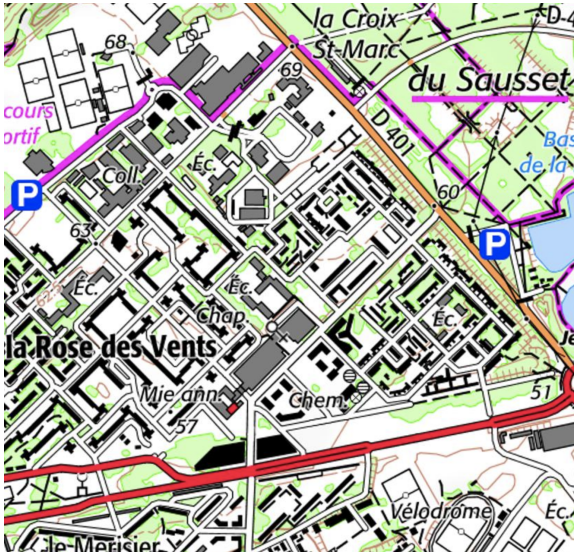
Research objective:

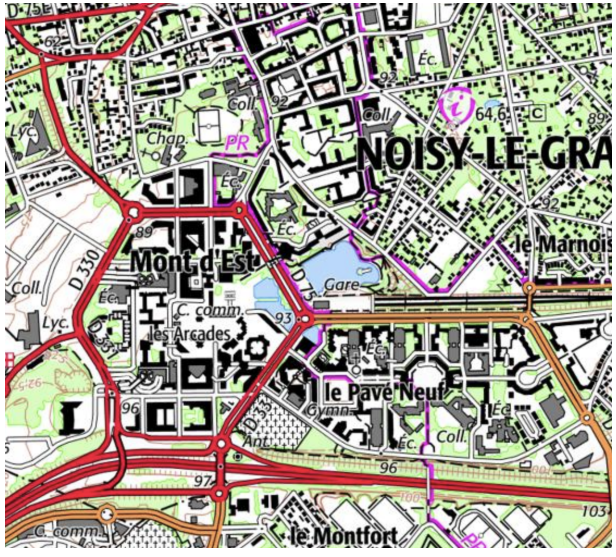
Introduce simple generative models for urban configurations at the district scale; introduce a set of indicators to classify model outputs; investigate the potentiality of generative models to produce existing configurations.

Generating building layouts

Complementary heuristics:

- random building blocks (modern urbanism)
- thresholded kernel mixture (hybrid configurations / preferential attachment for population)
- percolation of roads through a compact urban core (transportation flows)



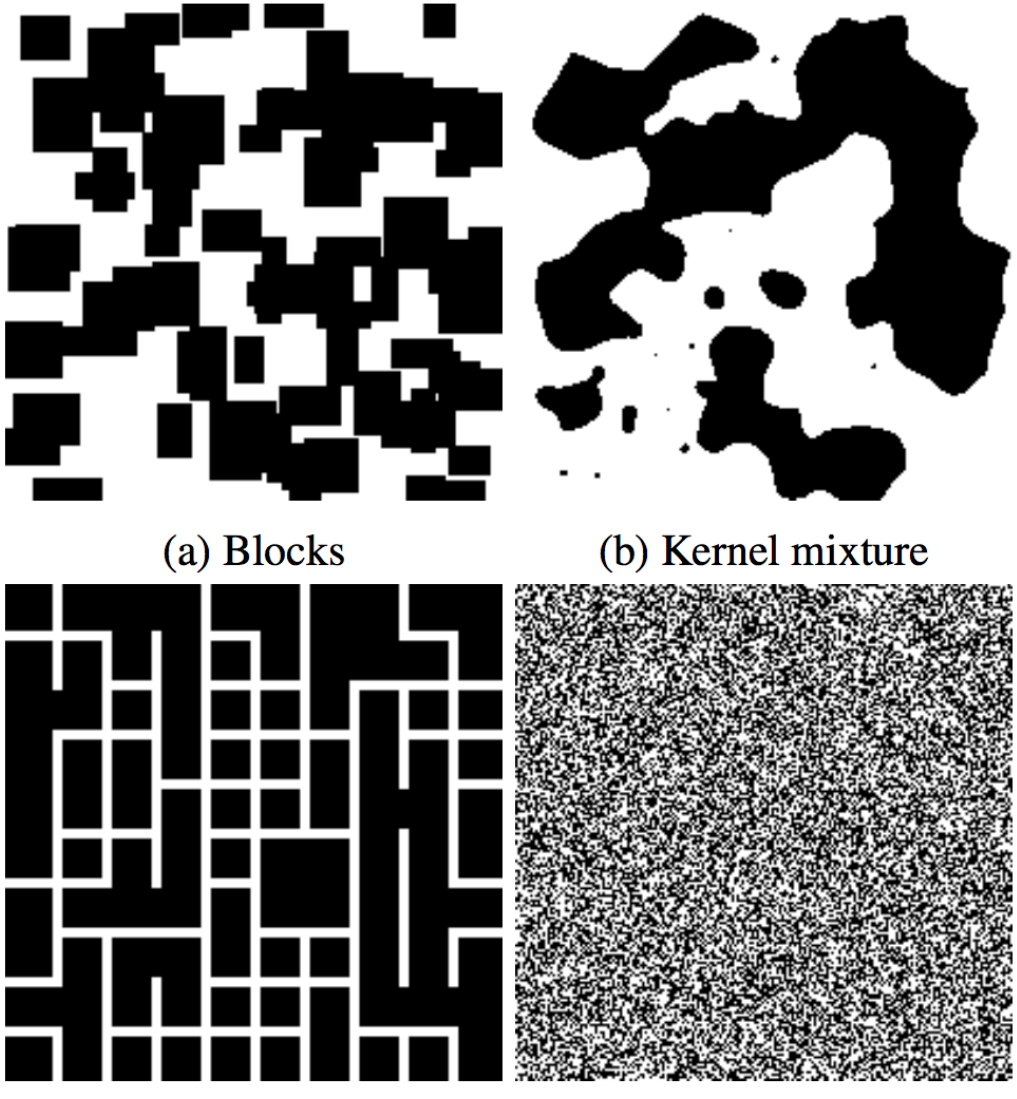


Quantifying urban form

Urban form indicators for building layouts:

- Density, number of buildings, average area
- Moran index (spatial autocorrelation) and average distance on rasterized representation
- Average detour in the free space
- Mathematical morphology indicators (steps for erosion and dilation) [Serra, 1983]

Generators



(a) Blocks (b) Kernel mixture

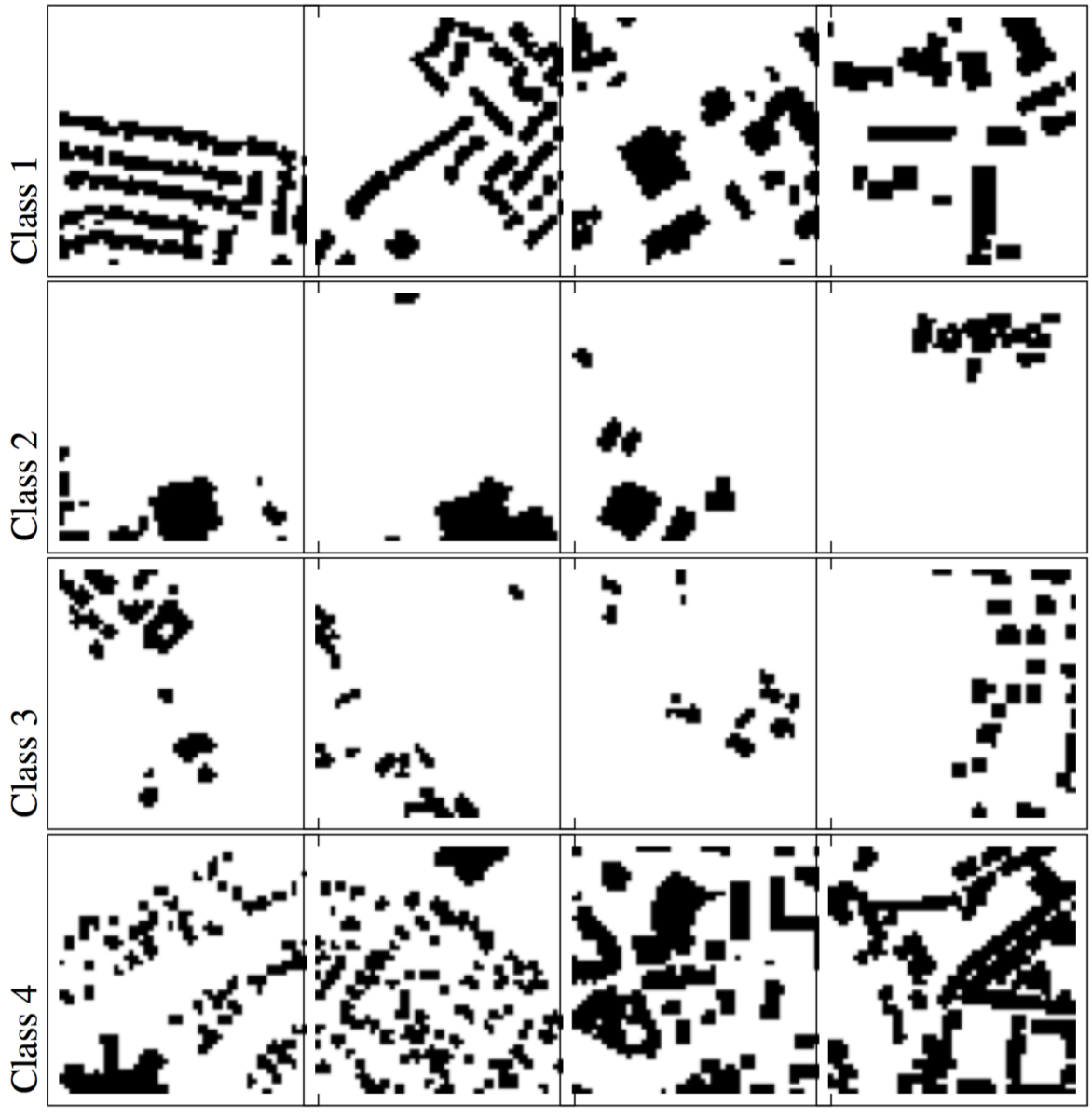
(c) Network percolation (d) Random

Examples of urban forms for each generator (3 parameters each)

Real configurations

Sampled districts from OpenStreetMap (72,000 real district sampled accross European functional urban areas [Bretagnolle et al., 2019])

Classification of urban forms



Unsupervised classification of real morphologies (effective dimension: 85.9% of variance at second PC)

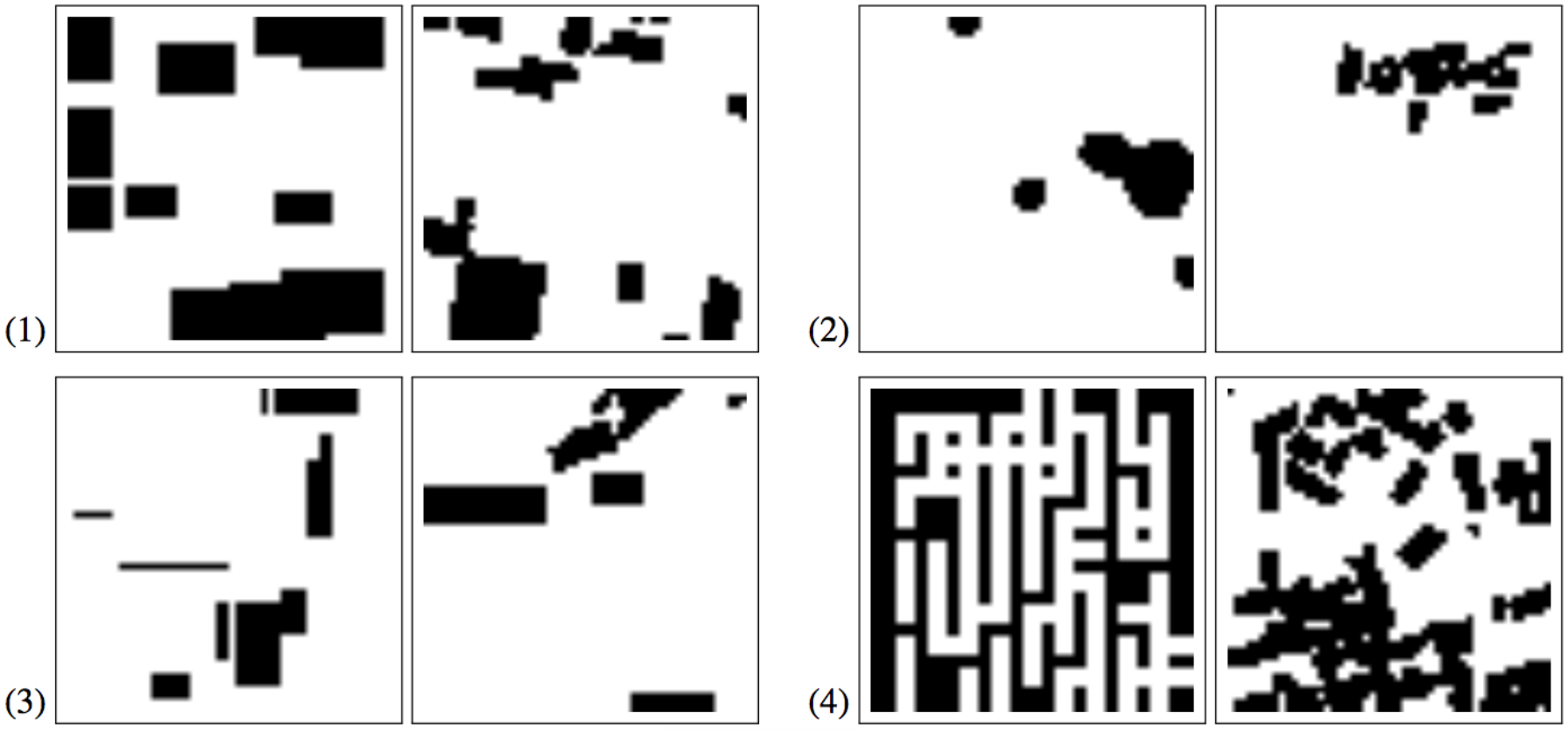
Model calibration tool

Models explored and calibrated with the OpenMOLE software [Reuillon et al., 2013]

OpenMOLE: (i) embeds any model as a black box; (ii) provides transparent access to main High Performance Computing environments; (iii) and to model exploration and calibration methods (sensitivity analysis, Design of Experiments, Genetic Algorithm calibration, Diversity Search).

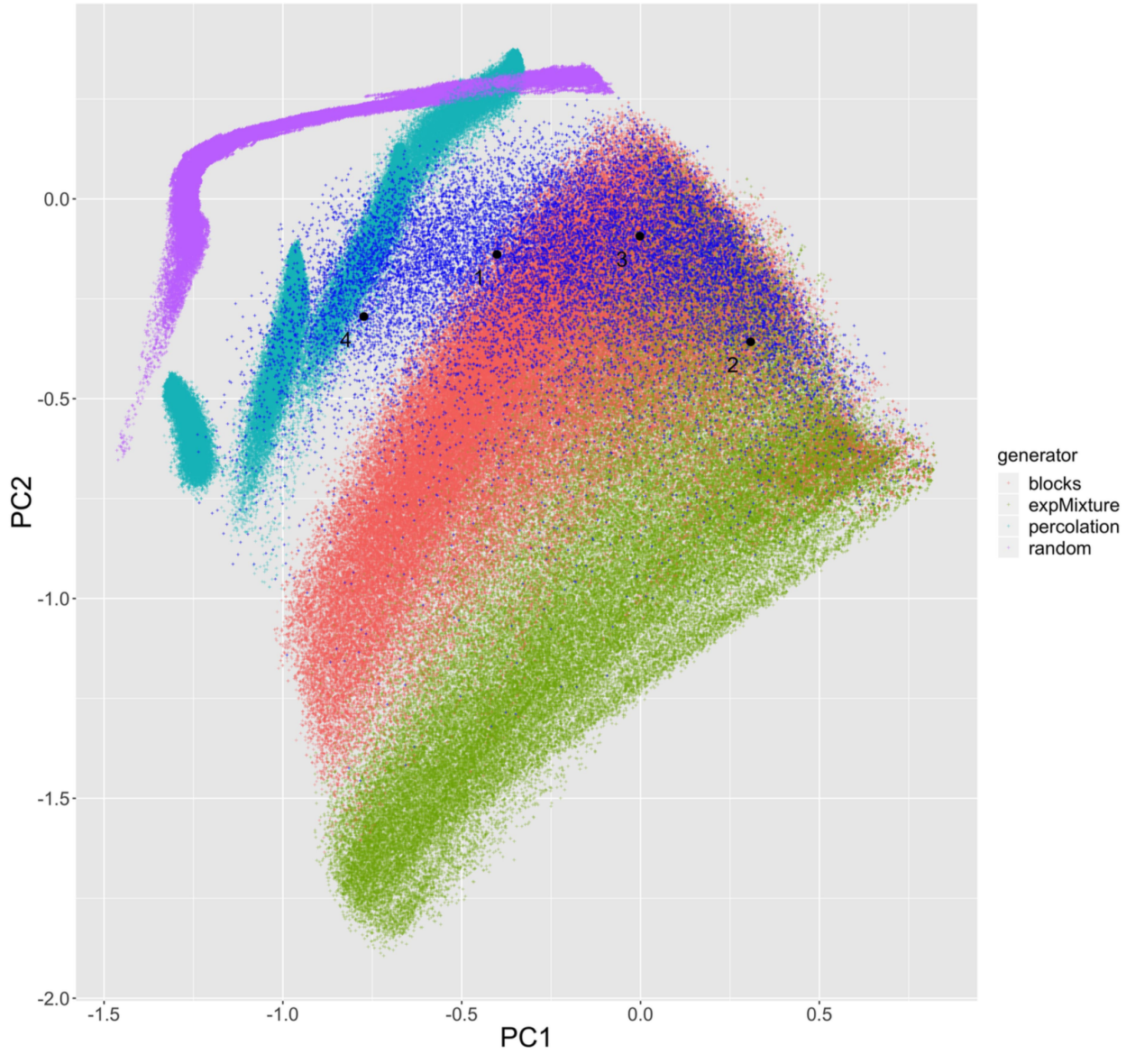
Free and Open Source, download at `https://openmole.org/`

Calibrated forms



Example of close real and simulated configurations, after running the model for 10,000 random parameter points (LHS) for each generator, with 100 stochastic repetitions each

Comparison of point clouds



Projection of simulated and real cloud points in the real PC space

Calibration on classification centroids

	Random	Blocks	Exp. Mixture	Percolation
Centroid 1	0.424 ± 0.011	0.106 ± 0.063	0.303 ± 0.101	0.325 ± 0.019
Centroid 2	0.809 ± 0.022	0.164 ± 0.099	0.184 ± 0.141	0.947 ± 0.019
Centroid 3	0.428 ± 0.019	0.095 ± 0.054	0.109 ± 0.064	0.541 ± 0.019
Centroid 4	0.515 ± 0.005	0.311 ± 0.077	0.589 ± 0.149	0.083 ± 0.025

Euclidian distances in the projected space, aggregated on stochastic repetitions, for each class centroid and each generator

Discussion

Extensions

→ Apply more elaborated calibration procedures and e.g. diversity search.

→ Dynamical calibration (issue of sparsity of dynamical urban data).

→ Take into account possible varying generator parameter number (compensate for overfitting in simulation models [Piou et al., 2009]).

Applications

→ Link between urban form and sustainability measures: towards insights from generative models.

→ Towards multi-scale and multi-dimensional models.

→ Hybridation with more operational approaches [Brasebin et al., 2017].

Conclusion

→ New set of urban morphological measures at large scales.

→ Simple generative models with complementary processes to reproduce existing European urban forms regarding morphological indicators.

→ Towards more elaborated models of urban morphogenesis.

Code and results available at
`https://github.com/openmole/spatialdata`

Download OpenMOLE at
`https://openmole.org`

References I

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