

Virtual Kyoto: 4DGIS Comprising Spatial and Temporal Dimensions

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Abstract

Virtual Kyoto is a virtual time-space created on a computer for the purpose of investigating the past, present and future of the historical city of Kyoto. Using the cutting-edge technologies in GIS and VR, we built Virtual Kyoto which is 4DGIS that comprise a series of 3DGIS at different points in time. Our 3D city modeling begins with the present Kyoto and then goes back to the past, including those soon after and before the World War II, the Taisho and Meiji eras, pre-modern Edo era and finally back to Heian era when the city of Kyoto was founded in late 8th century.

Creating Virtual Kyoto includes the following projects: a) Archiving geo-referenced materials such as current digital maps, old topographic maps, cadastral maps, aerial photos, picture maps, street photos, landscape paintings, archaeological sites data, and historical documents; b) Creating a database of all existing buildings including machiyas (traditional town houses), early modern buildings, shrines and temples including historical and cultural heritages; c) Creating 3D VR models of the above buildings; and d) Estimating and simulating land use and landscape changes over the study periods using aforementioned materials.

Virtual Kyoto is an infrastructure to place various digitally archived materials associated with the city, and to disseminate Kyoto's subtle and sophisticated forms of cultures and arts to the world over the Internet. The web-based system provides user-friendly interface to explore historical materials of cultures and arts in the geographical context of Kyoto with its historical landscapes. Virtual Kyoto should play a valuable role in the assistance for urban landscape planning of Kyoto as well as sending rich information about Kyoto to the world through the Internet.

Key words: virtual cities, 3DGIS, Historical GIS, Japanese arts and cultures, Kyoto

I. Introduction

Large amount of geo-spatial data of various kinds have been accumulated since the GIS

revolution of late 1980's, supported by advances in IT technology, new survey methods, and high-resolution satellite images (Longley *et al.*, 2001). Such evolutions in GIS envi-

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ronments have enhanced 3DGIS and Virtual Reality (VR) models in terms of precision and quality. Our Virtual Kyoto project uses the cutting-edge 3DGIS/VR technologies to restore historical urban landscapes of Kyoto.

This Virtual Kyoto project has been a part of "Kyoto Art Entertainment Innovation Research (2002–2006)" at Ritsumeikan University driven by the 21st Century COE (Center of Excellence) program funded by the Ministry of Education, Culture, Sports, Science and Technology (MEXT), and now handed over to the Global COE program (2007–2011) entitled "Digital Humanities Center for Japanese Cultures and Arts". It aims at reconstruction and visualization of historical landscapes in Kyoto using 4DGIS of Kyoto, 3DGIS of Kyoto with a time dimension (Yano *et al.*, 2006, 2007). This paper introduces our Virtual Kyoto and suggests the utilization of Virtual Kyoto for Digital Humanities research.

II. Virtual Kyoto

Numerous virtual cities exist on the Internet. In this paper we define virtual cities as 3D urban models using VR technologies and having various services, functions, and information contents with realistic buildings and allowing social interactions in the same way as in real cities (Dodge *et al.*, 1997).

In constructing 3D virtual cities, the three points are important (Shiode, 2001): (1) level of reality (amount of contents), (2) data input (retrieval of height and appearance) and (3) functionality (as practical and/or analytical tools). As intensity of geometrical content of them increases, automatic generation of the 3D models will become more difficult, and the cost of creation will increase.

One of the most advanced virtual city is being created in the Virtual London project by CASA (Centre for Advanced Spatial Analysis), University College London. Virtual London is a large scale 3DGIS with CAD models for Greater London using state of the art computer technologies. It is designed for professional use by architects and planning but

is also targeted at the wider public through various processes of public participation across the web (Hudson-Smith, 2007; Hudson-Smith *et al.*, 2007).

Our Virtual Kyoto basically follows conventional virtual city projects as mentioned above, but with a distinguished feature. It is 4DGIS including a time dimension to conventional two dimensional GIS and three dimensional CAD models. It is capable of storing various geographical information of different historical age. This feature has been crucial from the outset because goals of Virtual Kyoto project were to express the history of the city and to reconstruct the city's past urban landscapes.

In Virtual Kyoto we adopted MAP CUBE® data from CAD CENTER CORPORATION. The data consists of prismatic 3D building block models based on building footprint and height, for the whole city of Kyoto (Fig. 1). The 3D models are created by extruding building footprint data with air-borne laser-profiler data which took height values at an interval of 2.5 m within error of ± 15 cm as demonstrated in Fig. 2. Kyoto, a historical capital of Japan founded in 794 AD, retains large number of historical architectures such as temples, shrines, machiyas (townhouses) and modern western buildings of the pre-war period. This is a rare case in Japan in that the city avoided the World War II damages. Unlike other restoration project, our strategy in restoring historical Kyoto is to first model the present day Kyoto as a virtual city, and then replacing the newer buildings with the previous buildings going backwards to the past. As a consequence, we created 4DGIS (3D plus time dimension) of Kyoto. The system supports a number of new areas of geographic inquiry, especially in its ability to represent the implications of historic conditions for current and future policy in three dimensions over time.

III. Present Kyoto

We first modeled the present-day Kyoto before restoring the past Kyoto, because unlike



Fig. 1 3D city model of Kyoto.

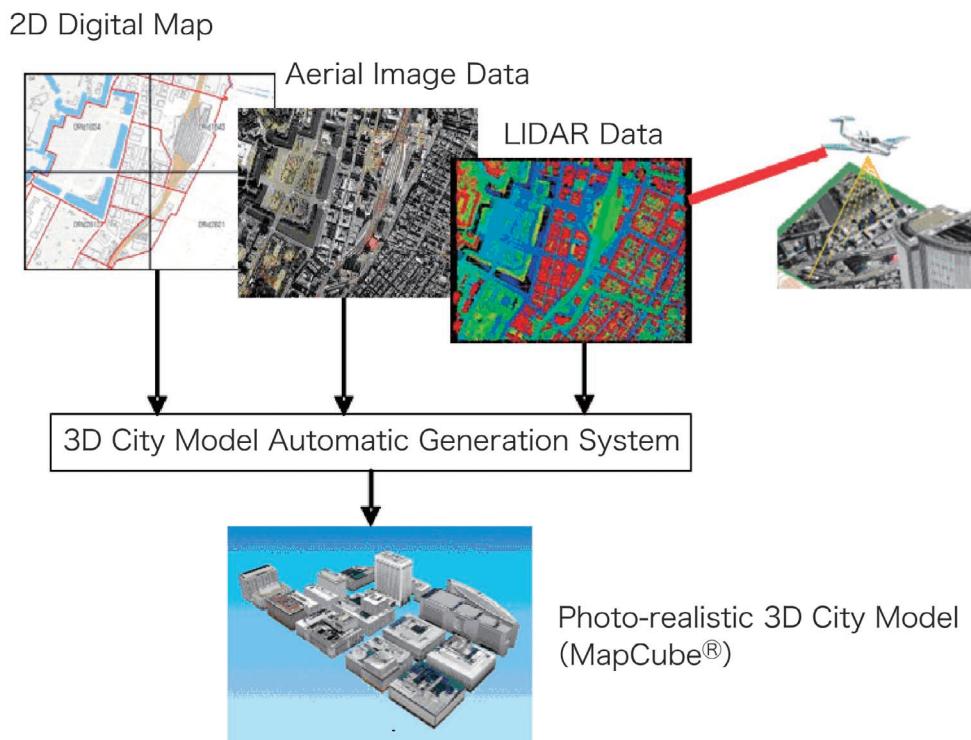


Fig. 2 MAP CUBE® data generation.

Source: INCREMENT P CORPORATION, CAD CENTER CORPORATION and PASCO CORPORATION.

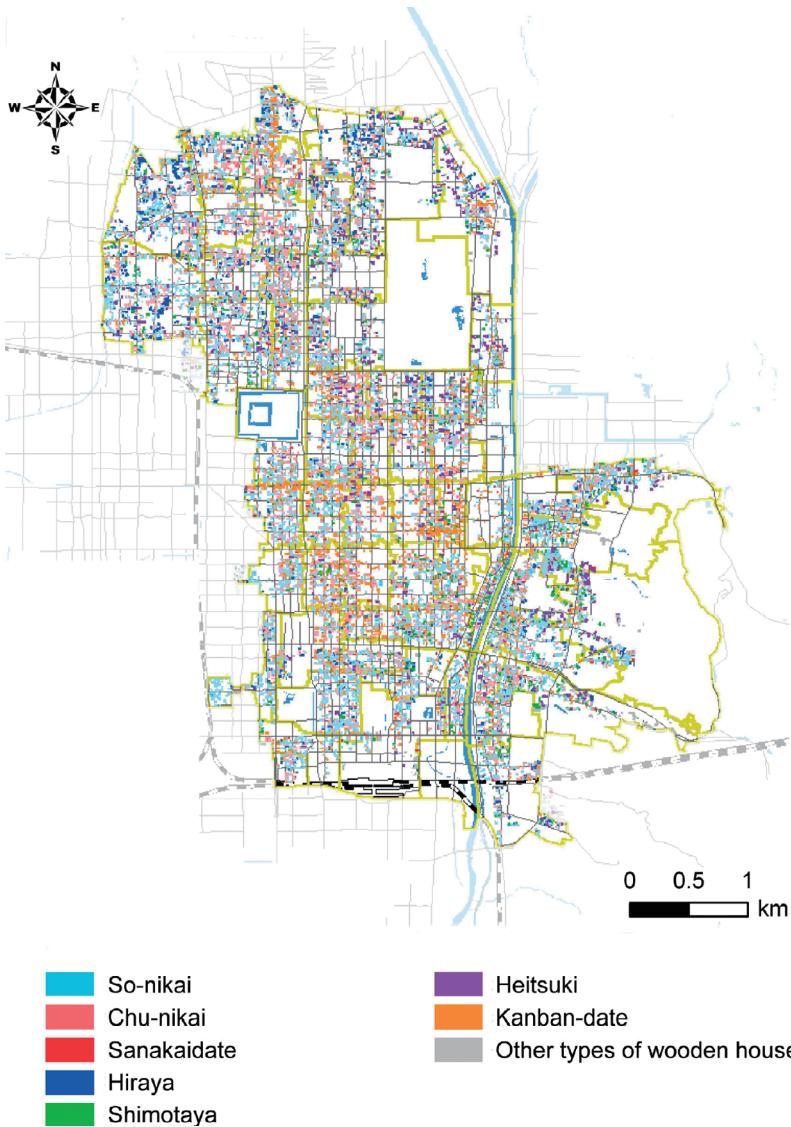


Fig. 3 Distribution of machiyas by type.
Sources: Machiya Community-building Survey (Kyo-machiya machizukuri chosa) and Authors' field survey.

other cities in Japan, Kyoto has been exempt from wartime air raid, and thus retained numerous building from pre-war period, such as machiyas, temples, shrines and western style buildings. Machiyas (Fig. 3), or townhouses, in particular are of special importance to our restoration project because most part of ur-

banized Kyoto consisted of them in the pre-modern period.

The landscape of Kyoto characteristically is composed of natural elements such as the mountains surrounding the city and the rivers, as well as the built elements including machiyas, temples, shrines and modern heri-

tage buildings. Therefore, the research firstly aimed at the construction of 2DGIS of those elements and then the 3DGIS were built based on them. In this paper, we take up the following major elements in Virtual Kyoto, which have formed the historical urban landscape of Kyoto from past through present.

1) Machiyas

Machiyas (Fig. 4), most of which had been built in between the 18th century and World War II, have been decreasing rapidly in recent decades. However, they still are dominant elements of the urban landscape of Kyoto, and there are approximately 22,000 units. Considering that there are still so many machiyas in Kyoto, a computer program for automatic generation of machiya 3D models has been developed as a macro package of Microsoft Excel. "Machiya VR Generation Macro" retrieves the coordinates and attribute data of machiyas from GIS database, applies one of machiya library models for each lot, resizes the model matching to the width and depth of the building lot, and places the model in the VR space (Fig. 5).

2) Architectural Heritages

Kyoto has been the cultural capital of Japan and consequently houses the largest collection of architectural heritages including

famous temples, shrines and Western-style modern buildings, which built before World War II. There are 375 designated or registered historical buildings, and the city itself constitutes the cultural legacy. There are about 2,000 early modern buildings, based on the recent survey by the Kyoto City. These buildings were designed and built just when



(a) So-nikai



(b) Chu-nikai

Fig. 4 Typical Machiyas in Kyoto.



Fig. 5 Machiya models in Virtual Kyoto.

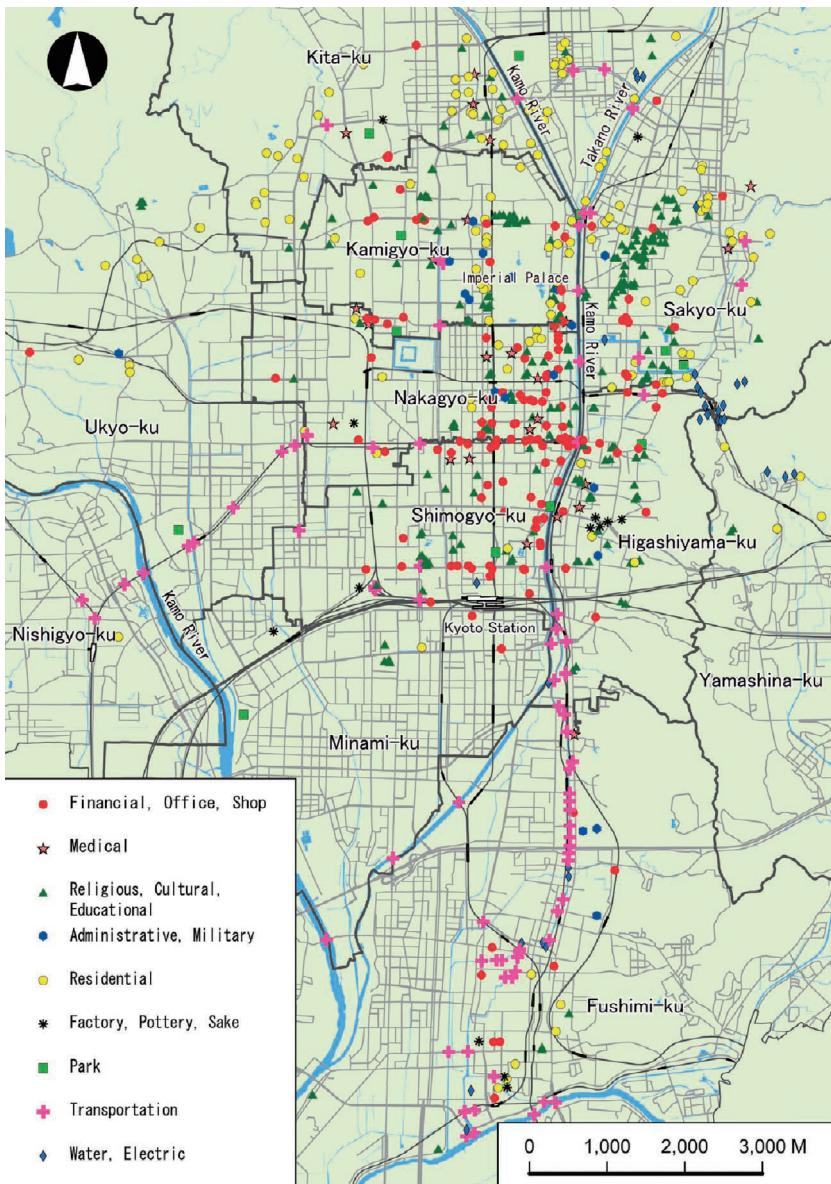


Fig. 6 Distribution of early modern buildings by type in Kyoto.
Sources: the Kyoto City and Authors' field survey.

Japanese architects began to incorporate Western techniques into their thinking. Most of the representative buildings are made of brick, but many different types of modern buildings including reinforced concrete buildings, wooden structures, and buildings that combined tradi-

tional wood and modern materials have also been present in Kyoto (Fig. 6). Needless to say, Kyoto has large number of temples and shrines: approximately 1,300 temples and 350 shrines (Fig. 7). Among them, 16 temples and shrines, and the Nijo Castle are design-

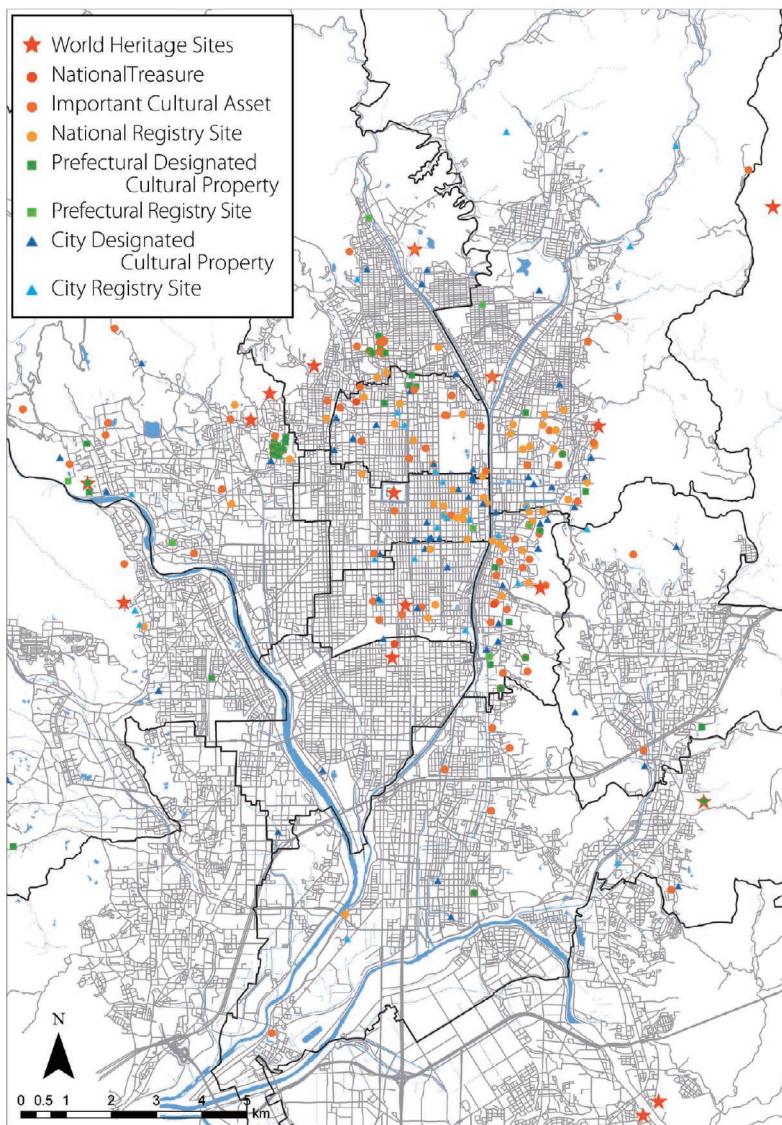


Fig. 7 Distribution of designated and Registered Cultural Properties (Buildings).
Source : the Kyoto City

nated as World Heritage sites, and the areas around them are subject to development restriction to preserve the landscape. Each individual building in these categories has its own unique character, and thus cannot be well represented by the prismatic model or automatically generated models. Several detailed VR models of those buildings are being

modeled using CG/VR software (Fig. 8).

3) Minamiza theater

Minamiza theater was originally constructed in 17th century on Shijo street, which is close to the place where the first Kabuki was performed in early 17th century. Although there were seven major theaters along Shijo street in 17-18th century, Minamiza theater



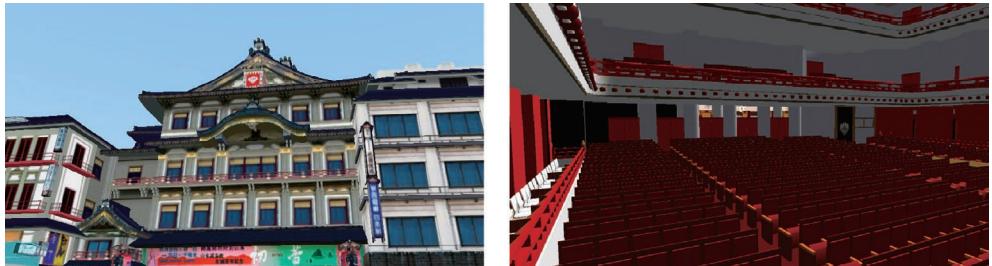
(a) Kiyomizu-dera

(b) Kinkakuji

Fig. 8 Detailed VR model examples.



(a) Shijo street



(b) Minamiza

Fig. 9 Shijo street and Minamiza theater.

solely remains on the street today. Creating a model of the theater has been an important issue in our project. Therefore, a detailed 3D model that includes the interior of the building was created based on blue prints. Along with the theater, we created a detail model of the street to the theater (Shijo street), allowing walkthrough experience of the street toward the entrance of the theater, the reception and the hall of Minamiza (Fig. 9). In

this VR environment, it is planned to stage virtual Kabuki performance or traditional dance, created by motion capture techniques of real performers.

4) Gion Festival and Yamahoko float

Gion Festival, held every July in Kyoto, is one of the most famous festivals in Japan. It originated in the mid 9th century, evolved to be the current form by mid 14th century and continues until today. During the festival, 32

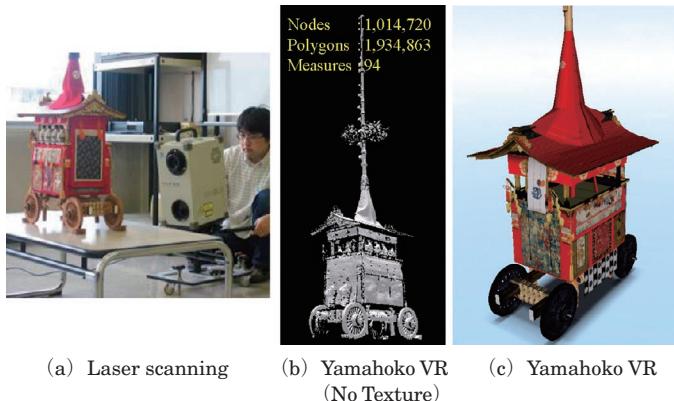


Fig. 10 Laser scanning of the miniature Yamahoko and its VR model.

Yamahoko floats representing downtown neighborhoods parade along the streets of downtown Kyoto, including Shijo street. Yamahoko parade of Gion Festival becomes a symbolic landscape of Kyoto during the festival period. At present, four VR models of representative Yamahokos have been created by laser scanning of detailed miniatures and digital images of the real Yamahokos taken by digital cameras during the festival, as well as by manual modeling (Fig. 10).

IV. Three dimensional reconstruction of Kyoto of the past

In this research, 3D reconstructions of Kyoto at various time slices have been and are being done, starting from the present to the past, including times of soon after and before World War II, Meiji and Taisho eras (late 19th to early 20th century), Edo era (17th to late 19th century), and finally up to Heian era (late 8th to 12th century). The five time slices are discussed in turn below.

1) Landscape changes before and after World War II

Machiya employ gable roof covered with roof tile. The observation of aerial photographs makes it possible to distinguish machiyas from other types of houses. Six sets of aerial photographs taken after World War II at approximately 13 years of intervals since

1928 have been used (Fig. 11). The photos are from the Kyoto City; 1928, US Army Air Force; 1946, Geographical Survey Institute; 1961, 1974, 1987, and Nakanihon Airline; 2000. These photos were scanned and rectified to fit to the map. Then gable roofs were traced to create the building footprint data of machiyas. Based on the distribution data of machiyas identified by aerial photographs, VR data of machiyas automatically generated by "Machiya VR Generation Macro" were placed into the Virtual Kyoto. It clearly shows that machiyas facing major streets disappeared first, and the disappearance gradually expanded inward the street blocks. Modern high-rise buildings have become more and more dominant in urban landscapes (Fig. 12).

2) Kyoto during the Meiji and Taisho eras

Fig. 13 shows landscapes of Shijo street at present and in 1910's. The landscape at present has been visualized based on MAP CUBE[®] of Kyoto with additional 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." Moreover, Yamahoko floats were placed on Shijo street in order to reconstruct Gion Festival at different times. The figure shows that Yamahoko floats looked impressively large in 1910's though they look smaller at present surrounded by highrise

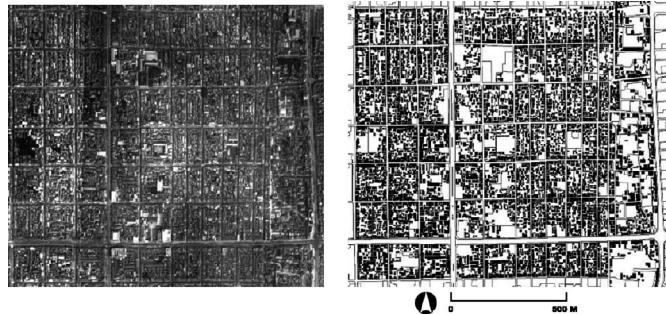


Fig. 11 Identification of machiyas in the aerial photograph as of 1928.
 (left) Aerial photo of Kyoto (Source: Kyoto University Library).
 (right) Polygons of machiyas on GIS.

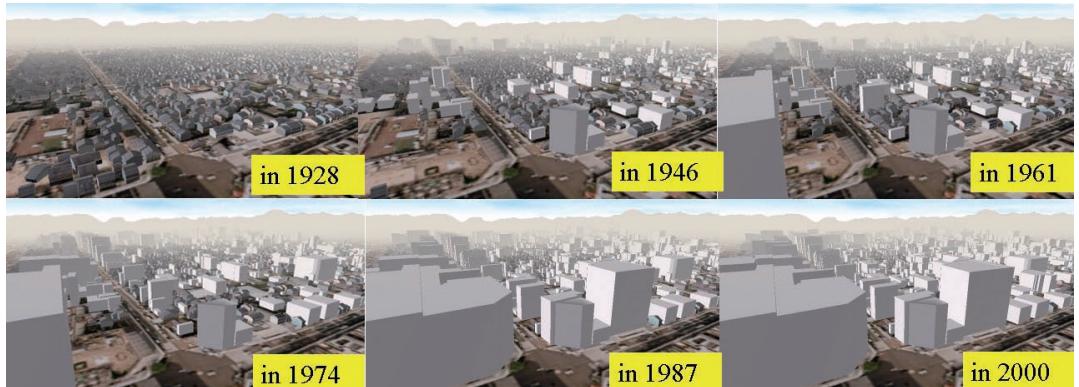


Fig. 12 Changes of urban landscapes in Virtual Kyoto.



Fig. 13 Landscape changes of Gion Festival.
 (left) in early Taisho era. (right) at present.

buildings. The visible ranges of mountains were much greater in older times.

3) Kyoto in early Edo era

Kanei-Go-Manji-Zen-Rakuchu-Ezu, drawn in

1640's and presently owned by Kyoto University, is known to be a considerably accurate map of Kyoto. It has the size of 636 cm by 282 cm and shows names of towns and

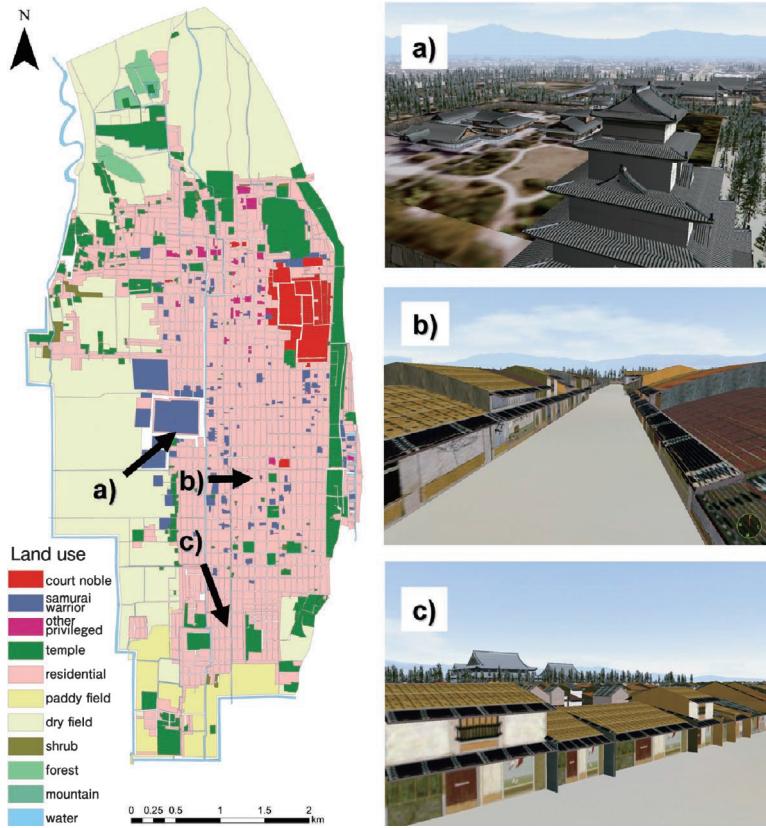


Fig. 14 Land use map of Kyoto in 1640's and the reconstructed Kyoto in Edo era.
Note: Right pictures are views from a), b), and c) in the left map.
Source: Rakuchi-ezu (Kyoto University Library).

streets, land use, widths of streets, widths and lengths of blocks and major building lots and names of landowners. The map was scanned, and rectified to fit to the modern map. After these geometrical adjustments, streets, blocks and major building lots were traced, and their attribute data were input on a 2DGIS system (Tsukamoto and Isoda, 2007). Using this GIS database 3D reconstruction of Kyoto in 17th century was conducted (Fig. 14).

4) Virtual Heiankyo

When Kyoto was founded in 794 AD as the capital of Japan, the city was called Heiankyo. The authors have started the reconstruction of Heiankyo, based on available historical documents and information. The topographical data has been reconstructed using excava-

tion and geological and archaeological results. Street blocks and buildings have been modeled using 3D CAD based on blue prints for miniature model of Heiankyo which was made by the Kyoto City celebrating its 1200th anniversary. The 3D CAD models have been automatically located according to the land use of the time (Fig. 15).

V. Virtual Kyoto 3D map on the web

With the rapid expansion of the broadband communications through the world, the potential for a web-based Virtual Kyoto has been greatly increased. At its foundation, Virtual Kyoto is constructed in a standalone 3DGIS that links the present and the past and displays the city in a high-resolution virtual

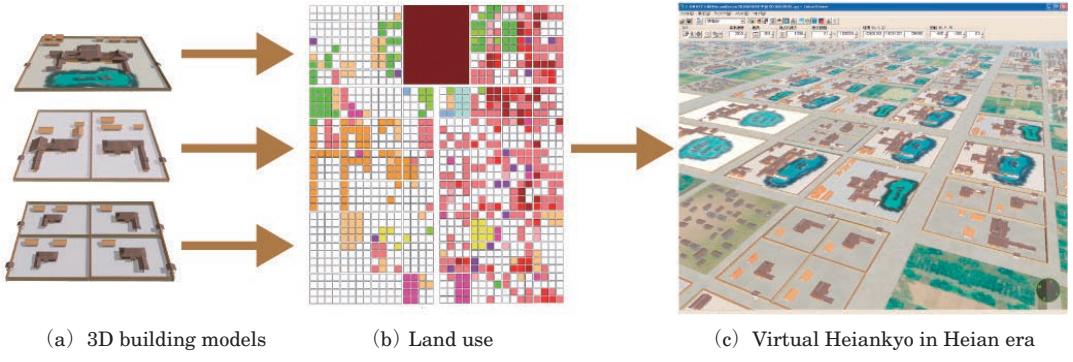


Fig. 15 Construction of Virtual Heiankyo.

reality, but on the web this kind of material needs to be displayed using 3D web-based GIS technology.

The model of Kyoto consists of building, landform and other shapes, and texture files; together this results in an extremely large amount of data. In order to distribute this huge data we need to use the following techniques: Data compression, Scalable topographic data, Texture files efficiently archived for application at different resolutions, Level of Detail (LOD) displayed relative to scale and Data streaming. Incorporation of these techniques allowed to distribute Virtual Kyoto over the Web.

The web-based version of Virtual Kyoto presents detailed models of temples, shrines, castles and other monuments that are UNESCO world heritage sites. A list of famous places of Kyoto is prepared on the left side of the screen so that users can instantly move their view points to the specified places. Users can also view the city from the selected site. Choosing a building on the map, viewer can call up web-search results that provide more information about it (Fig. 16).

We have also created a detailed model of the buildings and streets along Shijo high street that visitors can walk through and even enter the interior of the Minamiza Theater. In addition, we created a reconstruction of the same area of 1930's. This version of Virtual Kyoto works together with the 3D city

model of Heian era Kyoto, "Virtual Heiankyo on the Web". Keeping the same geographical position, users can switch the time period for the walk through scene just by clicking a button (Fig. 17).

VI. Conclusion: Towards the use of GIS in Digital Humanities

Our research will continue to reconstruct the historical city of Kyoto starting from the present going back to the past while making large varieties of digital contents which constitute urban landscapes at different time periods. At the final phase of this research, we intend to employ Virtual Kyoto as a platform to integrate a large collection of digital archives of arts and cultures in Kyoto. We are expecting that Virtual Kyoto will be a base for a newly launched project, "Digital Humanities Center for Japanese Arts and Cultures" in Ritsumeikan University.

According to Gregory (2007), Digital Humanities (also known as Humanities Computing or Computing in the Humanities), is a broad and rapidly growing inter-disciplinary field. It is concerned with using computational techniques to do the following: (1) Create databases concerned with documents or artifacts relevant to the humanities. This involves capturing, structuring, documenting, preserving and disseminating such data; (2) Develop generic methodologies to provide new insights into these datasets; and (3) Conduct



Fig. 16 Fly-through in Virtual Kyoto.
(upper) At Present.
(lower) At Heian era.



Fig. 17 Walk-through at Shijo street.
(upper) At Present.
(lower) At early Showa era.

new scholarship on these databases to increase our understanding of disciplines across the humanities. The last is the most important of the three but also perhaps the most neglected as it required inter-disciplinary collaboration between experts in technologies and methodologies on the one hand, and academics with specific research questions that they want to use information techniques to help answer. GIS with the time-dimension would provide a key tool in Digital Humanities because GIS can deal with any theme with spatial and temporal dimensions.

The capability of our web-based 4DGIS would form a new base for museology (museum studies). We can put various digital contents on our 4DGIS. The system would provide user-friendly interface to explore historical materials of arts and entertainments in the geographical context of Kyoto. This system should also play a valuable role in the assistance for urban landscape planning of Kyoto. Now in Kyoto we have serious issues concerning historical landscape conservation. Our virtual Kyoto would effectively support a decision making for alternative futures of Kyoto by contextualizing landscape planning in its historical settings.

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バーチャル京都

—時空間を取り入れた4次元GIS—

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バーチャル京都は、歴史都市京都の過去、現在、未来を探求することを目的に、コンピュータ上に構築されたバーチャル時・空間である。本研究では、最先端のGISとVR技術を用いて、複数の時間スライスの3次元GISからなる4次元GISとしてのバーチャル京都を構築する。本研究は、まず、現在の京都の都市景観を構築し、過去にさかのぼる形で、昭和期、明治・大正期、江戸期、そして、京都に都ができた平安期までの都市景観を復原する。

バーチャル京都を構築するためには以下のようないくつかのプロジェクトが行われた。a) 京都にかかる、現在のデジタル地図、旧版地形図、地籍図、空中写真、絵図、景観写真、絵画、考古学資料、歴史資料など位置参照可能な史・資料のGISデータの作成、b) 京町家、近代建築、文化遺産を含む社寺

など、現存するすべての建築物のデータベースおよびGISデータの作成、c) 上記建築物の3次元VRモデルの構築、d) 上記GISデータを用いた対象期間を通しての土地利用や都市景観の復原やミュレーション。

バーチャル京都は、京都に関連する様々なデジタル・アーカイブされたデータを配置したり、京都の繊細で洗練された文化・芸術を世界に発信したりするためのインフラストラクチャーである。そして、Webでのバーチャル京都は、歴史的な景観をもつ京都の地理学的文脈の中で、文化・芸術の歴史的データを探求するためのインターフェイスを提供する。さらに、バーチャル京都は、京都の景観計画を支援し、インターネットを介して世界に向けての京都の豊富な情報を配信するといった重要な役割を担うことになる。

キーワード：バーチャルシティ、3次元GIS、歴史GIS、日本芸術・文化、京都

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