



**HAL**  
open science

## ICI Project: Individual-based epidemic propagation simulator based on a Digital Twin

Maxime Colomb, Quentin Cormier, Josselin Garnier, Carl Graham, Julien Perret, Denis Talay

### ► To cite this version:

Maxime Colomb, Quentin Cormier, Josselin Garnier, Carl Graham, Julien Perret, et al.. ICI Project: Individual-based epidemic propagation simulator based on a Digital Twin. Health GIS: Spatial Thinking in Applied research 2024, O'Brien Institute for Public Health (OIPH); University of Calgary, Nov 2024, Calgary, Canada. hal-04794960

**HAL Id: hal-04794960**

**<https://hal.science/hal-04794960v1>**

Submitted on 21 Nov 2024

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

# The ICI Project: an individual-based epidemic propagation simulator based on a Digital Twin

---

**Maxime Colomb** <sup>1,2,3</sup>    Quentin Cormier <sup>1,2</sup>    Josselin Garnier <sup>1,2</sup>  
Carl Graham <sup>1,2</sup>    Julien Perret <sup>3,4</sup>    Denis Talay <sup>1, 2</sup>

November 20, 2024

<sup>1</sup> Centre de Mathématiques Appliquées (CMAP - École Polytechnique)

<sup>2</sup> Analyse d'interactions stochastiques intelligentes et coopératives (ASCI-INRIA)

<sup>3</sup> Laboratoire des Sciences et Technologies de l'Information Géographique (LASTIG-IGN)

<sup>4</sup> Laboratoire de démographie et d'histoire sociale (LDH-EHESS)

# What is the ICI Project?

ICI couples a generator of **realistic digital twins** of large geographic zones and their **populations** of mobile individuals with an individual-based disease **contagion model**

Given the generated geographic zone and the sampled synthetic population, **large scale Monte Carlo simulations** allow to obtain **precise statistical informations** on, *e.g.*,

- the dynamics of the number of infected individuals within each population class (age, comorbidity, housing area, working place, etc.)
- the future saturation level of given hospitals
- the compared effects of varied sanitary policies

# A modular approach

## Digital twin generation

- Building land-use
- Synthetic population
- Housing of individuals

## Dynamics

- Movement of individuals between their hourly activities

## Epidemic propagation simulations

- Probabilistic epidemiology model, 9 health statutes
- Digital implementation of sanitary policies
- Evaluation and comparison of sanitary policies by Monte Carlo simulations

# Digital twin generation

---

# Land-use and building interior model

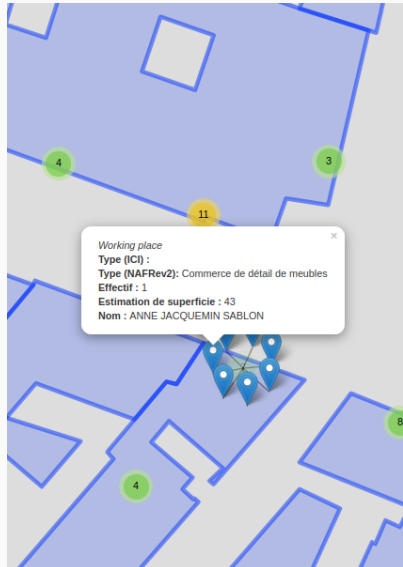
Exhaustive detailed and geolocalized model with building **interiors**.  
Two kinds of spaces:

- **Activities**

- A type
- Open to public
- Frequency indicator
- Number of workers
- Opening hour
- Behaviour during past lockdowns

- **Housing units**

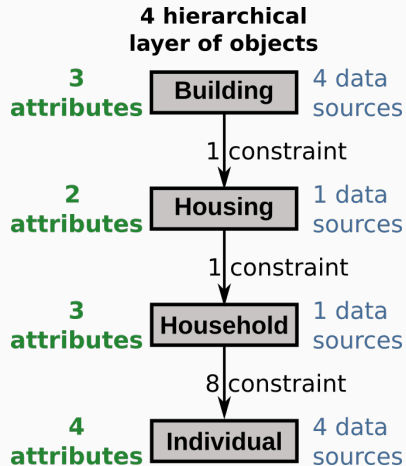
- Area and principal home status
- Linked to the synthetic population



# Four-layered hierarchical synthetic population

## An original generator

- Heavily **geolocalized** and data-driven.
- Plausible and hierarchized configuration, respecting:
  - macro-statistics (general statistics),
  - meso-statistics (statistical aggregates),
  - household and housing constraints.
- Well-described individuals.



# Dynamics

---



# Locations of individuals

## In and out fluxes

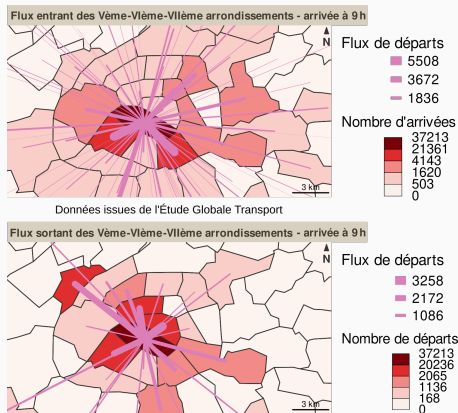
Fluxes based on surveys, mobile phone activity and common transportation counting

## Agenda generation

Based on surveys, relatively to:

- Socio-demographic characteristics, place of living,
- Hour and day of the week

Modelled by a Markov chain between 8 activities.



# Locations of individuals

## In and out fluxes

Fluxes based on surveys, mobile phone activity and common transportation counting

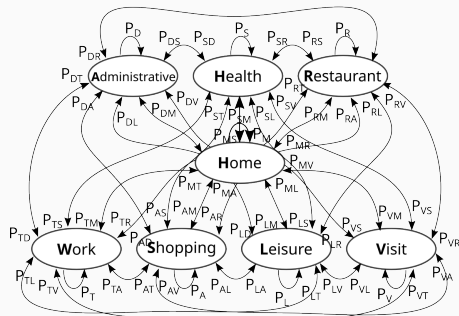
## Agenda generation

Based on surveys, relatively to:

- Socio-demographic characteristics, place of living,
- Hour and day of the week

Modelled by a Markov chain between 8 activities.

Markov Chain



# Epidemic propagation simulations

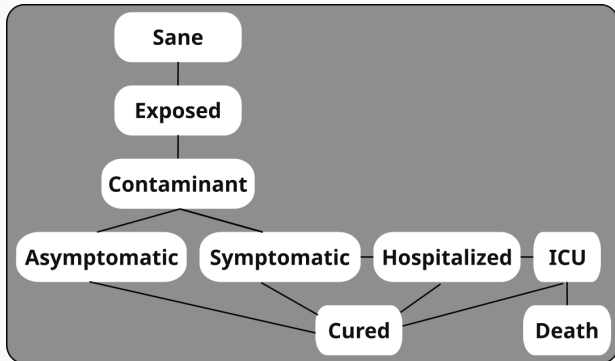
---

# Our epidemiology propagation model

**Probabilistic** simulation at an individual scale:

- **Simulate the movements** of the individuals according to their agendas
- **Locate** individuals inside building's activities
- **Sample** the probability distribution of **contamination** between two individuals when they meet in the **same place** at the **same time**
- **Run large scale Monte Carlo replications** for the statistical study of epidemiological spreading

# Epidemiology model with 9 health statutes



**Probabilities** to switch states **depend** on sex and **age** and other **individual** characteristics.

# Sanitary policies

The **fine scale** of the digital twin allows the digital implementation of **various sanitary policies**, for example:

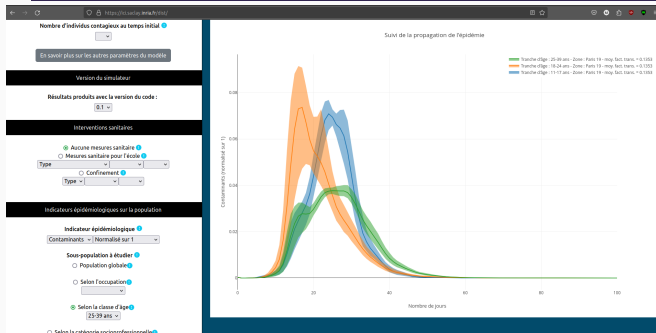
- **School** sanitary protocols
  - Close each class when a detected amount of student is reached.
  - Close every school when incidence rate is reached.
- **Lockdowns**:
  - Total, partial or targeted.
- **Vaccination** campaigns:
  - Random or on targeted population.

## Examples of results

---

# Pre-computed simulation results

ICI



<https://ici.saclay.inria.fr/dist/>



## We use the OpenMOLE platform



1. To explore model behaviours and sensitivities
2. To deploy large scale Monte Carlo simulations over HPC clusters
3. To search **optimal** sanitary policies

Reuillon, R., Leclaire, M. & Rey-Coyrehourcq, S. (2013). OpenMOLE, a workflow engine specifically tailored for the distributed exploration of simulation models, *Future Generation Computer Systems*.

# Sensitivity analyses, numerical search for optimal decisions

## Optimisation parameters:

- **Duration** of the policy.
- **Activation** threshold.

## Optimisation criterion:

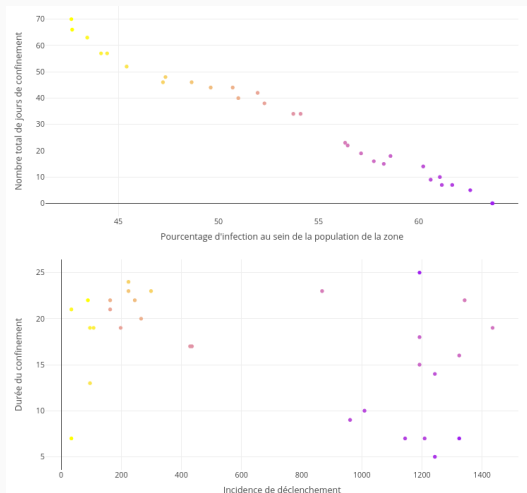
- **Sum** of total **contaminations**.
- Number of lockdown days, total missing days for **students**.



`https://ici.saclay.inria.fr/shiny/multicriterionoptim/schoollockdown/`

# Sensitivity analyses, numerical search for optimal decisions

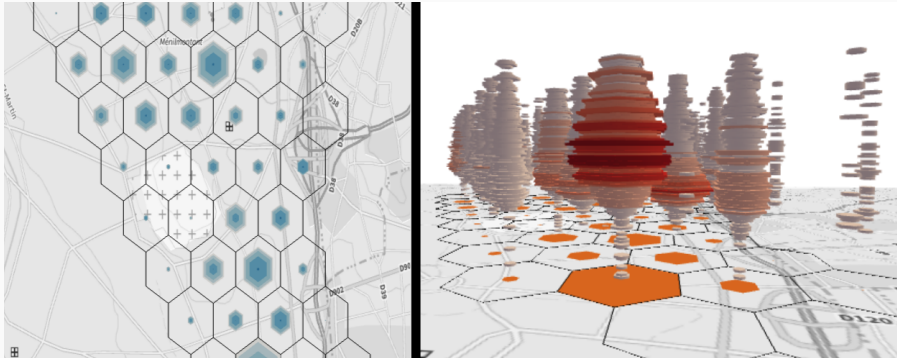
## Illustration: Optimization of **lockdowns** 19th arrondissement of Paris



<https://ici.saclay.inria.fr/shiny/multicriterionoptim/schoollockdown/>

# Advanced geo-visualisation: Geo-epidemiology

Partnership with the LASTIG-**Geovis** team for advanced visualisation of epidemiological dynamics.



Gautier, J., Lobo, M. J., Fau, B., Dugeon, A., Christophe, S., & Touya, G. (2021). COVID-19 geoviz for spatio-temporal structures detection. In *Proceedings of the ICA*.

## Future works and ongoing collaborations

- *With transportation modelling experts::* Modelling of individual behaviours in terms of sanitary constraints
- *With epidemiologists::* Extensions to various diseases and applications to future pandemics prevention
- *Within the Digital Twin of French territories program::* Integration of the ICI modules

Thanks for your attention !

<https://ici.saclay.inria.fr>

