

# From digital twins to their extended family: integration and validation of simulation models

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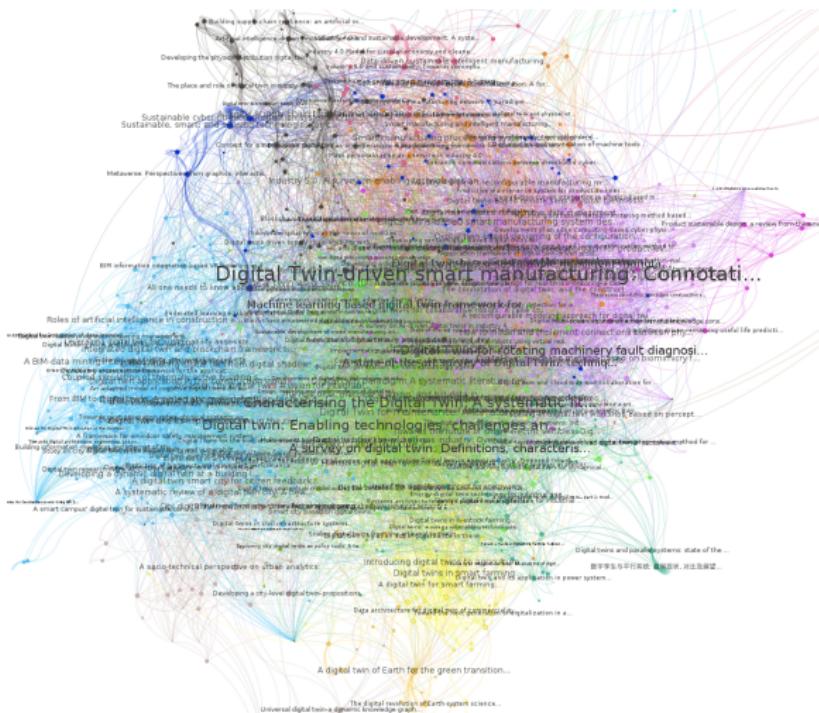
*Journée de la Recherche UGE-IGN-ENSG 2023*  
30/03/2023

*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 [Rimbault, 2019b] [Rimbault 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, 2018]

*"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?"*

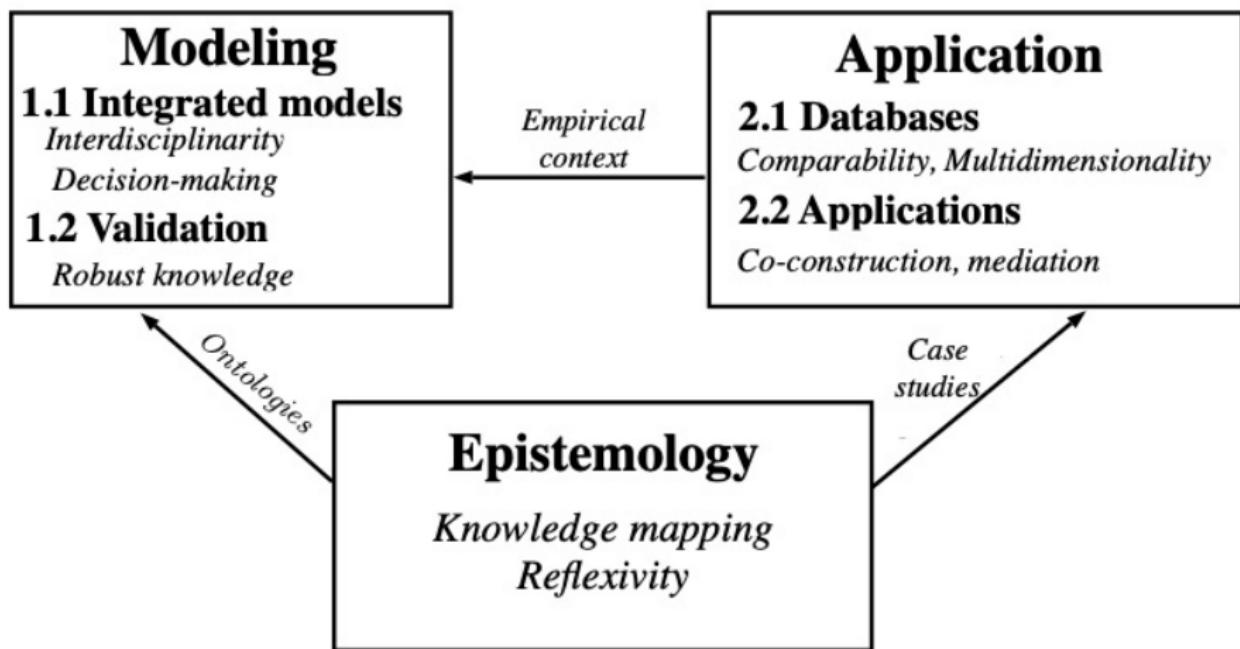
DT approaches too close to systems engineering, and often miss **social science/complexity** issues [Arcaute et al., 2021]

→ models at all time scales decision-making in the anthropocene.

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

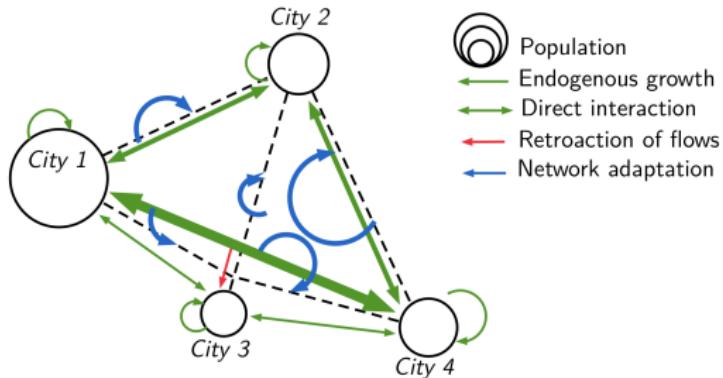
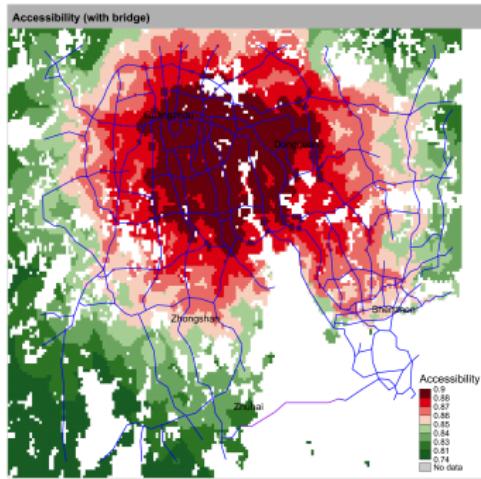
- smart cities are on the long run: urban analytics for policy  
[Kandt and Batty, 2021]
- unpredictability, multi-dimensionality, multi-scalarity of territorial systems: need for multiple models [Batty, 2021], multiple perspectives  
[Pumain and Raimbault, 2020]
- simulation models of territories for sustainable policies  
[Raimbault et al., 2020a]

# 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.

# 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.

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# Implementing horizontal model integration

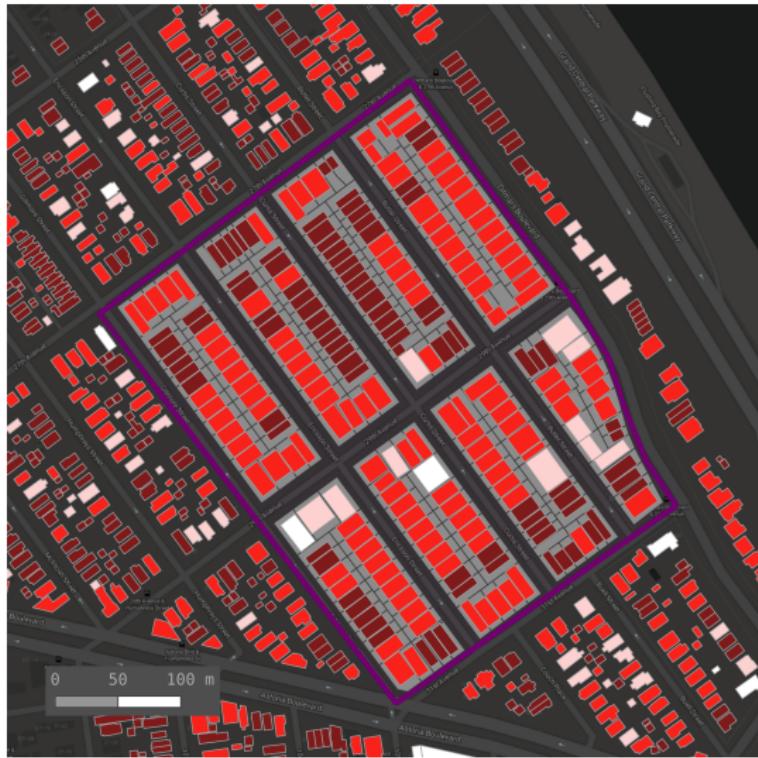
*Constructing a multimodal four step transport models by linking open components and data with scientific workflow engines*

## 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.

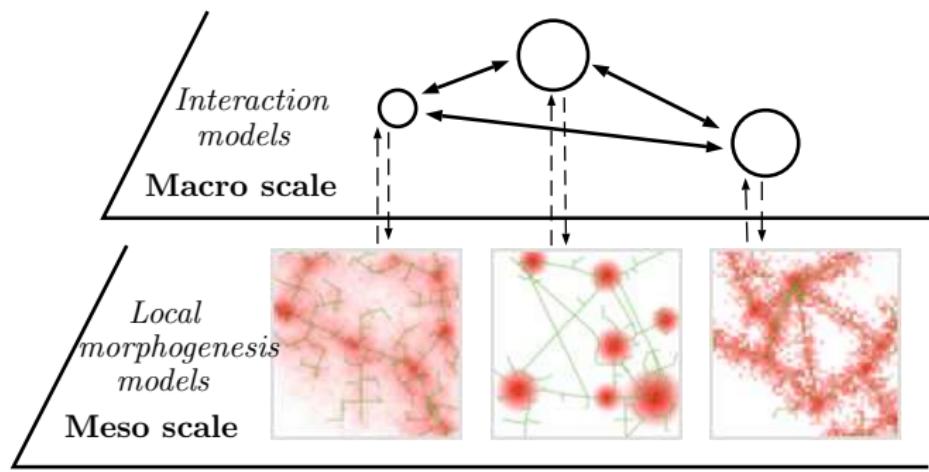
# Model coupling: urban design and UHI



**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.

# Vertical integration: towards multi-scale models



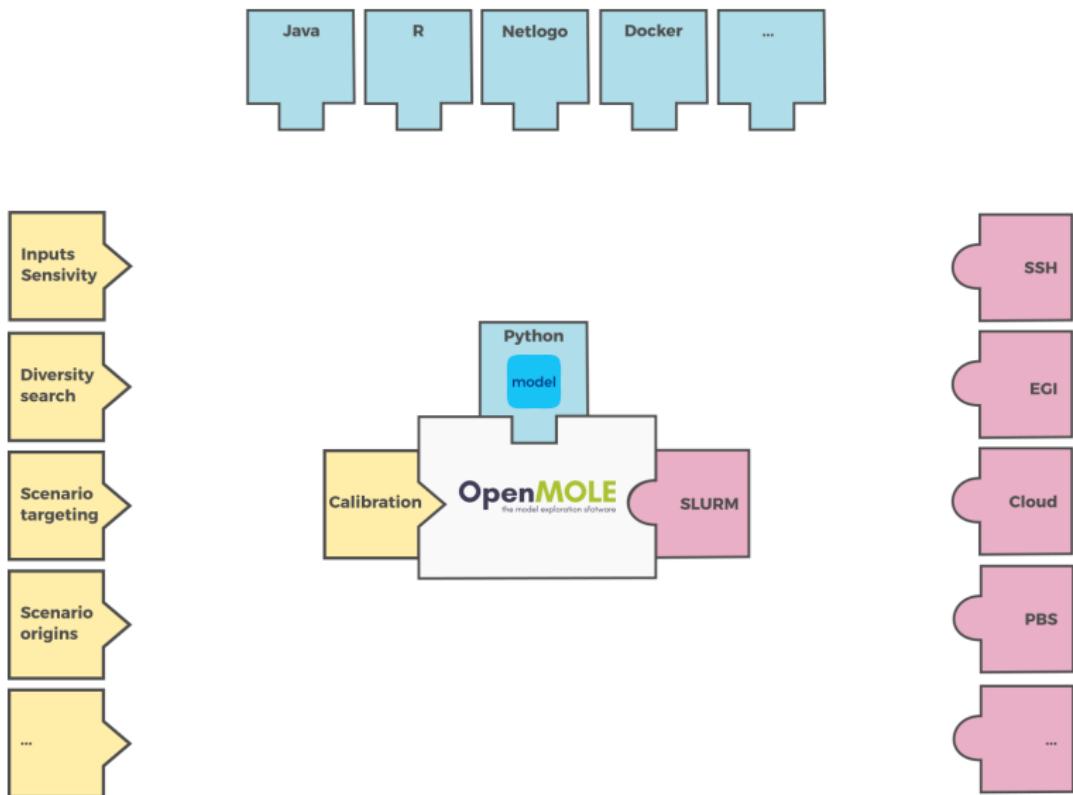
*Processes specific to scales, coupling implies dedicated ontologies*

Raimbault, J. (2021). Strong coupling between scales in a multi-scalar model of urban dynamics. arXiv preprint arXiv:2101.12725.

Raimbault, J. (2021). A multiscale model of urban morphogenesis. arXiv preprint arXiv:2103.17241.

Raimbault, J. and Pumain, D. (2023). Innovation dynamics in multi-scalar systems of cities. *Under review for ALIFE 2023*.

# OpenMOLE: validation of simulation models

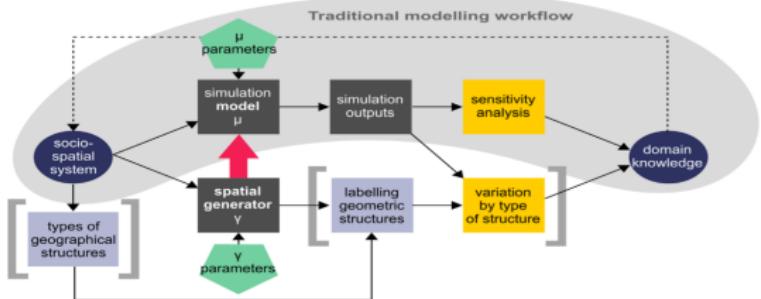


<http://openmole.org> [Reuillon et al., 2013]

# OpenMOLE: objectively the best

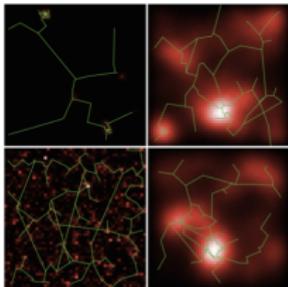
Type	Critères	Apache Taverna	Spark	Jupyter	R	Dakota	OpenTURNS	PEST++	OpenMOLE
Mo	Appel d'executable	Green	Green	Green	Green	Green	Green	Green	Green
Mo	Execution de containers	Red	Red	Red	Red	Red	Red	Red	Green
Mo	Transmission transparente de données structurées	Green	Red	Green	Red	Red	Red	Red	Green
Me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

# Novel validation methods: spatial sensitivity analysis

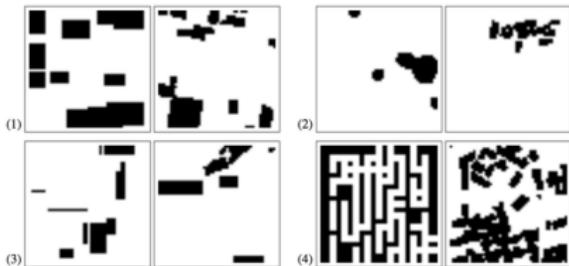


Raimbault, J., Cottineau, C., Le Texier, M., Le Nechet, F., Reuillon, R. (2019). Space Matters: Extending Sensitivity Analysis to Initial Spatial Conditions in Geosimulation Models. *Journal of Artificial Societies and Social Simulation*, 22(4).

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.



Raimbault, J., Perret, J. (2019). Generating urban morphologies at large scales. In *Artificial Life Conference Proceedings* (pp. 179-186).

- Digital twins **are** simulation models, and need to be thought this way **from the beginning**.
- Multiple models need to be included and integrated: **from the twin to the extended family**, at multiple time and spatial scales, but also from multiple disciplines and approaches.
- These models need to be **explored, calibrated, validated**: OpenMOLE is the best tool to do that as is an open and free software; this must also be integrated from the beginning.
- All this must be **open source, shared, modular** to become a common and be usable for policy-making.
- **Stakeholders** must be implied in the model (twin) development, exploration and validation process [Delay et al., 2020].

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