MODELING, VIEWING AND SIMULATING KYOTO STREET MODELS CREATED FROM GIS DATA

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ABSTRACT:

This paper explores a method for reconstructing large-scale 3D urban areas from 2D data of the Geographic Information System (GIS). Our approach enables automatic reconstruction of 3D models of houses using the GIS data. The main target of the automatic generation of 3D models is the city of Kyoto in the Edo era and the houses peculiar to the urban area of Kyoto called *kyomachiya* are generated using parametric models of ten different types of *kyomachiya* and allocated based on the GIS. Houses are created from polygon data, fences from line data, and pedestrians and trees from point data. In our system, 3D models of some specific landmarks giving much effect to the landscapes of the city are produced and placed individually and manually. Some results of landscapes simulations of the Kyoto streets of Edo era and of the modern age are presented and compared. The method is applied to the project 'Virtual Kyoto Time-Space' in which the whole city of Kyoto during the Edo era is re-created.

1. INTRODUCTION

Urban 3D models are currently generated by computer for use in fields such as townscape planning, urban environmental planning, car navigation systems, and the real estate industry. Demand for urban 3D models is also growing for academic research and for presentation of research results in the humanities and social sciences; however, generating such models over large areas requires a substantial amount of money and time. Consequently, urban 3D models are usually only generated and used in highly profitable practical fields.

In the mean while, GIS revolution that began in the latter half of the 1980s, the collection of 2D data has improved as the development of new measurement techniques and the availability of high-resolution satellite data have led to an extensive accumulation of a range of geographical data in digital forms (Yano, 2006a).

Technical innovations associated with the IT revolution have made it possible for individuals to easily access a more familiar virtual space (Yano, 2006a). For example, Second Life provides a 3D virtual world, and Google Earth provides the real world in a virtual 3D space. Both of these applications use a standard Internet connection to deliver data from the server to the client online, thus achieving a virtual space in which the user interacts with the virtual environment.

This paper establishes a method for automatically generating urban 3D models using existing GIS data to meet the demands for computer-generated urban 3D models at low cost. There has been a great deal of research concerning the development of a method for the automatic generation of houses from housing polygons in GIS data (Haala et al., 1998; Sugihara and Hayashi, 2004). This paper provides a comprehensive discussion of the automatic generation of 3D features, including the creation from figure types other than polygons (lines and points). As a specific example of an application of this method, an urban 3D model of the entire Kyoto area is generated using GIS data of Edo-era Kyoto, which is being developed by the "Historical Geographical Information Research" unit of Ritsumeikan University's Global COE Program, the Digital Humanities Center for Japanese Arts and Cultures project (Yano et al., 2004a, 2004b, 2006b, 2007). This project undertakes to disseminate Kyoto's traditional culture all over the world by distributing the urban 3D model over the Web and placing the tangible and intangible cultural heritage of Kyoto within a 3D model. For this purpose, an urban 3D model is generated that can be delivered over a standard Internet connection.

2. GIS DATA SOURCES

In this section, we describe the sources of GIS data on Edo-era Kyoto, which we use to demonstrate our method in this paper. The urban 3D model of Edo-era Kyoto created in this paper is based on historical GIS data prepared in Ritsumeikan University's Global COE program. The primary data source was an old map from the early Edo era, the *Kanei-go-manji-zen-*

rakuchu-ezu (Kyoto University Library; hereafter referred to as the *rakuchu-ezu*), about 1642. The high level of accuracy of this map allows near exact identification of samurai residences, temples, shrines, and palace grounds. The map was digitized by the Geography Department, College of Letters of Ritsumeikan University, and we used the data that adjusted distortions to match with modern maps (Yano et al., 2007). The urban 3D model of Edo-era Kyoto was created by automatically generating town-house models in residential areas, fence models for plot perimeters (boundaries), and trees in homestead woodlands and mountain woodlands on the GIS version of the *rakuchu-ezu* (Figure 1).

Information corresponding to the elevation view must be added to the 2D plan obtained from the historical GIS data in order to generate the historical 3D model. The *shihonkinjichakushoku-rakuchu-rakugai-zu-rokkyokubyoubu* (Hayashibara Museum of Art; hereafter referred to as the *rakuchu-rakugai-zu*), also created early in the Edo era, was used as the source of this information. The *rakuchu-rakugai-zu* is a pair of artworks on folding screens, one of the inner city and one of the suburbs, drawn as if looking from above, depicting various buildings and the way of life of the townspeople. The types of houses in the *rakuchu-rakugai-zu* were investigated to find the frequency of each type of house. Images of buildings and pedestrians were also extracted to create the textures to be pasted on the 3D models. As the data were sourced from works of art, they cannot be considered as objective data on the streets of the Edo era; however, as there were no objective data to begin with, the 3D model was created to match the *rakuchu-rakugai-zu*. If more reliable data or hypothetical data should become available, it would be easy to re-generate a 3D model covering the whole city based on the new data using the current method. This is an advantage of generating 3D models by computer.

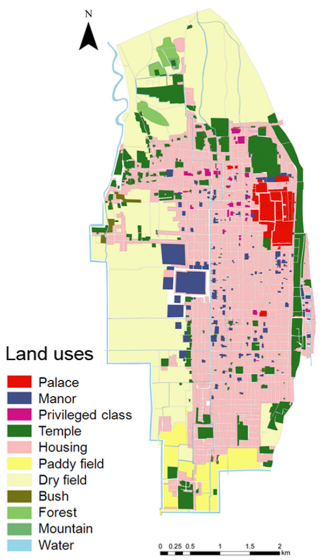


Figure 1. *Rakuchu-ezu* Converted to GIS Data

3. 3D MODEL AUTO-GENERATION PROGRAM

For the purpose of developing the "3D model auto-generation program" that automatically generates urban 3D models from 2D GIS data, we used Excel, Microsoft's spreadsheet software, and VBA, its associated macro language. The developed program can be used on any PC with Excel installed.

Spreadsheet software was adopted as the platform for the program to run on because the geometric information on houses, which forms the basis for the automatic generation, is in the form of "parametric 3D models". 3D models are generally made up of surfaces defined in terms of a set of nodes in three dimensions. In parametric 3D models, the coordinates of these nodes are represented by mathematical expressions using parameters rather than explicit values. Spreadsheets, in which a macro function refers to values in cells to calculate the required value, are exceptionally well suited to describing such nodes.

The 3D model auto-generation program employs a user form (Figure 2) that allows users to specify which variables are the coordinates that make up the 2D geometry (plot shape, plot boundaries, and trees) in the GIS data. For each record in GIS, the program substitutes the coordinate values into one of the multiple spreadsheets that describe a parametric 3D model in accordance with the GIS attribute data (e.g., type of house). Similarly, the appropriate textures are selected from the provided texture libraries according to the attribute data and pasted onto the surfaces of the generated 3D model. The program repeats this sequence for all records in the GIS database to generate street scenes of the entire city.

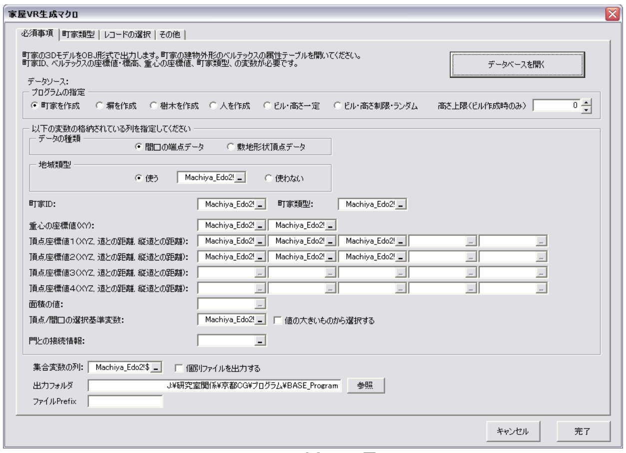


Figure 2. User Form

Our program can use all database file formats that can be read by Excel as GIS attribute data. Moreover, the parametric 3D models described on each sheet conform to the Wavefront OBJ file format (Kurihara, and Anjyo, 2003), meaning that the calculation results after coordinate substitution can be output as OBJ files. The OBJ file format is a text file for describing three-dimensional shapes, and has become widespread because of its simple structure. Furthermore, OBJ files only describe geometric information based on the connections between coordinates; texture information is recorded separately in MTL files. The 3D model is rendered by inputting these OBJ files, MTL files and texture libraries (collections of image data used to provide textures and referred to by the MTL files) into an appropriate visualization application.

4. AUTOMATIC GENERATION OF 3D MODELS

There are three types of GIS 2D data: data that can be represented by points, such as people and trees; data that can be represented by lines, such as railroads and fences; and data that can be represented by polygons, such as houses. These geometrical data types represent a range of real-life features. In this paper, we first create VR models of *kyomachiya* (Kyoto town houses) as an example of transforming polygons into 3D images. A VR model of a wall is then created as an example of transforming lines into 3D images. Furthermore, trees and people are created as an example of making 3D images from points (Isoda, 2006). Note that specific landmark buildings are not generated automatically; instead, accurate 3D models are created based on blueprints. The urban 3D model is generated by integrating the created VR models. The integration is easily performed by adding data into OBJ files.

4.1 Automatic Generation of Houses from Polygon Data

4.1.1 Parametric 3D Model of *Kyomachiya*. In the streets of historic Kyoto, the *kyomachiya*—the dwellings of ordinary people—occupied the majority of the area (Yano et al., 2007). For existing *kyomachiya*, the *Kyomachiya* Database (Ritsumeikan University, Kyoto City, *Kyomachiya* Reconstruction Research Association) provides the attribute data in GIS data format, including the distribution of around 24,000 *kyomachiya* buildings and seven types of *kyomachiya* houses (full two-story, mezzanine level, three-story, single-story, converted residence, fenced residence, signboard house) (Yano et al., 2006). Parametric 3D models of these seven types of town houses were created from existing *kyomachiya*. In addition to the seven types of existing *kyomachiya*, we added three different types of parametric models: storehouse placed in back of the houses and two types of houses with firewalls on both sides of the houses. Their parametric models are generated based on the pictures in *rakuchu-rakuza-ezu*, a historical painting of Edo-era. Figure 3 illustrates the ten parametric models.


(a) Full two-story


(b) Mezzanine-level


(c) Three-story

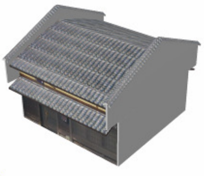

(d) Single-story


(e) Converted residence


(f) Fenced residence


(g) Signboard house


(h)storehouse


(i) Mezzanine-level with firewall

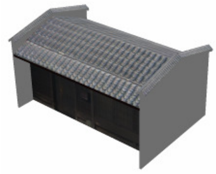

(j) Single-story with firewall

Figure 3. Parametric 3D Models of the Ten Types of *Kyomachiya*

In reality, we do not know the types of individual houses that were used in Edo-era Kyoto. To begin with, even the individual plots in the Edo-era districts are unknown. Therefore, GIS was used to integrate the area blocks shown on the *Kyoto-chiseki-zu* (Kyoto Cadastral Map), published in the first year of the Taisho era, onto the city districts shown in the *rakuchu-ezu* to create the town-house plots of the Edo era. The composition of the house types was calculated from the aforementioned *rakuchu-rakugai-zu* (Tsukamoto et al., 2006), and the house types were allocated at random based on these frequencies.

4.1.2 Specifications of the *Kyomachiya* Auto-Generation Program. *Kyomachiya's* are characterized by their long plots and narrow fronts, to the point where they are referred to as “beds for eels”. The front of the building stretches right across the entire plot to the very edge of the adjacent houses. No space was left between the houses and the road, and the houses were built facing directly onto the street. Therefore, the first important point in creating a *kyomachiya* model from a parametric 3D model is where to put the front door, which is the entrance to the house (Figure 4). To do this, the distances between the road and the front door are calculated in advance as node attributes using GIS, and the two nodes with the smallest distances are selected (nodes (1) and (2)). If $\theta \leq 120°$, where θ is the angle between the center and each pair of nodes, and if the distance of these two nodes is 1.2 meters. or more, then the line segment created by these nodes is considered to be the front door. If nodes (1) and (2) do not satisfy these conditions, nodes (1) and (3), where node (3) is the next-closest to the road, are checked as to whether they meet the conditions regarding the front door. If the conditions are again not satisfied, a different side of the house is investigated to determine the location of the front door.

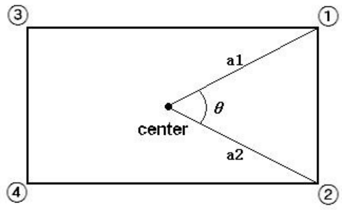


Figure 4. Determining the Position of the Front Door

Once the front door has been determined, the house’s *kyomachiya* ID, *kyomachiya* type, center coordinates, and coordinate values for the first and second nodes are substituted in the spreadsheet that describes the parametric 3D model. If the *kyomachiya* type is unknown, it is selected at random from the ten types of *kyomachiya*. Then the depth, height, and other parameters of the *kyomachiya* on each sheet are calculated, and the *kyomachiya* is created. At this time, the texture is also chosen using the MTL file that sorts the images from the provided textures. This process is repeated for all the *kyomachiya* in the premises data.

4.2 Automatic Generation of Fences from Line Data

In creating the streets, it is necessary to model the structures facing the roads. Since the front doors of the *kyomachiya* face directly onto the streets, it is necessary to model the houses; however, in the case of *bukeyashiki* (samurai residences), a fence faces the street. Therefore, the fences of the *bukeyashiki* are also automatically generated.
The fence auto-generation program requires the following input information: the coordinates of the nodes that describe the geometry of the plot, the type of fence, and whether or not there is a gate. First, the coordinates for two consecutive nodes are taken to represent the start (node (1)) and end (node (2)) points, as shown in Figure 5. Nodes (3) and (4) are then created by

adding the wall height to the z coordinate (elevation). The created nodes are then connected in the order of (1), (2), (4), and (3) to construct the fence. Similarly, the nodes are connected in the order of (2), (1), (3), and (4) to generate the fence on the inner side. This process, followed to complete one section of fence, is then repeated to complete the fence that encloses the plot on which the *bukeyashiki* stands.

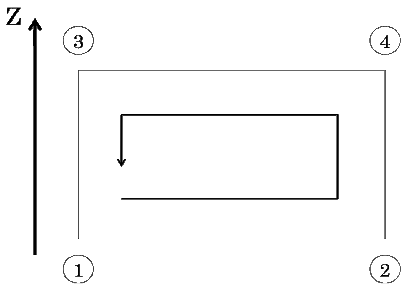


Figure 5. Method of Creating a Fence

When the texture is pasted, more than just a single image is pasted: the length of the side is calculated and divided by the standard length of the texture. If the result is a decimal, it is rounded up to give the number of images to be pasted. This approach minimizes the number of points at which the image is significantly distorted due to enlargement of the image.
If a side contains a gate, then nodes (1) and (6), provided as input data, are taken to be the ends of the wall, and new nodes (2), (5), (10), and (9) are created to define a gate of the prescribed width (here, a width of 1 *jo* [= 3.03 m] was used) from the center point, as shown in Figure 6. These nodes are used to split the fence, thereby defining the gate region (represented by nodes (2), (5), (10), and (9)). Furthermore, nodes (4) and (7) are defined such that the gate section is taller than the fence; the surfaces enclosed by nodes (1), (2), (4), and (3) and by (5), (6), (8), and (7) are connected and created.

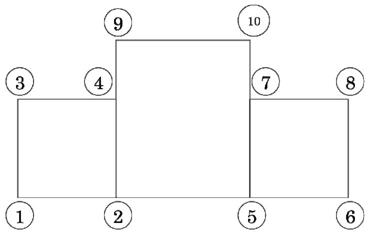


Figure 6. Method of Creating a Fence Containing a Gate

Moreover, since this program uses all of the node coordinates that describe the geometry of a plot, even fences with complex shapes with a mixture of acute and obtuse angles can be generated automatically (Figure 7).

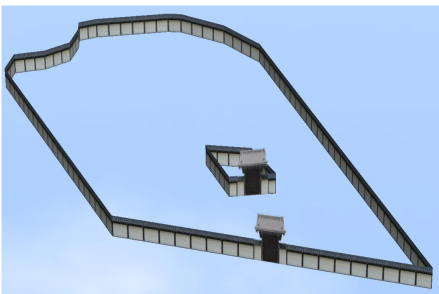


Figure 7. Created Fence Model

4.3 Automatic Generation of People and Trees from Point Data

4.3.1 Creation of Point Data. We have described the automatic generation of buildings, but this only achieves inactive, lifeless streets. Therefore, we attempted the automatic generation of people and trees from GIS point data to breathe life into the historical streets. Billboards (billboard models) were used for the people and trees. Naturally, no GIS data exist for people or trees. Therefore, the billboards were placed at randomly chosen points to create people and trees.

4.3.2 Specifications of the People Auto-Generation Program. People were represented by cutting out and processing images of people from the *rakuchu-rakugai-zu* and *sanjo-aburanokojicho-higashigawa-nishigawa-machinami-emaki* (Kyoto Prefectural Library and Archives, painted in 1820) to create the textures, and by pasting them onto billboards. Moreover, in the pursuit of realism, the billboards for pedestrians were angled by randomly rotating them a certain range off the centerline of the street. By automatically generating and constructing people in *Shijo-dori*, we recreated the street scene shown in Figure 8.

Figure 8. Recreated *Shijo-dori* in the Edo Era

4.3.3 Specifications of the Tree Auto-Generation Program. Tree billboards were created such that they cross perpendicularly at the given data point (Figure 9). An α channel was added to the used textures, as with the people textures, to ensure that only the tree parts of the texture are displayed.

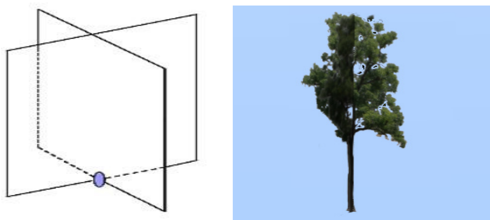


Figure 9. Method of Creating Trees (Billboards)

Furthermore, by using random numbers for the height and rotation angle of the billboards, approximately 10 texture types of trees can be represented, thus avoiding any impression of uniformity (Kosaka et al., 2006). Figure 10 shows an example of automatically generated city with trees.

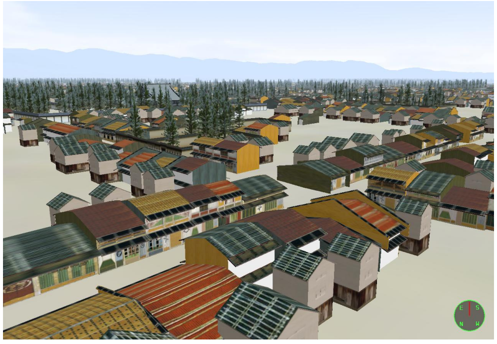


Figure 10. Reconstructed Streetscape in *Rakuchu*

4.4 Incorporation of Landmarks

To reconstruct more realistic scenes, it is necessary to add remarkable buildings in the area. For example, the Keep of Nijo Castle and the Five-Story Pagoda of Toji Temple, which served as landmarks, were separately modeled based on blueprints (Tani, 2003). These models were integrated with the automatically generated data by adding the data into the OBJ file (Figure 11).

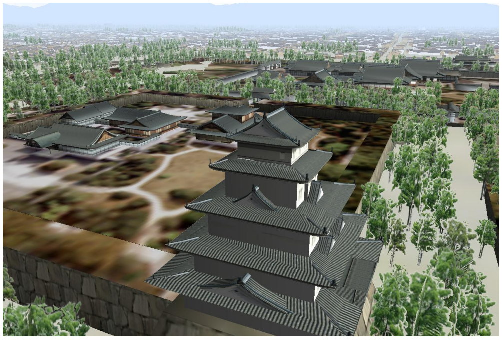


Figure 11. Reconstructed Street Scene of *Rakuchu* Integrated with *Nijo Castle*

5. CONTEMPORARY AND FUTURE LANDSCAPE SIMULATION

5.1 Simulation of landscapes with modern buildings

The program is also capable of creating extruded buildings from building footprint data and pasting appropriate texture on the 3D geometry, and thus is applicable to contemporary cities with modern buildings. The system possesses a function to control the heights of the extruded buildings depending on the restriction imposed to urban planning zones to preserve the landscape of the city. The function allows us various kinds of simulations such as generation of buildings with the actual heights, random heights or those with a user specified height restriction as shown in Figure 12.

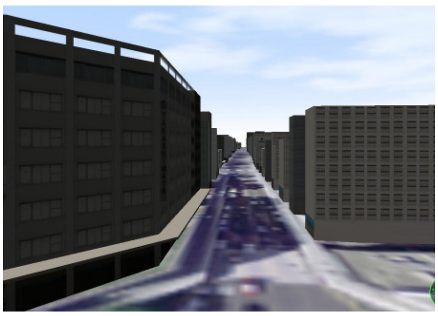


Figure 12. Modern buildings with height restriction (20m)

5.2 Simulation of landscape change

The program also enables simulations of landscape change (Takase et al., 2006). A lot of *kyomachiya* have been lost in the last century especially at the commercial districts in Kyoto and have been replaced by densely arranged modern buildings. It is possible to generate the scenes of different ages which give landscape change of the city in a certain period. Figure 13 shows the landscape change of Kyoto in the period from 1928 to 2000.

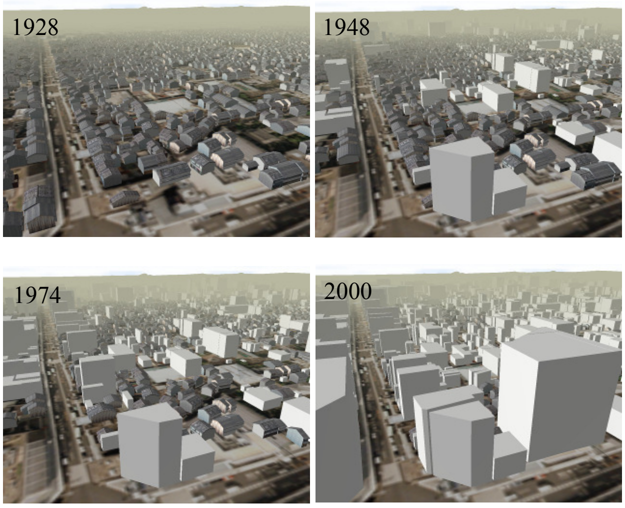


Figure 13. Simulation of landscape change of Kyoto

6. CONCLUSIONS

This research led to the development of a method and application program to automatically generate and position, on a large scale, houses and storehouses from GIS polygon data concerning house shapes and attributes; fences from GIS line data created from a cadastral map; and VR models of people and trees from GIS point data created hypothetically. This program can be used to easily generate urban 3D models automatically from 2D data that are either hypothetical or reconstructed from fact. In particular, this paper described the employment of this method and application program to the reconstruction of Edo-era Kyoto streetscapes, thereby confirming the effectiveness of the method.

The greatest advantage of this method when creating historical urban 3D models is its flexibility: the 3D model can be created from factual data, where such data exist, and a certain amount of hypothetical data can be used to construct imaginary models in cases that no factual data exist. A complete collection of historical data, covering the entire area of interest, will rarely be obtainable. Accordingly, hypotheses are established from qualitative or quantitative data that can be partially obtained based on historical materials such as pictures. The proposed method can be used to easily visualize these hypotheses via simulations. For example, if the density distribution of trees or the pictorial materials were changed to form a different hypothesis, visualization could be achieved in the same way, simply by altering the parameters and re-pasting the textures, thereby making it easy to compare various hypotheses.

The streetscapes of Edo-era Kyoto created in the course of this research serve as a basis for interdisciplinary discussion between historians, historical geographers and historical architects on how the past streetscape should have been; the outcome of the discussion can be fed back to the model creation. Outside research fields, the model can be also used in historical education, in museums, or pre-visualization platform for the filming historical dramas.

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