Towards geocommons for sustainable territorial planning and management

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Territorial systems and SDGs

SDG 11: "Make cities and human settlements inclusive, safe, resilient, and sustainable" [Nations, 2015]

→ Cities as a transition state? [Batty, 2018b] Incubators of social change and innovation, both the source and solution to sustainability issues? [Pumain, 2010]

→ Environmental Kuznet Curve hypothesis [Dinda, 2004, Stern, 2004]: inverted U-shaped relationship between environmental impact and income per-capita; not validated empirically [Harbaugh et al., 2002]

→ Trade-offs between SDGs in **urban systems** [Viguié and Hallegatte, 2012], and more generally **territorial systems**.

Research at IGN: Digital twins and sustainability

Digital twins and sustainability: literature mapping

How do the two main themes of the conference go along in the literature?

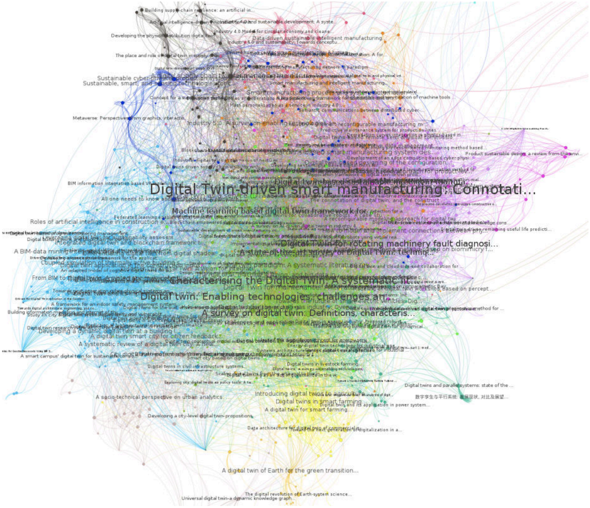
What principal fields of study applying digital twins to sustainable development?

→ Using the methods and tools of [Raimbault, 2019b] [Raimbault et al., 2021] we do a systematic literature mapping using citation networks, constructed from google scholar data.

→ Starting from a seed corpus of 100 papers obtained with the request `"digital twin" AND "sustainable development"`, we retrieve backward citations at depth two, to obtain a corpus of **14042 papers** with **24229 citation links**.

→ We analyse the citation network using community detection, to retrieve endogenous research fields.

Main research areas from the literature mapping



- "Smart manufacturing" (21.9%)
- Epistemology of DT (14.6%)
- Civil engineering/BIM (11.4%)
- Supply chain (6.8%)
- Circular economy (5.6%)
- Energy systems (5.1%)
- Urban analytics/smart cities (5.0%)
- "Metaverse" (4.5%)
- "Industry 4.0" (4.2%)
- "Smart farming" (4.0%)

Digital twins: concepts and reality

Definition of a DT? Coined in the 2000s from engineering [Batty, 2018a]

"*A digital twin is a mirror image of a physical process [. . .], usually matching exactly the operation of the physical process which takes place in real time.*"

→ in practice not identical (example for cities: real-time GIS [Li et al., 2020]); often not in real time or even dynamical.

The **link between the model (twin) and the system** is complex: which level of detail, which modelling choices, how to handle the resulting hybrid cyber-physical system? [Batty, 2019]
"*A map is not the territory, or is it?*"

DT approaches too close to systems engineering, and often miss **social science/complexity** issues [Arcaute et al., 2021]
→ models at all time scales decision-making in the anthropocene.

How to link digital twins and decision-making for sustainable development?

→ smart cities are on the long run: urban analytics for policy [Kandt and Batty, 2021]

→ unpredictability, multi-dimensionality, multi-scalarity of territorial systems: need for multiple models [Batty, 2021], multiple perspectives [Pumain and Raimbault, 2020]

→ simulation models of territories for sustainable policies [Raimbault et al., 2020a]

Digital twins as commons?

More general framework of "*géo-communs*", launched by IGN since January 2021
https://www.ign.fr/institut/la-demarche-geocommuns.

→ all IGN data is now open data
→ mutualisation, collaboration around tools, methods, databases
→ public consultation in May 2021 (165 stakeholders from various backgrounds)

Definition: "*Geographic Information databases co-producted or co-maintained, and co-developped tools and methods, following an open common governance, to garantee a full appropriation by communities of users/producers/stakeholders/citizens*"

Open questions for geocommons

1. Governance of geocommons: mediator $\neq$ technical coordinator
2. Economic model: public service (open public good)
3. Core data: static digital twin at the national scale?
4. Data production: e.g. link with OSM
5. Licence: open licence but not ODbL?
6. Methods and tools: ecosystem of open source softwares
7. Open science as a part of geocommons
8. Crucial role for environmental data
9. Link with European directives for open data; European geocommons?

Implementation of geocommons

La Fabrique as a project incubator, *Geoplateforme* as the future technical basis for data sharing (successor of geoportail)

Examples of application themes: public health and environment, renewable energy, urban planning, local governments.

Examples of current projects: *Base Adresse Nationale* (ANCT, DINUM, IGN), *Panoramax* (immersive views; OSM, IGN), *BAT-ID* (national building database; CSTB, ADEME, IGN).

The national Digital Twin and geo-commons

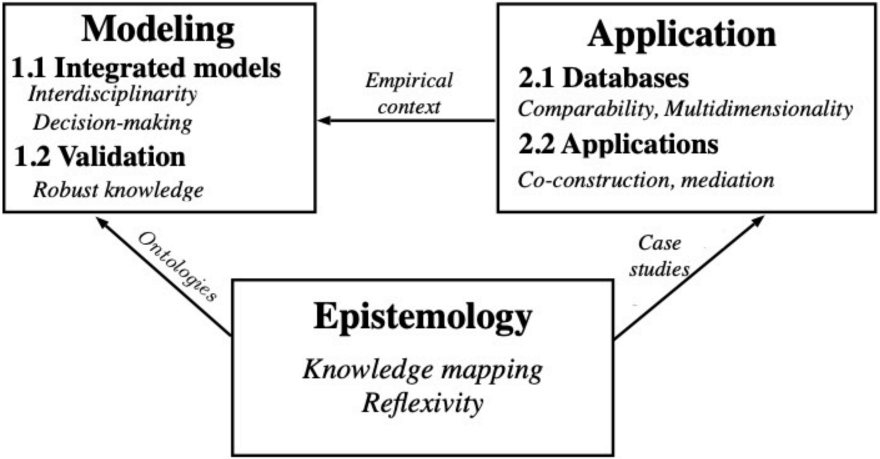
Current project proposal being prepared at IGN: a national Digital Twin providing a high resolution 3D model of the country (collaboration IGN, INRIA, CEREMA, still open to other agencies).

Main axis:

1. Specification of the 3D model
2. Production of the 3D model
3. Updates of the 3D model
4. Link and integration with other data
5. Online visualisation and interaction
6. Simulation: downstream application

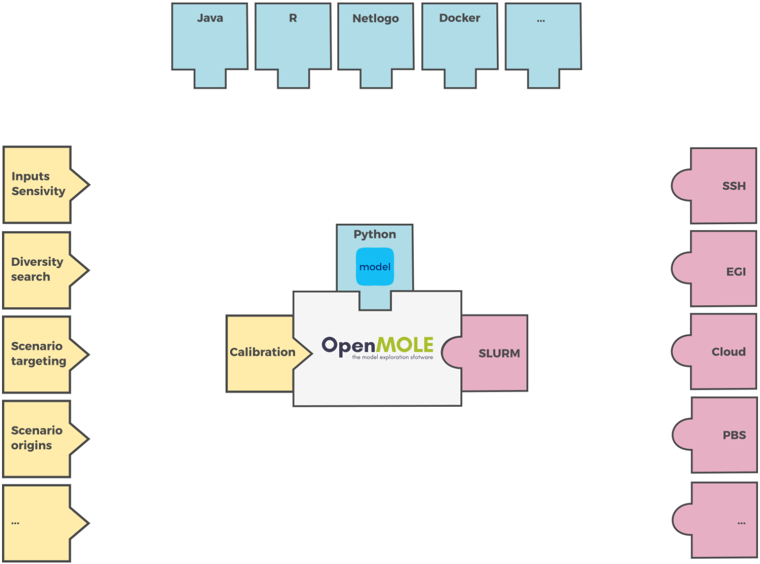
→ strong interaction with geo-commons expected
→ however simulation not central (against the strict definition of a DT): **we propose a project focused on simulation models to contribute to geo-commons**

Towards sustainable decision making for territories by integrating and validating simulation models



Integrated models to simulate multiple dimensions of **urban systems** towards decision-making in the context of **sustainable transitions**.

OpenMOLE: validation of simulation models

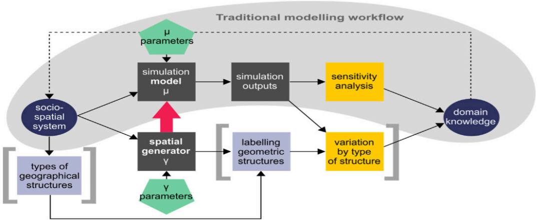


http://openmole.org [Reuillon et al., 2013]

OpenMOLE: objectively the best

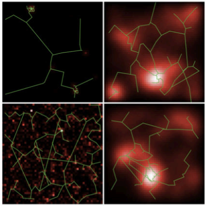
Type	Critères	Apache Taverna	Spark	Jupyter	R	Dakota	OpenTURNS	PEST++	OpenMOLE
Mo	Appel d'executable								
Mo	Execution de containers								
Mo	Transmission transparente de données structurées								
Me	Méthodes d'exploration								
Me	Échantillonage adaptatif								
Me	Optimisation globale								
Me	Recherche de diversité								
E	Calcul distribué								
E	Zero-deploiement								
C	Communauté exploration de modèles								
I	Logiciel installable								
I	Service en ligne								
I	Langage généraliste								
I	Système de workflow								
I	Programation Graphique								

Novel validation methods: spatial sensitivity analysis

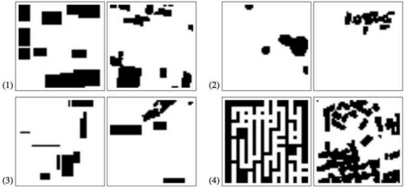


Raimbault, J., Cottineau, C., Le Texier, M., Le Nechet, F., Reuillon, R. (2019). Space Matters: Extending Sensitivity Analysis to Initial Spatial Conditions in Geosimulation Models. *Journal of Artificial Societies and Social Simulation*, 22(4).

Raimbault, J., Perret, J., & Reuillon, R. (2020). A scala library for spatial sensitivity analysis. *GISRUK 2020 Proceedings, 32.*



Raimbault, J. (2019). Second-order control of complex systems with correlated synthetic data. *Complex Adaptive Systems Modeling*, *7*(1), 1-19.



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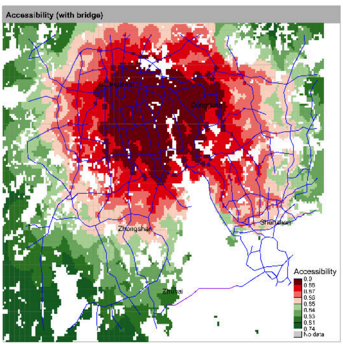
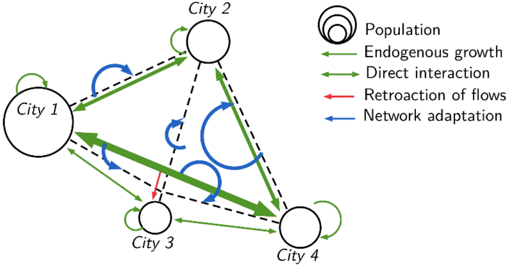
Model integration: land-use transport interactions





A modeling approach to the issue of structuring effects of transport infrastructures: co-evolution of networks and territories as a strong model integration

Raimbault, J. (2019). Evolving accessibility landscapes: mutations of transportation networks in China. In Aveline-Dubach, N., ed. *Pathways of sustainable urban development across China - the cases of Hangzhou, Datong and Zhuhai*, pp 89-108. Imago. ISBN:978-88-94384-71-0

Raimbault, J. (2020). Indirect evidence of network effects in a system of cities. Environment and Planning B: Urban Analytics and City Science, 47(1), 138-155.

Raimbault, J. (2021). Modeling the co-evolution of cities and networks. In Handbook of Cities and Networks. Edward Elgar Publishing.

Implementing horizontal model integration

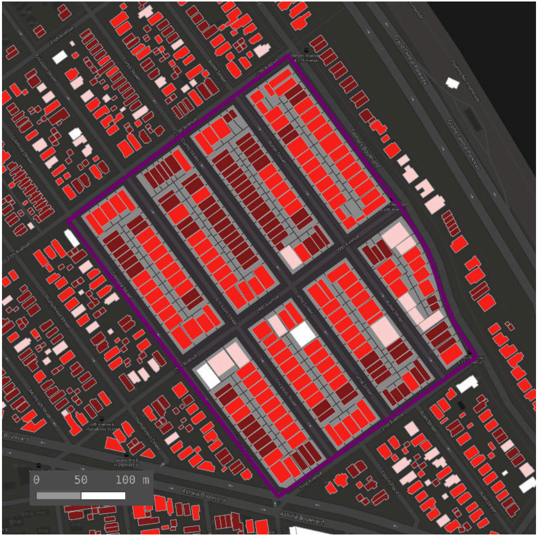
Constructing a multimodal four step transport models by linking open components and data with scientific workflow engines

Integrated models:

- MATSim model (MATSim Community) for transport [W Axhausen et al., 2016]
- SPENSER model (University of Leeds) for synthetic population [Spooner et al., 2021]
- QUANT model (CASA, University College London) for spatial interactions [Batty and Milton, 2021]
- spatialdata library (OpenMOLE community) for data processing [Raimbault et al., 2020b]

Raimbault, J., & Batty, M. (2021). Estimating public transport congestion in UK urban areas with open transport models. GISRUK 2021 Proceedings.

Model coupling: urban design and UHI



SURe project (collaboration LASTIG, ISC-PIF, EPI-DAPO)

→ coupling the SimPLU3D urban generative model [Brasebin et al., 2017] with an Urban Heat Island model to find compromises between density and the UHI effect.

Generic multi-model of urban dynamics for SDGs trade-offs

Other dimensions benchmarked by [Raimbault et al., 2020a] to fit population dynamics on several large urban systems

Models integrated:

- Innovation diffusion urban evolution model [Raimbault and Pumain, 2022]
- Marius model for economic exchanges [Cottineau et al., 2015]
- Co-evolution model for cities and infrastructure networks [Raimbault, 2021b]

"Semi-weak" coupling of submodels:

$$S_0 \rightarrow \left[S_1^{(0)} = M_0(S_0) \rightarrow \ldots \rightarrow S_1^{(K-1)} = M_{K-1}(S_1^{(K-2)}) = S_1\right] \longrightarrow \ldots$$
$$\longrightarrow \left[S_T^{(0)} = M_0(S_{T-1}) \rightarrow \ldots \rightarrow S_T^{(K-1)} = M_{K-1}(S_T^{(K-2)}) = S_T\right] \quad (1)$$

Remarks: strictly weak coupling does not capture dynamics nor synergies; stronger coupling may exist to better capture interdependencies processes (here no specific coupling ontology, only population and distance matrix are shared between submodels)

SDGs trade-offs: optimised objectives

Proxies for SDGs:

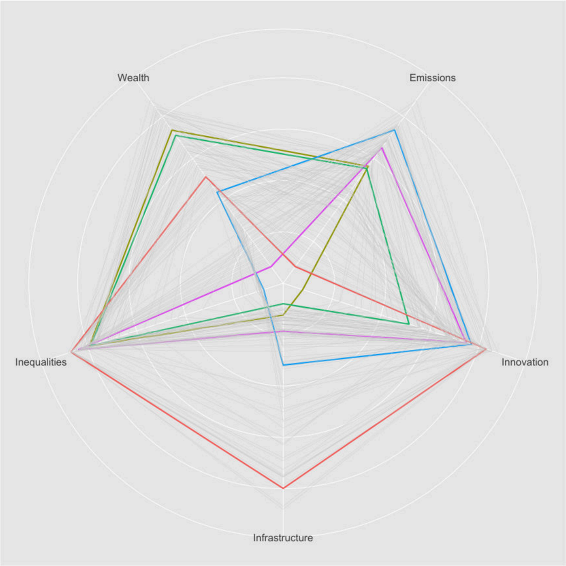
- Total utility of innovations (SDG 9 “Innovation”)
- Total spatial interaction flows across submodels (SDG 13 “Climate”)
- Average distance between cities (SDG 9 “Resilient infrastructure”)
- Economic inequalities (SDG 10 “Inequalities”)
- Total wealth of cities (SDG 8 “Economic Growth”)

Optimisation parameters: fixed synthetic urban system parameters but random configurations (10 repetitions); 8 parameters for innovation; 6 parameters for economic exchanges; 6 parameters for co-evolution

SDGs trade-offs: optimisation results

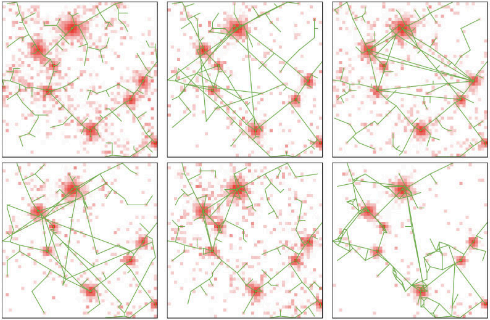
Scatterplots of the 5D Pareto front. Color level: Gini economic wealth.

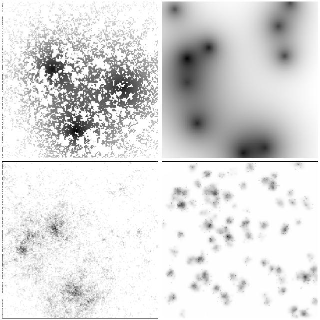
SDGs trade-offs: optimisation results



Radar plot for the many-objective optimisation (colour: best solution along each dimension)

Horizontal integration: multi-modeling and benchmarks





Benchmarking network and urban morphogenesis models

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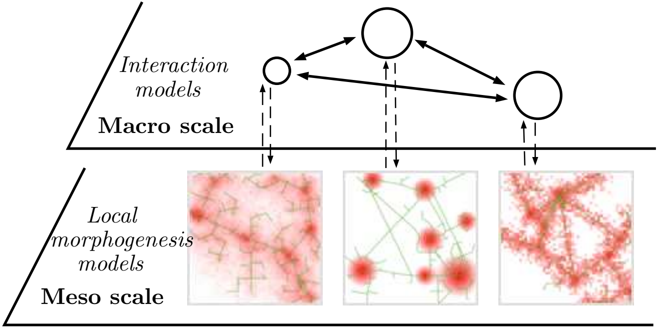
Raimbault, J. (2020). A comparison of simple models for urban morphogenesis. arXiv preprint arXiv:2008.13277.

Raimbault, J. (2021). Complementarity of generative models for road networks. arXiv preprint arXiv:2109.15206.

Vertical integration: towards multi-scale models



Processes specific to scales, coupling implies dedicated ontologies

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Conclusion

→ Digital twins are a rebranding of simulation models remaining too far from human and social sciences and sustainable development goals.

→ Multiple models need to be considered, coupled and integrated, at multiple time and spatial scales, but also from multiple disciplines and approaches: **model sharing and coupling as a geo-common**.

→ These models need to be **explored, calibrated, validated**, using open tools such as OpenMOLE, in a reproducible way.

→ All this must be **open source, shared, modular** to contribute to geo-commons and be usable for policy-making.

→ **Stakeholders** must be implied in the model development, exploration and validation process [Delay et al., 2020].

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