Constructing a Digital City on a Web-3D Platform

Simultaneous and consistent generation of metadata and tile data from a multi-source raw dataset

Toshikazu Seto
Center for Spatial Information Science
University of Tokyo
Chiba, Japan
tosseto@csis.u-tokyo.ac.jp

Yoshihide Sekimoto
Institute of Industrial Science
University of Tokyo
Tokyo, Japan
sekimoto@iis.u-tokyo.ac.jp

Kosuke Asahi
Association for Promotion of Infrastructure Geospatial Information Distribution
Tokyo, Japan
asahi@aigid.jp

Takahiro Endo
Association for Promotion of Infrastructure Geospatial Information Distribution
Tokyo, Japan
takahiro.endo@aigid.jp

ABSTRACT

In this study, we develop a platform that can display approximately 20 types of data via a web browser to realize a digital twin of a wider area, including a detailed reading display of block units and individual three-dimensional point cloud data (point cloud) of a city. Using actual data, we examine if the data model and visualization design correspond with the zoom level. Owing to the comparative examination of the wide-area display performance and the map representation design in a JavaScript-based open-source library, we were able to develop a platform with light architecture and an easily customizable display. Furthermore, prototyping, based on Mapbox GL JS and Deck.GL, and the display of spatiotemporal flow layers, such as background maps, point cloud data in many places, dozens of layer display types, and the General Transit Feed Specification (GTFS) allowed for the seamless transition from the local government to the wide-area display in the prefecture unit in approximately 10-20 s.

It is recommended that this digital smart city platform should be standardized by other local governments, especially in areas where higher-order data visualization is yet to advance. To display this digital city in a lightweight environment, we consider the digital data situation of local governments in Japan. It is necessary to define the visualized design for each zoom level according to the characteristics of the data. We then arranged the display model of each zoom level for 20 types of urban infrastructure data related to the digital smart city by referring to the style schema of the tile form. Through these tasks, we organized the commonality and optimization of data models and formats.

CCS CONCEPTS

•Information systems → Data management systems →Database design and models

KEYWORDS

Digital city, Infrastructure 3D tiles, Deck.GL, Mapbox GL JS

ACM Reference format:

Toshikazu Seto Yoshihide Sekimoto, Kosuke Asahi, and Takahiro Endo. 2020. Constructing a Digital City on a Web-3D Platform: Simultaneous and consistent generation of metadata and tile data from a multi-source raw dataset. In *3rd ACM SIGSPATIAL International Workshop on Advances on Resilient and Intelligent Cities (ARIC'20)*, November 3–6, 2020, Seattle, Washington, USA. ACM, New York, NY, USA, 9 pages. https://doi.org/10.1145/3423455.3430316

ARIC'20, November 3–6, 2020, Seattle, WA, USA

ACM 978-1-4503-8165-9/20/11…$15.00
https://doi.org/10.1145/3423455.3430316

1 Introduction

In recent years, as information communication technology (ICT) and the digitalization of cities have progressed worldwide [1], we have noted a growing number of digital smart cities. In addition to the sensing data measured in real-time, there is a vast amount of data, including three-dimensional (3D) models. This digitalization is an essential step in the construction of a digital city that integrates these data. In the realization of smart cities, a need to build digital city infrastructure exists, especially for administrative agencies. Because the amount of data is vast, there are high expectations for secondary use, such as maintaining and updating the data by converting it into a database as big data and sharing it appropriately through licenses, such as open data.

To promote open innovation in Japan, electronic delivery data, such as point clouds, which are datasets that represent objects in space, and aerial photography data captured by drones, have been accumulated by public institutions, including local governments. It is expected that the open data and distribution environments, such as "My City Construction" developed by the authors, will make it easier to use the construction results.

In contrast, infrastructure data, such as 3D point clouds, measured in design and construction drawings, are used for designing and constructing individual items. They are not only handled as data but also seamlessly integrated with various two-dimensional (2D) map data and 3D building models. As a result, it is possible to visualize a city block by block and survey the entire city by combining the infrastructure data. Furthermore, it is possible to understand the distribution and status of the infrastructure systematically.

In this study, we propose a method for seamlessly analyzing the raw data of urban models on the web. Open source GIS (FOSS4G) is well suited to the flexibility of the multidimensional and diverse forms involved in smart cities, and can be applied to urban spaces of varying scales by focusing on techniques for visualizing the administrative data generated in a city. We create a platform to explore architectural designs to ensure efficient conversions and a unified visualization that enable users to visualize the data in three dimensions. Through this approach, we also developed the necessary features. In this study, we focus on Susono city, Shizuoka Prefecture, where Toyota plans to build a new smart city called "Woven City."

In Section 2, we focus on the visualization of 3D city models using the Web Graphics Library (WebGL), referring to the relevant research on the platform and the need for a platform with data integration. Section 3 provides an overview of the regions and the data covered in this study. In Section 4, we examine the architectural design of an integrated visualization of these data, and Section 5 describes some of the actual data transformations in which we determine how much we can reduce the data size of the browser. Section 6 describes the results of integrating and visualizing the transformed data. Section 7 provides the conclusion and discusses future issues.

2 Related Works

In the past, visualizing city model data with 2D and 3D elements involved using stand-alone applications and drawings, which needed equipment with a high degree of computational power. The release of Google Earth in 2006 and the rise of various open-source technologies have led to the development of several new technologies. As a result, the generalization of the visualization system has rapidly progressed. In particular, a standard specification for displaying 3D computer graphics on web browsers, i.e., WebGL, was established in 2011. Subsequently, the technical representation capability has improved dramatically, making it easier to share 3D models.

Stoter et al. [2] discussed smart cities, digital twins, and the current state of 3D urban modeling in computer-based urban spatial analysis in which they reviewed model consistency, standardization, data quality, data interoperability, and data maintenance. Albeaik et al. [3] developed a fully automatic 3D modeling pipeline that utilizes a low-resolution noisy LiDAR dataset to create a city-scale 3D model. Kang and Lee [4] examined WebGL-based tiles and developed a data-oriented rendering method for wide-area buildings. To integrate building information models (BIMs) in the industry foundation classes (IFC) data format, Chen et al. [5] discussed the visualization and stylization of 3D objects online. They used the 3D tiles specification, created by Cesium as an open specification for streaming IFC data using tiles as a case study. Netek et al. [6] studied markers with large-scale data. They conducted comparative experiments on clustering and heat map visualization techniques in which they established that Mapbox GL JS is better than Leaflet or OpenLayers, which have a long history of development. They achieved the best performance, partly because their techniques are suitable for GPU-based computing.

We used one or some types of big data from previous studies to create the dynamic visualization in this study. We then propose a new method of visualization through WebGL. However, when realizing a digital twin, it is crucial to be able to display not only individual data and management, as noted in previous studies, but also scalable building data at the city level, as well as the human and logistics flow data on a web browser to reproduce realism in a virtual space [7-8]. Therefore, in the following sections, we discuss the complex and multifarious datasets available in the study area, where we organize the data architecture and transformation flow, and build a prototype of the platform.

3 Data Properties of Study Area

Although smart cities are currently attracting worldwide attention, the digitalization of cities in Japan has not been widely observed. Conversely, the aging population, aging infrastructure, and citizens' concerns regarding future city planning have become social problems. It has become crucial for local governments to respond clearly to citizens in a data-driven environment. The applications and models that contribute to the maintenance and management of the infrastructure and forecasting the needs of the city should be easy to use.

In this study, we build a prototype platform for Susono city (located in the Shizuoka Prefecture, where Mt. Fuji is located, with a population of approximately 50,000 and an area of 138.4 km^2) which is considered as a data-driven city by the government because of its various types of infrastructure data. Moreover, we have made the platform available online.

Susono City is located at the foot of Mt. Fuji and is relatively close to the Tokyo metropolitan area. On the other hand, with a population of 51,000 and an aging population of 26.8% as of 2020, and with public facilities such as railways not being very convenient, the revitalization of local industry and the enhancement of urban infrastructure have become issues for the future of the people's lives. Therefore, in November 2018, the city became the first local government in the prefecture to formulate a plan to promote the use of public-private data, which includes a new perspective of data and digitalization in administration and urban planning to solve these issues. In July 2019, the "Digital Susono Research Group" was established with a partnership agreement with the Institute of Industrial Science of the University of Tokyo and Code for Japan through research activities. "Digital Susono Research Group" was established to specifically promote the use of data and digitalization in Susono City. It decided to carry out urban development with digitalization.

Also, Susono city announced the concept of the Susono Digital Creative City in March 2020. This was in response to Toyota's announcement of the Connected City project, which will be followed by a demonstration of the Woven City in a few years [9]. The flow of people and their lifestyles are expected to change significantly in the next few years. Therefore, it has become vital to propose future scenarios and data-driven city planning using existing urban data.

Based on the above, we discussed the data corresponding to the five issues on Working group (**Table 1**), which we are focusing on in the "Digital Susono Research Group", from various types of geospatial information held in or related to Susono City, with administrative officials of Susono City, and collected the basic contents, mainly from existing open data. The themes based on the "Data Academy" program training conducted with Code for Japan in previous years, and after repeated discussions with experts and stakeholders from the private sector who participate in the "Digital Susono Research Group".

Table 1: Major Issues and Data Usage Target in Susono City

Issues	Target	Task
Public facilities	A state of mind that citizens can use with confidence.	The public facilities management debate is not deep enough.
Public transportation	With no one bothering to use bus routes to get around.	Bus ridership is low, and at this rate, the bus route cannot be maintained.
Urban planning	Improving the station area's foothold and the state of interaction between the various generations.	Directing and consolidating urban functions and residential areas, which are daily life service facilities.
Industry and tourism	Regardless of size, the industry as a whole is capable of leading the region.	No consideration has been given to addressing the impact of Waven City once it is built.
Road management	Accidents among road facility users are now preventable.	Difficulty in ascertaining the appropriate timing for the repair and replacement of road facilities.

Table 2 shows an overview of the digital data that will be posted on the platform built in this study. There are 113 different datasets, ranging from tens of kilobytes to several gigabytes. Furthermore, some of the data are characterized by the fact that they have 3D shapes and time attributes. The 3D point clouds were not available for Susono city. Therefore, we used five samples from the Point Cloud Database (PCDB), an open data site in Shizuoka Prefecture [10]. This overview will be presented in the next section.

Table 2: Overview of Dataset in Susono City

Data type	Dataset	File format	Files	Total size
Back-ground data	Aerial photo	GeoTIFF	257	13.4 GB
	Building shape	ESRI Shape	1	1.98 GB
Point cloud	Point cloud (in Shizuoka Prefecture)	LAS	5	12.01 GB
Feature data	Facility	CSV	7	50 KB
	Road network	ESRI Shape	2	1.1 MB
	Road image	ESRI Shape	2	100 KB
	Railway	GeoJSON	2	810 KB
	Urban planning	ESRI Shape	8	635 KB
	Administrative boundary	ESRI Shape	1	470 KB
	Disaster mitigation zoning	ESRI Shape	21	2.1 MB
Flow data	Bus route and bus stop	GTFS	14	200 KB
	Business transaction	CSV	3	560 KB
	People flow	CSV	2	149.8 MB

4 Architecture Design

As outlined in Section 3, a detailed reading of the individual 3D point clouds and data management are not enough. Instead, it is necessary to integrate each data as a digital city. Alternatively, as 3D building data, multiple 3D point clouds, and, in the future, dynamic data, we have developed a system that allows for the scalable display of human and logistics flows and other data in a web browser. The feasibility of the architecture was then studied. Open-source software, such as Cesium.js, NASA World Wind, and mago3D, are typical platforms. In Japan, there is the Geographical Survey Institute Globe, among others. Of these platforms, Cesium.js and mago3D are the most popular WebGL-based libraries. The WebGL-based platform has a high degree of versatility and can be used to visualize urban data and introduce examples used in BIM/CIM.

In contrast, Japan has been promoting ICT and digitalization policies in civil engineering since the late 2010s, called i-Construction. The purpose of this study is to improve the productivity of the entire construction production system, from design data to post-completion surveying. The volume of infrastructure data is expected to increase in the future. Additionally, it should be noted that there are many other kinds of data, such as city model data, movement data of people, and data regarding other activities in cities. Lightweight rendering based on WebGL is required to seamlessly visualize the data on a web browser without increasing the load on the user side.

In this study, we adopted an architecture that is the lightest and most customizable, as shown in **Figure 1**, after comparing the performance and design of map representation in a JavaScript-based open-source library. It is mainly derived from Mapbox GL JS (Mapbox). Deck.GL (Uber Technologies) enables diverse data visualization at large scales. Prototyping a 3D infrastructure data collaboration platform using Mapbox GL JS v.1.6.1 is possible as of May 2020. Mapbox GL JS follows the v.0.50.0 Mapbox design and customization tool and several map APIs. It can be read and visualized in an integrated manner and rendered in conjunction with third party layers. Mapbox can read an extensive and wide range of map data at high speed. Mapbox was an early pioneer in the field of vector tiling and developed conversion tools for various types of tiling. The platform was built to handle data of various file formats smoothly.

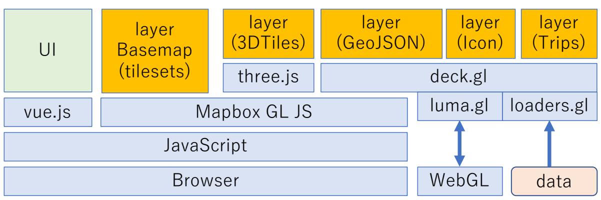

Figure 1: Configuring the architecture on the platform

In addition to large amounts of static data, there is also a need for building a realistic digital twin. Flow data, such as daily human movement and public transportation in a city, as well as laser-measured 3D point clouds of infrastructure, such as civil engineering and cultural heritage structures, are dynamic data that need to be implemented such that allows it them to be easily understood and visualized. The implementations that visualize dynamic movements, such as point cloud data, are necessary. For the flow data, Deck.GL v.7.3.9, which is a WebGL-based framework. This component is part of vis.gl, which speedily displays vast amounts of geodata. They are interactive visualizations of people's movements and clustering of data. The following point clouds are used to measure buildings and structures with high densities through laser surveying. We developed a new method for reproducing the state of the real space as digital data using the following methods. However, the size of the data was significant compared to the aerial photographs and outline data of the buildings. Therefore, a certain amount of thinning was performed to speed up the display of the data on the browser.

The 13 types of data displayed on the platform as layers are shown in Table 1. However, they are displayed as static GeoJSON, which converts the data to JSON and displays it with time elements, and Icon flow data which converts it to 2D, 2.5D, and 3D elements. They are classified into three primary conversion methods for the tile display, and then, displayed on the platform. The zoom level of the map is then set. The zoom level is determined based on Google Maps and other platform examples. While there are more data layers than ever before, the icons and shapes overlap with each other. Therefore, we selected the most appropriate zoom level to avoid displaying these overlaps. Additionally, visualizing multiple layers prevents unnecessary data from being read. In the next section, we describe the data conversion in detail, based on the method displayed in **Figure 2**.

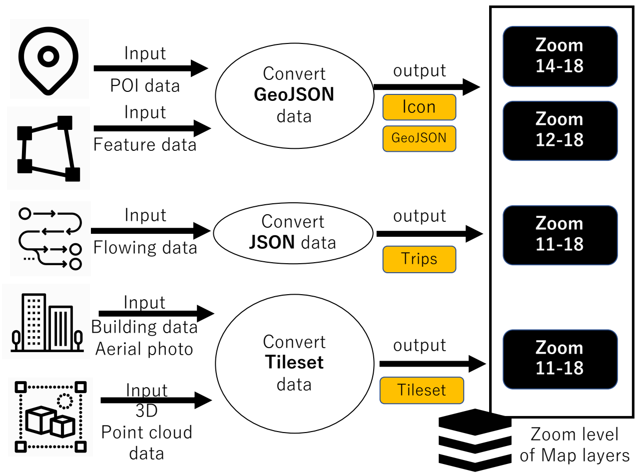

Figure 2: Conversion flow of the dataset and zoom level of the map layers for platform visualization

5 Data Transformation

5.1 Background data

The data used as a background map for the city model are from the Center for Spatial Information Science, University of Tokyo and are available in the Joint Research and Application System (JoRAS). In the Shizuoka Prefecture dataset, shape version in 2006, (provided by Zenrin Co., Ltd.), there are two datasets of buildings in the Shapefile-based dataset. These data were provided as polygon data for each building in a nationally uniform format. Because one of the main attributes is the number of stories, the height of the building can be changed according to the number of stories when it is rendered as 3D data. It is possible to express this as follows:

The data from approximately 2,347,000 buildings are lightweight and seamless on Mapbox GL JS. To read the vector tiles, which are tiled and machine-readable data delivery methods, we need to use the open-source conversion tool "Tippecanoe" to change the zoom level of the binary vector tiles (.pbf) from 14 to 18 (**Figure 3**). Based on the Mapbox style, it is possible to vary the number of floors of a building by a unit of 1 m and change them by a specific factor.

The background image was sourced from the GSI Tiles created by the Geospatial Information Authority of Japan. The latest aerial photographic layers (since 2007) were loaded, as well as the most recent ones obtained by Susono city independently. Additionally, the aerial photos were converted using gdal2tiles.

By applying these processes, even a static city model, which can be significant when drawn over a wide area, can be rendered using tiles. Therefore, the tiles were retrieved from the server in turn, each time according to the required spatial extent and zoom level. The volume of data acquired within the display range can be tens to hundreds of MBs.

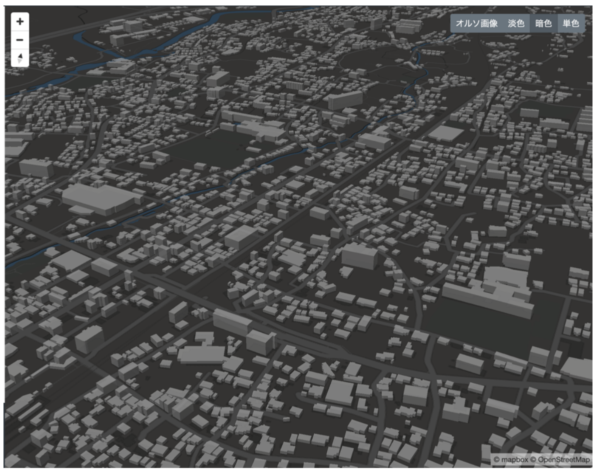

Figure 3: 2.5D tileset display using the building's external shape data

5.2 Flow data

The data that comprise the digital twin are not only static but also include human mobility and public transportation data. The existence of the flow data on the operation of institutions and the connections between regions is essential. However, some of these data are not necessarily standardized, and the data size tends to be considerably large, which puts a higher load on the memory than background data. Therefore, these data cannot be transformed uniformly. However, they can be converted to the JSON format using our Python script. The display on the platform was visualized using a feature of Deck.GL (Trip layer).

5.2.1 General Transit Feed Specification (GTFS) data. Stops.txt (stop coordinates) and shapes.txt (route shapes) converted the data to GeoJSON point and "LineString" data, respectively. We visualized this using the GeoJSON layer. Additionally, combining trips.txt (bus number information) and stop_times.txt (transit time) generated the combined data of latitude and longitude coordinates and timestamps. Because the data volume comprised 3 routes and 118 bus stops, no thinning was performed.

5.2.2 Business transaction data. Three years of transaction data (CSV), consisting of 350 nodes for each year from 2015 to 2017, was converted to the JSON format and visualized. The latitude, longitude, and volume data of the order were processed as JSON to generate "ArcLayer" and "ScatterplotLayer" using Deck.GL. We used "TripsLayer" to visualize these datasets.

5.2.3 People flow data. These original data collected from the University of Tokyo's CSIS, "People Flow 2016 Higashi Surugawan Metropolitan Area." They comprised a CSV file with the latitude, longitude, and time stamps for 600 IDs on weekdays and 800 IDs on holidays. The data were converted to the JSON format and visualized using TripsLayer. The original file was 63.1 MB on weekdays and 86.7 MB on weekends, and it is still available on the platform. We reduced the size to approximately two-thirds of the original size because of the high load on the display.

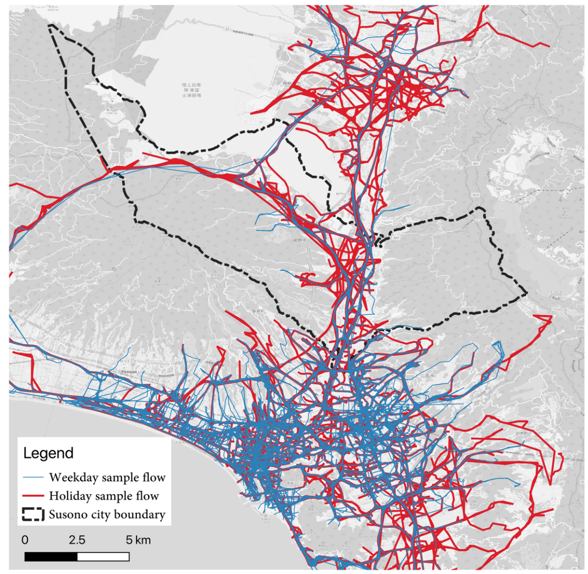

Figure 4: Display range for the flow of people Susono city on weekdays and holidays

5.3 Point clouds

In this section, we discuss the transformation and superimposition of 3D point clouds not found in Susono city. In this study, we use five samples collected from the Shizuoka Prefecture (**Table 3**). By overlaying these data with other data, it is possible to convert them into 3D tiles and display them.

Here, we readjust the coordinates of the LAS data to optimize the display on the browser. Using v.2.1.0 of the Point Data Abstraction Library (PDAL), we convert the point density to 3D tiles after thinning the density to approximately 10 cm. We used py3dtiles (Oslandia) to create five samples. The sample data size was increased from the original file size of 50 MB to 6.5 GB for the largest sample. However, by converting these tiles to 3D tiles, the data size was reduced from approximately one-half to one-tenth. It was noted that the size could be compressed from approximately 30 MB to a maximum of approximately 350 MB.

Figure 5 shows an example of a single layer after conversion. It represents the Nirayama Reverberatory Furnaces. The size of the converted data is 82.9 MB, which makes it possible to display the model on the browser with a relatively small footprint.

Table 3: Sample Point Cloud Datasets

Name	X, Y, Z points	Original file size (MB)	3D tiles file size (MB)
Place A (28-D0201-01)	22,854,836	594.2	344.1
Place B (29-K2452-01)	2,141,686	55.7	34.7
Place C (28-K2450-01)	2,301,317	59.8	32.3
Place D (Kakegawa Castle)	192,366,079	6,540.0	64.3
Place E (Nirayama Reverberatory Furnaces)	182,440,910	4,740.0	82.9

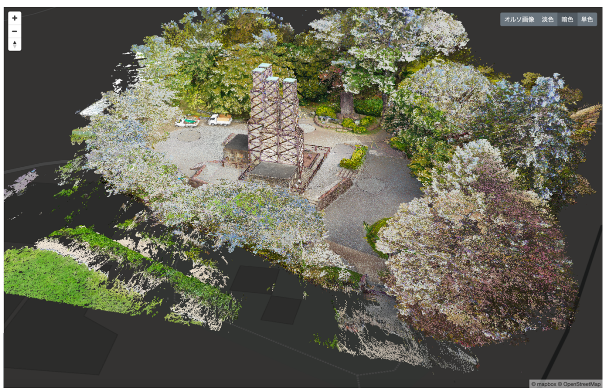

Figure 5: 3D tiles display using 3D point clouds (Place E)

5.4 Comparison of datasets

As described above, to build a digital city that can be viewed on a web browser, various conversions and optimizations were performed according to the raw data. The crucial points here involve the need to unify the data formats and reduce the size of the files that are suitable for rendering on the web. The conversion formats, size optimization, and zoom level settings for each data are shown in **Table 4**.

Figure 6 shows the results of the conversion of lightweight data, mainly at the level of a few MB, to the GeoJSON format. The zoning data and data with complex shapes, such as business transactions, can be used to reduce the data weight. However, the size of the road network data and administrative areas initially increased by two to four times. However, because the maximum volume after conversion was only 4 MB at most, there was no significant impact on data size.

Additionally, we decided to convert relatively large amounts of data to tile data. However, the comparison and verification of the compression ratio and processing time for the conversion of each data are still necessary. Therefore, the objects on this platform include aerial photos and the exterior data of buildings. We conducted a comparative study of the point cloud data, as shown in **Figure 7**. The hardware and software used for doing so were as follows:

- CPU Core: i7-9700k @3.60 GHz, Memory: 32 GB
- OS: Windows 10 Subsystem for Linux (Ubuntu 18.04)

As a result, by tiling all three types of data, we can reduce the size of the data to between one-fifth and one-tenth of the original size. Conventional visualization methods had difficulty in displaying multiple, large-volume layers simultaneously. By using such a conversion method and optimization, it is possible to have many points of interest. Additionally, the background map, building outlines, and point clouds can be displayed simultaneously. Furthermore, the processing time for building outlines and point clouds was not significant.

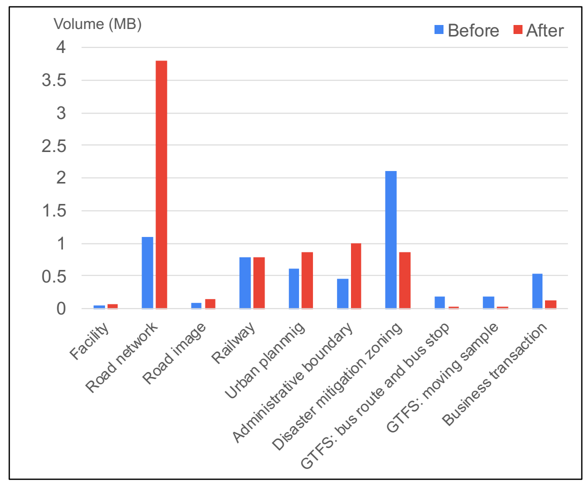

Figure 6: Comparison of transformation data size of fundamental geospatial datasets

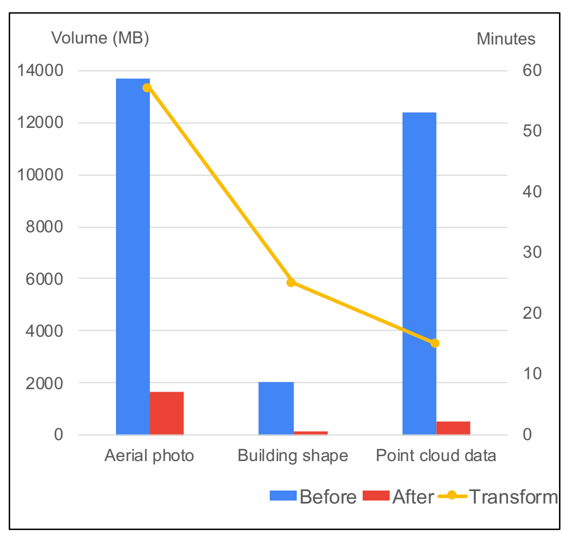

Figure 7: Comparison of transformation data size and conversion time of large geospatial datasets

Table 4: **Summary of Datasets for Constructing the Platform**

Data type	Dataset	File format	Files	Total size	Number of objects	Transform file format	Transform file size	Zoom level
Back-ground data	Aerial photo	GeoTIFF	257	13.4 GB	257 photos	Raster tile	1.6 GB	11-18
	Building shape	ESRI Shape	1	1.98 GB	871705 shapes	Binary vector tile	145.9 MB	13-18
Point cloud data	Point cloud data	LAS	5	12.01 GB	5 places	3D vector tile	531 MB	11-18
Feature data	Facility	CSV	7	50 KB	224 points	GeoJSON	80 KB	13-18
	Road network	ESRI Shape	2	1.1 MB	1938 routes	GeoJSON	3.8 MB	14-18
	Road image	ESRI Shape	2	100 KB	291 shapes	GeoJSON	150 KB	12-18
	Railway	GeoJSON	2	810 KB	7 routes	GeoJSON	810 KB	Route: 9-18 Station: 12-18
	Urban planning	ESRI Shape	8	635 KB	73 shapes	GeoJSON	900 KB	12-18
	Administra-tive boundary	ESRI Shape	1	470 KB	100 shapes	GeoJSON	1 MB	12-18
	Disaster mitigation zoning	ESRI Shape	21	2.1 MB	443 shapes	GeoJSON	884 KB	14-18
Flow data	Bus route and bus stop	GTFS	14	200 KB	3 routes 118 points	GeoJSON	40 KB	Route: 12-18 Bus stop: 15-18
	Business transaction	CSV	3	560 KB	300-350 nodes	JSON	130 KB	11-16
	People flow	CSV	2	weekday: 63.1 MB holiday: 86.7 MB	weekday: 600 IDs holiday: 800 IDs	JSON	weekday: 27.6 MB holiday: 37.3 MB	11-18

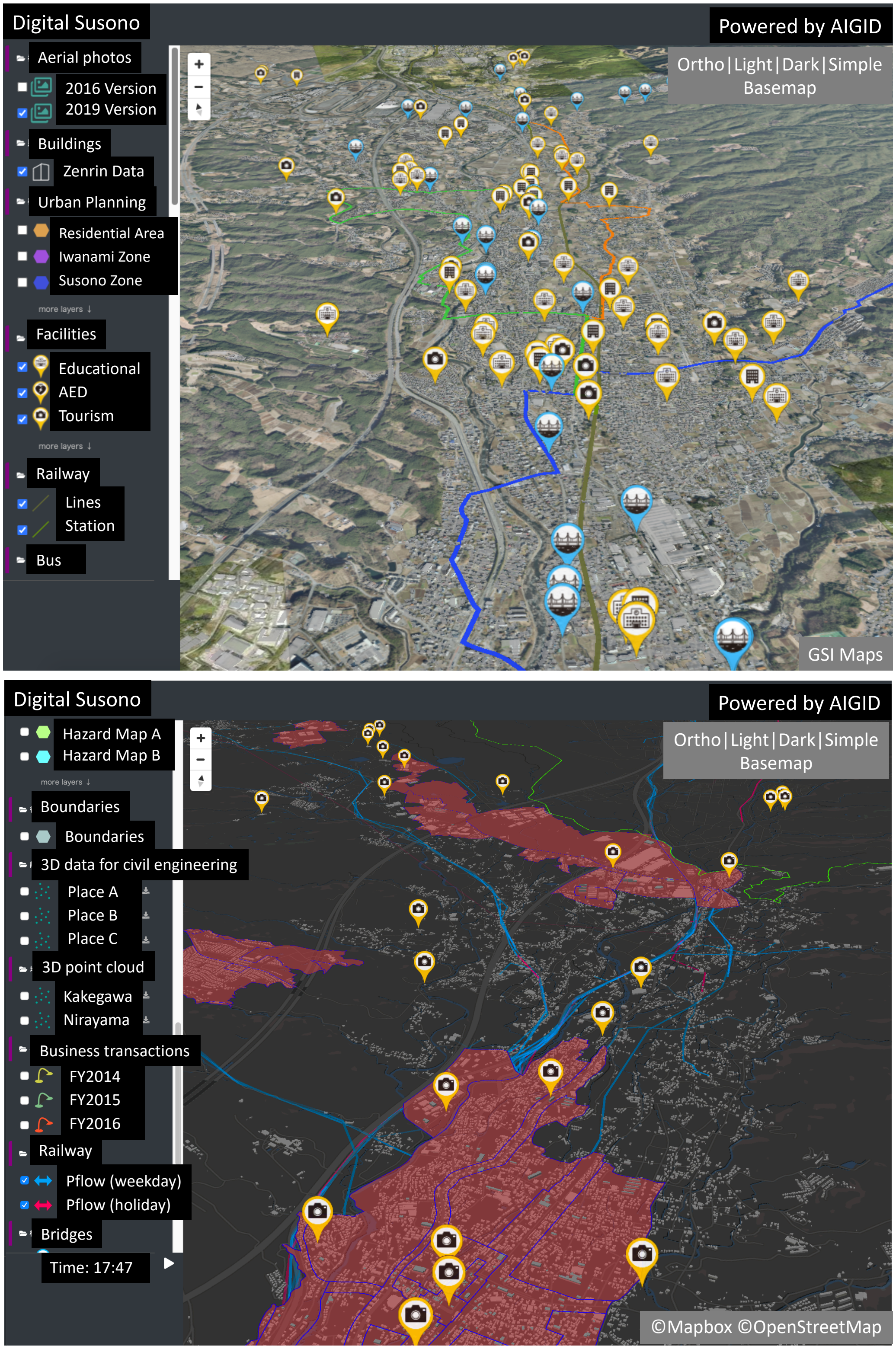

Figure 8: Construction of a digital city platform interface for Susono city (up) and the initial screen (below) overlaid with zoning data and human flow data with time range

6 Data Integration

After processing and transforming the abovementioned various data based on their architecture, the digital city platform prototype with three dimensions and time axis data integration was built. Figure 8 shows the initial screen of the platform with some superimposed data, which we measured using Firefox v.67.04 (Zoom level 16). The read cache size of approximately 180 MB is within the intended range, and the memory usage is about 780 MB. The CPU usage was approximately 10%. Additionally, dynamic display examples tested using the regional zoning data of weekday and holiday human flow data were superimposed on the regional zoning data for weekdays and weekends. The results show that the additional cache size is approximately 60 MB when two types of people flow data are added. The memory size was approximately 800 MB. However, the CPU used about 20-30% of the memory, whereas the GPU used approximately 30%.

Similarly, it was found that the load on the 3D point cloud data, such as the people flow data, increased at the same rate. Specifically, in the vicinity of the Nirayama Reflection Furnace (the original data was about 4.8 GB, compressed into tiles and compressed to about 80 MB) as shown in **Figure 5**, the cache size was 780 MB for the 3D point cloud data of the Nirayama Reverberatory Furnaces, but the load would increase even more if there was no complex content to be displayed simultaneously in the vicinity. It can be viewed stably on a web browser only.

Technically, it is possible to view the content on smartphones and tablets, but the memory size is generally lower than in the PC environment, and it has been observed that the content cannot be viewed properly when multiple contents are piled up. In the future, the number of layers and types of data to be displayed will increase in the digital base, so control on the application side, such as memory release when hiding data, will be an issue.

7 Conclusion

In this study, we built a fully functional prototype platform for quick 3D visualization. We developed (1) an efficient conversion method for 13 types of data by data type; (2) considered the architectural design for unified visualization; and (3) developed the necessary functions, after which we reduced the data capacity, memory, and CPU usage on the browser. Subsequently, the performance was measured. As a result: (1) we found that the types and volumes of data related to digital cities have various formats. However, there are three significant patterns (GeoJSON, JSON, and Tileset) that allow for easy integration of data. Then, (2) we determined that it is possible to combine Mapbox GL JS and Deck.GL to create multiple dynamic visualizations with patterns. Moreover, (3) on the platform we built, we mainly used the first display and a web browser. The performance was measured for point cloud and human flow animations. The memory usage and caches did not increase, and it was found that the load was constant.

The main issues for future architectural design and development involve the ease of use and efficiency of data conversion. For the former, the zoom level is defined according to the type of data, and the actual display is automatic. However, point clouds have a different angle of view and scale that are suitable for display on a 3D map. Because the data volumes are different, they should be defined using bounding boxes. To change the perspective of the operation screen, we need to extend the types of views. In this platform, we limited ourselves to operating from the perspective of the map view. However, if the ability to view the point cloud from the inside or the side is implemented, it will make it more convenient to use. In the latter case, the biggest challenge is to create a mechanism for the automatic conversion of each data. The data volumes and attributes vary by region, as can be seen in some data types and categories in this study. The standardization of these data on Web3D platforms has been achieved to some extent because they need to be expanded. In addition to enriching the digital twin, the fusion of BIM data, including the attributes and structures within the building, and the challenge of large-scale flow data, such as sensing data, necessitates further study. At this point, the development of WebGL technology has reduced the computational burden but more examples are required.

ACKNOWLEDGMENTS

We would like to express our gratitude to the staff of Susono City Office for providing the data for our analysis. This study was supported by Joint Research Program No. 901 at CSIS, the University of Tokyo.

REFERENCES

[1] Germaine R. Halegoua. 2020. *Smart Cities*. The MIT press essential knowledge series. The MIT Press, Cambridge.

[2] Jantien Stoter. State of the Art in 3D City Modelling: Six Challenges Facing 3D Data as a Platform. *GIM International*. https://www.gim-international.com/content/article/state-of-the-art-in-3d-city-modelling-2

[3] Saleh Albeaik, Mohamad Alrished, Salma Aldawood, Sattam Alsubaiee, and Anas Alfaris. 2017. Virtual Cities: 3D Urban Modeling from Low Resolution LiDAR Data. In *Proceedings of the 25th ACM SIGSPATIAL International Conference on Advances in Geographic Information Systems (SIGSPATIAL '17)*. Association for Computing Machinery, New York, NY, USA, Article 86, 1–4. DOI: https://doi.org/10.1145/3139958.3140025

[4] Seokchan Kang and Jiyeong Lee. 2017. Developing a Tile-Based Rendering Method to Improve Rendering Speed of 3D Geospatial Data with HTML5 and WebGL. *J. Sensors*, 1-11. DOI: https://doi.org/10.1155/2017/9781307

[5] Yiqun Chen, Erfan Shooraj, Abbas Rajabifard and Soheil Sabri. 2018. From IFC to 3D Tiles: An Integrated Open-Source Solution for Visualising BIMs on Cesium. *ISPRS Int. J. Geo-Inf.* 7, 393. DOI: https://doi.org/10.3390/ijgi7100393

[6] Rostislav Nétek and Jan Brus Tomecka. 2019. Performance Testing on Marker Clustering and Heatmap Visualization Techniques: A Comparative Study on JavaScript Mapping Libraries. *ISPRS Int. J. Geo-Inf.* 8, 348. DOI: https://doi.org/10.3390/ijgi8080348

[7] Candan Eylül Kilsedar and Maria Antonia Brovelli. 2020. Multidimensional Visualization and Processing of Big Open Urban Geospatial Data on the Web. *ISPRS Int. J. Geo-Inf.* 2020, 9(7), 434. DOI: https://doi.org/10.3390/ijgi9070434

[8] Fabian Dembski, Uwe Wössner, Mike Letzgus, Michael Ruddat and Claudia Yamu. 2020. Urban Digital Twins for Smart Cities and Citizens: The Case Study of Herrenberg, Germany. *Sustainability*, 12(6), 2307. DOI: https://doi.org/10.3390/su12062307

[9] Toyota Motor Corporation. 2020. "*Toyota to Build Prototype City of the Future*" https://global.toyota/en/newsroom/corporate/31171023.html

[10] Shizuoka Prefecture. 2016. "*Shizuoka Point Cloud DB (PCDB)*" https://pointcloud.pref.shizuoka.jp/