Land Use Pattern Scenario Analysis Using Planner Agents: a Preliminary Study

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Abstract

Land use pattern, or land use layout, is one of the key issues in the compilation of an urban master plan. Government, planners and residents, all with various requirements and preferences, are the agents participating in this process in China. Among them, planners play a role in negotiating with related agents and then establishing land use patterns. In this paper, we propose the Planner Agent theory to support land use pattern scenario analysis (LUPSA), based on existing Planning Support System (PSS) research. Planner Agents are divided into three types: Non-spatial Planner Agent (NPA), Spatial Planner Agent (SPA) and Chief Planner Agent (CPA). The NPA is responsible for formulating special plans (such as transport, municipal public facilities or nature reserve plans) that correspond to available data (such as road network, public facilities and nature reserve patterns) from LUPSA. The SPA is responsible for establishing and evaluating land use patterns. The SPA considers constraints of local development conditions, communicates and coordinates with the NPA to confirm special plans formulated by the NPA that can support implementation of the established land use pattern. The CPA is responsible for determining the final land use pattern after a public participation process involving local residents. This theory was initially tested in a hypothetical city, followed by an experiment in Beijing. Results show that the proposed Planner Agent theory is suitable for LUPSA. Combined with other tradi-

tional measures, the LUPSA process can be more efficient and scientific using Planner Agent theory and relative methods.

1. Introduction

Urban master planning is a key tool of the Chinese government to regulate urban growth. Land use pattern, or land use layout, is one of the key issues in compiling an urban master plan. In China, the government, urban planners and local residents are the agents participating in analyzing the land use pattern. Among these, government has a role on determining the overall goal of social, economic and environmental development under the constraints of local development conditions; planners play a role in negotiating with related agents, then establishing and evaluating land use patterns. Residents provide suggestions and feedback to the related agents. All these participants have varying requirements and preferences for the land use pattern. For example, government wants to improve social, economic and environmental development simultaneously, planners emphasize implementation of a specific planning concept or theory, and residents are concerned with parks or shopping centers being situated near their living space. In reality, however, demands and inclinations frequently do not meet city development regulations, or contradict them. Establishing land use patterns using traditional planning means depending largely on the planners, and this is likely to cause ignorance of or weak compliance with the requirements and preferences of other agents, especially residents, thereby reducing the plan's suitability as a result.

A Planning Support System (PSS), a computer-aided instrument specifically designed to support comprehensive tasks in urban planning, is mainly based on theories and technologies such as Geographic Information System (GIS) and planning model and visualization (Klosterman 1997; Brommelstroet 2012). Compared with traditional planning methods, PSS can process and analyze spatial data, support the design process, evaluate urban planning schemes more efficiently, and improve public participation.

PSS has been widely discussed and applied in the field of urban planning for decades (Stillwell 2002; Geertman and Stillwell 2004; Conclelis 2005; Mao et al. 2006; Long 2007; Brail 2008; Vonk and Ligtenberg 2009; Long et al. 2010a; Curtis 2011). There are several research works related to land use pattern scenario analysis (LUPSA). For example, California Urban Futures (CUF) developed by Landis (1994) can replicate realistic urban growth patterns and the impacts of development policy at various levels of government, and allocate urban growth to sites based on development profitability. What if?, developed by Klosterman (1999), can efficiently indicate the influence of planning management, and has been widely used in other studies such as growth management strategy evaluation and land use forecasting (Klosterman et al. 2006; McColl and Aggett 2007). INDEX, developed by Criterion Planner, can evaluate planning influence in multiple aspects, including environment, energy, transport and public finance (Allen 2001). iCity (Stevens et al. 2007), based on vector Cellular Automata (CA), is a novel model for urban growth simulation to aid spatial decision making for urban planners. Long et al. (2011) developed an urban containment PSS in Beijing for automatically compiling the urban containment plan, which represented constraints on the land use pattern. Niu et al. (2008) formulated a land use plan based on Scenario Planning, Qin et al. (2010) simulated land use allocation based on CUF, and both used Goals Achievement Matrix (GAM) for scenario evaluation. The above studies, however, are not applications that are only aimed at the land use pattern, and they can generally only complete a portion of LUPSA tasks, such as urban land boundary formulation, planning evaluation, and constraints acquisition. Moreover, these applications do not deal with the LUPSA process from the planner perspective, which is closer to the real situation. Aspects such as model parameter acquisition, evaluation method, and considered planning impact factors (PIFs) should be improved to better support LUPSA.

There are several studies related to Planner Agents (PAs). For example, Ligtenberg et al. (2001) defined actors as players (both individuals and groups) in the process of spatial planning. Actors would communicate, negotiate and decide upon the spatial organization of their environment, and simulate spatial change as a result of actor-based decision making. Agent iCity, developed by Jjumba and Dragicevic (2011), is an upgraded version of iCity, and can simulate the land use pattern by incorporating interactions of various stakeholders. Ligtenberg et al. (2009), based on their preliminary study (Ligtenberg et al. 2001), extended an existing approach with the principle of sharing knowledge among participating actors. Saarloos et al. (2005) defined agents as land use experts that initiate the development of plan proposals and communicate with each other over time, for drawing up proposals incrementally. The above, however, are mostly at a preliminary level and lack empirical studies. In addition, communication is generally limited among planners, and coordination between the land use pattern and other types of plans (e.g., those for transport and public facilities) is not considered. In China, there is as yet no research related to Planner Agents.

In this paper, we propose the Planner Agent theory for supporting LUPSA, based on existing PSS research. In this theory, we determine characteristics of and interactions among government, various planners and resident agents. We identify Planning Rules (PRs) for reflecting planner requirements and preferences through existing plan archives and questionnaire surveys, conducted at professional institutions in China. The land use pattern can be established by the Spatial Planner Agent (SPA) combined with identified PRs, comprehensive constraints made by the Government Agent (GA), and special plans formulated by the Non-spatial Planner Agent (NPA). The established land use pattern can be evaluated by the SPA from multiple aspects, and the Resident Agent (RA) conducts a satisfaction evaluation of the established land use pattern. Finally, the Chief Planner Agent (CPA) determines the final ideal land use pattern. The framework of Planner Agent theory is proposed and described in detail in Section 2. The theory is initially tested in a hypothetical city in Section 3, followed by the experiment in Beijing to demonstrate the validity of this theory, described in Section 4. Finally, we conclude and propose the benefits and future research venues of this study in Section 5.

2. Theory and methods

2.1. Basic concepts

2.1.1. Planner Agents

According to the content of the work performed by urban planners in supporting LUPSA, Planner Agents can be divided into three types: Non-spatial Planner Agent (NPA), Spatial Planner Agent (SPA) and Chief Planner Agent (CPA). The NPA is responsible for formulating special plans such as for transport, municipal public facilities and nature reserves, which correspond to data from LUPSA such as road network, public facilities and nature reserve patterns. The SPA is responsible for establishing and evaluating land use patterns. The SPA considers constraints of local development conditions, and communicates and coordinates with the NPA to confirm special plans that can support implementation of the established land use pattern. The CPA is responsible for determining the final land use pattern after a public participation process involving local residents.

2.1.2. Planning rules

As we define them, PRs are criteria or guidelines of planner thinking and action during the LUPSA process. The main content of PRs consists of the planner's considered PIFs and their weights. There are many PIFs for land use patterns, such as roads, rivers, parks and traffic noise. Different planners with varying demands and inclinations will consider different sets of PIFs, for which weights are usually different. For example, planner A may believe parks and rivers are the most critical PIFs for a residential parcel pattern, whereas planner B only considers the park as a PIF, but just a normal one. In this case, the river is not a PIF for planner B, but only a normal factor. The planner's PRs reflect his or her requirements and preferences. For example, whether to consider the river and the determination of its weight for a residential parcel pattern reflects the demands and inclinations of a riverfront development strategy. In the following, planner requirements and preferences are uniformly replaced by PRs.

According to LUPSA tasks, PRs mainly consist of parcel partitioning, land use type and development intensity determinations. Considering that this is the first discussion of Planner Agent theory, we focus on how to determine land use type at present, with primary consideration of planner requirements and preferences regarding parcel size, street scale, riverfront development, transit-oriented development (TOD), compact city, mixed use, and others.

2.2. LUPSA flow using Planner Agents

The flow of LUPSA using Planner Agents is as follows:

1. The GA determines comprehensive constraints.
2. PRs are identified through existing plan archives, questionnaire surveys, or other means.
3. The NPA formulates special plans (this formulation is not considered here, and formulated special plans are treated as exogenous variables).

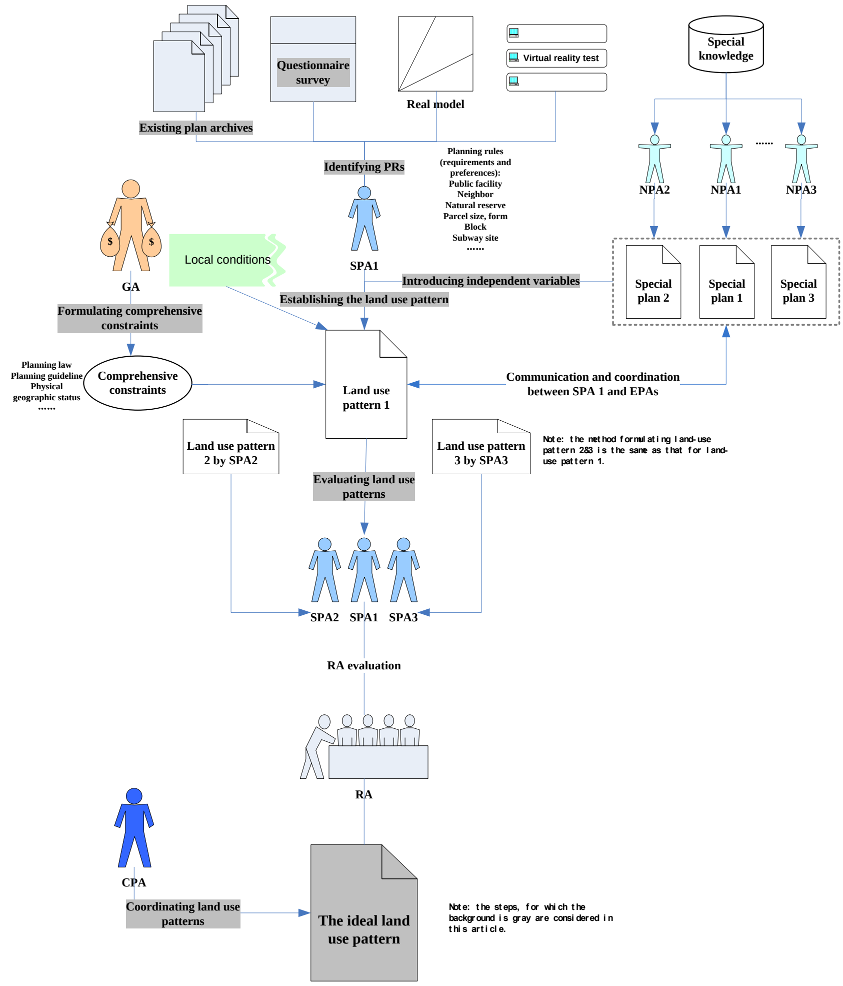


Fig. 1. Flow diagram of LUPSA using Planner Agents

4. The SPA establishes the land use pattern, combining the identified PRs, comprehensive constraints, and formulated special plans.
5. The SPA communicates and coordinates with the NPA to confirm any special plans can support implementation of the established land use pattern. If there are none, the SPA revises the established land use pattern or the NPA revises any special plans, until they meet the formulation requirements above (not considered here).
6. The SPA evaluates the established land use pattern from multiple aspects.

7. The RA does an evaluation of the established land use pattern (not considered here).
8. The CPA coordinates the established land use patterns, and determines the final ideal one.

2.3. Obtaining comprehensive constraints

The erosion of open space and natural resources caused by urban sprawl has become a worldwide concern. If urban growth was not constrained (or control), it would result in the fragmentation of urban construction, which is lack of integrity, and even bring serious environmental problems. As a result, many urban policies, such as urban growth boundaries and greenbelts, have been adopted to achieve the goal of urban growth control in western countries. Compared with those countries, Chinese government plays a more important role in the urban planning process. When establishing the land use pattern, the GA considers constraints of relevant laws, regulations, planning standards, and physical geographic status of land use patterns when determining overall goals of social, economic and environmental development. These are called comprehensive constraints, which can reflect the political influence to the LUPSA. Comprehensive constraints can be divided into several types, including land use type, land use quota, building height, underground construction, and city activity constraints etc. We consider the previous two types in this paper. Land use type constraints mean parcels are constrained to distribution as certain land use types, and they can be identified by the uniform analysis zone (UAZ) method (Long et al., 2006, 2010b). Land use quota constraints mean that the total areas of parcels of a certain land use type should be as similar as possible, but no more than the planned quota for an established land use pattern. This can be determined according to the specific objectives of city development; for example, the area of residential parcels should be no more than a certain quota according to the urban master plan.

2.4. Identifying PRs

We identified PRs (PIFs and their weights) through existing plan archives and questionnaire surveys, conducted at professional institutions in China. On the other hand, the identification may also be implemented using methods, such as real models or virtual reality tests. For example, Hatna and Benenson (2007) identified the rules of city construction using building blocks, and Crompton (2012) calculated information content using LEGO® sets as a language.

PRs can be identified through existing plan archives using multinomial logistic regression (MLR). In this process, the parcel is treated as a research unit, the parcel's planned land use type as a dependent variable, and the PIF as an independent variable to identify the weight of every PIF for every planned land use type. The detailed calculation method is as follows:

$$T = \{t_k | k = 1,2,3, \dots K\} \quad (1)$$

$$F = \{f_i | i = 1,2,3, \dots I\} \quad (2)$$

$$P = \{p_n | n = 1,2,3, \dots N\} \quad (3)$$

$$W = \{w_{ik} | i \in [1, I], k \in [1, K]\} \quad (4)$$

$$P_{nk} = \frac{e^{r_k + \sum_{i=1}^{I} w_{ik} \times f_i}}{1 + \sum_{k=1}^{K-1} e^{r_k + \sum_{i=1}^{I} w_{ik} \times f_i}}, \quad (5)$$

where t_k is the planned land use type, K is its number, f_i is the PIF, I is its number, p_n is the parcel, N is its total amount, w_{ik} is the weight of f_i for t_k, P_{nk} is the probability of p_n for t_k, and r_k is the corresponding constant term.

For existing plan archives, variables T (Residential R, Commercial C and Industrial M, plus others), F (corresponds to special plans), P and P_{nk} (0 or 1) are known, so W can be calculated, and W and F constitute PRs.

PRs can also be identified through questionnaire surveys at the professional institutions. After discussion with survey respondents, PIFs can be confirmed by survey specialists, and PIF weights are reflected in scoring by the respondents. For example, for the R pattern, if respondent A feels strongly about whether a parcel is close to a main road, the weight of the PIF main road would be 9; if this PIF is not important to the respondent, the score would be 0. Accumulating the information from a certain number of such questionnaires, the identified PRs become reasonable.

2.5. Establishing the land use pattern

The NPA formulates any special plans; however, this formulation is not considered here. Existing special plans are used to identify PRs, and the formulated special plans are used to support establishment of the land use pattern.

According to identified PRs and formulated special plans, variables T, F, P and W are known, so P_{nk} can be calculated. Then, combined with comprehensive constraints, the land use pattern can be established. Using T (which includes R, C, and M) as an example, the detailed flow is as follows.

1. Calculate P_r, P_c, and P_m of parcel n, combined with identified PRs, formulated special plans, and land use type constraints (if parcel n is constrained by land use type constraints, P_k will be 0).
2. Compare the size of P_r, P_c, and P_m of parcel n, to determine n's suitable land use type CompType, for which the value is R, C or M.
3. According to land use quota constraints, compare the size of P_r (then P_c and P_m) of all parcels, to determine which parcels are suitable to be distributed as R. The total area of suitable R parcels should be close to but no more than a certain planned quota. If parcel n is suitable to be distributed as R, then the comparative value of CompTypeR is R; otherwise, it is NULL.
4. For parcel n, if there is one of the variables CompTypeR,CompTypeC or CompTypeM for which a value exists (all other values are NULL), for example CompTypeR, n's final distributed land use type FinalType is R.
5. For parcel n, if there are at least two of the variables CompTypeR, CompTypeC or CompTypeM for which values exist, there is a contradiction of the land use pattern. Then, the determination of FinalType is made according to size of the values of P_r,P_c, and P_m.
6. Calculate the distributed areas of R, C and M. If the distributed area of a certain land use type is smaller than the land use quota constraints, such as for R, then distribute the FinalType as R for the remaining parcels, for which the value of CompType is R, until the requirement quota is met.
7. After step (6), if the distributed area of a certain land use type is still smaller than land use quota constraints, then determine the FinalType for the remaining parcels randomly, until the quota is met.

2.6. Evaluating the land use pattern

The SPA evaluates the land use pattern, taking into account multiple considerations. For example, the SPA analyzes spatial distribution using spatial clustering methods (Moran's I and others), evaluates urban forms using FRAGSTATS (Mcgariga and Marks, 1994), and calculates potential transport energy consumption using the Urban Form-Transportation Energy Consumption-Environment MAS model (FEE-MAS) developed by Long (2011a). Various evaluation indexes are listed in Table 1, and a certain combination of indexes can be selected for evaluation, according to a specific objective.

Table 1. Evaluation indexes

Index A	Index B	Index C	Index D
Average Area	Dimension index	Moran's I index	Shannon evenness index
Average Center	Division index	Nearest Neighbor Distance	Smallest Parcel Area
Average Perimeter	Edge density	Perimeter Area Ratio	Smallest Parcel Perimeter
Connectance index	Largest Parcel Area	Potential transport energy consumption	Total Number of Parcels
Contagion index	Largest Parcel Perimeter	Shannon diversity index	Total Perimeter

2.7. Evaluating the land use pattern by RA

As the basic economic and social unit of the city, residents should be the core interests of other agents participating in the LUSPA process. At first, the GA, NPA, and SPA should always maintain the communication with RA while determining comprehensive constraints, establishing special plans, and land use patterns. After that, the RA evaluation should be treated as a separate step to understand the degree of satisfaction for the established land use pattern.

This step can reflect the public participation, and we will improve it in the future.

2.8. Coordinating land use patterns

When coordinating established land use patterns, the CPA first checks whether they contradict existing comprehensive constraints. Then, the

CPA coordinates different elements according to results of the satisfaction survey completed by local residents. Third, the CPA determines the final ideal scenario based on the coordination results. In the present stage, the CPA technically analyzes the evaluation results to determine the final ideal scenario, according to a comprehensive score. The detailed formula is as follows:

$$S = \sum_{n=1}^{N} \alpha_n \times p_n, \quad (6)$$

where N is the number of elements considered in the evaluation, α_n is the weight of element n, p_n is the comparative score, and S is the comprehensive score.

3. Virtual space test

To verify the Planner Agent theory, we test it in virtual space, the details of which are as follows.

1. There are 10×10 parcels in virtual space, and the length of each parcel is 1. The transportation network is of a homogeneous grid shape (corresponds to the parcel boundary). See Figure 2A.
2. There are three land use types – R, C, and O (others). The numbers of existing R and C parcels are 5 and 6, respectively. Twenty-five R parcels and 15 C parcels are increased, which correspond to land use quota constraints in the LUPSA process.
3. Land use type constraints consist of R (land use type is constrained to be R), C, R&C, and no constraint. Existing R and C parcels remain unchanged.
4. School plan, road plan and central business district (CBD) location, which correspond to PIFs, are special plans formulated by the NPA.
5. Existing PRs are known (Table 2).
6. Land use pattern scenarios are schematically evaluated using Perimeter Area Ratio (PARA_MN), Euclidean Nearest Neighbor (ENN_MN) and Edge Density (ED), via FRAGSTATS software.

Table 2. Existing PRs

Weight / PIF	PR 1			PR 2			PR 3		
	R	C	O	R	C	O	R	C	O
High school	0.5	0.3	0.2	0.5	0.4	0.1	0.4	0.4	0.2
Town center	0.3	0.4	0.3	0.3	0.5	0.2	0.6	0.3	0.1
Main road	0.5	0.4	0.1	0.4	0.5	0.1	0.5	0.4	0.1

The Planner Agent model was developed using Python language and Geoprocessing, to support LUPSA. Here, only accessibility is considered. The shortest Euclidean distance $dist$ from the parcel to the PIF can be calculated using the Distance/Straight Line tool in ArcGIS. The impact f ,, determined by $dist$, is calculated according to Equation (7), and we set $\beta = 0.001$ empirically.

$$f = e^{-\beta * dist} \tag{7}$$

Combined with comprehensive constraints, existing PRs and formulated special plans, the SPA establishes the land use pattern. The results are shown in Figure 2B, C, and D. In scenario 1 (corresponding to Figure 2B), increased R parcels are mainly distributed in the east, close to the high school and main road; increased C parcels are mainly distributed in the south, close to the CBD or main road. Overall patterns of scenarios 2 and 3 are similar; increased R parcels are distributed in the northeast, and increased C parcels in the south. The pattern of scenario 3 is different than those of scenarios 2 and 3, and increased R and C parcels are distributed in the southeast and northeast.

The evaluation step is realized by calculating PARA_MN, ENN_MN and ED, using FRAGSTATS software. To estimate in this step, we presumed that the smaller the above indexes, the better the results for city development. The range of score is standardized to 0–1 (0 and 1 correspond to the largest and smallest scores), and index weights are all 0.33. Land use type score is calculated by Equation (6), and the comprehensive score is the average of these scores. The evaluation results are shown in Table 3. According to land use type score, the distribution of R and C parcels of scenario 3 is optimum; the distribution of R parcels in scenario 2 and that of C parcels in scenario 1 are worst. According to the comprehensive score, scenario 3 is the best, and scenario 2 the worst. Thus, the CPA determines that the final ideal land use pattern is scenario 3.

The results of the virtual space test above indicate that the Planner Agent theory is feasible for supporting LUPSA.

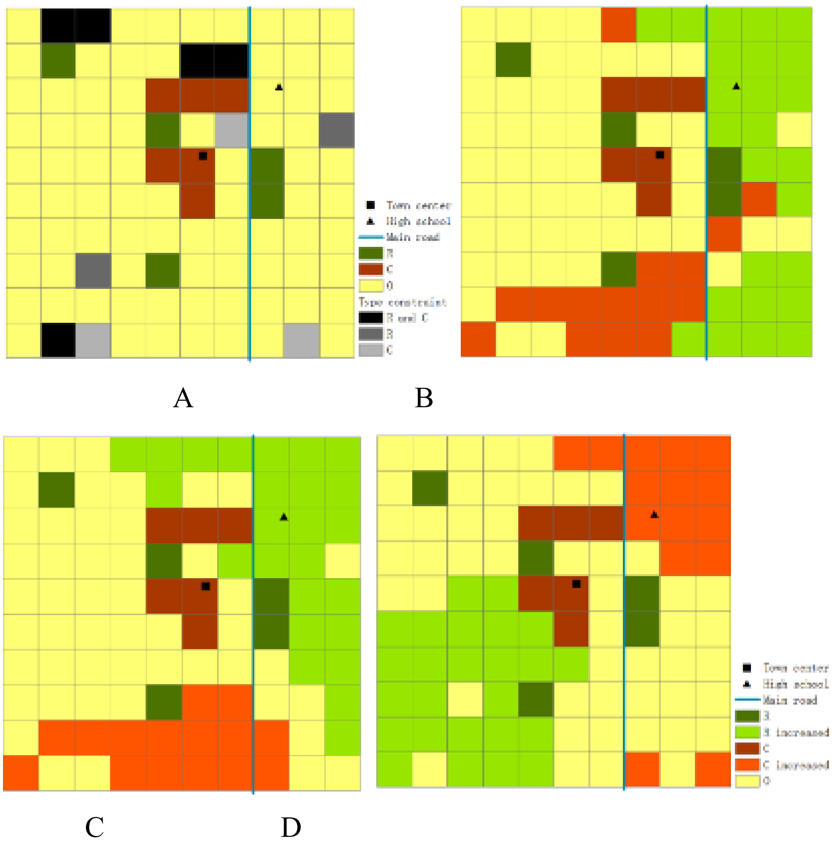


Fig. 2. Virtual space and established land use patterns; A, B, C, D respectively represent virtual space and scenarios established using PR 1, 2, 3

Table 3. Evaluation results of LUPSA

Sce-nario	Land use type	PARA_MN	ENN_MN	ED	Land use type score	Comprehen-sive score
1	R	0.70	1.00	0.69	0.79	0.57
	C	0.96	0.00	0.06	0.34	
2	R	0.00	0.70	0.69	0.46	0.48
	C	0.82	0.67	0.00	0.49	
3	R	0.45	1.00	1.00	0.81	0.75
	C	1.00	1.00	0.06	0.68	

4. Beijing experiment

4.1. Study area

The Beijing Metropolitan Area (BMA; Figure 3) has an area of 16,410 km2. It has experienced rapid urbanization in terms of GDP and population growth since the Reform and Opening Policy of 1978, established by the Chinese central government. There are 16 districts under BMA jurisdiction, and four main districts under the jurisdiction of the Beijing Central Area (BCA). In 2010, the BCA urban area was 987.5 km2, and areas of residential, commercial and industrial parcels were 194.6 km2, 129.2 km2 and 64.3 km2, respectively.

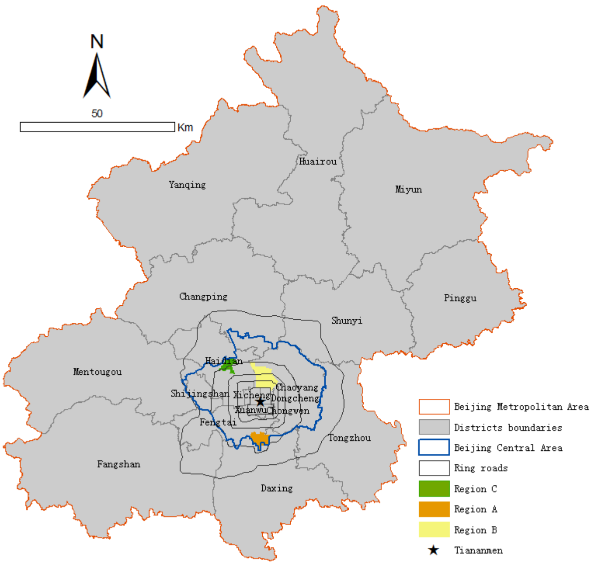


Fig. 3. Beijing Metropolitan Area

In the Beijing experiment, there were four land use types in the LUPSA process, namely R, C, M and O. Existing plan archives included the BCA Detailed Controlling Plan (BCA-DCP) (Figure 4) and special plans. To identify PRs, planned parcel samples were selected from the BCA-DCP. To identify three PRs by which we can establish three different land use pattern scenarios, three sets of planned parcel samples were chosen. These are distributed over the entire BCA, Regions A and B. Region C in the Beijing Haidian District was chosen as an experimental area, in which the established land use pattern will be distributed. Because parcel division is not considered and the impact of the current land use pattern is not addressed in the Beijing experiment, Region C is treated as a “clearing space”, in which parcel division is the same as that in the BCA-DCP, but has no current land use pattern. The boundaries of the aforementioned regions are shown in Figure 3. The existing plan of Region C is shown in Table 4 and Figure 5. There are 336 parcels in Region C, with area 107.67 km2. Areas of R and C parcels are the largest, with about 41% of the total area. The area of M is the smallest, about 0.4% of that total.

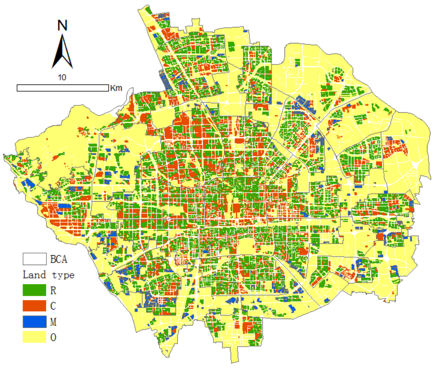


Fig. 4. BCA-DCP

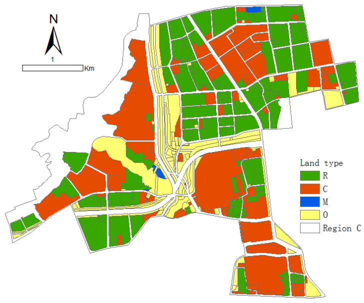


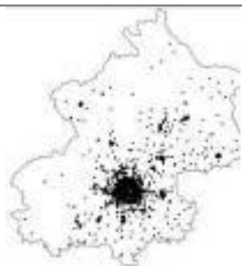
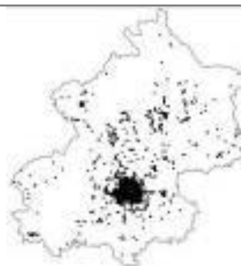
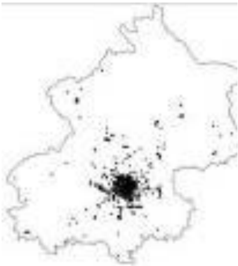
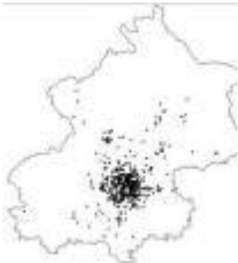
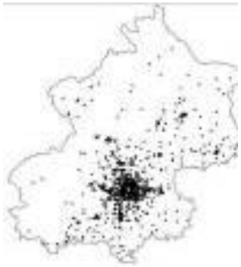
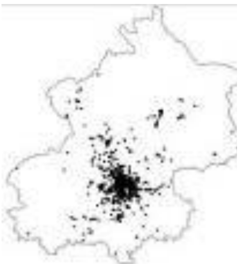
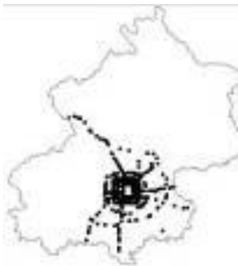
Fig. 5. Land use pattern of Region C

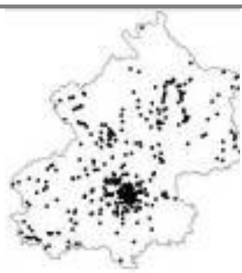
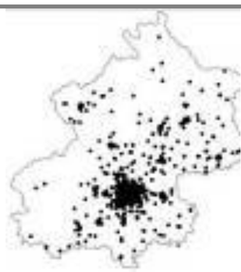
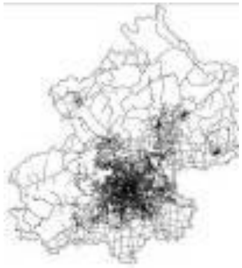
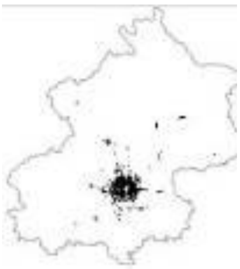
Table 4. Land use pattern of Region C

Land use type	Parcel distribution		
	Number	Area (km^2)	Percentage
R	114	43.85	0.41
C	97	44.41	0.41
M	4	0.47	0.004
O	121	18.94	0.18
Total	336	107.67	1.00

Subject to availability, The existing special plan data, which support PR identification, and formulated special plan data by the NPA, which support establishment of the land use pattern, are the same, for which are all from the spatial database of Beijing Institute of City Planning. The fact that the planned parcel samples are from different regions means that there are differences among the three identified PRs, so the established land use patterns will vary, even using the same special plan data. Table 5 shows the GIS spatial distribution of special plans in PIF format. The data of special plans covers the entire BMA. the impact f was calculated by Equation (7).

Table 5. Existing special plans (also formulated special plans)

NO.	1	2	3
Data			
Name	C21 Markets	C22 Banks and insurers	C25 Hotels
NO.	4	5	6
Data			
Name	C3 Recreational facilities	C4 Sports facilities	C5 Medical and health institutions
NO.	7	8	9
Data			
Name	C6 Education and re-search institutions	CBD	Exit Expressway exits
NO.	10	11	12

Data			
Name	G Park and attractions	Gov Government depart-ments	Hwst Highway stations
NO.	13	14	15
Data			
Name	Newcty New city centers	Railst Rail stations	Rd06 Road distribution in 2006
NO.	16	17	18
Data			
Name	Rvr Rivers	Subst Subway stations	Tam Tiananmen
NO.	19	20	21
Data			

Name	Xzl Office buildings	Yizhg Yizhuang Develop-ment Zone	Zgc Zhongguancun Area

4.2. Obtaining comprehensive constraints

The GA determines land use type constraints according to Beijing Limited Construction Zone Planning (Long et al. 2006; see Figure 6). Land use quota constraints are determined according to the existing plan of Region C, such that areas of R, C and M parcels are no greater than 43.85 km2, 44.41 km2 and 0.47 km2, respectively.

Fig. 6. Land use type constraints of Region C

4.3. Identifying PRs

Using identification of PR 1 as an example, the planned parcel samples are distributed throughout the entire BCA, and are analyzed by multinomial logistic regression in the SPSS software. In the BCA, there were 29799 parcels included in the identification process. Among these, there were 9594 R parcels (32.2% of the total number), 7516 C parcels (25.2% of total), and 753 M parcels (2.5% of total). Table 6 shows the identified parameters, i.e., the PIF weights. If the parameter is a positive number and closer to the particular factor, the parcel is more likely to be distributed as this land use type. If the parameter is a negative number and closer to the certain factor, the parcel is less likely to be distributed as this land use type. The −2 log likelihood decreases from 69795.728 (intercept only) to 62575.235 (final), and the significance of the likelihood ratio test is 0.000, which indicates that the regression model is significant overall.

Table 6. Results of multinomial logistic regression

Parameter	Weight		
	R	C	M
Intercept	−.70203***	−2.24992***	−1.78990***
C21	.59824***	.10866	−1.50529***
C22	1.69092***	1.98993***	1.48453***
C25	.27165***	.63531***	−1.50131***
C3	.54465***	.53033***	.09401
C4	.19670**	.20072**	.34227
C5	1.01238***	.71570***	−.37010
C6	.59667***	.83476***	.57046***
CBD	−3.13736***	−.73107***	−7.74911***
Exit	−.77072***	−.81033***	.21059
G	.06680	.14353*	−.52322**
Gov	−.22590***	.11004	.78724***
Hwst	−.08708	−.28315**	−.95491*
Newcty	−8.33651**	−.01048	−1.21120
Railst	−.29179**	−.14296	.79214***
Rd06	−2.09906***	−1.19993***	−1.10308**
Rvr	−.26074***	−.71772***	−1.32691***
Subst	.36312***	.57882***	−.41520**
Tam	.52299	1.24361***	−39.32950***
Xzl	.31318***	.52759***	1.24840***
Yizhg	−91.77109***	−101.64079***	33.57548**
Zgc	−1.49658***	.16891	−23.24940***

Note: ***p (significance) = 0.01; **p = 0.05; *p = 0.10

When PRs are identified by the questionnaire surveys and after receiving suggestions and confirmation from urban planning specialists, we divide PIFs into five categories – basic topography, accessibility, parcel property, socioeconomic characteristics, environment, and 28 secondary categories. A total of 20 questionnaire surveys were completed. Half of these were from planners at the Beijing Institute of City Planning, and the rest were from graduate students in Urban and Regional Planning at Peking University. Table 7 shows PIFs and standardized PRs determined by these individuals, who have either professional or educational backgrounds in urban planning. The results show that for the R pattern, the most influential PIF is educational and research institutions, and the least influential is development zones. For the C pattern, the most influential PIF is the CBD, and the least influential are educational and research institutions, and medical and health institutions. The most influential PIFs for the M pattern are development zones and highways, and the least influential are subways and CBD.

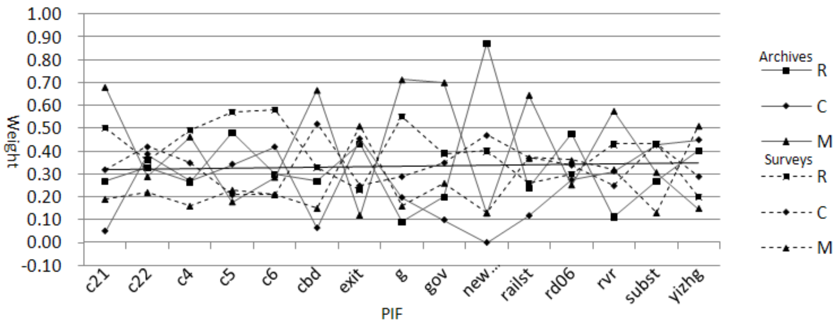
Table 7. Considered PIFs and questionnaire survey results

Category	PIF	Weight		
		R	C	M
1. Basic topography	1. Elevation	0.32	0.31	0.37
	2. Slope	0.30	0.32	0.39
2. Accessibilities				
2.1Transport facilities	3. Airports	0.26	0.31	0.43
	4. Rail stations	0.26	0.37	0.37
	5. Highways	0.23	0.25	0.51
	6. Main roads	0.30	0.34	0.36
	7. Subway stations	0.43	0.43	0.13
	8. Bus stops	0.42	0.40	0.19
2.2 Public facilities	9. Government departments	0.39	0.35	0.26
	10. Entertainment facilities	0.49	0.35	0.16
	11. Amenities (such as supermarkets)	0.50	0.32	0.19
	12. Medical and health institutions	0.57	0.21	0.23
	13. Educational and research institutions	0.58	0.21	0.21
	14. Banks and insurers	0.36	0.42	0.22
	15. Parks and attractions	0.55	0.29	0.16
2.3 Location	16. CBD	0.33	0.52	0.15
	17. Town centers	0.40	0.47	0.13
	18. Development zones	0.20	0.29	0.51
	19. Rivers and wetlands	0.43	0.25	0.32
3. Parcel properties	20. Current land use type	0.36	0.31	0.33
	21. Parcel area	0.29	0.30	0.41
	22. Land price	0.33	0.32	0.35
4. Socioeconomic characteristics	23. Population density	0.36	0.41	0.23
	24. Employment rate	0.30	0.37	0.32
5. Environment	25. Air quality	0.46	0.34	0.21
	26. Traffic noise	0.56	0.28	0.17
	27. Vegetation coverage	0.49	0.28	0.23
	28. NIMBY facilities	0.46	0.36	0.18

Table 8 compares similar PRs identified by existing plan archives and questionnaire surveys, similar PIFs within the Yizhuang Development Zone (Yizhg in Tables 5, 6 and 8) and corresponding PIF development zones, and the road distribution in 2006 (rd06 in Tables 5, 6 and 8) and corresponding main roads. The results show that the differences between weights identified by existing plan archives are larger than those identified by surveys. For example, the respective weights of town center to R, C, and M are 0.87, 0.00 and 0.13 for the archives, while the respective weights of town center to R, C, and M are 0.40, 0.47 and 0.13 for surveys. This is partly because weight identification through plan archives is much more affected by the original data, whereas in the survey respondents could consider the situation more comprehensively. The weights for R and C from existing plan archives are usually larger than those from questionnaire surveys, and the weights for M from the former are usually smaller than those from the latter. This shows that these factors are more influential on the R and C patterns identified through plan archives than those through surveys, and less influential on the M pattern identified by the former than those by the latter.

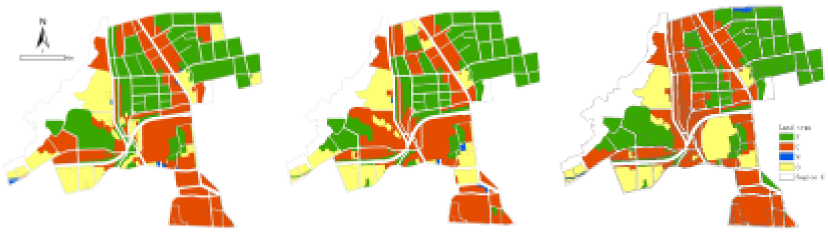
Identification of PR 2 and 3, namely the planned parcel samples in Regions A and B, is the same as that of PR 1, so the corresponding results and processes are omitted.

Table 8. Comparison between PRs identified by existing plan archives and questionnaire surveys



4.4. Establishing land use patterns

Being limited by PIF data availability for questionnaire surveys, the SPA establishes the land use pattern using only PR 1, 2, and 3 from existing plan archives. The scenarios are shown in Figure 7 and Table 9. The number of R and C parcels for scenarios A, B, and C varies, but these scenarios are relatively consistent. The middle and northeast parts of the region are predominantly R parcels, and C parcels are mainly distributed in the south. Scenarios A, B, and C are also relatively consistent with the existing plan (Figure 4). The difference is mainly focused on parcels along the river; for scenarios A, B, and C there are mainly C parcels, whereas there are mainly O parcels for the existing plan. This is partly because the existing plan is constrained more effectively by land use type constraints, which have kept these parcels as O types as a result of adopting no development strategy.



A B C

Fig. 7. Established land use patterns; A, B, and C represent scenarios using PR 1, 2, and 3, respectively

Table 9. Results of established land use patterns

Land use type	Parcel number (scenario A)	Parcel number (scenario B)	Parcel number (scenario C)
R	163	157	130
C	116	146	182
M	11	7	8
O	46	26	16
Total	336	336	336

4.5. Evaluating land use patterns

To schematically evaluate and coordinate land use patterns, we adopted a method that is the same as that of the virtual space test. The results are shown in Table 10. According to land use type score, the R pattern of scenario A, C pattern of scenario C, and M pattern of the existing plan (Figure 4) are the best. The R pattern of the existing plan, C pattern of scenario B, and M pattern of scenario C are the worst. According to the comprehensive score, scenario A is best, followed by the existing plan; scenarios B and C are worst. According to comparison among scenarios A, B, C, the CPA determines that scenario A is the final ideal land use pattern. Given this comparison between scenarios A, B, C and the existing plan, it may be useful to investigate potential laws or problems that could either support or hinder LUPSA.

Table 10. Evaluation results of land use patterns

Scenar-io	Land use type	PARA_MN	ENN_MN	ED	Land use type score	Comprehen-sive score
A	R	0.85	0.99	0.40	0.74	0.65
	C	0.71	0.97	0.23	0.63	
	M	0.60	0.13	0.99	0.57	
B	R	0.78	0.98	0.24	0.66	0.60
	C	0.79	1.00	0.07	0.61	
	M	0.65	0.00	0.99	0.54	
C	R	0.77	0.93	0.42	0.70	0.60
	C	0.91	1.00	0.36	0.75	
	M	0.00	0.11	1.00	0.37	
Exist-ing plan	R	0.87	0.93	0.08	0.62	0.63
	C	0.65	0.93	0.28	0.62	
	M	1.00	0.97	0.00	0.65	

5. Conclusion and discussion

This paper introduced two aspects of our work. First, the Planner Agent theory was proposed for supporting LUPSA. PRs can be identified by several methods, such as the use of existing plan archives, questionnaire surveys, real models and virtual reality tests. Combined with identified PRs, comprehensive constraints and formulated special plans, the land use pattern can be established. These land use pattern scenarios can be evaluated from multiple standpoints. Following this, the CPA coordinates these scenarios and determines the final, ideal one. Second, the Planner Agent theory was applied in a virtual space and in Beijing. PR identification was implemented through plan archives and by questionnaire surveys completed by planning professionals. Scenario evaluation and coordination of land use pattern scenarios were accomplished by calculating PARA_MN, ENN_MN, and ED indexes using FRAGSTATS.

As the results reveal, the Planner Agent theory determines the characteristics of and interactions between government, planners and resident agents; it emphasizes the uniqueness and importance of planners, providing a useful framework that reasonably reflects the requirements and preferences of different agents in supporting LUPSA. Results show that the proposed Planner Agent theory is suitable for LUPSA. The introduction of Planner Agents, and combined with other traditional planning measures, can improve the efficiency and effectiveness of the LUPSA process. Our theory and comparative methods use the parcel as the analysis unit, are based on existing traditional research on urban land coverage, and establish the entire city's spatial form scenario from the bottom up. Considering the rapid urbanization in China, the requirement for urban planning is much more stringent than before, so this paper has potential practical application. For applicability to real world situations, the qualification of identified PRs and efficient public participation by the RA are crucial to establish a reasonable land use pattern. Although PRs can be identified quantitatively by diverse methods, it remains difficult to comprehensively reflect PR elements, especially the planner's subjective uncertainties. Moreover, participation by other agents is limited or excessive by many aspects of real society. The reasonability of LUPSA can be promoted by improvement of the Planner Agent theory, and by developing complementary social situations and technologies.

In the future, the Planner Agent theory could be improved in the following ways. First, communication and coordination between the SPA and NPA should be considered. This could be achieved by referring to the Form Scenario Analysis (FSA) approach proposed by Long et al. (2010b). Second, we aim to improve the methods for identifying PRs; for example, by considering PIFs more comprehensively and improving their data availability, identifying PRs using real models or virtual reality tests, and comparing effects of different methods. Third, we must take public participation into account by introducing resident agents into our research, which would facilitate evaluation of land use pattern scenarios based on the principle of resident utility maximization. Finally, we intend to extend application of the Planner Agent theory, e.g., by supporting the formulation of floor-area ratios in addition to the land use types used herein.

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