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# Multiscale cellular automata model for simulating land use change at regional/local scales

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**FCT** Fundação para a Ciência e a Tecnologia

MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E ENSINO SUPERIOR Portugal

## Definition and Historical Timeline

→ The concept of Cellular Automata (CA) has its origins in the work of von Neumann and Ulam, two mathematicians that were facing the problem of devising mathematical rules for biological systems and evolution

→ Automata comes from the consideration of theoretical mechanisms capable of universally process any given code (defined by a set of states) – the Universal Turing machine

→ Important dates

- 1940s – pioneer work of von Neumann and Ulam
- 1970 – Conway's Game of Life
- 1979 – “Cellular Geography”, Waldo Tobler
- 1980s – Stephen Wolfram's work on CA (mathematical approach, wide set of applications)
- 1985 – dissemination of Geographical CA, Helen Couclelis, Michael Batty, Roger White
- 1990s, 2000s – Intensive research on Geographical/Urban CA

# Conceptual Formulation

“...an automaton is a processing mechanism with characteristics that change over time based on its internal characteristics, rules and external input...” (Benenson and Torrens, 2004)

→ Conceptual formulation of a 2D CA

Each cell  $A$  (an automaton) is defined by a given state from a finite set of cell states  $S$  and evolves in time according to a set of transition rules  $T$ , considering an external input  $I$

$$A_t \leftarrow (S, T) \mid S = \{S_1, S_2, \dots, S_N\} \mid T : (S_t, I_t) \rightarrow S_{t+1} \mid A_{t+1} \leftarrow (S, T)$$

If we consider the neighborhood  $R$  of cell  $A$  and the cross influence of every cell state of every cell in  $R$  in the state of  $A$  than we have the definition of CA

$$A_t \leftarrow (S, T, R) \mid S = \{S_1, S_2, \dots, S_N\} \mid T : (S_t, I_t) \rightarrow S_{t+1} \mid A_{t+1} \leftarrow (S, T, R)$$

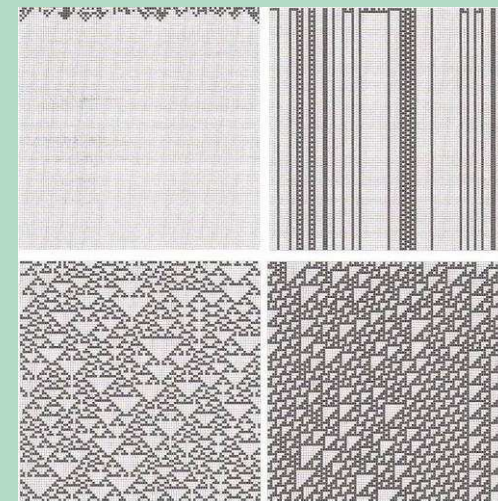
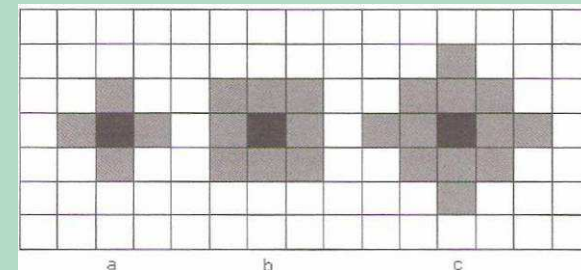
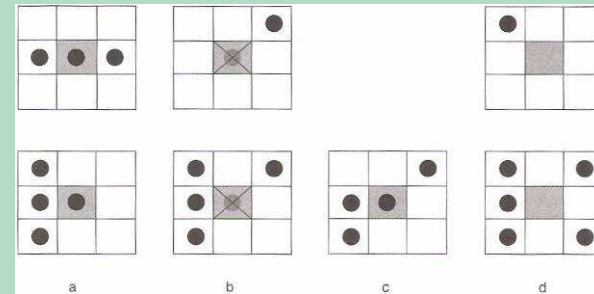
# Concept

## → Five components

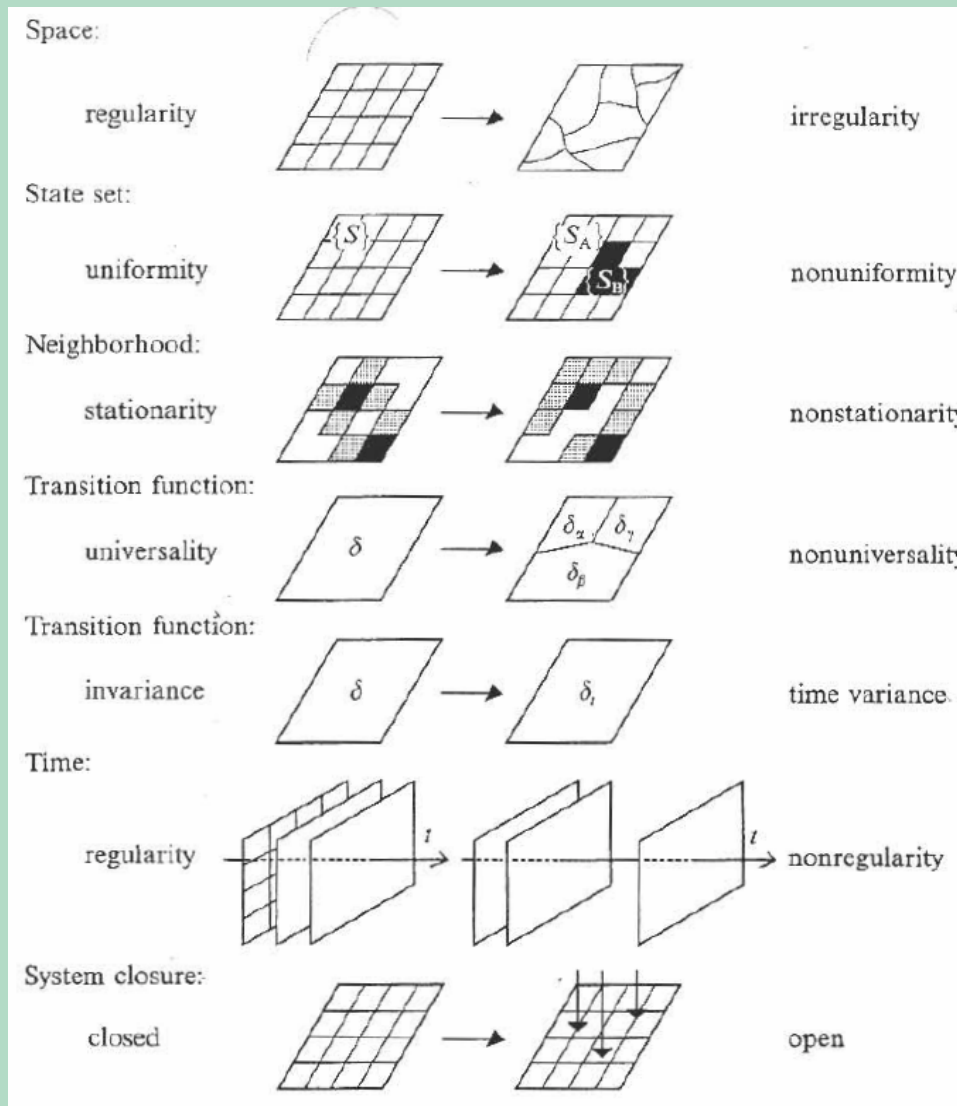
- Cells and Cell Structure
- Neighborhood
- Cell States
- Transition Rules
- Time

## → Mathematical Approach

- 1D (vector) or 2D (matrix) cell space
- Contiguous neighborhoods (n cells)
- Binary cell states (1 or 0)
- Probabilistic transition rules



# Relaxations



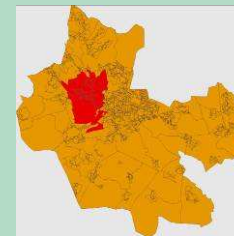
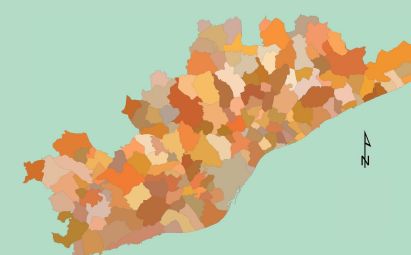
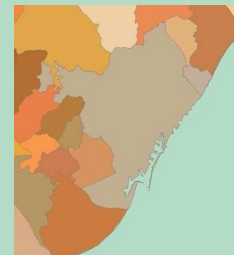
Couclelis, H., 1997, "From cellular automata to urban models: New principles for model development and implementation", *Environment and Planning B: Planning and Design* 24(2) 165-174

# Components

→ **Approach** – Unconstrained/constrained CA model with urbanized land demand based on population and employment density calibrated by an optimization procedure (Particle Swarm)

→ **Five major CA components**

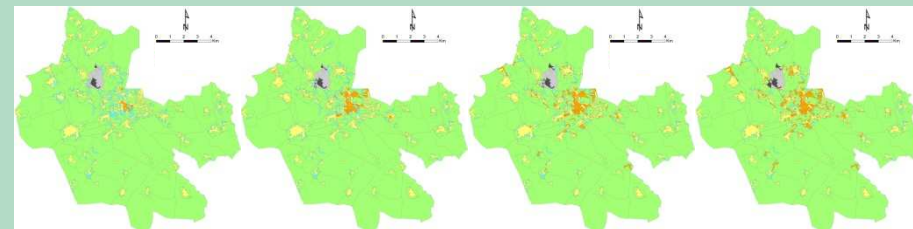
- Cell and Cell Structure
- Neighborhood
- Cell States
- Transition Rules
- Time



% Urbanized Area (agg)

Finite set of states

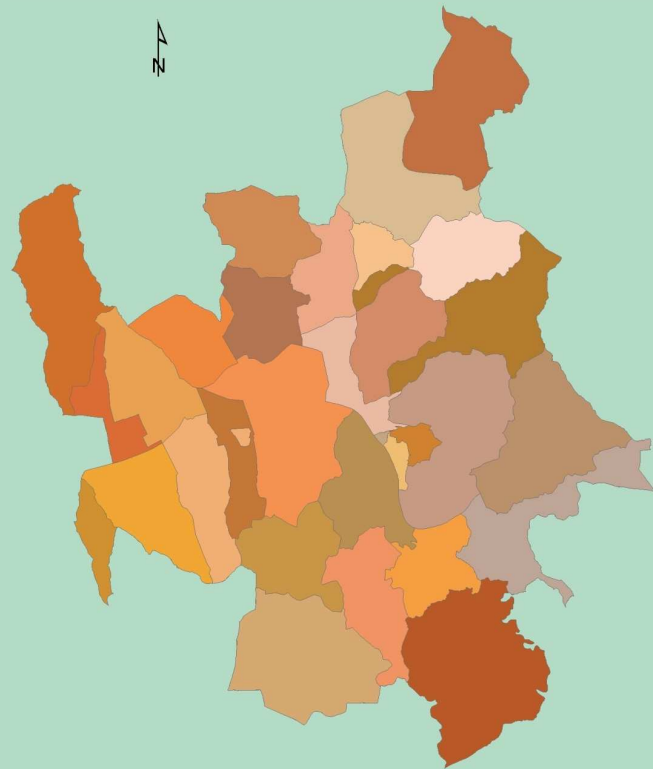
$$T : (S_t, I_t) \rightarrow S_{t+1}$$



→ time

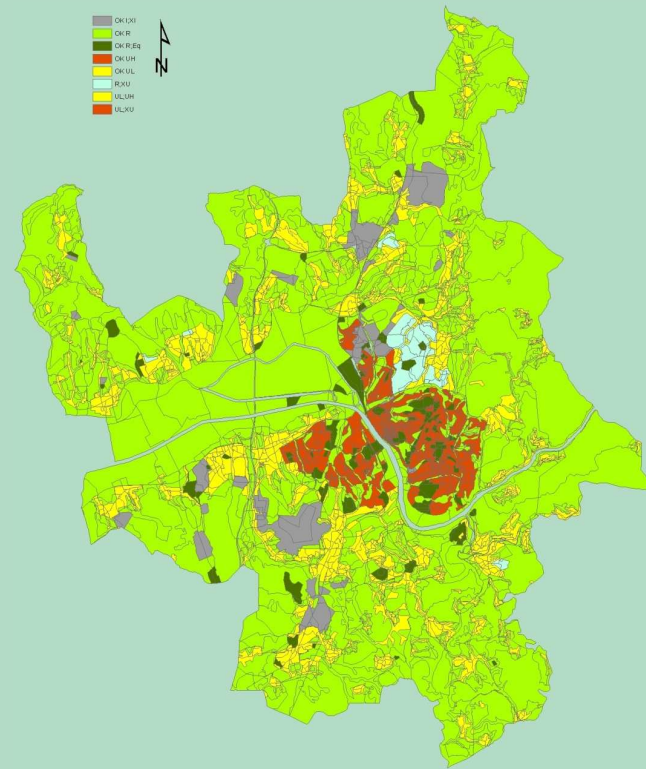
# Cells and Cell Structure

## Macroscale



- Boroughs, municipalities, ...
- data for POP, EMPL

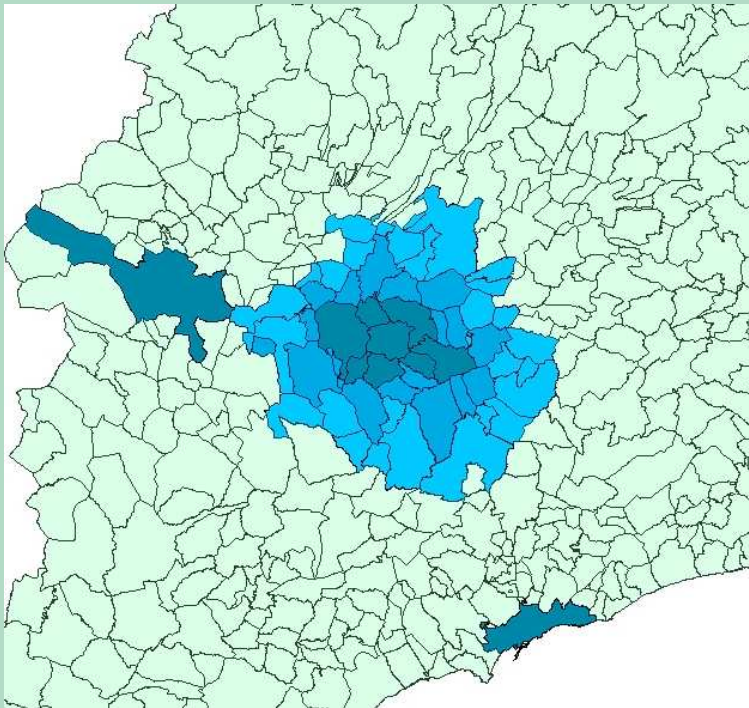
## Microscale



- Census blocks based, ...
- data for POP, EMPL, land use, transport, ...

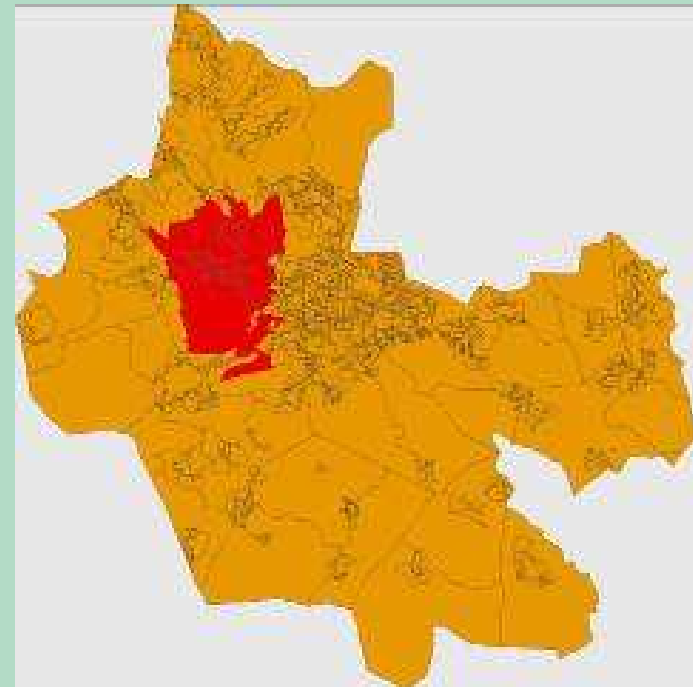
# Neighborhood

## Macroscale



- Calibrated by the model
- Discontinuous, dual value
- Variable (?)

## Microscale



- Calibrated by the model
- Continuous (?)
- Variable (?)

# Transition Rules

## Macroscale

$$V_i = f(P; E; A; \\ AvailableLand_P; AvailableLand_E)$$

- Based on the concept of potential
- Potential of interaction considering existing population and employment and potential capacity for more occupation
- Logit based distribution of population and employment allocation

## Microscale


$$V_i = f(A; N; S; Other)$$

- Based on the concept of potential
- Potential of interaction of land uses considering accessibility, land suitability and other constraints

# Conceptual Structure [1]

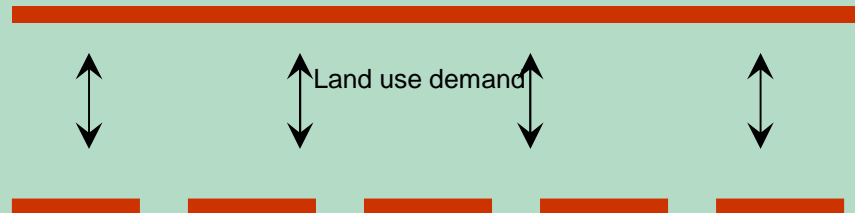
## Traditional Approach

Local-scale CA, One regional problem



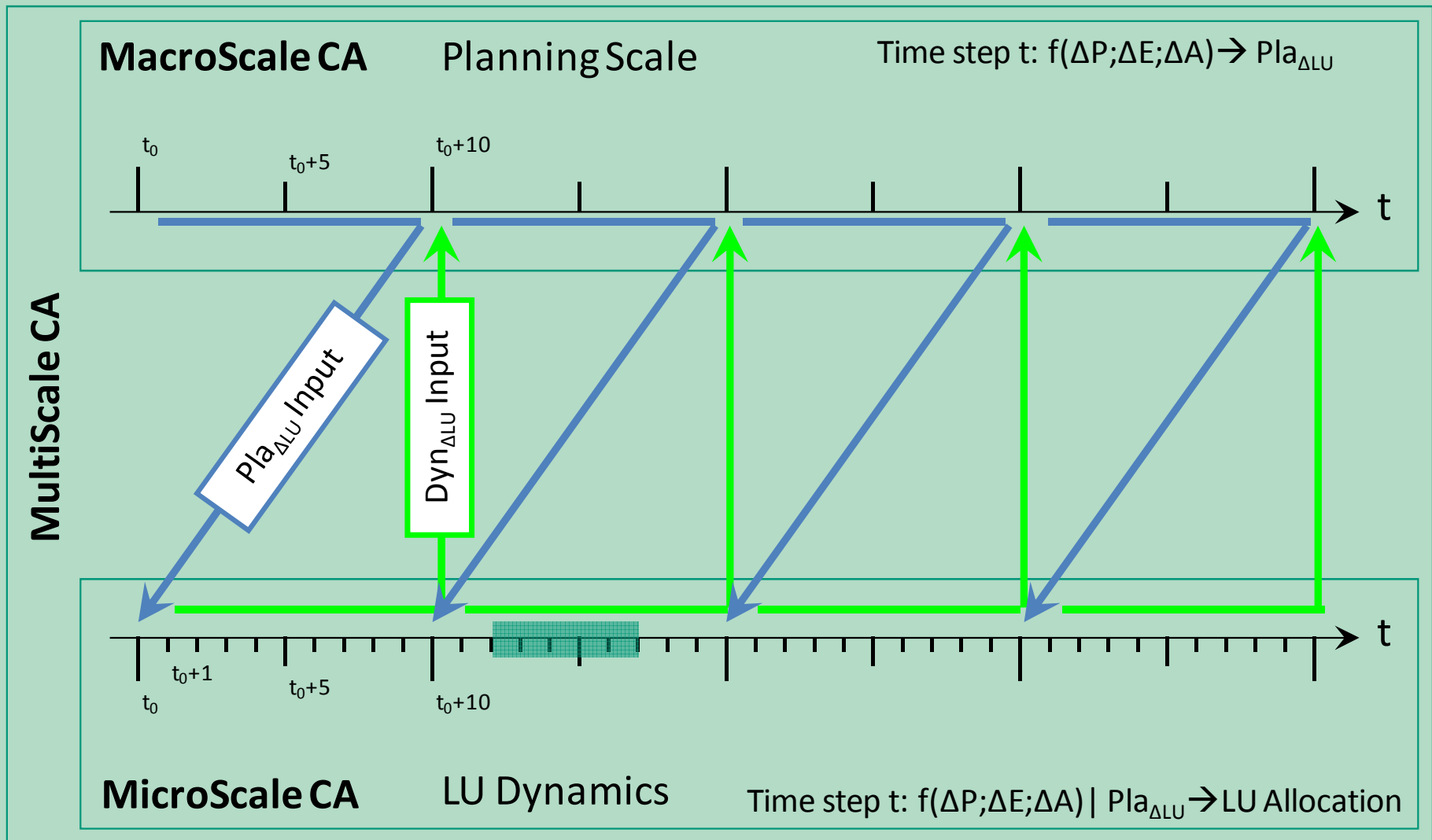
## Multiscale Approach

Regional-scale CA, One regional problem



Local-scale CA, Local problems

# Conceptual Structure [2]



# Macroscale Model

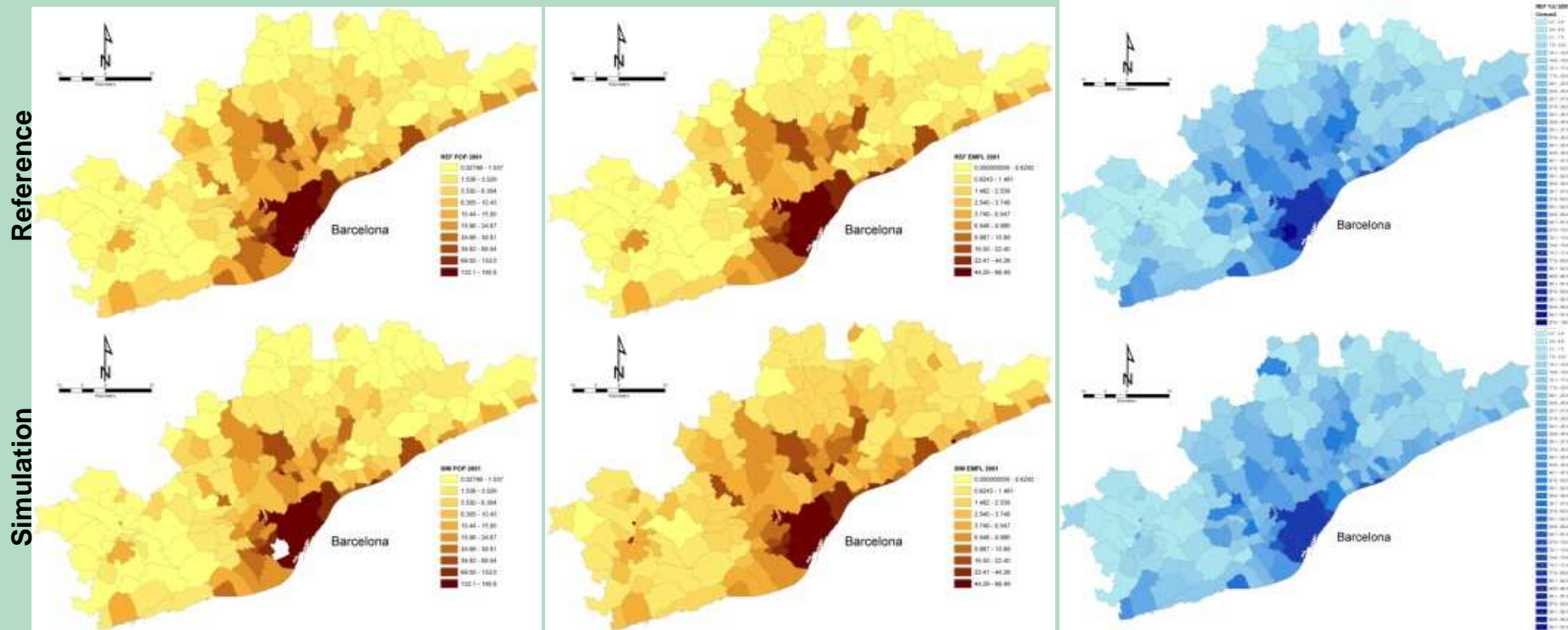
## Barcelona Metropolitan Area, Spain

approximately 3250 km<sup>2</sup>, 4.4 M inhabitants

(a) Population 2001

(b) Employment 2001

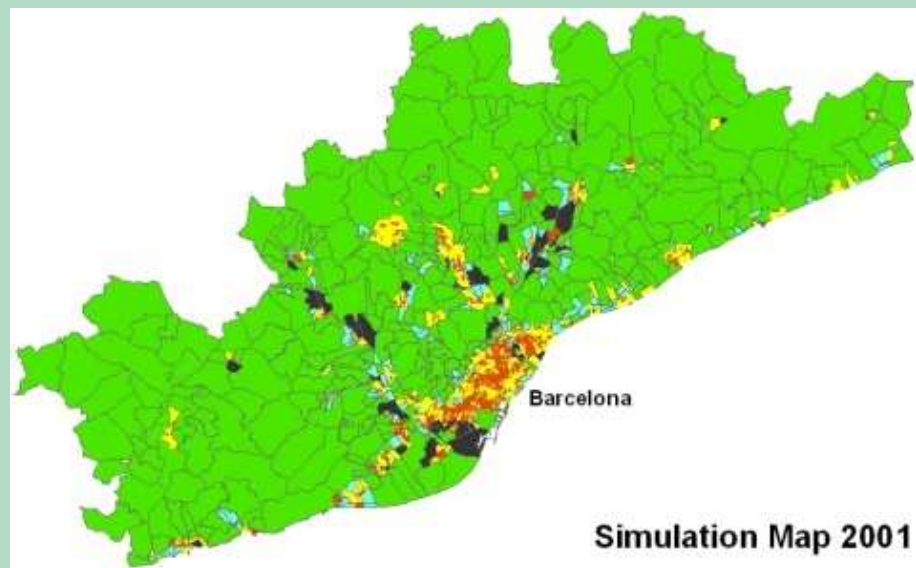
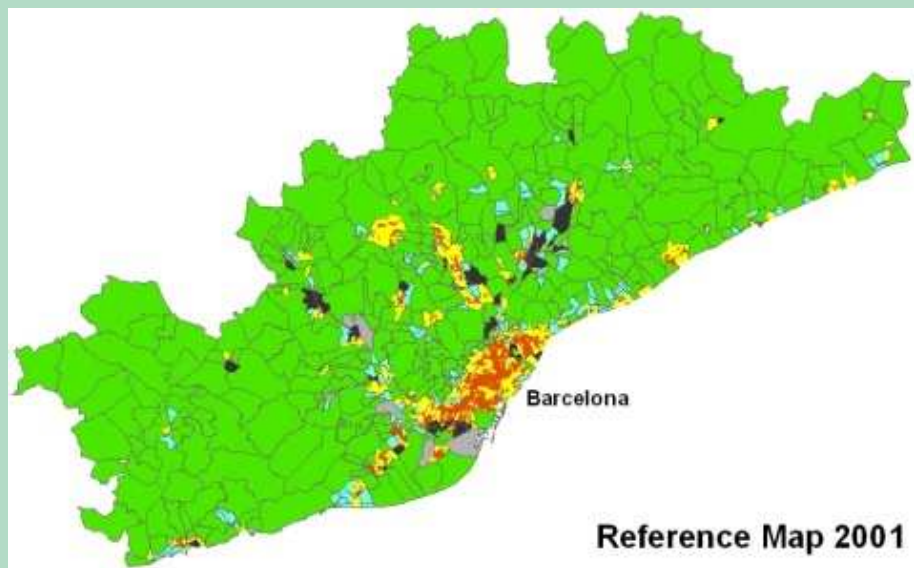
(c) Urbanized land 2001



# Microscale Model [1]

## Barcelona Metropolitan Area, Spain

approximately 3250 km<sup>2</sup>, 4.4 M inhabitants



# Microscale Model [2]

## Municipality of Coimbra, Portugal

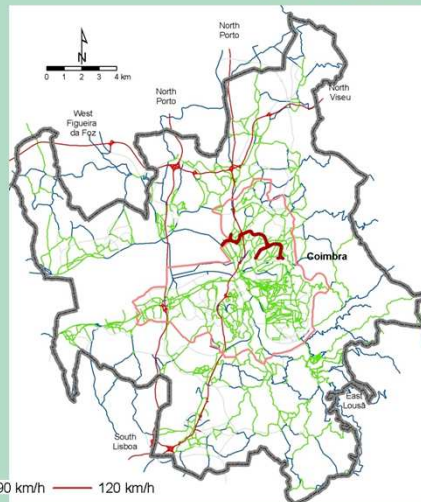
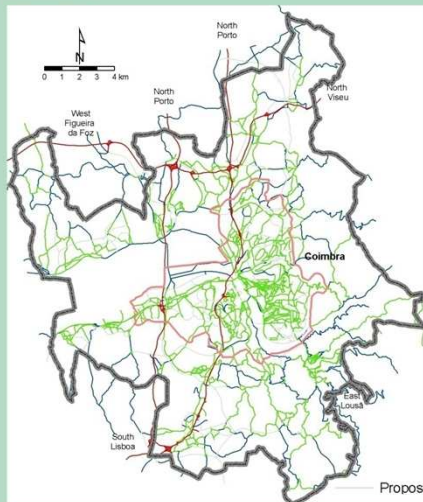
approximately 320 km<sup>2</sup>, 150 K inhabitants

Growth Rates

	2001-2011	2011-2021
Population	+3%	+2%
Employment	+2%	+2%

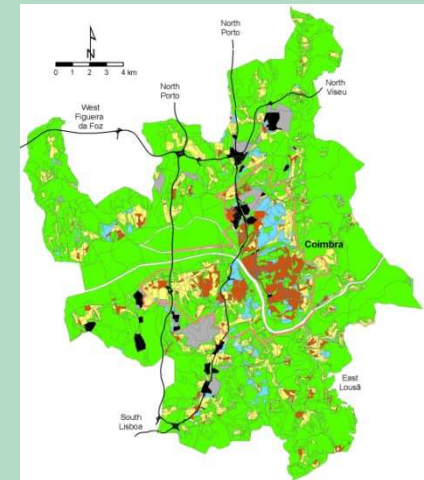
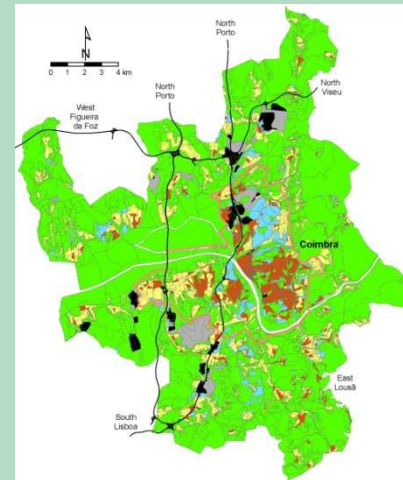
Baseline

Anel Pedrulha



Baseline 2021

Anel Pedrulha 2021



## Advantages, Problems, Ongoing Work

### Advantages

- Use of meaningful spatial units at each scale
- Calibrate different phenomena at different scales, different parameters
- Different neighborhood perceptions
- Possibility of testing spatial competition of municipalities for inhabitants, employment

### Problems

- Computational costs, data availability, ...

### Ongoing work

- Multiscale approach
- Neighborhood, dynamic, discontinuous
- Different transition rules
- New measures of agreement
- Use multimodal accessibility measures

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