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A tool to analyze urban development strategies

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Department of Built Environment

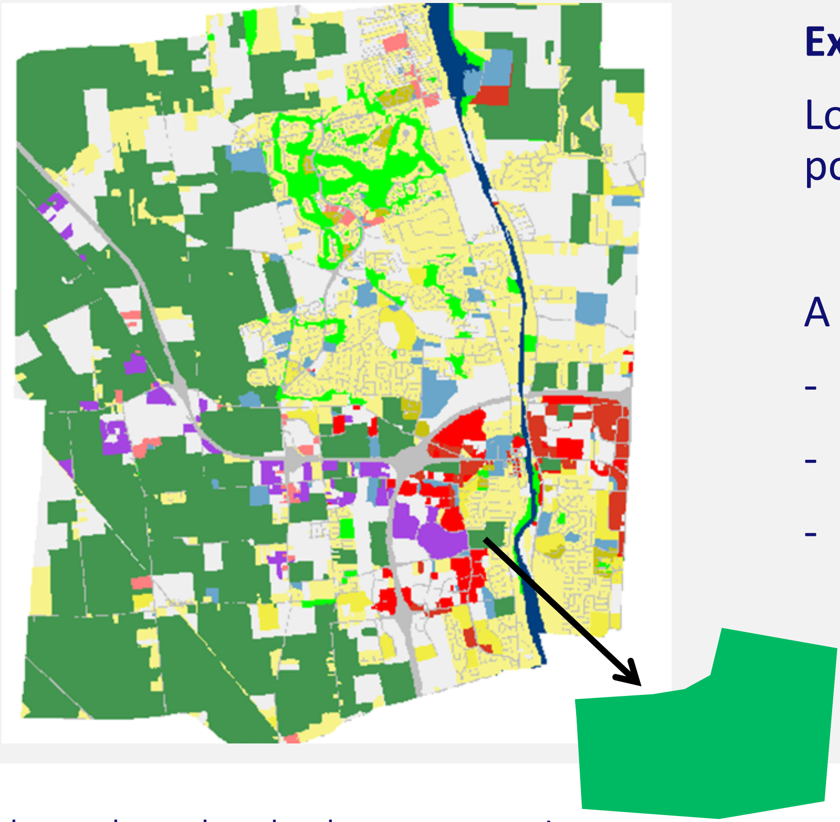
Land-use modeling

Major approaches

1. Land-use allocation models
2. Cellular automata models
3. Integrated land-use and transportation models
    - regional economic base and spatial interaction models (e.g., Muplan)
    - micro-simulation models (e.g. UrbanSim)

Compared to transportation modeling – the focus is on more long-term development where one cannot assume that the land-use stays constant

Land-use allocation models



Example - The What-if model

Location units are irregularly shaped polygons

A two-step approach

- specify the demands for *K* land-uses
- specify land-suitability functions
- determine the best allocation

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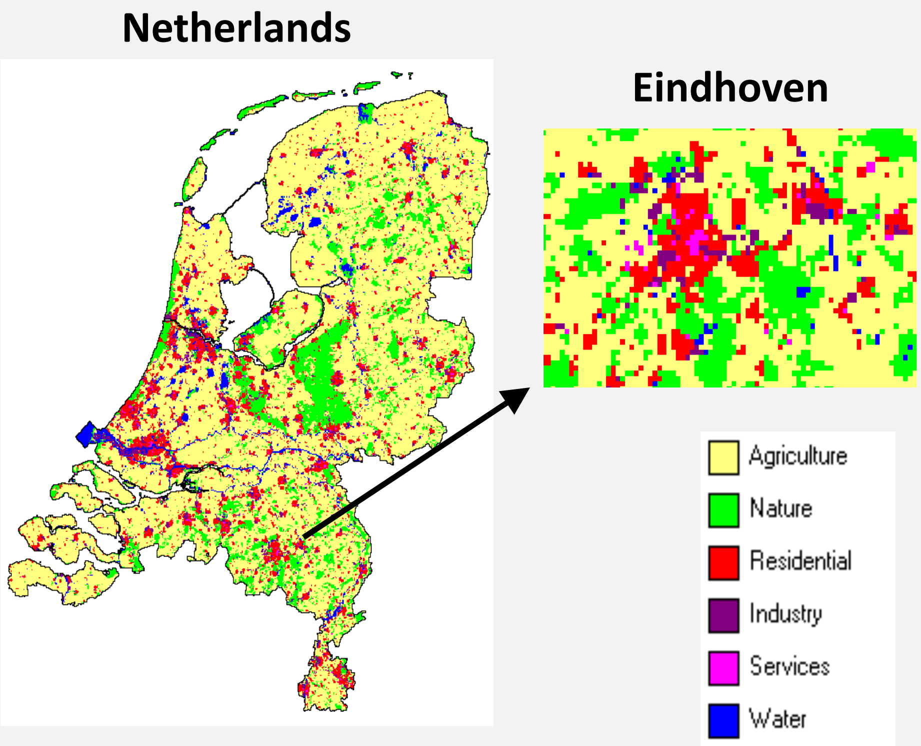
Cellular automata models



Source: Hagen-Zanker (2008)

Example - The Environment Explorer

Location units are cells in a regular grid

Uses transition rules to determine the land-use change in each cell per time step

Regional economic + interaction models

Residential location

$$T_{ij}^k = E_i \frac{R_j \exp(-\lambda^k c_{ij}^k)}{\sum_{jk} R_j \exp(-\lambda^k c_{ij}^k)}$$

$$P_j = \sum_{ik} T_{ij}^k$$

$$if\ P_j > P_j^{\max} \rightarrow R_j^* = R_j \frac{P_j}{P_j^{\max}}$$

Retail location

$$S_{jz}^k = P_j \frac{W_z \exp(-\lambda^k c_{jz}^k)}{\sum_{jz} W_z \exp(-\beta^k c_{ijz}^k)}$$

$$S_z = \sum_{jk} S_{jz}^k$$

$$if\ S_z > S_z^{\max} \rightarrow W_z^* = W_z \frac{S_z}{S_z^{\max}}$$

Capacitated Transport Constraints

$$if\ F_{ij}^k (= T_{ij}^k + S_{ij}^k) > CAP_{ij}^k \rightarrow c_{ij}^{k*} = c_{ij}^k \frac{T_{ij}^k + S_{ij}^k}{CAP_{ij}^k}$$

Employment location

$$E_i = X_i + \phi S_i$$

$$X_i = X \frac{\sum_q \alpha_q x_{qi}}{\sum_q \sum_i \alpha_q x_{qi}}$$

$$E_i^* = X_i + \phi S_i$$

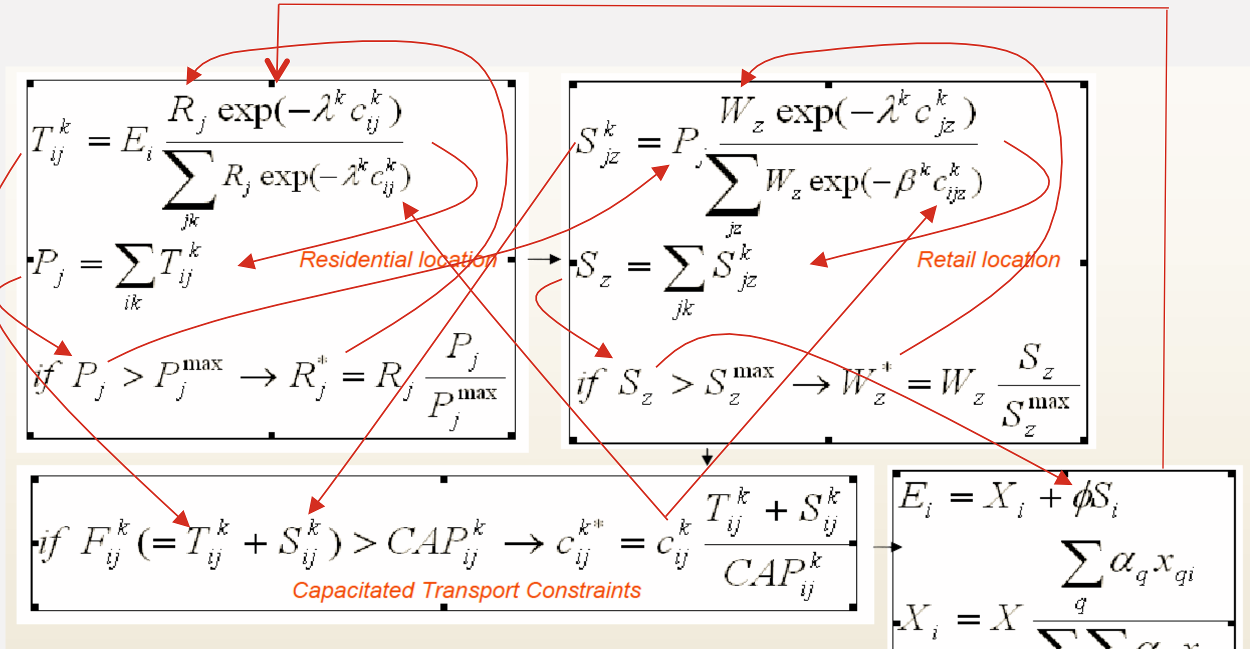
Source: M. Battey
http://www.casa.ucl.ac.uk/rits/Rits-Lecture-5.pdf

Given is employment in the basic industry

The model determines

- the residential locations
- the retail locations (generally service industry)
- the transportation flows

Regional economic + interaction models



Source: M. Battey
http://www.casa.ucl.ac.uk/rits/Rits-Lecture-5.pdf

There are many feedback loops

- Transportation congestion influences attractiveness of locations
- New service industry generates employment and thus demand for residence and new services

The system iterates until equilibrium is reached

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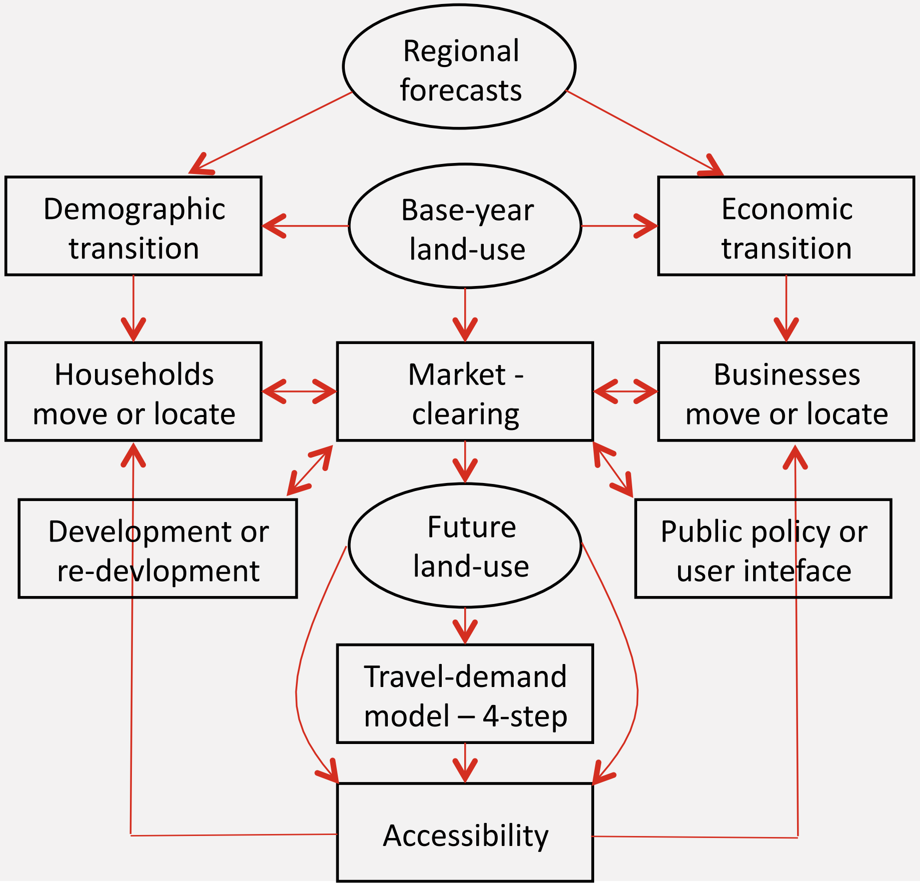
Micro-simulation approach

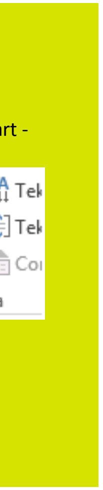


Example UrbanSim

Transporation model is used to evaluate accessibility of locations

Market prices of locations

- respond to accessibility
- Inlfuence location decisions of firms and households
- Influence development decisions of developers



A tool to analyze urban development strategies

Problem background and aim

How can we make sure that cities in the future are better adapted to the climate change – how can we create *climate adapted cities*?

More green vegetation in urban area has beneficial properties

- Cooling – mitigating the urban heat island effect
- Water absorption – reducing the risk of flooding

But: more green space means lower urban density – in conflict with compact city goal?

Aim: develop a tool to analyze urban green strategies from a land-use perspective

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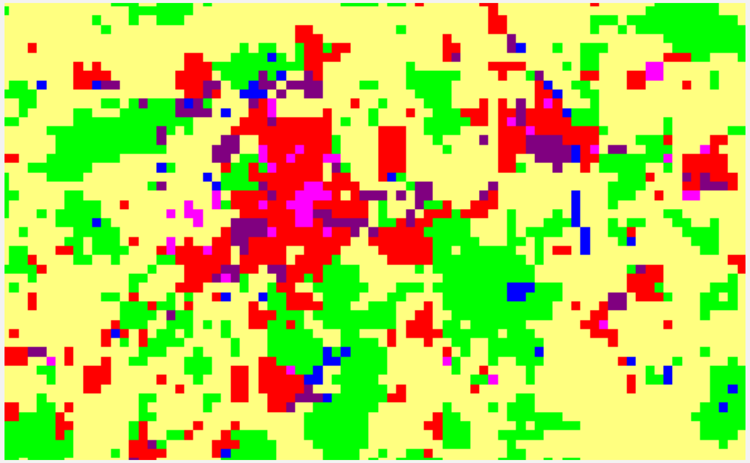
The HARA model



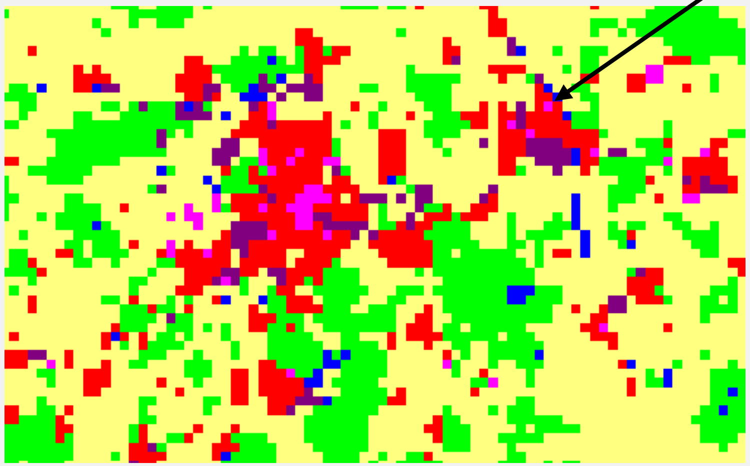
Focusing on housing

Given the demands for different housing types (e.g., apartments, standalone houses)

What is the best allocation of the demands?

Is the current allocation optimal or could it be improved?

The HARA model



Value of a housing development *k*

$$Z_{ijk} = Vcon_{ijk} + Vnbh_{ijk} + Vacc_{ijk} - Cdev_{ijk} - Clnd_{ij}$$

$Vcon_{ijk}$ = base value

$Vnbh_{ijk}$ = neigborhood value

$Vacc_{ijk}$ = accessibility value

$Cdev_{ijk}$ = costs of the development

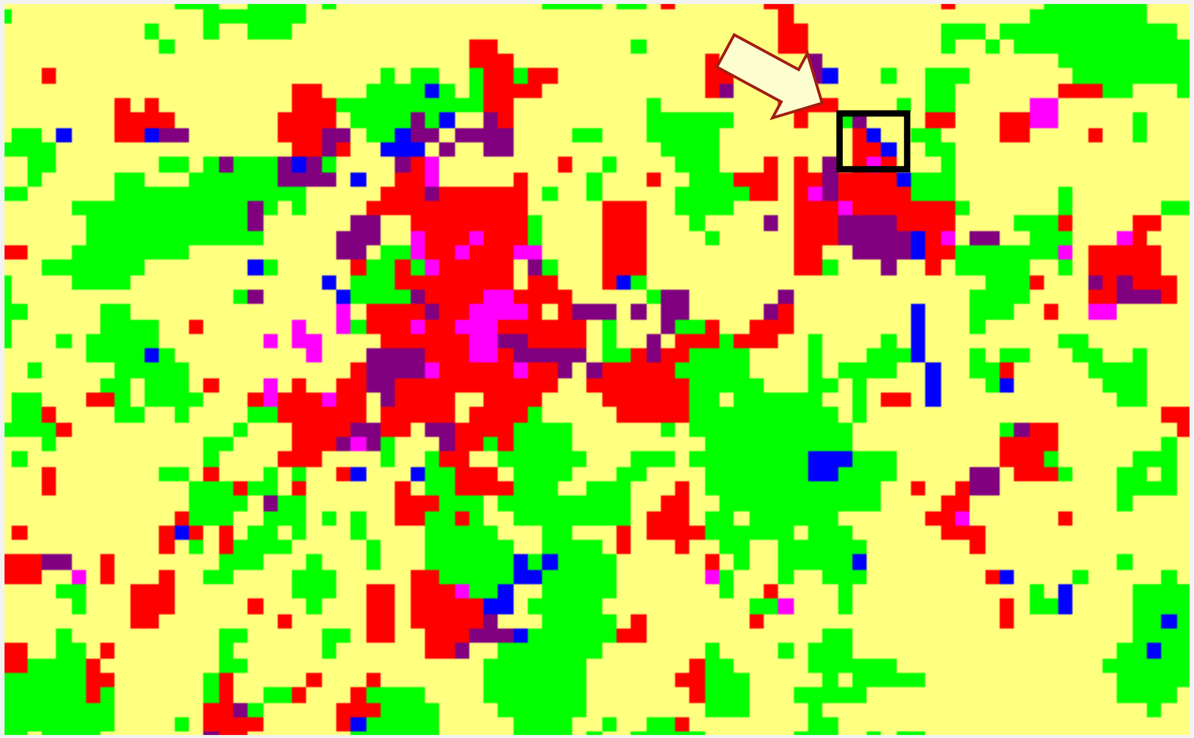
$Clnd_{ij}$ = costs of (acquiring the) land

Value of a cell

$$ZW_{ijk} = \omega_k \cdot Z_{ijk}$$

ω_k = density – number of housing units

Neighborhood value



Housing

Attraction

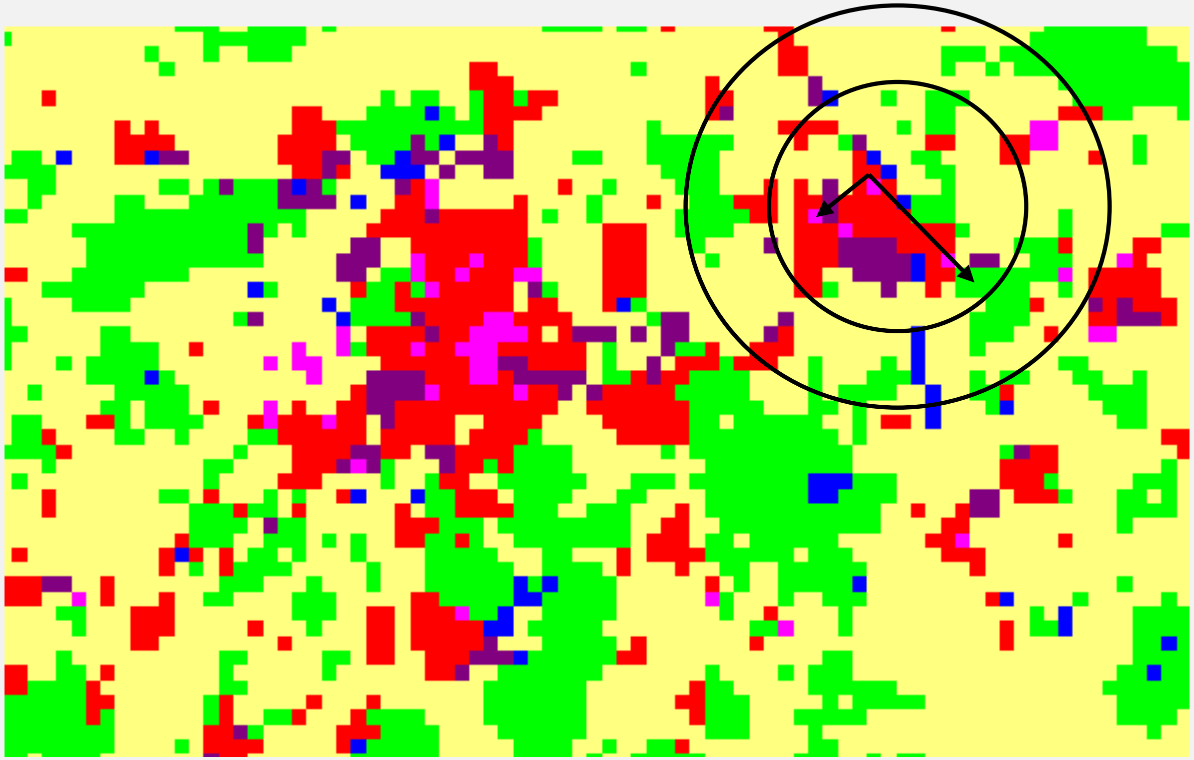
Green, water, open area

Playgrounds

Repulsion

Industry, traffic

Accessibility value



Housing

Attraction

Number and type of facilities in particular distance bands

Available employment within certain distance bands

Distance to facilities of certain types

- CBD
- train station
- shops
- etc.

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Hedonic price modeling

The value function can be estimated empirically given transaction data in the housing market

$$Z_{ijk} = Vcon_{ijk} + Vnbh_{ijk} + Vacc_{ijk} - Cdev_{ijk} - Clnd_{ij}$$

Sale price of the dwelling

Structural data

Neighborhood data

Accessibility data

Variable	(6)
Lettable Floor Area *(Log)*	0.9610***
Building Height *(Log)*	0.0362*
Parking Spots *(Log)*	0.0002**
Energy Label: Below C	-0.0138
Energy Label: C	-0.0538*
Energy Label: B	0.0303
Energy Label: Above A	0.2259***
Year Built: before 1906	0.3214
Year Built: 1906-1945	0.0975
Year Built: 1946-1970	-0.0998
Year Built: 1971-1990	-0.1114*
Year Built: 1991-2000	-0.1192**
Year Built: 2001-2010	-0.1231**
Walkscore	0.0034***
Leefbaarometer Score	0.2407***
Train Station Distance *(Log)*	
Highway Distance *(Log)*	
TRI per sqm. *(Log)*	1.0458***
Vacancy Percentage	-0.3243***
WALE incl. Vacancy *(Log)*	0.2266***
Rental Difference: Under	-0.1074***
Rental Difference: Over	-0.1246***
District Type: Business	
District Type: Mixed	
District Type: Other	
City category: Large	0.2453***
Centrality: Central	
Transfer Year 2010	0.0508
Transfer Year 2011	-0.0450
Transfer Year 2012	-0.1149
Transfer Year 2013	-0.3903***
Transfer Year 2014	-0.3794***
Transfer Year 2015	-0.2443***
Transfer Year 2016	-0.1525***
Transfer Year 2018	0.1540***
Intercept	1.8161***
R^2	0.94
MAPE OLS *(Out-of-Sample)*	21.9%
MAPE GLS *(Out-of-Sample)*	21.8%
LOOCV	22.6%
Simulation 2018	19.5%

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Simple example of parameter settings

Construction costs (kEuro/dwelling)

Type 1	Type 2	Type 3	Type 4
153.0	118.2	105.8	110.3

Density (dwellings / ha)

Type 1	Type 2	Type 3	Type 4
16	32	56	169

Accessibility – distance to facilities
value decay in kEuro per km distance

Housing	Daily	CBD
Type 1	2	1.5
Type 2	3	2
Type 3	4	2.5
Type 4	5	3

Neighborhood – green, open area, water in
kEuro all green cells

Housing	kEuro all green cells in neighborhood (8 cells - green)
Type 1	32
Type 2	24
Type 3	16
Type 4	8

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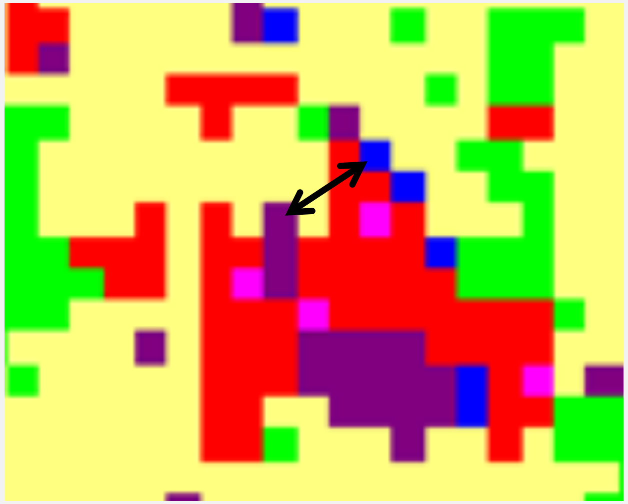
The HARA model



Optimization

The model considers all possible swaps of the landuses between cells

$$gain_{ij} = \left(ZW_i^{after} - ZW_i^{before}\right) + \left(ZW_j^{after} - ZW_j^{before}\right)$$

If the gain is positive the swap is implemented and the next swap is considered

The process stops when no further improvements are possible – the system has reached an equlibrium

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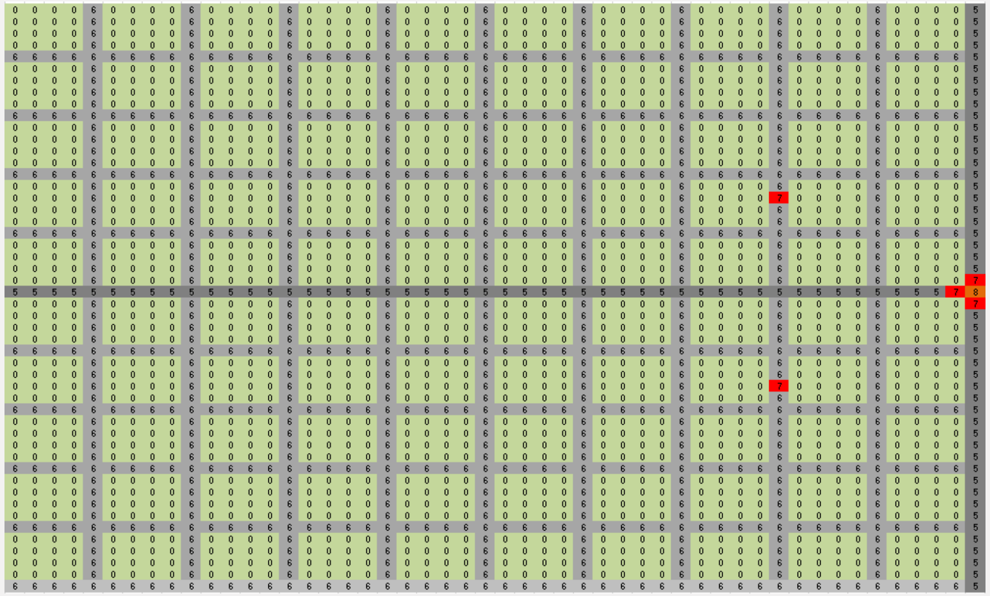
Illustration

City expansion area (hypothetical)



Housing demand scenario

area total size (ha)	2500			
population	22500			
number of dwellings	10700			
	Stand-alone	Semi-detach	Row-houses	Appart-ments
% dwellings of total	20.0	22.0	45.0	13.0
number of dwellings	2140	2354	4815	1391
lot size (m2)	612.25	308.92	177.35	177.35
layers	1.00	1.00	1.00	3.00
dwellings/ha	16	32	56	169
land (ha)	131	73	85	8

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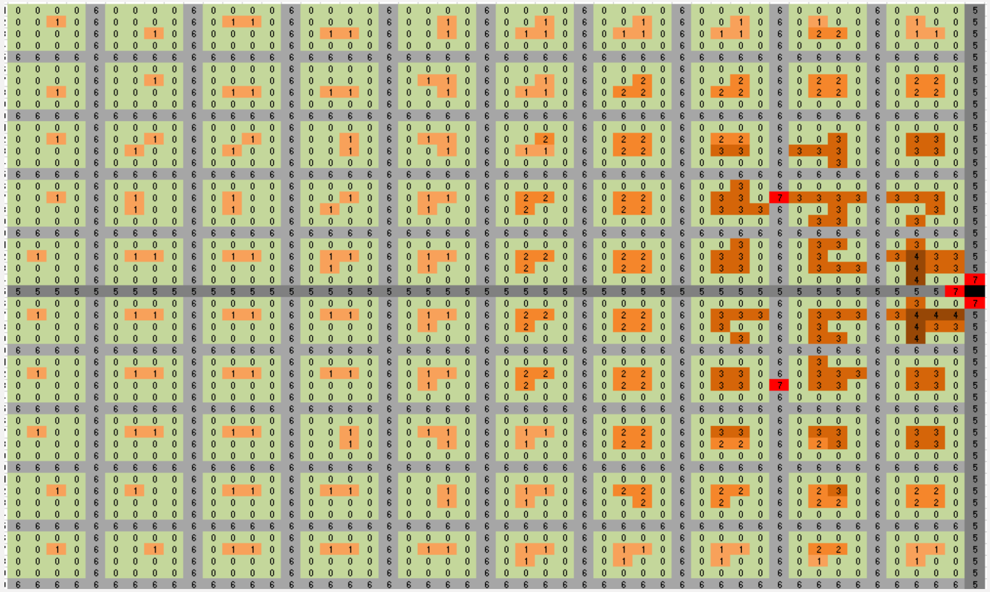
Illustration

Distance to facilities increases

Green area increases



Trade-off

- distance to facilities and CBD
- being in green, open area

High density types of housing

- more sensitive to distances

Low density types of housing

- higher value green area

An estimate of the total land value can be derived from the model

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Scenarios

High-density housing strategy

- Increase of people living in high-density type of housing
  - Stand-alone -> semi-detached
  - Semi-detached -> row houses
  - Row houses -> apartments

Low-density housing strategy

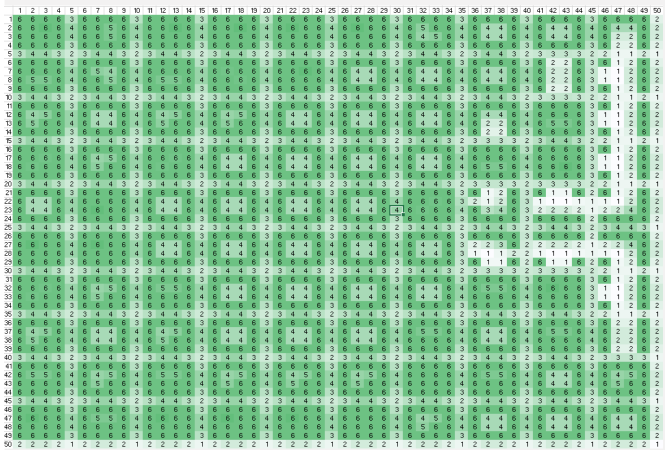
- Increase of people living in low-density type of housing
  - Stand-alone <- semi-detached
  - Semi-detached <- row houses
  - Row houses <- apartments

Climate effects

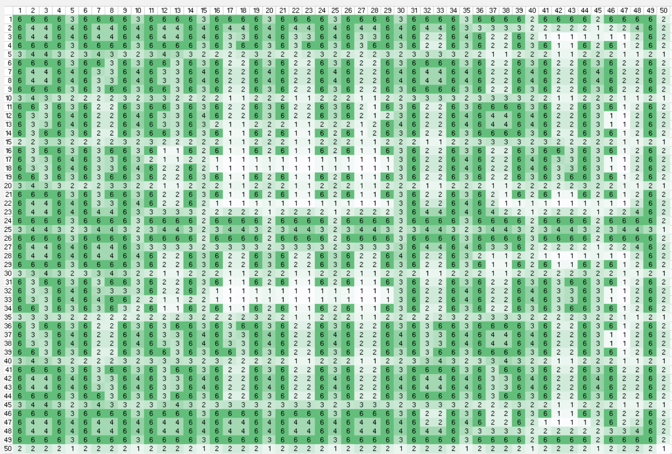
Urban green cooling effect parameter setting		
Description	Symbol	value
Direct cooling effect	β	6
Indirect cooling effect from zero distance	γ_0	2
Decay effect of indirect cooling	γ_1	-1

Urban cooling effect

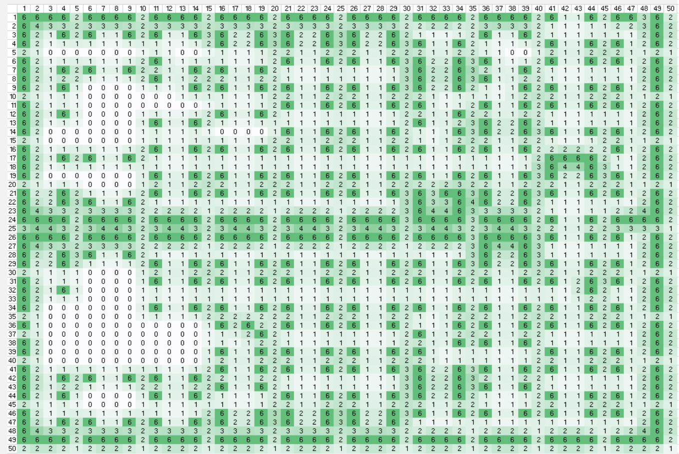
High-density housing strategy



Medium-density housing strategy



Low-density housing strategy



4. New model illustration

Evaluation index		scenarios	Land use								
			Total	Nature	Housing1	Housing 2	Housing3	Main road	Small road	Industry	CBD
Description	Cells number of each land use	Initial	2500	1440	*	*	*	98	801	0	1
		High-density	2500	1240	176	116	68	98	801	0	1
		Medium-density	2500	870	110	505	115	98	801	0	1
		Low-density	2500	520	100	520	460	98	801	0	1
	Housing ratio	High-density	100%	*	48.89%	32.22%	17.78%	*	*	*	*
		Medium-density	100%	*	15.28%	70.14%	15.97%	*	*	*	*
		Low-density	100%	*	9.26%	48.15%	42.59%	*	*	*	*
	Population of each housing type	High-density	50000	*	44000	4640	1360	*	*	*	*
		Medium-density	50000	*	27500	20200	2300	*	*	*	*
		Low-density	50000	*	25000	20800	9200	*	*	*	*
	Land value	High-density	38188.5	*	*	*	*	*	*	*	*
		Medium-density	68998.0	*	*	*	*	*	*	*	*
		Low-density	93792.5	*	*	*	*	*	*	*	*
Indicators	Cooling area	High-density	2500	1240	176	116	68	98	801	0	1
		Medium-density	2500	870	110	505	115	98	801	0	1
		Low-density	2345	520	100	520	369	98	737	0	1
	Cooling effect	High-density	11601.15	7440	402.91	484.74	345.42	256.49	2670.42	0	1.17
		Medium-density	9066.76	5220	177.47	980.22	342.38	256.49	2089.03	0	1.17
		Low-density	5807.56	3120	128.86	583.00	512.59	243.46	1218.48	0	1.17
	Cooling effect ratio of whole cooling effect	High-density	100%	64.13%	3.47%	4.18%	2.98%	2.21%	23.02%	0	0.01%
		Medium-density	100%	57.57%	1.96%	10.81%	3.78%	2.83%	23.04%	0	0.01%
		Low-density	100%	53.72%	2.22%	11.20%	8.83%	4.19%	20.98%	0	0.01%
	Cooling effect benefits population	High-density	50000	*	44000	4640	1360	*	*	*	*
		Medium-density	50000	*	27500	20200	2300	*	*	*	*
		Low-density	48180	*	25000	20800	7380	*	*	*	*
	Cooling effect for public land use	High-density	10368.08	7440	*	*	*	256.49	2670.42	0	1.17
		Medium-density	7566.69	5220	*	*	*	256.49	2089.03	0	1.17
		Low-density	4583.11	3120	*	*	*	243.46	1218.48	0	1.17

Table: Scenario results shown in evaluation index

5. Conclusions and discussion

Conclusions

This Hara model system is a practical tool to investigate different scenarios of land use allocation impact on the land value and climate (cooling effect) based on given housing demand and limited space for housing.

Discussion

Future research will consider

- finer land-use classifications (green and urban)
- empirical estimation of the parameters (hedonic price analysis)
- real-world applications

Thank you for your attention