

# Research on the Methods of Automatic-generation of 3D Virtual City

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**Abstract.** This paper makes research on the methods of automatic-generation of 3D virtual city from the view of urban cellular automata model. The evolution process of the urban land units can be simulated by constructing urban cellular automata model, and then the results of evolution will determine the space location and corresponding building types of land units. Our research makes use of MultiGen Creator to build 3D scenes, and scene management technology of OpenGVS to generate buildings at random, then these buildings will be set on corresponding locations of 3D scene so as to generate 3D virtual cities. We develop 3D virtual city automatic-generation system and also discuss the application potential and value of it in the field of municipal administration, urban planning, urban research, etc.

## Introduction

Recent years, with the presentation of “Digital Earth” and acceleration of global informatization, the spatial information technologies are also developing at a higher speed than ever, and “3D Virtual City” is one of the research hotspots. Virtual cities are virtual geographical environments which used to simulate realistic cities constructing by using computer virtual reality technology. And this breaks the limitations of traditional 2D GIS and allows people to enter the 3D virtual environments, interact with them directly, and thereby gives people more intuitionistic and profound feelings. Recently, academic circles in this field have discovered some new research methods, and with the development of computer software and hardware technology, developed many excellent 3D modeling and 3D GIS software. As the technological support of the new methods, these software yield a series of achievements. The present achievements of scientific research and the modeling technologies they used can be divided into three kinds: (1) modeling methods based on DEM and image; (2) modeling methods based on regular geometry and 2D GIS; (3) modeling methods based on 3D data models. Because of the texture distortion and lack of reality in constructing urban landscape, the first method is just only suitable for rude 3D urban landscape modeling; the second method uses urban regular buildings and plenty of existing height data of buildings to construct large-scale and simple 3D urban models, but the biggest limitation about this method is it can only express regular buildings, not includes complicated urban landscape entities; for the third method, there is no well real 3D space data model recently still, but it represents the direction of research on the 3D modeling<sup>[1]</sup>.

If we can integrate the advantages of three methods mentioned above, then the best choice we expect is to find the automatic-generation method of 3D virtual cities that can generate large-scale urban landscape rapidly as well as reconstruct complicated urban landscape entities. The researches related to this field are also limited at home and abroad at present. Scholars of Australia, Stefan Greuter presents an approach to procedural generation of ‘pseudo infinite’ virtual cities in real-time. The building generation parameters are created by a pseudo random number generator, seeded with an integer derived from the building’s position<sup>[2]</sup>. Lu Jiacheng, scholar of Taiwan, proposes that simulating the buildings and generating cities by using Cellular Automata and Genetic Algorithms. Cellular Automata is used to set models of buildings in virtual cities, and Genetic Algorithms are used to generate the changes of virtual cities in the whole time<sup>[3]</sup>. Scholar of Japan, Kato, N proposes that virtual cities can be generated automatically using Genetic Algorithms.

This paper researches the process of automatic-generation of 3D virtual cities from the view of urban Cellular Automata (CA) models. We use urban CA to generate states of land types in different

periods of the cities, and then the 3D display technology will be used to set corresponding urban buildings models automatically according to the land types generated before, so as to reflect the process of growth in urban development.

### **Urban Cellular Automata Models**

The development of the city is mostly expansion and derivation of the original city. There are many similarities between the expansion of urban land and growth of cells in CA models. Every lot in the city is a cell, and situation of land use in the lot corresponds to the state of the cell. The concentration effect in the development of the city can be considered as neighbor effect in CA models. And in the same way, the laws that transform the non-urban land into urban land in cities corresponds with transformation rules in CA models. So it is possible that we use the improved CA models to simulate process of city development<sup>[5]</sup>.

Because of the complexity of the urban geographical system, the standard CA must be expanded in order to meet the requirements of city space and time simulation, then simulates and predicts the process of city evolution more real and accurate<sup>[6]</sup>. We expand CA mostly from cellular space, cellular state collection, cellular state transformation rules and time, and then it evolves into urban cellular automata models. We also match the urban cellular automata models to 3D space, and consequently simulation of city space-time evolution turns to be more accurate<sup>[6]</sup>.

#### **The Preparation and Processing of Data.**

**Data Collection.** This paper sets Kaifeng City, Henan Province as research case, the prepared data are maps of present land use of Kaifeng in 1995 and 2002, 1:50000 topographic map, maps of Kaifeng's land use planning, and maps of recent construction planning.

**Classification of Land Types.** We use 1:50000 topographic maps as registration reference to do the geometrical correction on maps of present land use of Kaifeng in 1995 and 2002 respectively using Erdas, which is RS image processing software, then, unify two maps into the same spatial scale. And after digitization of the maps, the land use types can be merged into five kinds: business, industry, residence, spare land and other land. We transform the vector data which are classified into raster data that the resolution is 30M\*30M. The spare land indicates that all the land use which non-urbanized except other land (include agricultural land). Other land refers to rivers, lakes and public leisure square, government buildings, train stations, parks, cultural relics and historic sites, etc. these are present buildings and planned land.

**Abstract Control Layers.** Because the development of the city is influenced by many factors, such as nature, economy and policies. These factors must be considered in constructing the models, we set urban transportation, topographic maps and non-constructive land as the control factor layers.

**Determine Seed Point of the Models.** Seed point is the initial state of urban CA models; the growth of the city is based on the seed point in models. We use Kaifeng's land types raster data (grid cell is 30M\*30M) in 1995 as the seed point of the models to simulate the evolution of the city.

#### **Construct Urban CA Models.**

**Cellular Space and Neighborhood.** In urban CA models, 2D cellular space corresponds to the grid data models in geographical space. Every grid in geographical space corresponds to a cell in cellular space. The cell dimension we adopt is 30M\*30M.

Neighborhood is the cell collection that is divided according to the shapes around the cells. We use the cellular space of MOORER neighborhood, which are eight cells around one cell are the neighbors to this cell.

**States of Cells.** According to the land types we mentioned, the states of cells can be divided into six kinds: business, transportation, industry, residence, spare land and other land. The collection of the states is: {business, transportation, industry, residence, spare land, other land}, all the states of cells come from this collection.

**Time Expansion.** Time is abstract in standard CA models, so we must reset it so as to set up corresponding relationship to the real time. In the research, our seed is land types data in 1995, the validation data is land types data in 2002, and set evolution cycle as year and the evolution time. Under these conditions, we simulate calculation and optimize parameters.

**Rules of States Transformation.** Transformation rules are the cores of CA, they express the logical relationships of the processes of being simulated; determine the results of space change<sup>[6]</sup>. We adopt Luo Ping’s concept of “Life Mechanism”. “Life Mechanism” treats city as life system, and every land unit in the city is a cell of city life system, the precondition of development of city life system is the life cells can coexist harmoniously, and desires of every one of them can be met at maximum. The “Desire” indicates that city life cells’ requirements to the living environment which is suitable for them.

There are huge differences among the desires of every kind of cells. According to Luo Ping’s method, the values of desires we set is: 0, 0.25, 0.5, 0.75 or 1, represents disgust, aversion, indifferent, favor and love, etc. respectively.

The driving force of evolvement of urban land use types is all the cells’ desires in the neighborhood space. The land use type which has highest value of desire will be the destination of transformation. So we introduce the concepts of genetic desire, neighborhood desire and integrated desire. Genetic desire means the inertia which central cells keep the states of present land use; neighborhood desire refers to neighborhood cells’ expectation that central cells evolve into all kinds of land use types; integrated desire indicates the sum of genetic desire and neighborhood desire. Three values are all arrays, and represent demand score of every kind of land type respectively.

Our research presents desire parameters table of land types according to the actual situations of Kaifeng and Luo Ping’s parameters table, as shown in table 1.

Table 1. Desire parameters table of land types.

Values of desire		Cell types					
		business	transportation	industry	residence	Spare land	Other land
cell types	business	1	0.75	0.25	0.5	0	0.5
	transportation	0.75	1	0.75	0.5	0.5	0.5
	industry	0.5	0.75	1	0.25	0.5	0.25
	residence	0.5	0.75	0.25	1	0.25	0.5
	Spare land	0	0.25	0.5	0.5	1	0.5
	Other land	0.5	0.5	0.25	0.5	0.25	0.5

### Building Urban CA Models Parameters Library

Urban expansion is a process of city space evolvement that affected both by urban macro and local restriction factors. The urban CA models parameters library must be built in simulating urban expansion. We take early urban land types data as seed point of CA models, then further adjust and optimize the parameters of CA models by comparing results of simulation and corresponding actual conditions of development. We can control the models in more accurate and effective way setting parameters library, make them accord with reality. And we can also get more reliable results in the future urban development simulation.

For increasing more flexibility and controllable in urban CA models, we set urban transportation, terrain and non-constructive land as control factor layers. We propose the concept of non-constructive land, actually it is other land, can fall into absolute non-constructive land and relative

non-constructive land. The former includes rivers, lakes, cultural relics and historic sites and planned land, they have absolute repulsive effect upon the development of the city; and the latter includes present buildings land (except cultural relics and historic sites), they only have general restrictive effect upon the development of the city. We design four kinds of parameters in urban CA models. They are random parameters, transportation parameters, slope parameters and non-constructive land parameters.

**Determine the Random Parameters of Models.** We make use of a threshold value  $\mu \in (0, 1)$  in constructing urban CA models for incarnating randomness of urban expansion and land types transformation. According to this parameter, we can adjust and control the models and obtain the expectant results of simulation.

**Determine Transportation Parameters.** The traffic capacity and grade level influence the land types transformation of neighbor units, so we set a transportation parameter  $T \in (0, 1)$ , and it can incarnate that transportation factor's effect on urban expansion.

**Determine the Slope Parameters.** Different buildings have different requirements on terrain slope, and different terrain slopes are suitable for different activities of constructions, and consequently form different space structures of land use<sup>[7]</sup>. Our research defines the slope which is unsuitable for constructing houses as Critical Slope. And this critical slope is slope parameters  $S$ , its extent is  $[0, 100]$ .

**Determine Parameters of Non-Constructive Land.** We divide non-constructive land into absolute non-constructive land and relative non-constructive land, and set two parameters: AF and CF. the extent of AF is  $\{0, 1\}$ . When AF is 0, parameter has no effect on evolvement of models, possibly this land type may transform into other type. When AF is 1, parameter has absolute effect on models, this land type do not transform into other type.  $CF \in [0, 1]$ , the change of parameter from 0 to 1 represent the process that non-constructive land's power of keep its state unchangeable from weak to strong.

**Abstract Results of Simulation.** The final result of urban CA models simulate development of city is to generate control data of models. Then match the urban CA models to 3D space through control data of models, thereby set 3D buildings models accurately, and finally, generate 3D virtual city. We train the models continuously, adjust and perfect parameters, finally get the optimized models parameters library. And furthermore, we get the land use data from 1996-2012 based on that in 1996.

### 3D City Modeling

3D city modeling is one of the most important technologies in virtual city design. The main task in 3D city modeling is to build data models for virtual city, implement dynamic display and operation of terrain and buildings in urban models<sup>[8]</sup>. 3D city modeling includes three parts: terrain modeling, buildings modeling and texture edit.

**Terrain Modeling.** Terrain modeling is absolutely necessary for 3D city models. There are two of them have representatives: one is based on GRID structure, and the other is based on TIN<sup>[9]</sup>. We adopt modeling method based on TIN for complexity and accuracy of urban terrain features. The data we used is 1:50000 topographic maps in Kaifeng urban district. Firstly, we digitally process the topographic maps, and then use the interpolation method to generate DEM data, and transform the coordinate system of DEM into geodetic coordinate system. We resample the DEM data to generate 30M \* 30M Grid DEM data. We use MultiGen Creator to transform DEM data into terrain elevation file in ded format that can be identified by function module inside, use Creator's terrain processing module to import ded files, choose Delanunay triangular mesh dissection method to triangularize the terrain models, and finally, generate corresponding terrain models.

On this basis, after a series of image color processing, we can get corresponding basic terrain textures.

**Ground-objects Modeling.** There are many kinds of artificial and natural ground-objects on the surface of 3D virtual city's terrain, we need to build models for them and overlay the terrain surface with them. We ignore the secondary ground-objects and only take the main ones into account for simplicity of city models. The main ground-objects can be divided into models of roads, rivers, lakes, present buildings and simulated buildings.

**Models of Roads, Rivers and Lakes.** Generally the models of roads and rivers can be considered as linear ground-objects and lakes as area ground-objects. The corresponding models can be generated automatically by integrating the information, such as linear ground-objects code and width, which supported in GIS database. Now we discuss the methods of building these models by setting roads models as example.

For building roads models accurately, firstly we use ArcGIS to collect feature points of roads axis in large-scale topographic maps, then generate linear ground-objects code setting RS images as references, and generate surface of roads DEM models by integrating real width information of roads. Secondly, we control the road inside (include axis) independently, use triangular mesh construction method of region inside to form triangular surface of internal road, meanwhile, calculate the normal vector of apex and texture coordinate, then put on the roads texture.

We build space polygons' boundaries of roads models, then these boundaries will be embedded into terrain models as feature lines to rebuild network in local area. Cleaning the terrain triangular mesh within the boundaries and then overlaying the roads models in this area. Finally we get the new terrain models overlaid <sup>[10]</sup>.

We use MultiGen Creator to transform DEM data into terrain elevation file in ded format, use terrain processing module to import ded files, choose Delanunay triangular mesh dissection method to triangularize the terrain models, and finally, generate corresponding terrain models.

**Urban Buildings Models.** Generally we should sacrifice certain degree of reality to meet the real-time of system. So the urban buildings divide into present buildings and simulated buildings in constructing urban buildings models. Present buildings refer to some important or marked buildings which are political centers, transport junctions or leisure recreational centers. They are generally permanent structures, and have no change in evolitional process recently. Because they have different architectural forms and every building has different style and feature, the methods of automatic-generation are not suitable for these kinds of buildings. Simulated buildings mean that they will be generated in 3D virtual city automatically. Different from the former, this kind of buildings have similar styles and features, they are very common, and will be changed in urban evolitional process. Because of this, we adopt methods of automatic-generation. (1) Present buildings models. For these kinds of models, we can get the geometry features data and height data of buildings using RS or measured data with large-scale urban topographic maps, make use of MultiGen Creator to generate corresponding 3D models, and add suitable texture according to the shapes of buildings or land use types. Then these prepared models will be added to corresponding ground surface. It must be assured that the coordinate and evaluation between the buildings and DEM are matched when overlay ground surface with models of buildings. (2) Models of simulated buildings. According to the urban land use types divided before, the simulated buildings fall into three kinds: business, industry, residence. We design a unary array ConGen[13] in integer form, and this array will be the generation parameters of simulated buildings on land units of business, industry and residence. In ConGen[13], the position of elements from 0 to 2 represents roof shape, from 3 to 5 represents building textures, from 6 to 11 represents building heights and the 12th position represents building types. We use modeling tools of MultiGen Creator to build roof shapes library of business, industry and residence, and prepare all kinds of buildings texture. According to the algorithm above, we get corresponding height, building texture ID, roof shapes ID randomly, and integrate the planned building models and texture, then the models can be generated in 3D simulation display platform automatically.

### 3D Virtual City Automatic-Generation System

**Functional Structure Design of the System.** The work flow of the system is data input and preprocessing, construction of the urban CA models, transformation of simulated data, construction, management, display and analysis of 3D models. System integrates urban CA models, CA models parameters library, models control database, architecture models and simulation of the virtual city, etc. The main modules and architecture of the system is shown below:

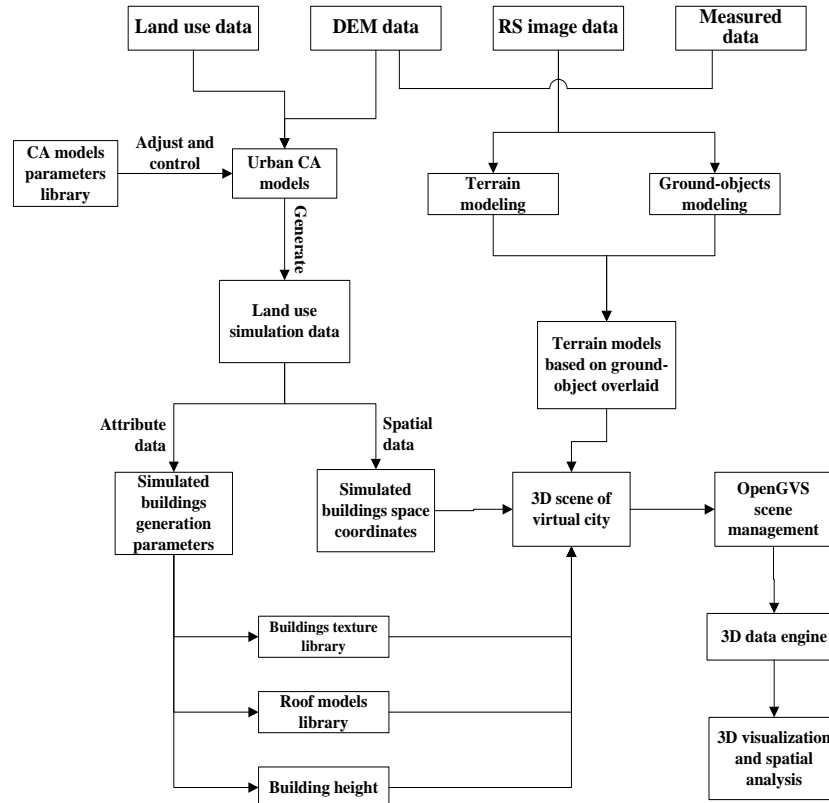


Fig.1 The architecture of 3D virtual city automatic-generation system.

#### Key Problems in Development of the System.

**Data Structure of Urban Cell Entity.** In the process of 3D virtual city’s evolutionary growth, the urban cells, as the smallest land units, are the keys in simulating city evolvement. During the process of city evolvement, it has some realistic significance only when the parameters of the models are adjusted, controlled and operated. The type of a cell determines the type of the buildings directly on this land unit in virtual city; influence the building texture and roof shape indirectly. And also, cell’s space location determines that of buildings in 3D virtual city. Then it is necessary to set up cell entity data structure for controlling cell entity in effective way.

**Entity Data Structure of Simulated Buildings.** 3D virtual city automatic-generation system sets buildings in terrain models according to land use types, and this involves space location and types, texture, height, roof shapes of buildings, etc. It is not enough that just only depend on cell entity data structure, because the cell entity only provides information about space location and buildings type, moreover, the space location does not transform into the row and rank numbers of space coordinate. On the other hand, the rest of the members of the structure lead to surplus burden in processing data and waste of system resources. So we set up entity data structure of simulated buildings, it is shown below:

```

struct SimConstruction
{
    float x;           //x coordinate in space coordinate system
    float y;           //y coordinate in space coordinate system
    float z;           //z coordinate in space coordinate system
    int ConTypeID;     //ID of building type
    int TextureID;     //ID of building texture
    int RoShapeID;     //ID of roof shape
    int ConHeight;     //height of buildings
};

```

Because the registration reference maps of terrain models adopted in Creator and urban CA models come from the same data source, they have the same coordinate system. The space coordinates that calculated by cell entity or DEM can be used in space location of buildings in terrain models.

**Space Coordinates Conversion.** It is the row and rank numbers of present cell that stored inside the cell entity, not plane location coordinates. And moreover, there are no elevation values of grid units in the cell entity. So it is necessary to convert the space coordinates so as to get 3D coordinates of simulated buildings. Here is the formula of conversion between row and rank numbers and plane coordinates:

$$X_i = X_0 + i * D_X, (i = 0, 1, \dots, N_X - 1); \quad (1)$$

$$Y_j = Y_0 + j * D_Y, (j = 0, 1, \dots, N_Y - 1). \quad (2)$$

In the formulas,  $X_0$  and  $Y_0$  are separately horizontal and vertical coordinate of grid units in southwest of DEM data,  $i$  and  $j$  are row and rank IDs of present cell entity,  $D_X$  and  $D_Y$  are row and rank numbers, and  $N_X$ ,  $N_Y$  are numbers of row and rank of DEM grids.

**The Results.** Our system had a series of simulation experiments under the platform of hardware and software, and we get satisfactory results. The system implemented city generation, models construction, space allocation and virtual city display, etc. it showed the process of 3D city evolvement using methods of 3-D visualization.

## Conclusions and Improvements

The methods of 3D virtual city automatic-generation and the corresponding system not only make us understand the development of city better from the new point, but also offer us a new platform that research the city. In the future, they can be used in many fields, such as municipal administration, city planning, city research, etc. The influence of the city in economic development is increasing nowadays, and the application of 3D virtual city will be more comprehensive. It is predicted that with the development of spatial information technology, the value and potential of 3D virtual city will increase continuously.

In the future, we will deeply research the process, mechanism and rules of city evolvement, expand the functions of urban CA models, add state types, and deeply optimized the mechanism of adjustment and control upon every parameter, so as to simulate evolvement of urban land use units more precise. About the automatic-generation of buildings models, we will further study the random generation algorithms of models and scene management mechanism of OpenGVS, and enhance the functionalities on 3D-visualization and spatial analysis.

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