Observations of Earthquake Vulnerability Transitions to Tokyo's Marunouchi Area Using a Urban Recovery Digital Archive on Google Earth

M., Igarashi[1] , O., Murao[2] and T., Sasaki[3]

[1] *Graduate School Student, Graduate School of Systems and Information Engineering, University of Tsukuba, Ibaraki, Japan*

[2] *Associate Professor, Graduate School of Systems and Information Engineering, University of Tsukuba, Ibaraki, Japan*

[3] *Former Student, College of Policy and Planning Science, University of Tsukuba, Ibaraki, Japan*

Email: igaras20@sk.tsukuba.ac.jp

ABSTRACT :

Worldwide historical evidence indicates that disasters result in changes to damaged cities during the recovery processes. Recent geoinformatic technologies now enable us to show the historical changes of cities on digital models of the Earth, such as Google Earth, by using old maps and aerial photographs. These representations can demonstrate the post-disaster recovery processes. As a case study, this paper explains how Google Earth was used to create an urban recovery digital archive for Tokyo's Marunouchi area that covered the period from 1907 to 2000 by applying the methodology the authors proposed in a previous research. The contents located onto Google Earth consisted of three-dimensional building diagrams, land use layers, viewpoints on earthquake vulnerability risks for building collapses, conflagration, and evacuation safety. The author used four criteria; the number of buildings, the building area, the road ratio, and the fireproof area ratio, in the analysis of the earthquake vulnerability risk transitions. First, using seven maps from 1907 to 2000, the author created land use polygon layers and analyzed the risk transitions by Geographic Information System (GIS). Second, the author constructed three-dimensional building diagrams at each point of in time using Google Sketch Up. The results were then loaded onto Google Earth and set up the urban recovery archive program so they would as they change according to timescale on the Google Earth.

KEYWORDS: urban recovery archive, Google Earth, historical event, earthquake vulnerability risks, Marunouchi

1. Background

The major disasters that destroy urban areas and facilities are often reflected in the recovery process and subsequent urban planning of the effected areas. Huge cities, such as London, Chicago and San Francisco were significantly altered by the conflagrations and earthquakes they experienced. Historically, Japan has suffered numerous disasters, and those disasters have significantly and dramatically altered the development of the nation's cities. They have also caused Japan to focus efforts on improving knowledge and technology related to disaster prevention and urban recovery, because it is felt that gaining a clear understanding of relations between disasters and the recovery processes is a very important component in urban planning and disaster prevention.
Today, geotechnology innovations are seen affecting urban environments. This technology is expected to be an important tool in the field of disaster prevention and recovery because, using this technology, it is now possible to see spatial changes before and after disasters. A notion of Where 2.0, which means next generation spatial information service, has possibilities of advancement for efficiency of disaster prevention. This is important because the technologies used to share and customize spatial information can help people become more conscious of the disaster risks of daily life.
Google Earth, which is one of the tools for sharing spatial information, offers strong potentials for raising such awareness because it is well-known, simple and easy to use. Saito *et al.* (2007) demonstrated how it is possible to use Google Earth to display the chronological transitions seamlessly by use of three-dimensional computer graphics and map data. Other research efforts also demonstrated applied possibilities of Google Earth as a common platform. Sasaki *et al.* (2007) proposed a construction methodology of urban recovery archive for using

Google Earth. While Murao *et al.* (2008), in order to record the reconstruction conditions of the Chi-Chi Township in Taiwan, which was struck by an earthquake in 1998, used a three dimensional representation of the city on a digitalized model accessible via Google Earth to create a networked visual representation. The Google Earth website also shows the chronological construction of skyscrapers in London since 1950. As a result, the authors felt that putting these research results to practical use would contribute to developing the field of urban disaster prevention.

2. Purpose of this research

The Authors intention is to record changes to urban environments and clarify the risks resulting from historical events such as major disasters in a way that allows ordinary people visualize such changes. By applying the methodology developed by Sasaki *et al.* (2007), this paper demonstrates the trial creation of an urban recovery digital archive of the Tokyo Marunouchi area (District 1 to District 3), from 1907 to 2000 and uses it as a case study on the methodology using Google Earth. The author chose Marunouchi is because it is a very characteristic area which developed rapidly as a Japanese business center after the Meiji era. The research began by using seven chronological maps of the area to create land use polygon layers, and utilizing GIS data to analyze the relation between urban environments, disaster risks and major historical events such as the 1923 Great Kanto Earthquake, World War II, the postwar Japanese economic miracle, the Japanese economic bubble, and other factors. In the second stage, three-dimensional building diagrams were constructed at each point in time relating to a specific map. The author then loaded the data onto Google Earth where the relationships and transitions scan be easily seen. Because the risk of earthquake disaster is omnipresent in Japan, this research will proceed from the viewpoint of building collapse risks, conflagration danger, and danger to evacuees.

3. Research methodology

Section 3.1. describes the methodology of the urban recovery archive constructed by Sasaki *et al.* (2007). In Section 3.2, using that methodology, a procedure is described that can be used to construct an urban recovery archive using the loaded urban environment transitions and earthquake vulnerability risks for the Marunouchi area. Section, 3.3 describes the criteria used by the author access earthquake vulnerability.

3.1. Construction of urban recovery archive methodology

3.1.1 Characteristics of Google Earth

The characteristics of Google Earth are provided below:

1) Function for unifying spatial information

Using this function, it is possible to combine aerial photographs, map data, digital contents, and diverse spatial layers and to apply them to the surface of a "Digital Earth". Because information on practically every urban area worldwide has been collected, systemized and uploaded onto the Google Earth networks, it can be expected that such information will be utilized in the recovery process of future disaster.

2) Ease of use

No special knowledge or skills are required to operate the system.

3) Interaction

Google Earth enables you to upload and share information on broadband network.

3.1.2 Archive construction procedure

The basic system used for constructing the urban recovery archive is described below:

1) Embedding image data

In the first step, digitalized map data needs to be trimmed and saved as image data. This image data should be linked to information that will explain to the viewer both the time and location the map data represents. These links are constructed using the A-GtoKML which is capable of creating KML files based on address, latitude, and longitude. When creating new KML files, users will be required to provide their name, address, explanatory text for the thumbnail image along with start and end timestamps for the image itself. This process is for setting up the location timescales and inserting place-marks. Both timescales and place marks are explained below.

2) Place-mark setup
This function allows you to load place marks onto Google Earth. It is also possible to load text information in the properties function using HTML tags. Users can also add the altitude to the thumbnail shown on the viewer. This function allows users to create a database with map layers shown at different altitudes.
3) Overlaying digitalized maps
The Google Earth overlaying function is used to layer image data. To use this function, images should first be loaded onto the viewer, in order, to create multiple overlaid maps. In the second stage, images need to be positioned accurately using the green marker for size changing, position, rotating, etc. (Figure 1). Alternatively, coordinate positioning can be performed precisely using the geo cording function.
4) Time scaling
Timescale is a function used to change the date seen by the viewer by making changes in the KML file. In order to use this function, after overlaying data onto Google Earth, the image file data must first be saved on the Desktop in KML file form. The user then needs to open the file as text and write the following programs into the file:

```
<TimeSpan id="ID">
<begin>...  </begin> <!-- kml:dateTime -->
<end>...  </end> <!-- kml:dateTime -->
</TimeSpan>
```

When used, it is first necessary to enter the time and date at which the data display starts between <begin> and </begin>, and when it will be finished between <end> and </end>. If the date contains single digit days or months, they must be written in the double-digit format using a zero in front of the digit, as seen the following example 1867-01-01. Then when the file is opened in Google Earth, the timescale should be correctly displayed (Figure 2).

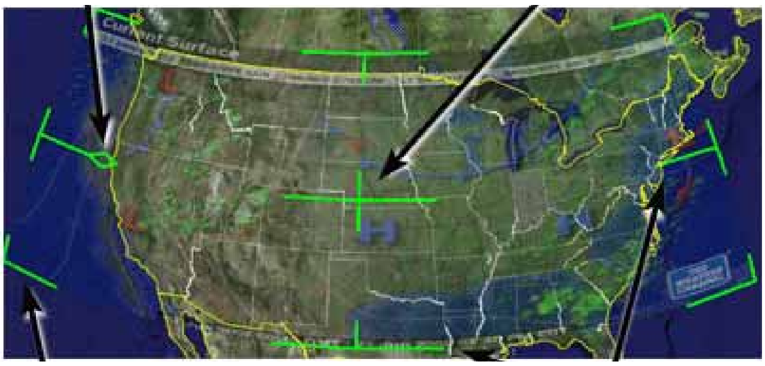

Figure 1 Marker for changing size, allocation, and revolve of the image

Figure 2 Timescale bar

3.1.3 Tokyo urban recovery archive
From left to right, Figure 3 shows transitions of Tokyo using the urban recovery archive. The pictures show the Edo period, the period of the 1923 Great Kanto earthquake and the World War II period.

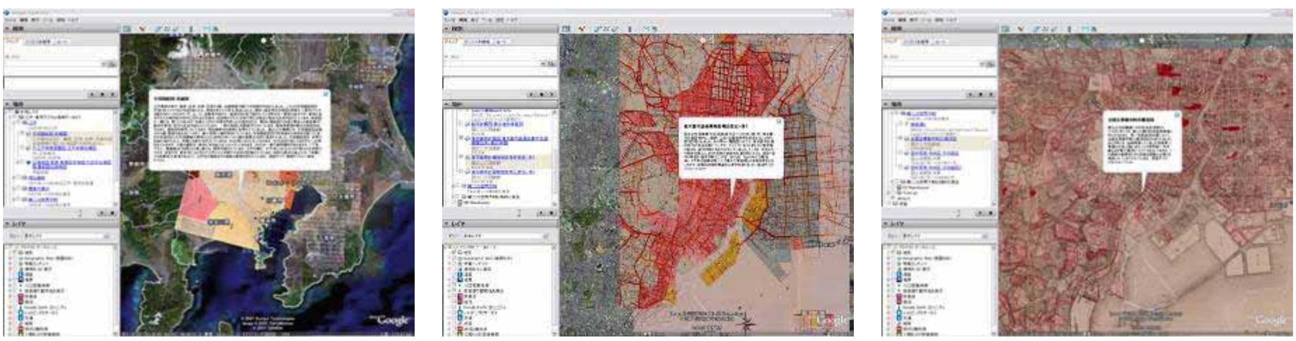

Figure 3 Tokyo urban recovery archive

3.2. Procedure for constructing urban recovery archives containing urban environment transitions and earthquake vulnerability risks

3.2.1 Collecting Map

The authors used seven maps (three different types) in this research. Table 1 shows the maps and provides specific information on each map.

Table 1 Maps used in this research [1]

No	Name of maps	Year	Information			
			Building			Land use
			name	structure	Floor	
1	The map of Kojima Ward in Tokyo	1907	×	×	×	block, road, river
2	The map of fire insurance before World War Ⅱ	1935	○	classifyed fireproof building and wooden building	×	block, road, rail road,etc
3	The map of fire insurance after World War Ⅱ	1955	○	classifyed fireproof building and wooden building	○	block, road, rail road,etc
4	ZENRIN Residential Maps of Chiyoda Ward, Tokyo 1976	1976	○	×	○	block, road, rail road,etc
5	ZENRIN Residential Maps of Chiyoda Ward, Tokyo 1986	1986	○	×	○	block, road, rail road,etc
6	ZENRIN Residential Maps of Chiyoda Ward, Tokyo 1993	1993	○	×	○	block, road, rail road,etc
7	ZENRIN Residential Maps of Chiyoda Ward, Tokyo 2000	2000	○	×[2]	○	block, road, rail road,etc

3.2.2 Creating a database

In the first step, the author scanned, digitalized and unified the seven maps using Adobe Photoshop, after which the map data was dragged to Arc Map, fitted with current division by manual geo coding and applied to the coordinates Japan_Zone_9. Once this was done, layers were constructed by creating building polygons, road polygons, etc., based on the loaded map data (Figure 4).

We analyzed the transitions of urban environments and earthquake vulnerability risks in Marunouchi, using map layers classified by land use and the criteria provided in 3.3 as they related to earthquake vulnerability risks. The overlaid data was then loaded onto Google Earth, and the polygon layers were set up so they could be modified with changes to the timescale.

3.2.3 Constructing three-dimensional building images with Google Sketch Up

We created three-dimensional renderings of Marunouchi area buildings using Google Sketch Up for six of the maps after 1935, which contained appropriate building information (Figure 5). These three-dimensional building diagrams were configured to change along with changes in the Google Earth timescale on the polygon layers. However, because there is no information regarding building heights for buildings in 1935 and 1955, the information had to be collected from the Internet.

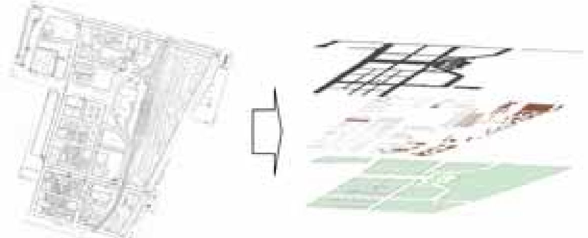

Figure 4 Constructing layers

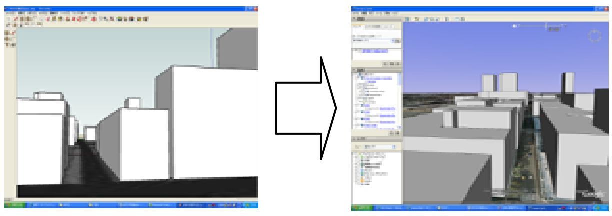

Figure 5 Constructing three-dimensional building images with Google Sketch Up

3.3. Regarding earthquake vulnerability

The earthquake vulnerability risks identified in this research are risks of building collapse, conflagrations, and evacuation danger. The criteria used for calculating these risks are provided below:

1) Number of buildings

Building types are classified into fireproof buildings and wooden buildings. Fireproof buildings are generally made from reinforced concrete or steel. When the number of fireproof buildings in an area increases, the risk of building collapse and conflagration declines. Alternatively, an abundance of wooden buildings in an area will result in an increase in risk of collapsing building and conflagration.

2) Building area

While building types are classified into fireproof buildings and wooden buildings, areas are classified based on the majority type of building they contain. Generally speaking, when the size of a building area increases, risks of conflagration and evacuee dangers increase as well. However, when both building types are present in the same building area, locations with more fireproof buildings have less fire risk.

3) Road ratio

This is a criterion that is calculated based on how roads are divided and distributed. The relations between road ratio and earthquake vulnerability risks are generally the opposite of the relations between building areas and risks because a bigger road surface ratio decreases conflagration dangers and facilitates evacuation efforts.

4) Fireproof area ratio

This criterion expresses the ratio of fireproof areas (fireproof building area, road area, open environment, etc) against the total area. The fireproof area ratio is calculated by use of the following equation:

$$FA = R + O (1- R- O) \times FB \quad (3.1)$$

FA: fireproof area ratio, R: Road ratio, O: Open space area ratio, FB: fireproof building area ratio

The author defined the open space area ratio according to the calculation method used by Tokyo Fire Department. If a fireproof area ratio is around 30% and a major earthquake occurs, the area ratio that can be expected to be totally destroyed by fire will be over 80%, so it is clear that such an area will be very dangerous when earthquake occur. However, if the ratio of fireproof buildings is 40%, the expected destruction declines to between 20% and 25%. And, if 60% or more of the buildings are fireproof, the very little destruction is likely to occur. Based on this and utilizing the criteria related to earthquake vulnerability risks the author analyzed the relationship between historical events, urban environment transitions and earthquake vulnerability.

4. Archive of urban environment and earthquake vulnerability for Marunouchi

Using the data from the seven maps for 1907, 1935, 1955, 1976, 1986, 1993, 2000, the author clarified the interrelations for urban environments and earthquake vulnerability on Google Earth while taking into consideration historical events such as the 1923 Great Kanto Earthquake, World War II, the Japanese post-war economic miracle, the Japanese economic bubble, etc. In Section 4.1, the results of the analysis are explained by criteria transitions, land use, and three-dimensional building images. In Section 4.2, Google Earth is used to introduce the urban recovery archive containing the results of the analysis.

4.1. Analysis of the transition of urban environments and earthquake vulnerability

Using the criteria related to earthquake vulnerability and three-dimensional building images constructed on Google Earth, the author analyzed transition of urban environments and earthquake vulnerability. Figures 6, 7, and 8 show transitions for the criteria of those buildings. Points from 1955 and 2000 are joined by dotted line in the case of criteria related to building structures, (Figures 6, 7, and 8). Next, Figure 9 shows the transitions of land use in Marunouchi from 1907 to 2000 created by use of Arc Map. Because there is no information regarding building structures during the period of 1976, 1986, and 1993, all the buildings for those years are shown as fireproof. Then, Figure 10 shows three-dimensional building images constructed from 1935 to 2000.

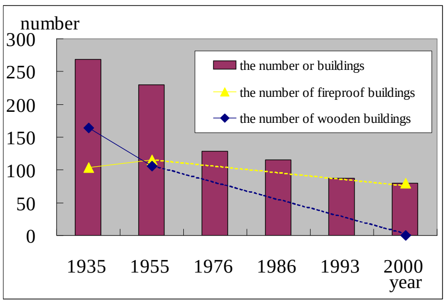

Figure 6 number of buildings

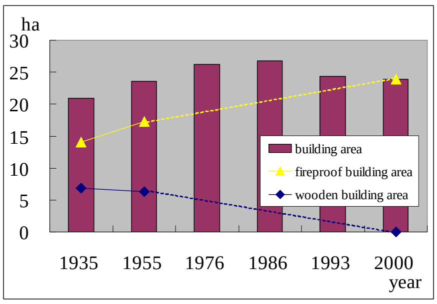

Figure 7 building area

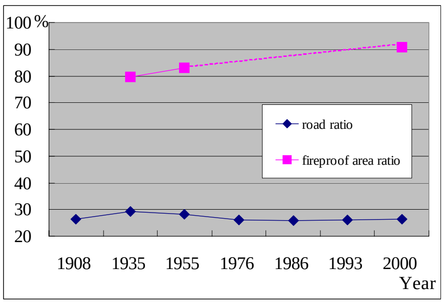

Figure 8 Road ratio and fireproof area ratio

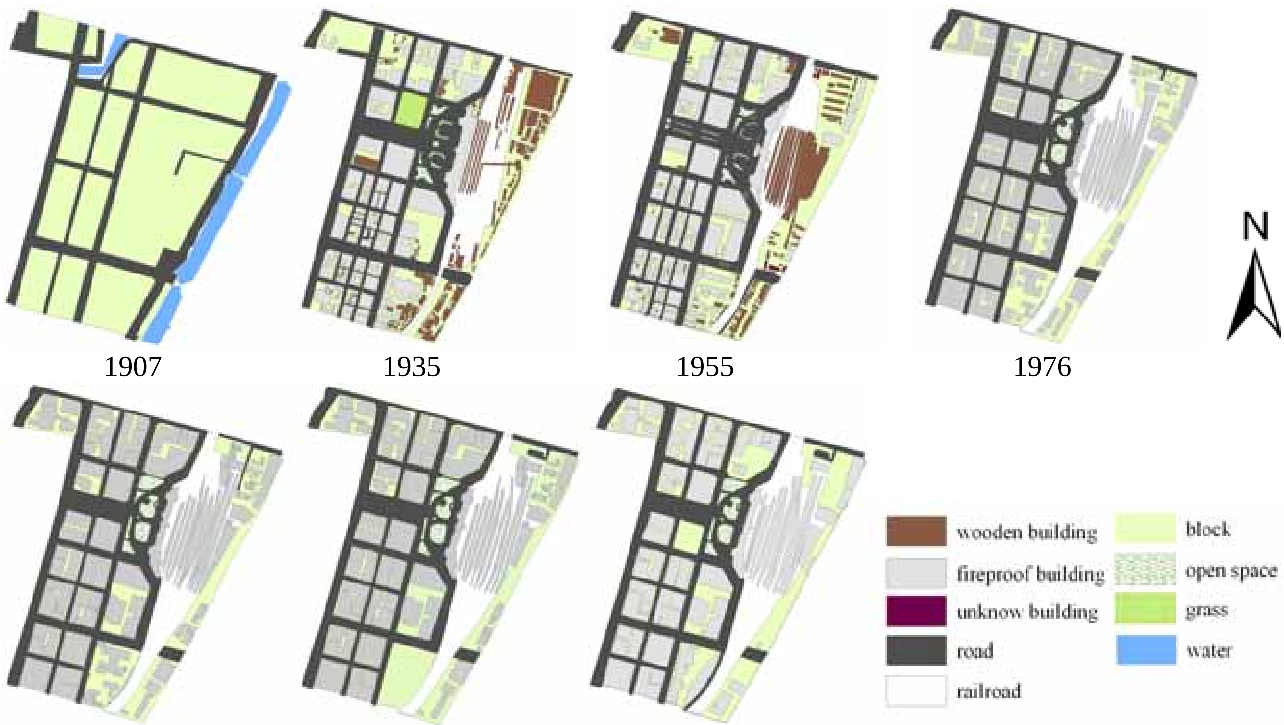

Figure 9 The transitions of building and land use in Marunouchi

Figure 10 three-dimensional building images in Marunouchi

4.1.1 Number of buildings

By observing Figures 6 and 9, it can be seen that the chronological decrease in the total number of buildings closely follows decreasing number of wooden buildings, while the number of fireproof buildings remained nearly stable since 1935. In 1955 the number of fireproof buildings and wooden buildings became equal, but by 2000 no wooden buildings remained. Because the Marunouchi area did not suffer major damage during the bombing of Tokyo in World War II, urban environment transitions were affected more by the building construction rush of the Japanese post-war economic miracle and the Japanese economic bubble than they were by the war. In Figure 10, the transitions of building aspects in Marunouchi can be seen. The decrease in the overall number of buildings and increase of high-rise structures were remarkable between 1955 and 1976. Due to the transitions based on the number of buildings, and building structure types, the risk of building collapse and conflagration in Marunouchi has continued to decrease.

4.1.2 Building area

Looking to Figure 7 and 9, it can be seen that the building area increases generally from 1935 to 2000. With the exception of the Tokyo International Forum, which was constructed in 1993, there were no new buildings built in the south small block of Marunouchi. As a result, the total building area decreased in 1993 compared with 1986. Then, in 2000, the total building area also decreased compared with 1993. This was caused by reconstruction of Marunouchi that began in 2000. This extended a trend that began in 1935 when the number of wooden buildings began declining and the number of fireproof structures began increasing rapidly. Figure 9 and 10 show the differences between 1955 and 1976. While there were many small buildings in 1935 and 1955, by 1976 almost all had been replaced by large office buildings. The number of large fireproof buildings constructed increased dramatically after World War II and The chronologically progress of Marunouchi kept pace with the overall decline in conflagration risk due to its declining wooden building area and increasing fireproof building area.

4.1.3 Transitions of blocks, road ratio and fireproof area ratio

Figure 8 shows transitions to the road ratio and fireproof area ratio. As can be seen in Figure 9, land use in Marunouchi made significant transitions between 1907 and 1935. Areas of the Imperial Palace Moat were reclaimed and roads were constructed, with the most outstanding change being the construction of the road that accompanied the construction of Tokyo station itself. It was called Gyoko road and it extends from Tokyo station to the Imperial Palace. A number of other roads surrounding of Tokyo station were constructed at that time. Even though the Great Kanto Earthquake occurred in 1923, historical evidence indicates very little in the way of relations due to the earthquake. This is because Marunouchi did not suffer much damage from the earthquake, and the Tokyo metropolitan government did not designate the Marunouchi area for readjustment. It is apparent that community leaders and government officials had decided that Marunouchi was to be the biggest office center in Japan.

While roads were constructed between 1907 and 1935, there was little change to the road ratio. This is because the roads that were in the east of Marunouchi were moved out from Marunouchi area into Yaesu area after the moat area was reclaimed. As a result, the road ratio remained mostly stable for 90 years. Roads construction was well-balanced between 1907 and 1935, and evacuation procedures improved during that period. Meanwhile, the ratio of fireproof buildings continued to increase. This change was most evident in the fireproof building area which kept expanding until it comprised over 90% of the area by 2000. Taken all together, it is clear that Marunouchi has been extremely resistant to earthquake related disasters since 1935.

One characteristic of the urban spatial transitions in Marunouchi resulted more from the Japanese post-war economic miracle and the Japanese economic bubble than by disaster (such as the 1923 Great Kanto Earthquake and World War II) is that in the last years of the 19th century, the design of Marunouchi as the nation's business center was solidified. This design resulted in the dramatic transitions to Marunouchi after World War II and resulted in a reduction of earthquake vulnerability accompanied by continuous modernization.

4.2. Presentation of urban recovery archive on Google Earth

Figure 11 shows the urban recovery archive constructed in this research. Three-dimensional building images and land use layers change according to the time scale. Information on the results of analysis and explanation are also folded in the place mark locations. Using Google Earth it is possible to see transitions of three-dimensional building images, land use and earthquake vulnerability for the Marunouchi district.

Figure 11 Urban recovery archive constructed in this research

5. Conclusion

The author created an urban recovery archive consisting of transitions relating to buildings, land use, and earthquake vulnerability risks for the Marunouchi and uploaded it to Google Earth, applying the methodology constructed by Sasaki *et al.* (2007). During the first part of the project, the author created polygon layers at seven points in time, from 1907 to 2000 and analyzed transitions of earthquake vulnerability. In the second phase, the author created three-dimensional buildings using Google Sketch Up and then loaded the polygon layers, three-dimensional building images, and earthquake vulnerability assessments onto Google Earth. Risk explanations and related transitions were also loaded. This paper explains how these transitions can all be easily visualized using the Google Earth platform.

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Note
[1] The map of Kojimach Ward in Tokyo, The map of fire insurance before World War Ⅱ,and The map of fire insurance after World War Ⅱwere provided by Tokyo Metropolitan Library. ZENRIN Residential Maps of Chiyoda Ward, Tokyo from 1976 to 2000 were provided by National Diet Library.
[2] According to the Sixth Report of Survey of the Earthquake Area Vulnerability Assessment, there are no wooden buildings in Marunouchi in 2000. Therefore the author regarded all buildings as fireproof buildings in 2000.

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