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Complex constrained CA urban model:

long-term urban form prediction for Beijing metropolitan area

Oral presentation at ISOCARP, Dalian, China

Long, Ying (China)
Beijing Institute of City Planning
School of Architecture, Tsinghua University
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1. Introduction

- **Urban Growth Without Sprawl: A Way Towards Sustainable Urbanization**
  (44th ISOCARP Conference topic)
- **Urban growth is currently a hot issue in urban planning aspect, and modeling and simulating is one effective means to study urban sprawl.**
- **Recently, it is prevailing to simulate urban growth using cellular automata (CA).**
- **We bring forward the term of complex constrained CA (CC-CA in short), integrating the constrained conditions of macro socio-economic, spatial, neighbor and institutional.**
- **CC-CA is applied in Beijing metropolitan area, and two scenarios, one for trending growth and the other for planning controlled growth, are simulated to show how to realize more sustainable urbanization and less sprawl.**

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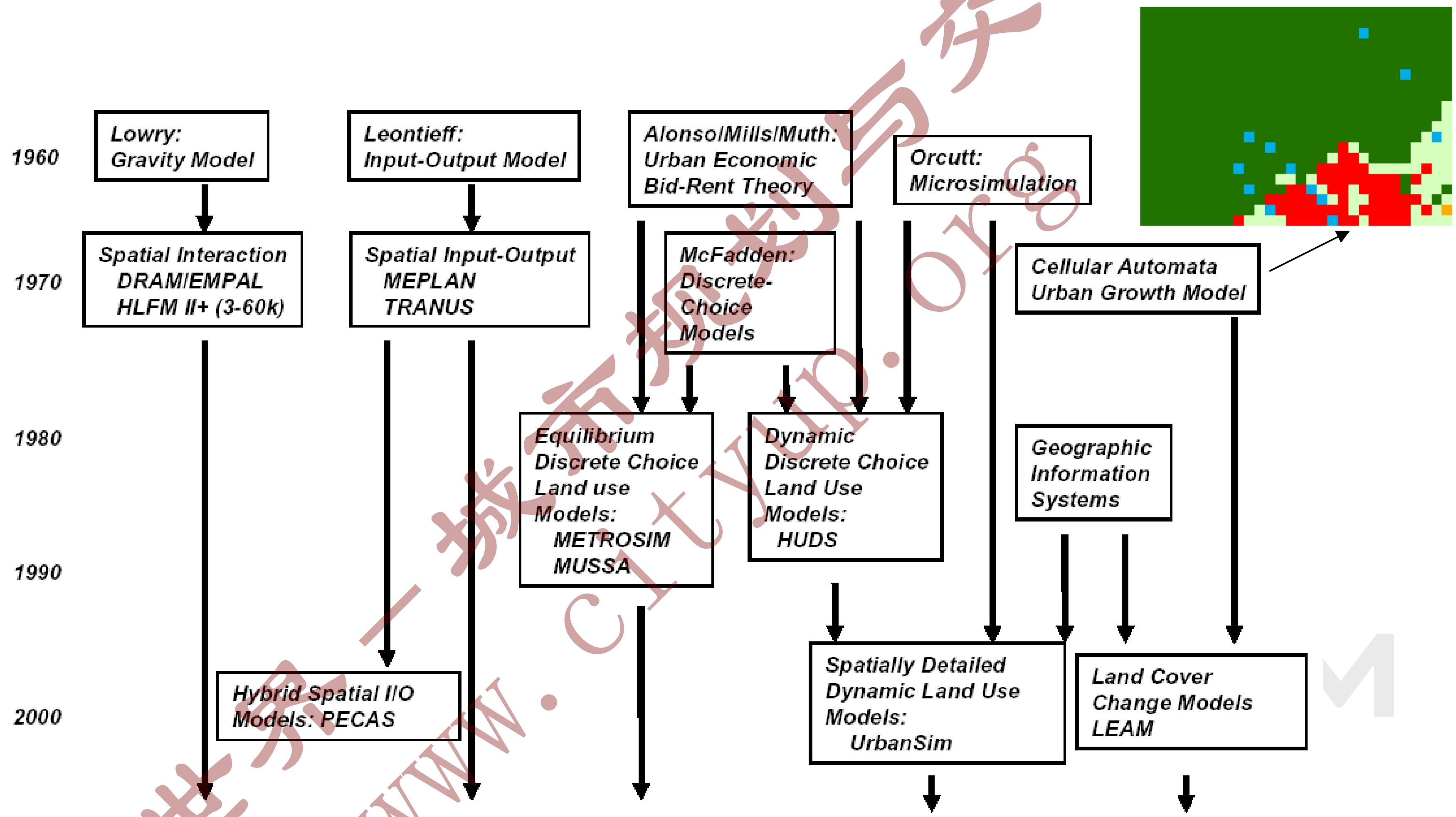

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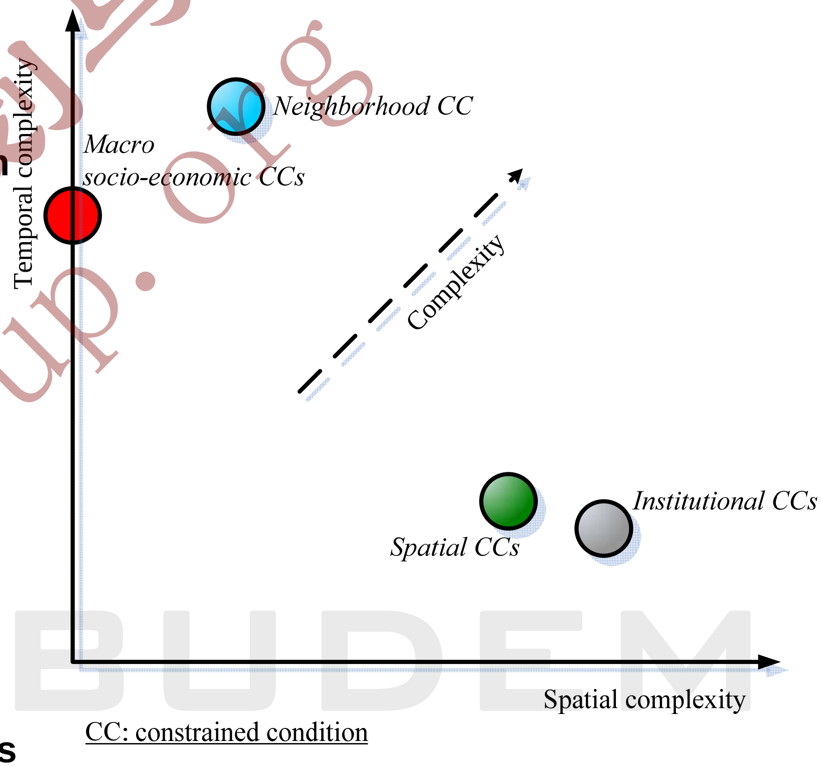
Complex constrained CA urban model

- Some researchers are inclined to control the urban growth simulation via introducing constrained conditions to CA model, such as:
  - Clark and Gaydos(1998), White *et al* (1997), Engelen *et al* (1997), Wu (1998), Ward *et al* (1999, 2000), Li and Yeh(2000), Yeh and Li(2001), David *et al* (2000), White *et al* (2004), Alkheder and Shan (2005), Guan *et al* (2005), Zhao and Murayama (2007), Liu *et al* (2007).
- The shortcomings of current constrained CA research:
  - Seldom one model simultaneously considering all four types of constraints.
  - Less attention is paid to institutional constraint (always set over simple)
  - The influence of historical institutional conditions is not identified (model calibration problems)



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2. Approach

Spatial factors selection

Select spatial factors using hedonic model (location, neighborhood, structure)

- **Location**
  - **Minimum distance to hierachical urban center**
    - **Tian an men *d_tam*、important new city *d_vcity*、new city *d_city*、important town *d_vtown*、town *d_town***
  - **Minimum distance to wetland *d_river***
  - **Minimum distance to regional road *d_road***
  - **Minimum distance to ward (town level) boundary *d_bdtown***
  - **Regional attraction of greater Beijing area *f_rgn***
- **Neighborhood**
  - **Developing intensity in neighborhood *neighbor***
- **Government**
  - **Urban master planning *planning***
  - **Cultivating suitability *landresource***
  - **Constrain zoning**
    - **Constructing forbidden area *con_f***

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$$V_{i,j}^{t+1} = f\{V_{i,j}^{t}, Global, Local\}$$

$$= \{V_{i,j}^{t}, LOCATION, GOVERNMENT, NEIGHBOR\}$$

$$= f\left\{\begin{array}{l} V_{i,j}^{t}, \\ d\_tam_{i,j}, d\_vcity_{i,j}, d\_city_{i,j}, d\_vtown_{i,j}, d\_town_{i,j}, \\ d\_river_{i,j}, r\_road_{i,j}, d\_bdtown_{i,j}, f\_rgn_{i,j}, \\ planning_{i,j}, con\_f_{i,j}, landresource_{i,j}, \\ neighbor^{t}_{i,j} \end{array}\right\}$$

Urban growth from undeveloped to developed only

Conceptual model

- **Lattices**
  - **16410sqkm (adjustable)**
- **Cells**
  - **500m * 500m**
  - **65628 cells**
- **Cell States**
  - **V=1：urban built-up**
  - **V=0：none urban built-up**
- **Status Transition Rule**
  - **Multi-criteria evaluation, MCE**
- **Neighborhoods**
  - **Moore**
  - **3*3, rectangle, 8 adjacent cells**
- **Discrete Time**
  - **1 iteration/step = 1 month**

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Status transition rule

$$s_{ij}^{t} = \beta_0$$
$$+\beta_1 * d\_tam_{ij} + \beta_2 * d\_vcity_{ij} + \beta_3 * d\_city_{ij} + \beta_4 * d\_vtown_{ij} + \beta_5 * d\_town_{ij}$$
$$+\beta_6 * d\_river_{ij} + \beta_7 * r\_road_{ij} + \beta_8 * d\_bdtown_{ij} + \beta_9 * f\_rgn_{ij}$$
$$+\beta_{10} * planning_{ij} + \beta_{11} * con\_f_{ij} + \beta_{12} * landresource_{ij}$$
$$+\beta_{13} * neighbor^{t}_{ij}$$

$$p_g^{\ t} = \frac{1}{1+e^{-s_{ij}^{\ t}}}$$

$$p_{ij}^{\ t} = \exp\left[\alpha\left(\frac{p_g^{\ t}}{p_{g\ \max}^{\ t}} - 1\right)\right]$$

$$if\ \ p_{ij}^{\ t} > p_{threshold}\ \ then\ V_{ij}^{\ t+1} = 1$$

Where:

1. $s_{ij}^{\ t}$ is the potential/suitability of conversion
2. β is coefficient from logistic regression
3. $p_g^{\ t}$ is the primary probability of conversion
4. $p_{g\,max}^{\ t}$ is the lattice-wide maximum $p_g^{\ t}$ of each iteration
5. $p_{ij}^{\ t}$ is the final probability of conversion
6. $p_{threshold}$ is the benchmark of conversion
7. α is the dispersion parameter ranging from 1 to 10
8. γ is the random number ranging from 0 to 1

- **Revising and integrating the method of Wu(2002), Clark and Gaydos(1998)**
- **Weights for all spatial variables, except *neighbor*, are retrieved by logistic regression**
- **Weight for *neighbor* is identified by MonoLoop method, details in Long *et al*(2008)**
- **More accurate, more efficient**

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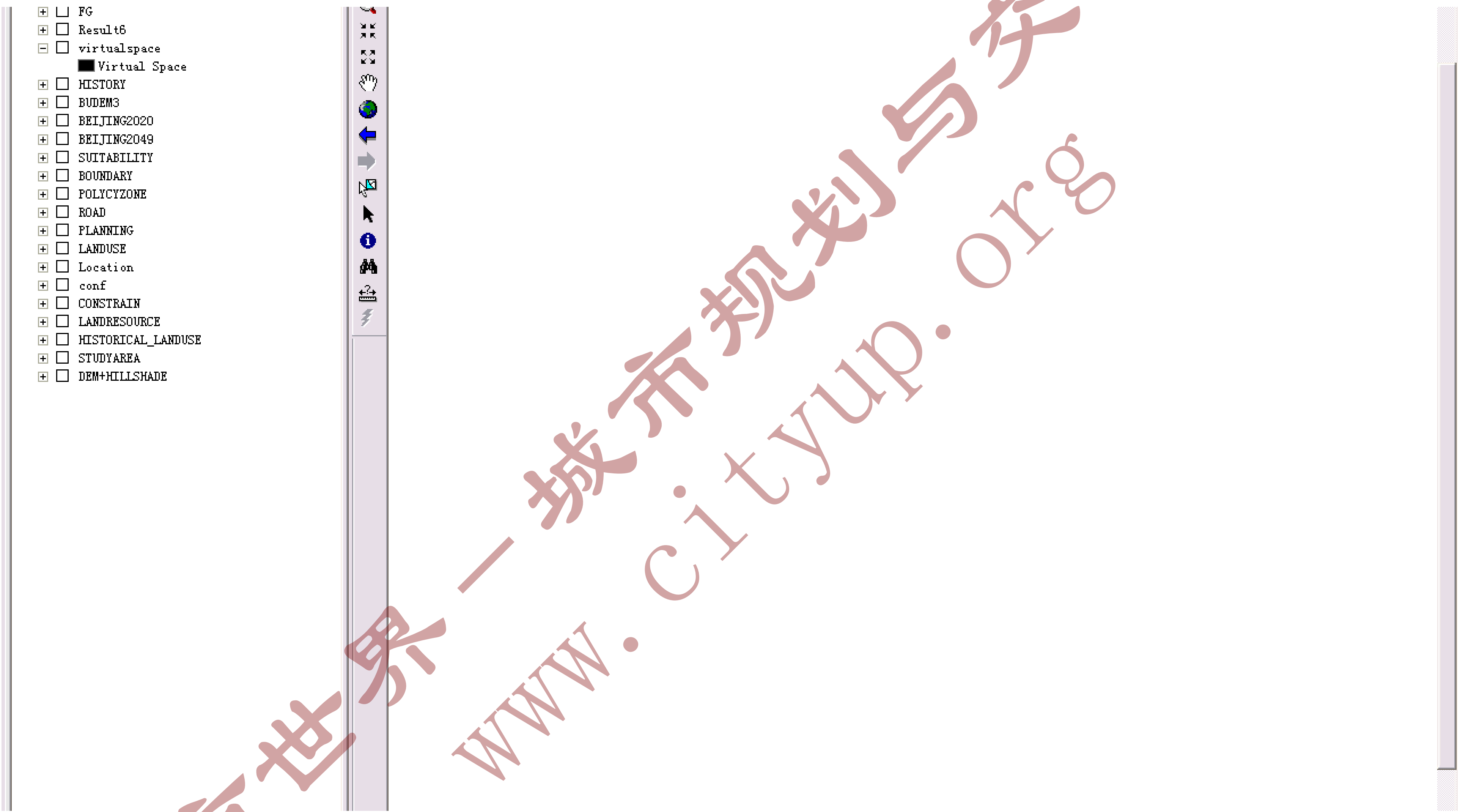

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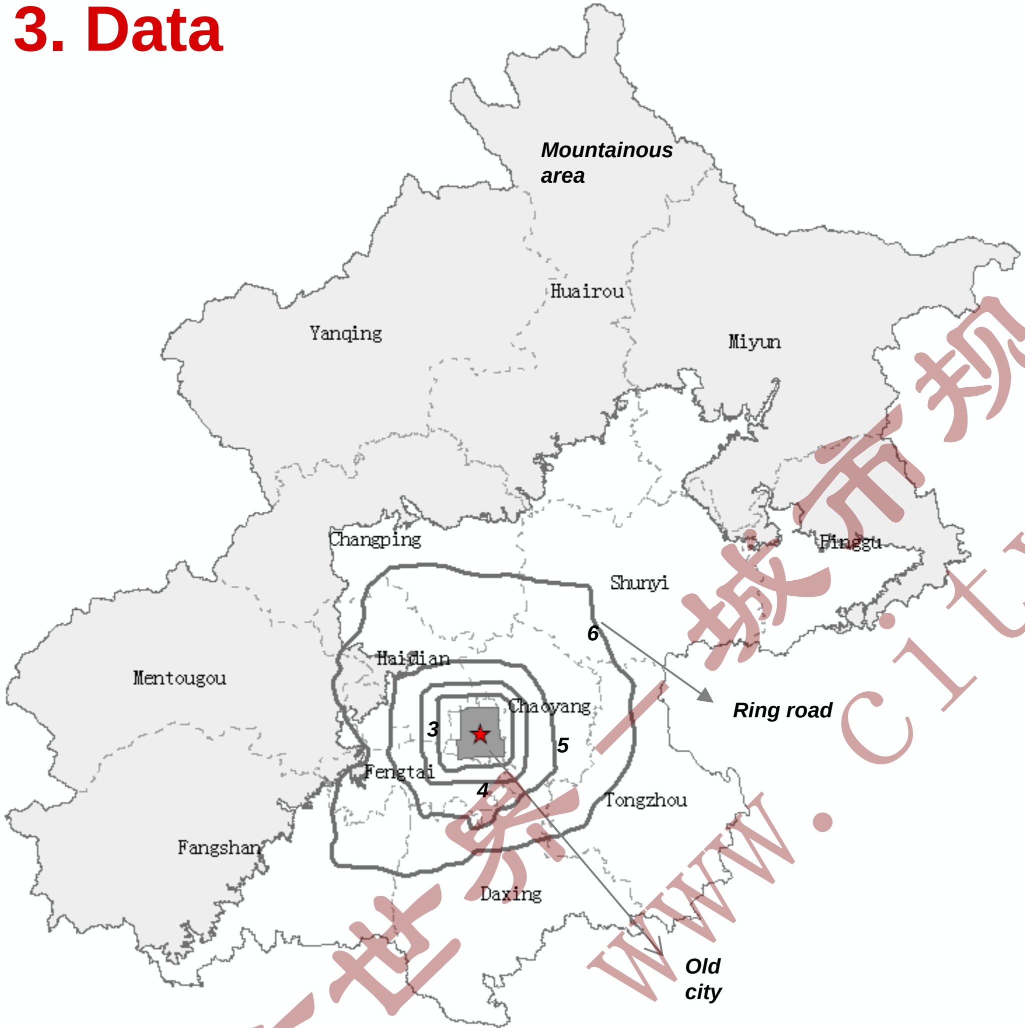
3. Data



Study area

- Capital of P. R. China, northern china, adjacent to Tianjin and Hebei
- 16410 sqkm
  - mountainous:10071 sqkm
- Ring road 2nd, 3rd, 4th, 5th, 6th

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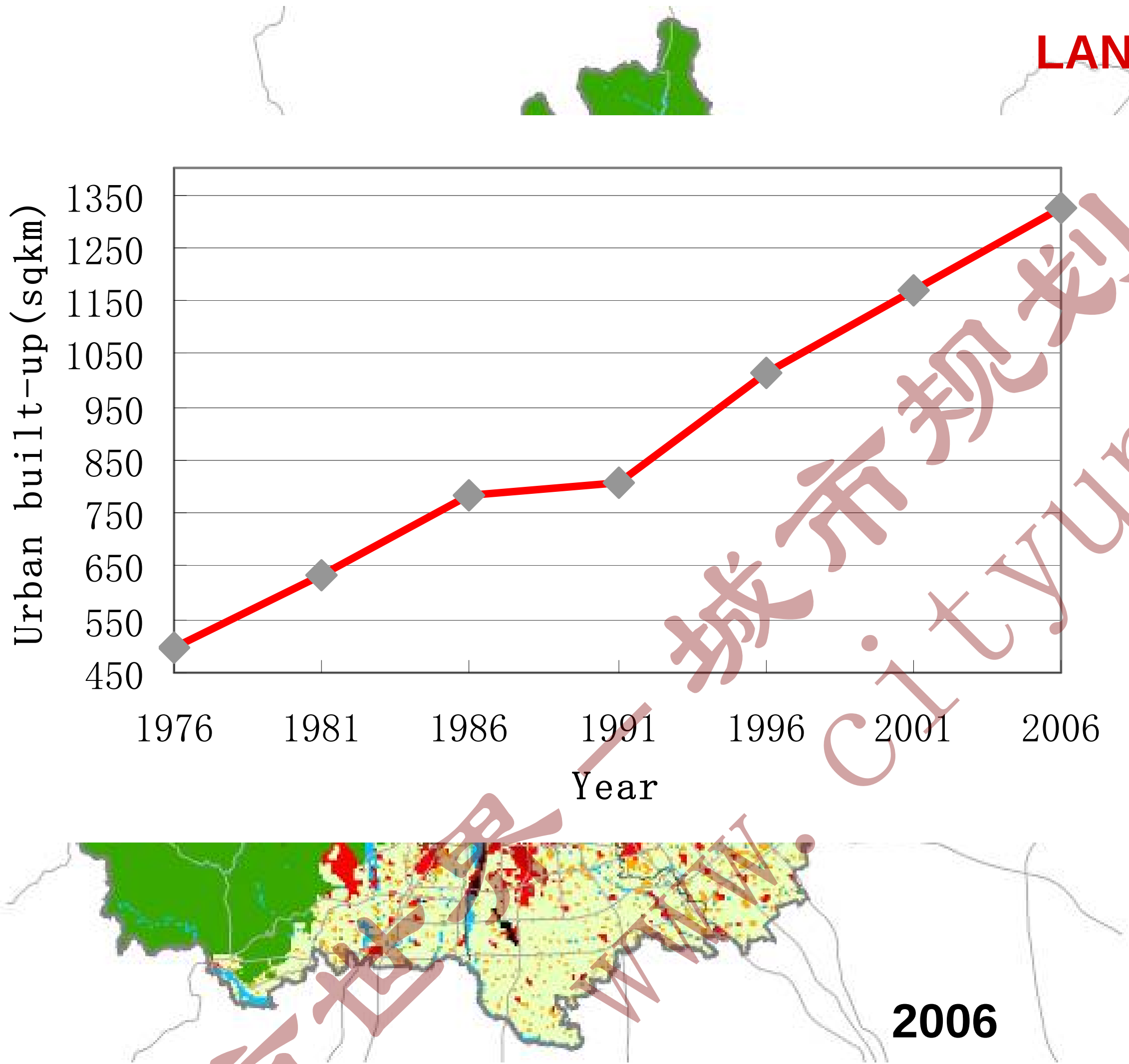
LANDUSE



Land use data for different year

- 1947-2006

Data source: TM, MSS, history map, relief map

- Land2006TM
- Land2001TM
- Land1996TM
- Land1991TM
- Land1986TM
- Land1981MSS
- Land1976MSS
- Land1964DISP
- Land1955-1982RELIEF
- Land1947MAP

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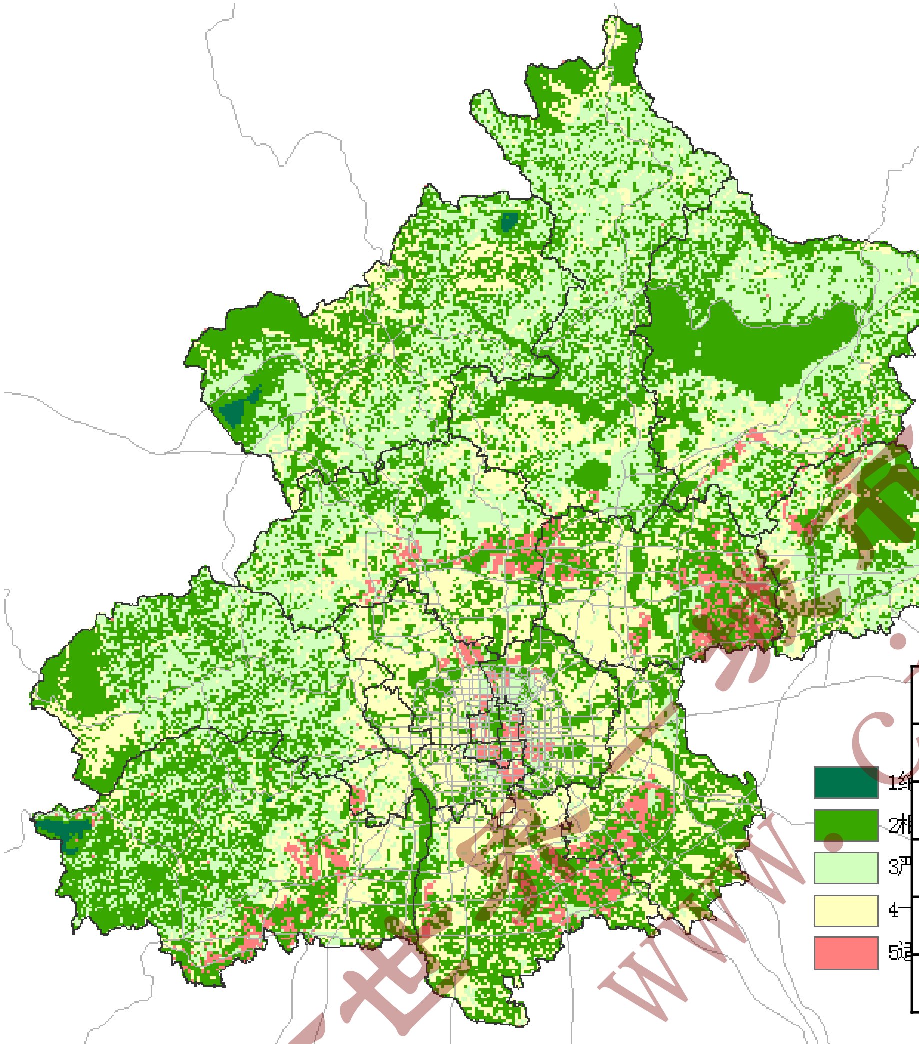

CONSTRAIN

- Constrained zoning data, reflecting the degree to which urban growth is constrained
- Generated by 5 classes (water, green, geology, environment, vestige), 16 types, 110 spatial factors of natural resource protection and hazard prevention
- Details in He at workshop 6 (coming soon)

Zoning level	Area (sqkm)	Percentage (%)
1 Absolutely forbidden	55.5	0.3
2 Relatively forbidden	7130.1	43.5
3 Seriously restricted	4819.2	29.4
4 Normally restricted	3878.2	23.6
5 Suitable	527.1	3.2

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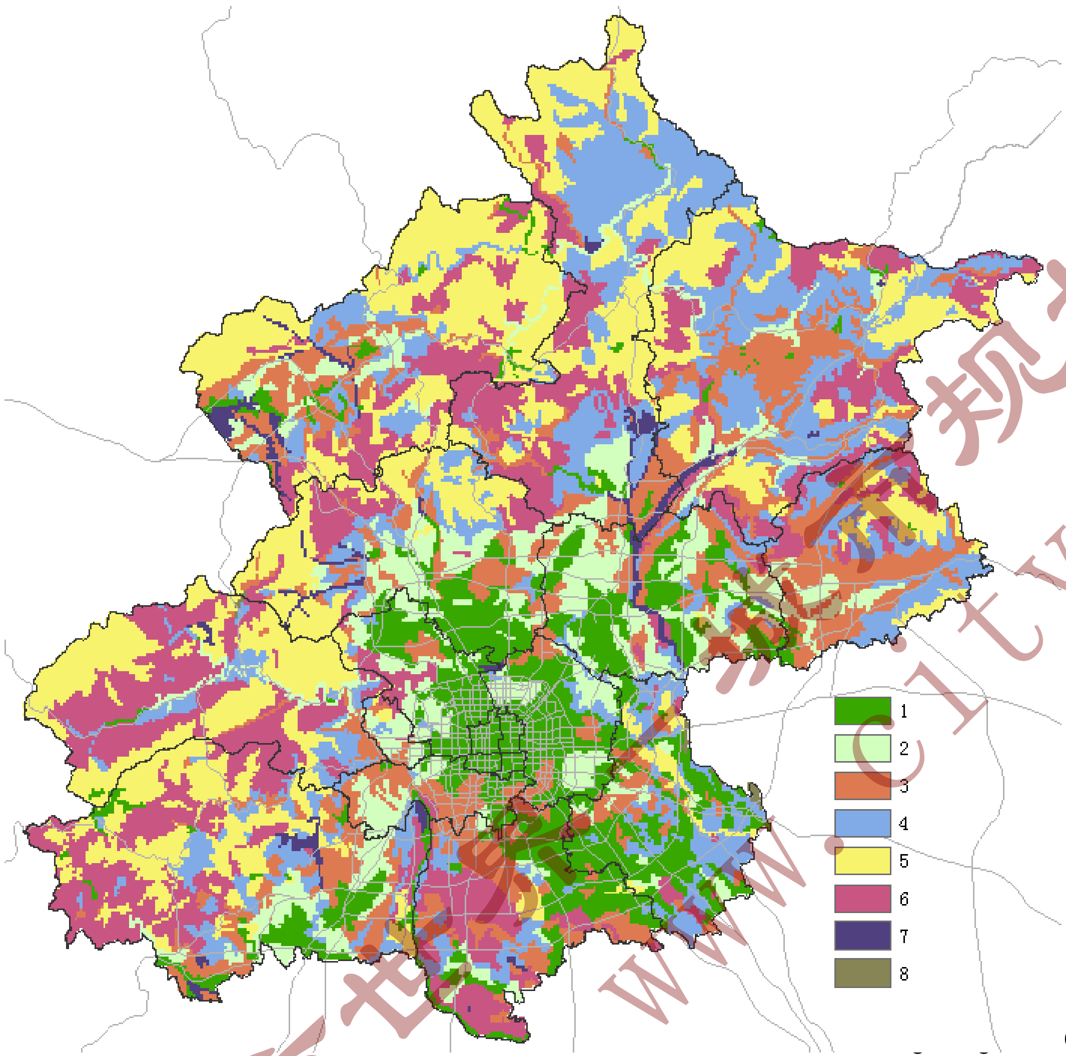

LANDRESOURCE

- Suitability of agricultural land use (natural condition)
- Classified into eight levels ranging from 1 to 8, signifying the suitability in turn
  - 1 most suitable
  - 8 lest suitable

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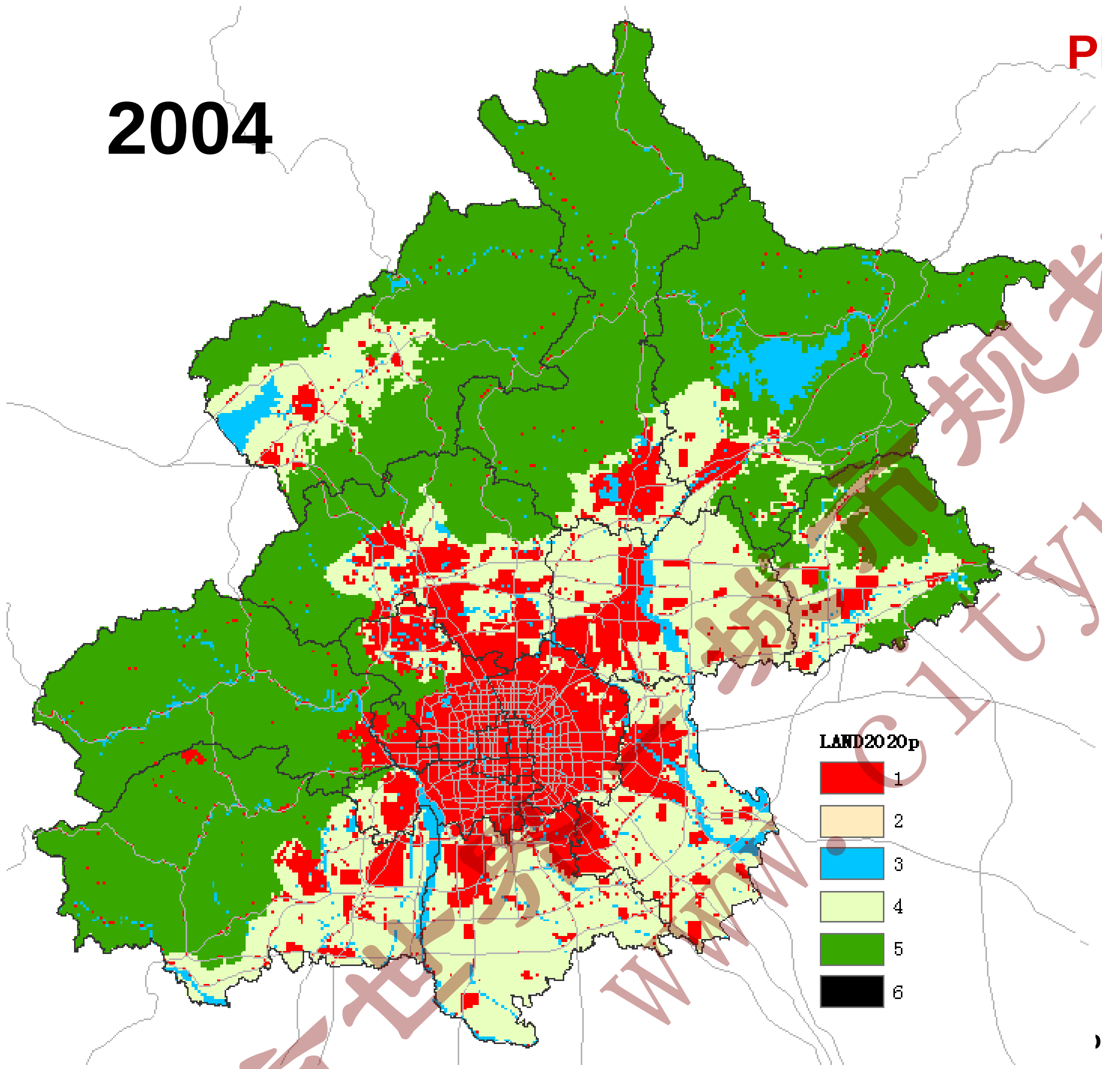

PLANNING

- Urban master planning of Beijing metropolitan area, as the capital city, since the foundation of P. R. China
  - 2004
  - 1992
  - 1982
  - 1973
  - 1958

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4. Calibration

Logistic regression

- Urban growth rules in different historical phases can be acquired by logistic regression, including 1986-1991, 1991-1996, 1996-2001, and 2001-2006, as to identify and compare urban growth mechanism
- Variables *d_road, planning* vary from the historical phases
- Variable *neighbor* is not considered in logistic regression (Calibrated in MonoLoop)
- Coefficients of logistic regression can be applied as model input parameters to forecast future urban form or re-display historical urban form

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Logistic regression result of various historical phases

variable	B(2001-2006)	B(1996-2001)	B(1991-1996)	B(1986-1991)
d_tam	-0.000016*	-0.000035*	-0.000041*	
d_vcity	-0.000025*	-0.000031*		-0.000031*
d_city	-0.000019*	-0.000066*	-0.000033*	
d_vtown			0.000025*	0.000058*
d_town		0.000089*	0.000066*	
d_river	-0.000138*			
d_road	-0.000256*	-0.000804*	-0.000524*	-0.001092*
d_bdtown		-0.000377*		
f_rgn	4.302458*	-13.737258*		
planning	-0.410472*	0.254173	0.575671*	1.310654*
con_f	-0.521103*	-0.453115*	-0.497453*	-1.506241*
landresource			-0.075543	-0.233262
Constant	-0.174524	0.588961	-0.998267*	-3.610055*

*Significant at 0.001 level

Result

- **Variable in different phases differ greatly (market and government balancing, macro-policy)**
- **Common character: road directing developing, constructing forbidden area protected**
  - **2001-2006：river>new city>region**
  - **1996-2001：new city developing, slow town developing, negative regional influence**
  - **1991-1996：center city>city, planned area developing, agricultural land with high suitability encroached**
  - **1986-1991：new city promoted, agricultural land protected, planning promoted**

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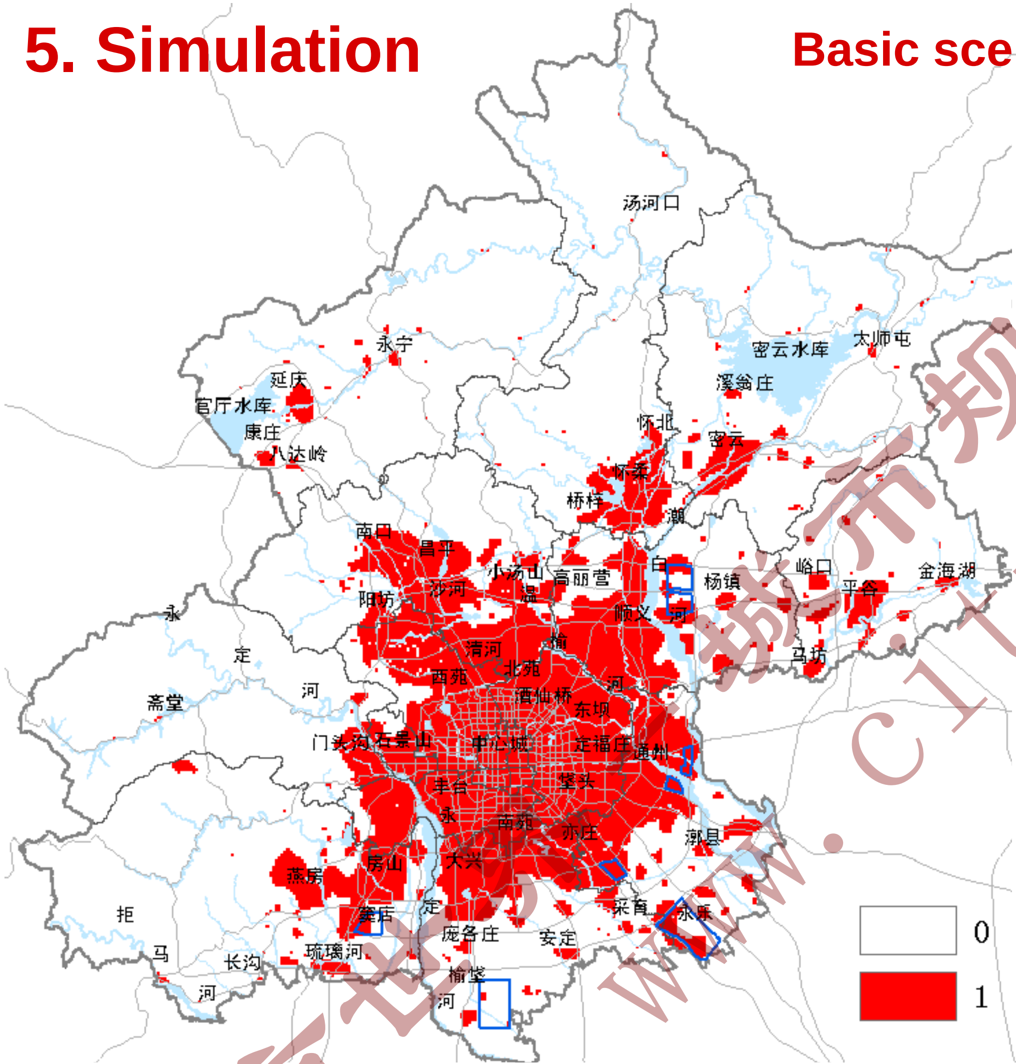
5. Simulation



Basic scenario with current developing trend

- It will be more accurate to forecast Beijing urban form of 2049 basing on the planned form of 2020.
- Basic scenario for BEIJING2049
  - Using the parameter set of 2001-2006 (trend growing)
  - 30sqkm new developed land annually, 3412 sqkm developed in 2049 (13659 cells)
- Sprawling from central city.

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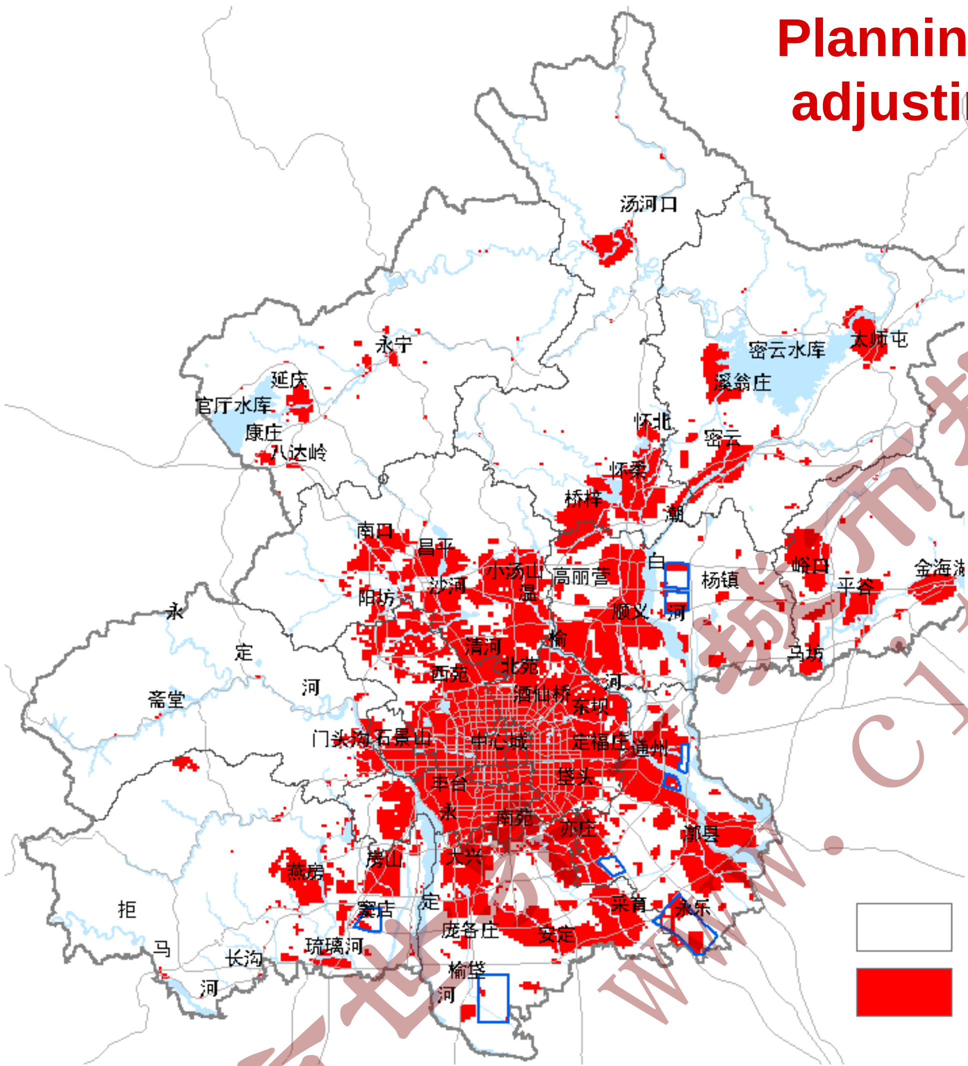

Planning controlled scenario through adjusting complex constrained conditions

- The same urban growth speed with that of trend scenario, and only the weights of evident for spatial variables are adjusted to alter the corresponding institutional constrained condition.
  - The intensity for constructing constrained zoning *w_conf* is increased to -2 (-0.521103 in trend scenario)
  - The intensity for urban planning *w_planning* is increased to -3 (-0.410472 in trend scenario
- Urban built-up land is more scattered, less natural resource is destroyed, and environmental hazard is influenced. The scenario is regarded as one more sustainable urban growth pattern than trend scenario.

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Scenarios comparison

Contrast of 2001-2006 trend scenario and planning controlled scenario

Unit of are: sqkm

Scenario name	conf	green	rural	Moron I
BEIJING2020 planned form	538	1128	169	0.14
Trend scenario	843	1595	284	0.25
Planning controlled scenario	765	1181	248	0.13

- **To compare the above two urban growth scenarios, selected are four indicators, including**
  - **encroached constructing forbidden area "conf"**
  - **encroached green belt area "green"**
  - **encroached rural built-up area "rural"**
  - **the urban disperse degree Moron I.**
- **The analysis result shows that relative with trend scenario, planning controlled scenario encroached less ecological sensitive land, namely more sustainable.**
- **Planning controlled scenario is also more dispersed than trend scenario.**

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6. Conclusion

- Complex constrained CA urban model is brought forward and introduced in detailed in the paper, which includes macro socio-economic, spatial and institutional constrained conditions.
- Particularly, constructing constrained zoning, as one institutional constrained condition, is introduced into the model. The zoning, combining 110 constructing constrained factors, together with urban master plan and cultivating suitable area, provide opportunities to reflect complex institutional constrained conditions for urban growth.
- The complex constrained urban model, integrating complex constrained conditions with classical CA urban model, is capable to simulate more practical and effective urban growth phenomenon/pattern in rapid urbanization area, and can be the urban growth policies simulation platform for the government by means of various factors' scenarios analysis.

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6. Conclusion

- In the model application, the role of complex constrained conditions in urban growth can be dynamically identified in various historical phases, by means of logistic regression.
- We let out the planning controlled scenario, generated by intensifying the implementation of urban planning and constructing constrained zoning basing on basic scenario with current developing trend.
- The planning controlled scenario shows that complex constrained conditions can be availed to affect the urban growth process, and simulate more practical urban growth pattern.
- In the further research, constructing constrained index is considered to be introduced into CC-CA model to simulate urban growth under more detailed constrained conditions. Meanwhile, we also plan to simulate competing land uses in block scale through considering the constructing constrained zoning for various urban land uses.

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More details is available in :

Long, Y., Shen, Z., Du, L., Mao, Q., and Gao, Z. (2008) "BUDEM: an urban growth simulation model using CA for Beijing metropolitan area".Geoinformatics, Guangzhou, China, 28 - 29 June.

THE END

Many thanks, welcome any discussion!

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