

# RECONSTRUCTION AND VISUALIZATION OF “VIRTUAL TIME-SPACE OF KYOTO,” A 4D-GIS OF THE CITY

Y. Takase<sup>a,b\*</sup>, K. Yano<sup>a</sup>, N. Kawahara<sup>a</sup>, S. Koga<sup>a</sup>, T. Nakaya<sup>a</sup>, T. Kawasumi<sup>a</sup>, Y. Isoda<sup>a</sup>, M. Inoue<sup>a</sup>, D. Kawahara<sup>a</sup>, S. Iwakiri<sup>a</sup>

<sup>a</sup> Ritsumeikan University, 56-1, Tojiin-kitamachi, Kita-ku, Kyoto, Japan  
- (takase@gr., (yano, kawahara, koga, nakaya, kawasumi)@lt., isoda@fc., (gr014008, lg004965, lg001972)@lt.)  
ritsumeik.ac.jp

<sup>b</sup> CAD Center Corporation, 23-1, Sakamachi, Shinjuku-ku, Tokyo, Japan – takase@cadcenter.co.jp

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### ABSTRACT:

The research aims at reconstruction and visualization of “Virtual Time-Space of Kyoto,” which provides Kyoto’s 3D-GIS starting from the present going back to the past through 20<sup>th</sup> to 17<sup>th</sup> century, and finally Heian period (12<sup>th</sup> to 8<sup>th</sup> century, when a capital was founded in Kyoto), based on 3D city model of present Kyoto, and available historical documents and information, employing new visualization technologies including virtual reality (VR). The research has introduced 3D city model of present Kyoto, which has been automatically generated by recently developed software, using LIDAR data, 2D digital map, and aerial photograph. There remain a lot of *Kyo-machiyas* (traditional townhouse in Kyoto, *machiya* hereafter), temples, shrines and modern heritage buildings in Kyoto because it eluded damage from World War II. At present, highly efficient GIS and VR technologies have been applied throughout the research; (a) to store locations and attributes of presently existing buildings including *machiyas*, shrines, temples and modern heritage buildings as a database; (b) to archive and geo-reference materials including *Yamahokos* (floats) of the *Gion Festival*, as well as old cadastral maps, street photos and aerial photos; and (c) to visualize urban landscape changes through times using aforementioned materials.

## 1. INTRODUCTION

Kyoto, an old capital of Japan which was founded 1,200 years ago and eluded damage from World War II, retains a great number of historical architecture such as temples, shrines, *machiyas* (traditional townhouses) and modern heritage buildings.

The research aims at reconstruction and visualization of “Virtual Time-Space of Kyoto,” which provides Kyoto’s 3D-GIS starting from the present Kyoto, based on automatically generated 3D city model, going back to the past, including those soon after and before World War II, Taisho and Meiji eras (early 20<sup>th</sup> to late 19<sup>th</sup> century), Edo era (late 19<sup>th</sup> to 17<sup>th</sup> century), and finally up to Heian era (12<sup>th</sup> to the end of 8<sup>th</sup> century). And the research also aims at making “Virtual Time-Space of Kyoto” open to the public through VR and Web3D.

The paper reports on on-going research project of “Virtual Time-Space of Kyoto,” which is a part of “Kyoto Art Entertainment Innovation Research” in Ritsumeikan University, a 21<sup>st</sup> Century COE (Center of Excellence) project funded by Ministry of Education, Culture, Sports, Science and Technology (MEXT) of Japan during the period from 2002 to 2006. “Kyoto Art Entertainment Innovation Research” aims at an interdisciplinary research on Kyoto as Japanese cultural center, gathering more than 30 researchers in varieties of fields including the humanities such as history, archaeology, geography and literature, as well as information science such as computer graphics (CG), VR, internet, image processing and artificial intelligence.

## 2. AUTOMATIC GENERATION OF 3D CITY MODELS AND VR APPLICATIONS

Traditional modeling method of 3D city models had required enormous amount of time-consuming manual works. Ordinary modeling method of 3D city used to be:

1. Scan paper map and get digital image,
2. Trace digital image of map with 3D CAD software resulting in 2D data of buildings outlines,
3. Manually make 3D models of buildings with 3D CAD by extruding 2D outlines to building height, and/or modeling manually detailed 3D geometry referring to drawings and photographs also with 3D CAD.

Especially, manual modeling with 3D CAD software was most time-consuming and required operators’ expertise. Therefore the method was not applicable for production of great area of city model in a short period of time.

The system development of automatic generation of 3D city model by CAD Center Corporation aimed great saving of production time. The new method has realized surprising reduction of time in production of 3D city model through automatic generation programs. Moreover, efficiency in texture mapping as well as quality and accuracy of 3D city model has been greatly improved. And presently, geometry model of all major cities of Japan, which is called MAP CUBE, is available on the market.

“Virtual Time-Space of Kyoto” has employed MAP CUBE of Kyoto as the platform of its 3D-GIS. It also has introduced recently developed VR viewer software named “UrbanViewer” developed also by CAD Center Corporation.

## 2.1 Automatic Generation of 3D City Models

The material data for the automatic generation system includes laser profiler data, aerial image, and 2D digital map (Table 1). With the material data, detailed and accurate 3D city model is automatically generated

| Material data       | Specification  |
|---------------------|--|
| Laser profiler data | -Point cloud data obtained by airborne laser profiler, which offers elevation of terrain and buildings.<br>-Distance of points: approx. 1m<br>-Elevation accuracy: 15cm<br>-Horizontal accuracy: 30cm<br>-Each point has latitude and longitude information. |
| Aerial photo data   | -Digital aerial photo data and standardized local coordination information.<br>-Resolution: 20-40cm per pixel.   |
| 2D digital map      | -Vector data based on 2D map of 1/2,500.<br>-Outlines and attribute data of objects including buildings, roads, railroads.   |

Table 1. Material data

The system consists of several programs including 3D city model automatic generation program, database management program, material data input program, and 3D CG/VR data output program (Figure 1).

3D city model automatic generation program, which consists of several tool programs, generates geometry data of building, terrain, and overpass and elevated object, using input material data including laser profiler data, aerial image and 2D digital map data as input data.

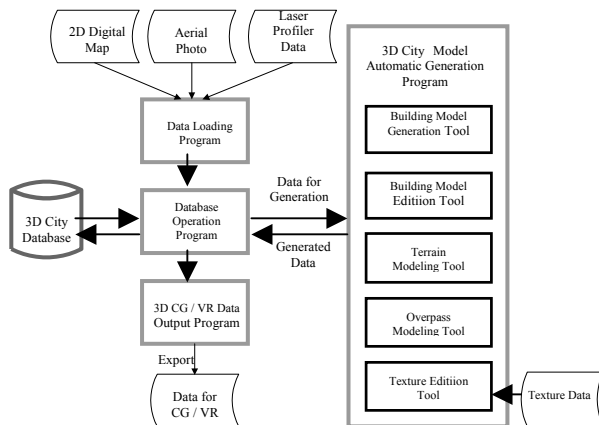


Figure 1. Program structure of the system

Through the application of 3D automatic generation program, accurate “geometry model” of terrain and building are automatically generated. Then, photo-realistic 3D city model with façade texture on geometry model, which is called “textured model,” is generated (Figure 2). Textured model is being produced along major roads of major cities with priority. Presently, geometry model of all major cities of Japan including Tokyo, Yokohama, Kawasaki, Osaka, Nagoya, Kyoto, Kobe, Fukuoka, Hiroshima, Sendai and Sapporo are available.

Geometry model of MAP CUBE is revised annually based on revision of 2D digital map data for car navigation systems. In addition to geometry model and textured model, 3D models of well-known buildings/objects, which are called “landmark models,” are being produced with more detailed geometry and texture (Figure 3). More than 1,000 landmark models are presently available.

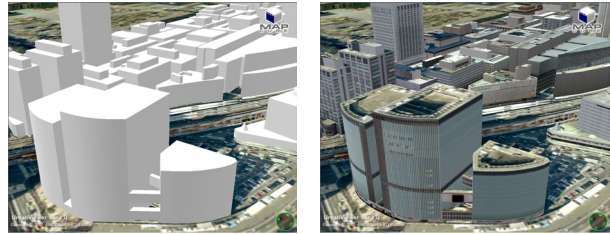


Figure 2. Geometry model (left), and textured model (right)

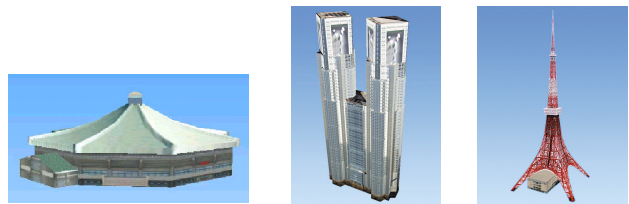


Figure 3. Examples of landmark models (Budoh-kan Hall, City Hall, and Tokyo Tower in Tokyo)

## 2.2 Application Developments for Virtual Reality

Applications for VR that deal with accurate and photo-realistic 3D city models are becoming indispensable in many fields including urban planning and navigation. However, there had been no VR viewer that can appropriately deal with a great amount of 3D city data in real time.

VR viewer software for popular use on the market has often difficulties when they are applied for specific purposes in terms of easy operation or drawing speed. It is also often difficult to put additional functions in those software. It was true too in the case of displaying 3D city model. In order to solve the problems, a new VR viewer software that can easily deal with wide areas of 3D city models has been developed, and it was named UrbanViewer (Figure 4). It has been available on the market since 2002.

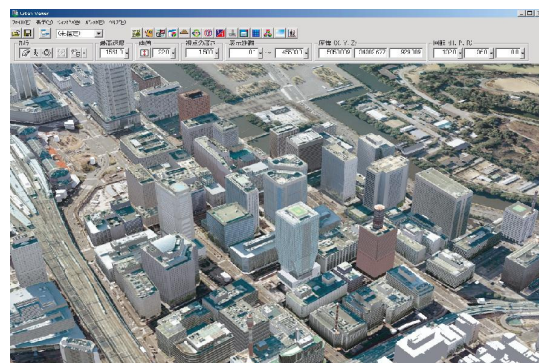


Figure 4. User interface of UrbanViewer

UrbanViewer provides a variety of functions that are useful and indispensable in urban design, real estate development, hazard prevention, urban navigation 3D-GIS and so on.

They include:

- Seamless display of wide area of city
- Fly-through and walk-through

- Jump to arbitrary viewpoint
- Control of movement speed
- Registration of viewpoints
- Measurement of height, distance and area
- Edition of objects

### 2.3 3D City Model of Kyoto

Since early stage of the research, “Virtual Time-Space of Kyoto” has introduced MAP CUBE of Kyoto, which is the most accurate and detailed 3D city model available in Japan (Figure 5), and UrbanViewer has been employed as VR viewer for it. Additional 3D modelling and texture mapping have been done by using CG/VR software which can output the data in OBJ format such as MultiGen Creator and form.Z RenderZone.



Figure 5. MAP CUBE of Kyoto

### 3. “VIRTUAL TIME-SPACE OF KYOTO”

At present, the research has been conducted on two major themes:

- 3D-GIS of Kyoto for monitoring *machiyas*, including;
  - Identification and visualization of *machiyas* in the years of 1995 through 1998, based on the field survey dealing with over 30,000 *machiyas*.
  - Additional field survey of *machiyas* in order to monitor the changes in the years of 1998 to the present.
- Reconstruction of landscapes and cultural heritages of Kyoto in the past, including;
  - Reconstruction of main street landscapes in Kyoto in early to mid-20th century and further older times, based on all historical data available, including old topographical maps, city planning maps, residential maps, aerial and on-ground photographs and land registration maps.
  - Reconstruction of activities and cultural heritages of Kyoto in the past including traditional festivals and dances performed in the landscapes and buildings of Kyoto at the times.

#### 3.1 2D-GIS of Kyoto at Present

**3.1.1 Machiya:** “Kyo-machiyas,” traditional townhouses of Kyoto, most of which had been built in between 18th century and World War II, have been decreasing rapidly in recent decades. Today, it is a very important argument how to evaluate *machiya* and how to hand their historical and cultural value to the future generations (Figure 6).

The research aims at reconstruction and visualization of “Virtual Time-Space of Kyoto,” a 4D-GIS, which provides both past and present city images based on 3D city model of Kyoto by employing new visualization technologies including CG and VR. The research has also introduced 3D-GIS of Kyoto that

makes possible to visualize the distribution of *machiya* through times as well as to monitor their changes through years.

In order to build up *machiya*'s 2D-GIS, the *machiya* database resulting from the community survey by the city of Kyoto in 1998 and the one by an NPO in 1995-1996 funded by Toyota Fund were available. The two database combined (*Machiya* Surveys hereafter) cover the central area of Kyoto that had been urbanized before the beginning of 20<sup>th</sup> century. In *Machiya* Surveys, the surveyers visited all buildings within the area and identified *machiya*, as well as recorded the type, condition and use of them. The *Machiya* Surveys identified 21,820 units of *machiyas* (Figure 7).



Figure 6. *Machiyas* in Gion area, Kyoto

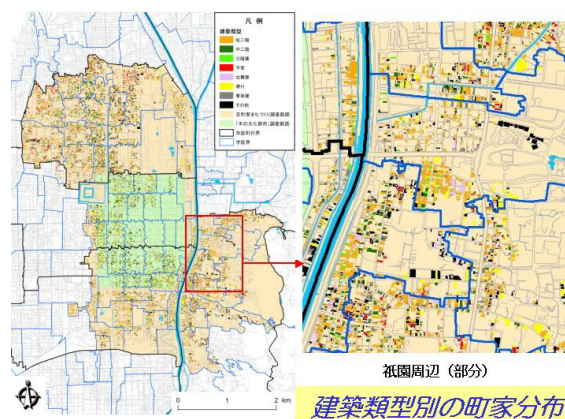


Figure 7. Distribution of *machiyas* in Kyoto by types (left), and the detail of Gion area (right)

Since the major purpose of *Machiya* Surveys was to find out the accurate number of existing *machiyas*, the geo-referencing information of identified *machiyas* was not very accurate. In order to match the survey results to MAP CUBE of Kyoto, supplementary surveys have been conducted. As the result, the changes in *machiyas* since 1995 until today were found out, and we are still continuing monitoring their changes.

**3.1.2 Temples and shrines:** In order to identify and locate existing temples and shrines on VR space, it is necessary to gather information on their precise locations and names. Several approaches are available for the task using existing digital data available.

“Digital Map 10,000” by Geographical Survey Institute of Japan (GSI) gives locations of 1,308 temples and 352 shrines as point data, but with no names (Figure 8). “Digital Map 25,000” also by GSI gives names of temples and shrines, but only for large ones. ZmapTown-II, digital street map by Zenrin, Co., Ltd. gives the names for individual building lots. Other methods include searching the internet phone directory by NTT Directory Services Co. (<http://itp.ne.jp/>) which returns 1,646 temples and 179 shrines, and it is possible to geo-reference

them according to their listed addresses. Combination of those methods enables building up most comprehensive database of temples and shrines.

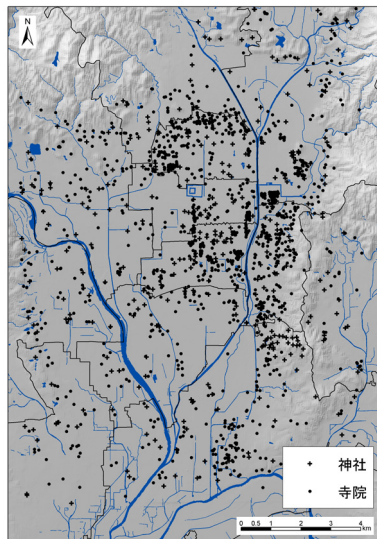


Figure 8. Distribution of temples and shrines in Kyoto (Source: Digital Map 10,000, GSI)

**3.1.3 Modern heritage buildings:** Western-style heritage buildings built in between late 19<sup>th</sup> century and World War II are listed in “Directory of Japanese Modern Buildings” by Architectural Institute of Japan (1983) and it identifies 570 heritage buildings in Kyoto. The directory lists the building’s name, address, built year, structure, architect and builder. However, a survey conducted in 2003 by the City of Kyoto identified no less than 2,000 buildings of the same category.

As for cultural heritage buildings designated by or registered to the government, there are 87 buildings in Kyoto (47 temples and shrines, 12 *machiya*s, 12 private houses, 13 modern western-style buildings, 2 modern Japanese buildings, and 1 unclassified building) and their names, locations and built years are available.

The information of those cultural heritage buildings can be installed into 2D-GIS of Kyoto by matching their addresses to the digital map.

## 3.2 2D-GIS of Kyoto in the Past

**3.2.1 Streets:** Kyoto experienced rapid urban expansion since the beginning of 20<sup>th</sup> century, especially during the post-war period. The process of urban expansion is observed from past topographic maps and city planning maps. The maps used for the research include past editions of 1:25,000 topographic maps since 1920’s, 1:20,000 in 1909, 1:20,000 in around 1900, and 1:10,000 in 1938 and 1951 by the Geographic Survey Institute of Japan (GSI), and city planning maps 1:3000 in 1935 and 1953 by the City of Kyoto. These maps are scanned and are re-projected to match to the current digital map using geo-referencing function of ArcGIS a GIS software.

**3.2.2 Building lots:** The allocation information of building lots in the past is available from old cadastral maps. The oldest cadastral maps available are those of 1884 owned by Kyoto Prefectural Library and Archive, but it lacks the registration books originally attached. Therefore, cadastral maps of 1912 with approximate scales between 1:1,300 and 1:1,500 owned by Ritsumeikan University Library have been used in the research. The matching of the past cadastral maps to current maps were

done by using the corners of neighbourhoods rather than using corners and edges of streets and intersections, because the streets in Kyoto were often broadened, narrowed or moved. Then each parcel of land was traced to examine the land division in the beginning of the last century (Figure 9).

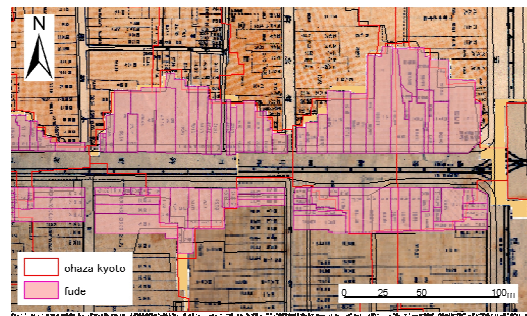


Figure 9. Digitised cadastral map 1912

**3.2.3 Machiya:** *Machiya* usually employs gable roof covered with roof tile. The observation of aerial photos makes possible identifying *machiya* as different from other type of houses such as modern-style house and Japanese traditional house, with considerably high probability. Those houses with hipped roofs were excluded from *machiya*’s identification since hipped roof with tile is commonly found in Japanese traditional houses and western-style houses, though there sometimes exist *machiya*s with hipped roofs. It is apparent that buildings with flat-roofs are not *machiya*s. The identification of *machiya*s solely with aerial photograph has obviously some limit in accuracy. To supplement the identification process, other information sources such as old on-ground photos and old house maps have been used. The house maps published by Yoshida Map Co. since 1955 have names of all buildings and residents.

Five sets of aerial photographs taken after World War II at 13 years intervals have been observed. Those are photographs by: US military force in 1948, GSI in 1961, 1974 and 1987, and Naka-Nihon Koku, Co. in 2000. The aerial photos were scanned, and rectified to fit to the map using ArcGIS geo-referencing function. After these geometrical adjustments, gable roofs were traced to make their polygons using ArcGIS editor (figure 10).

Figure 10. Identification of *machiya*s in aerial photographs

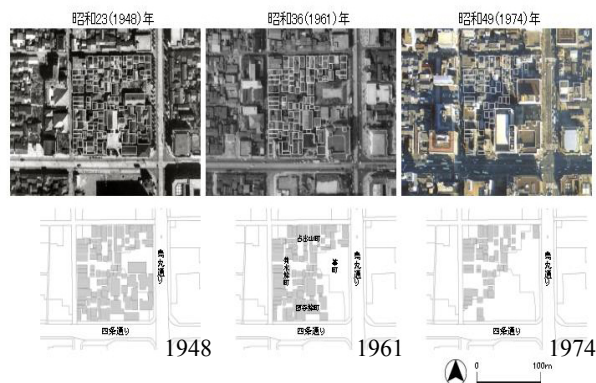


Figure 11 shows the distribution changes of *machiya* in central Kyoto from 1948 to 2000 at 13 years intervals. Here we can see the pattern of changes during the period. Those *machiya*s facing major streets disappeared early, then the disappearance of *machiya*s gradually expanded inward the street blocks.

The numbers of *machiya*s within the area were about 6,200 in 1948, 5,900 in 1961, 4,500 in 1974, 2,900 in 1987 and 1,800 in

2000. That is, the number of *machiyas* in the area decreased most rapidly in between 1974 to 1987.

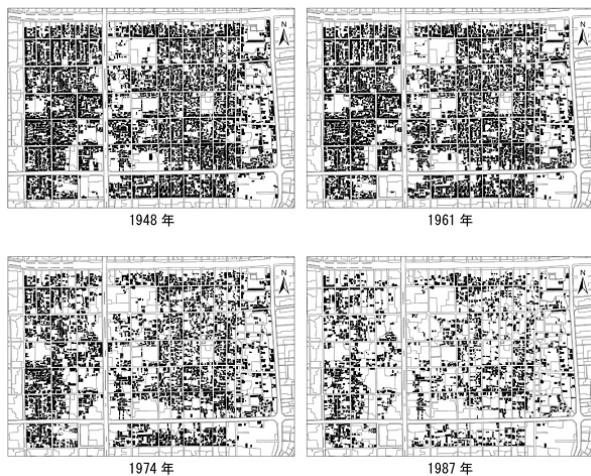


Figure 11. Distribution changes of *machiyas* in a central area of Kyoto

### 3.3 3D Reconstruction of Kyoto at Present and in the Past

In the research various 3D reconstructions of Kyoto are being done on MAP CUBE platform, including continuous addition of textured model of existing buildings along major streets, software development of automatic generation of *machiya* and modelling *Yamahokos* (floats) of *Gion Festival* using laser scanning, aiming at visualization of Kyoto at present as well as in the past.

**3.3.1 Detailed reconstruction of Kyoto at present:** Textured models of existing buildings have been added, starting from those along major streets of Kyoto (Figure 12). First, digital photos of building facades are rectified with Photoshop and façade textures are made. Then geometry models of MAP CUBE are mapped with the façade textures using CG/VR software such as MultiGen Creator and form.Z RenderZone. Those textured models are transferred to OBJ format and handed to UrbanViewer finally.



Figure 12. 3D model of Shijo Street

**3.3.2 Automatic generation of 3D Machiya:** Since there are so many *machiyas* (more than 20,000) in Kyoto, a method for automatic generation has been developed for *machiyas* based on GIS data constructed using results of Machiya Surveys. An Excel VBA Macro called “Machiya VR Generation Macro” has been developed for the purpose, which retrieves the coordinates and attribute data of *machiyas* from GIS database, applies one of the four prototype *machiya* models, resize the model for

width and depth of the building lot, and place the model in the VR space (Figure 13).

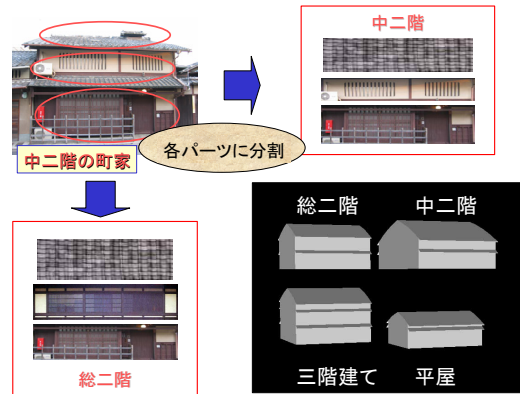


Figure 13. Automatic generation of *Machiya* VR model

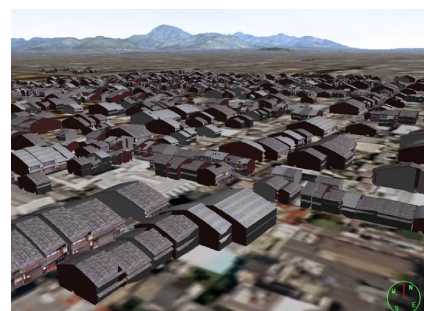


Figure 14. Distribution of *machiyas* at present

The advantage of this method is that it makes possible easy reconstruction of urban landscape based on information of building lots and *machiya* types. Although it is not a precise reconstruction, it would be a way of visualisation of urban landscape in the past with a reasonable certainty as a whole (Figure 14). It is also possible to model *machiyas* in details referring to architectural drawings, or laser scanning more important existing *machiyas*, and add them into the whole model.

**3.3.3 Gion Festival and Yamahoko:** The visual elements that consist urban landscape are not only buildings. We attempt to model *Gion Festival* that originated in the mid 9<sup>th</sup> century, evolved to be the current form by the mid 14<sup>th</sup> century and continues until today. During the festival, 32 *Yamahokos* (floats) representing each neighbourhood parade in the city center. *Yamahokos* in *Gion Festival* create symbolic landscapes of Kyoto during the festival period.

The 3D model of *Kanko-boko* (the *Yamahoko* representing *Kanko-cho* town) has been created by laser scanning of detailed miniature, and digital images of the real *Kanko-boko* taken by digital cameras during the festival (figure 15).

**3.3.4 Landscape of Kyoto at present and in the past:** Let us take a look at changes in urban landscapes of Kyoto with “Virtual Time-Space of Kyoto.”

Figure 15 shows urban landscape of Shijo Street at present as well as those in 1910’s and 19<sup>th</sup> century. The landscape at present has been visualized based on MAP CUBE of Kyoto with addition of textured models of the buildings along the street. The landscape in 1910’s has been visualized based on digitized cadastral maps of 1912 and “Machiya VR Generation Macro.” And the landscape of 19<sup>th</sup> century has been visualized using old paintings at the time, assuming that all *machiyas* were

one story houses at the time. Moreover, the mountains surrounding Kyoto and *Kanko-boko* float of *Gion Festival* were placed on Shijo Street.

The views from arbitrary viewpoints that UrbanViewer provides show that *Yamahoko* looks a very big object in 1910's and in 19<sup>th</sup> century though they look smaller at present surrounded by high buildings. And the range of mountains people can see was much greater in old times (Figure 15).

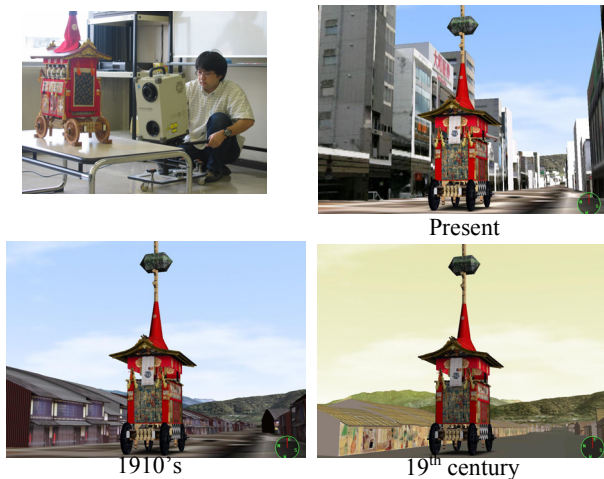


Figure 15. Laser scanning of *Yamahoko* miniature (upper left) and Landscape changes of *Gion Festival* through time

Next, let us take a look at the decrease of *machiyas* using “Virtual Time-Space of Kyoto.”

Based on the distribution data of *machiyas* identified by aerial photographs in 1948, 1961, 1974 and 1987, *machiyas* automatically generated by “Machiya VR Generation Macro” were located in MAP CUBE of Kyoto. Here the types of *machiya* were randomly selected. And those buildings other than *machiya* were MAP CUBE data (Figure 16).

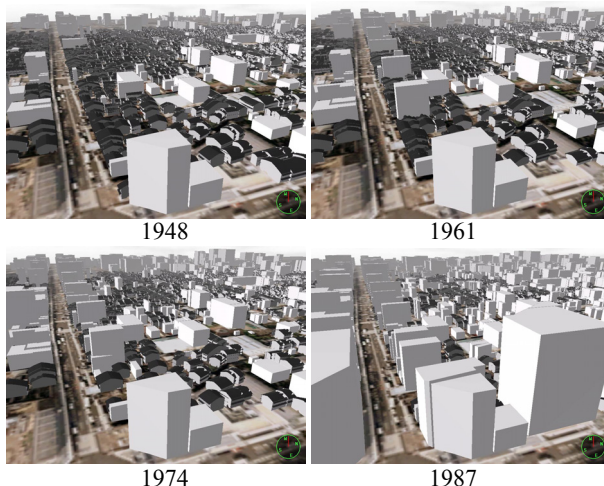


Figure 16. Changes in urban landscape of Kyoto

It clearly shows that *machiyas* facing major streets disappeared first, then the disappearance gradually expanded inward the street blocks. And as the result, modern high-rise buildings have become more and more dominant in urban landscapes.

#### 4. CONCLUSIONS

The research will continue to reconstruct historical city of Kyoto starting from the present going back to the past while making a variety of digital contents which constitute the landscapes at different times.

The reconstruction and visualization of VR city models used to be considerably in low quality of visualization. Some could deal with only small area because of the limit for amount of data it could handle, and others did not have accurate positional data or adequately detailed 3D models. We could solve the problem by employing MAP CUBE, which is the most accurate and detailed 3D-GIS model of Kyoto, as a platform of “Virtual Time-Space of Kyoto,” and UrbanViewer that made possible to handle a great amount of 3D city data in real time. We continue adding VR models based on all available historical information and documents, and at the final phase of the research we intend to apply “Virtual Time-Space of Kyoto” to the uses including assistance for urban landscape planning of Kyoto as well as sending rich information about Kyoto to the world through the internet.

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