ROLE OF 3D CITY MODEL DATA AS OPEN DIGITAL COMMONS: A CASE STUDY OF OPENNESS IN JAPAN'S DIGITAL TWIN "PROJECT PLATEAU"

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ABSTRACT:

This study aims to clarify the development and utilization of highly accurate and open 3D city models (3DCMs), which began in Japan in 2020. The background of the project is explained based on a review of past efforts in Japan for making geospatial information accessible, the flow of data standardization around CityGML, and the introduction of Free and Open Source Software for Geo-spatial (FOSS4G) tools for data management and visualization. Two aspects of the analysis are reported: quantitative geospatial analysis of LOD1 building data and qualitative evaluation of 40 use cases using these data. The results indicate that approximately 18 million building data points covering 150 cities in Japan have been converted to open data in formats such as CityGML with high accuracy, complementing OpenStreetMap (OSM) data in urban areas. In addition, a total of 40 use cases for these data are demonstrated in new fields, such as urban planning, citizen participation, and even entertainment, with a few of these tools becoming open-source software. Through this project, data related to 3DCMs, which have not necessarily been produced in a unified format or specification in Japan, can now be easily handled as CityGML through a one-stop viewer, and the data are expected to be enhanced, and new geo-services using 3DCMs will be provided under the concept of openness, regardless of the city scale.

1. INTRODUCTION

Digital technology and advanced data utilization are becoming important for solving increasingly complex and diverse urban problems and providing services and accountability to citizens. With progress in the informatization and digitization of cities through smart cities worldwide, basic urban map information is being developed. Furthermore, in recent years, sensing data recorded by various devices in cities are also being utilized, and the need for a vast data infrastructure centered on 3D city models (3DCMs) is growing (Halegoua, 2020). By contrast, in Europe and the United States, where smart cities have been promoted since the early 2010s, the data collected in cities are anticipated to accumulate and be transformed into open data as data commons, leading to a problem-solving social change, wherein citizens comprehensively utilize technology and data in collaboration with local governments (de Lange and Waal, 2019).

Visualization using 3D data is primarily a standalone application, and even in a web environment, devices with advanced machine power are required for rendering. However, since the advent of the Web Graphics Library, technical representation capabilities have improved, and 3D models can now be easily interactively represented on the Web using CesiumJS, Deck.gl, and Cloud Optimized Point Cloud files. Disseminating technologies capable of displaying individual data or visualizing data by city blocks, seamlessly displaying data from the city level to the city block level, and visualizing dynamic data such as human movement are important (Kilsedar, C.E. and Brovelli, 2019). In addition, digital twins—virtual replicas of the physical urban built environment (Shahat et al., 2021)—are gaining worldwide attention for understanding the current state and planning future scenarios in cities (Lei et al., 2023), and these can be applied to a wide range of urban issues, such as urban development, disaster prevention, and environmental and energy simulations. These scenarios have the potential to be used as intuitive approaches to urban planning through various geographic information system (GIS) tools (Kitchin et al., 2021; Schrotter and Hürzeler, 2020). The geospatial information required by a digital twin also must be accompanied by 3D geometric and attribute information regarding building units, which creates multiple technical challenges.

Intending to clarify the state of development and use of highly accurate and open 3DCMs in Japan starting in 2020, this paper reports a quantitative analysis on the volume and spatial coverage of 3DCMs, primarily for building data, and a qualitative comparative evaluation analysis of more than 40 use cases and related Free and Open Source Software for Geo-spatial (FOSS4G) applications. Section 2 discusses the history of the PLATEAU initiative, with a background on urban planning data in Japan. Section 3 explains the status of building data in 127 cities (150 areas) in Japan from the perspective of CityGML and open data and presents OpenStreetMap (OSM) building data in the central Tokyo area. Section 4 describes the development of elemental technologies using PLATEAU FOSS4G, focusing on the viewers. Section 5 compares trends in the 41 use-case development cases categorized by topic, data used, and open-source software (OSS) implementation, and Section 6 summarizes and discusses these perspectives.

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2. BACKGROUND OF PROJECT PLATEAU

The subject of this study is Project PLATEAU (PLATEAU), a digital twin initiative implemented by Japan's Ministry of Land, Infrastructure, Transport, and Tourism (MLIT) beginning in 2020, primarily for urban planning. Japan's Urban Planning Law of 1968 requires urban planning and building unit surveys with a scale of approximately 1:2500 to be conducted every 5 years on an update cycle to produce survey data on the population by industrial classification, urban area, land use, transportation, and landscape. However, a survey of the practical environment for urban planning has revealed that numerous local governments still excessively use paper-based maps and have been unable to convert public institutions to encourage citizens to participate in bottom-up urban planning.

In this context and in response to the growing interest in smart cities, we considered the possibilities of building environments and project introductions in Japan, referring to the Digital Building Twins (2020–2024) in Horizon 2020, Virtual Singapore (since 2013), and Helsinki 3D+ (since 2014), which have been the leading digital twins in cities (Ruohomäki et al., 2018). However, digital transformation remains a persistent issue. In addition, against the background of the establishment of a Digital Agency as a new government agency, the project began as a nationwide 3D city model development and technology demonstration project for urban planning.

In FY2020, (1) 3DCMs data in CityGML format for approximately 11 million buildings (approximately 10,000 sq. km) in 56 cities were developed and published as open data (CC-BY 4.0, ODC BY, ODbL licenses) via the CKAN Geospatial data portal in Japan in the formats of CityGML, 3D Tiles, GeoJSON, Mapbox Vector Tile (MVT), and ESRI Shapefile. (2) A viewer (v1.0) for TerriaJS, a library based on Cesium, was developed and made available as open source. (3) Various manuals and use cases for data maintenance were developed. In FY2022, the data coverage became more extensive, with a cumulative total of approximately 18 million building data points (19,592 square km) in 127 cities (150 areas). The viewer was also updated (v.2.0) to include the CMS and functional enhancements. Additionally, 41 use cases were developed, 12 community events (hackathons and competitions) were held to leverage the data, and open sourcing through GitHub expanded to more than 30 repositories.

3. 3DCMS DEVELOPMENT AND COVERAGE

3.1 CityGML

CityGML is a representative format for 3D city models defined by the Open Geospatial Consortium, with CityGML3.0 currently being modeled (Kolbe et al., 2021; Saeidian et al., 2022). Notably, PLATEAU uses CityGML2.0, which has a well-defined encoding standard, for the following reasons: (1) It is a model with both geometric and semantic elements, and it possesses a format that can describe the entire urban space, a characteristic shared with building information modeling. (2) Level of Detail (LOD) is used to define the spatial distributes of each model, and multiscale data can be freely set in a single format. CityGML can add an Application Domain Extension (ADE), with i-UR (v.1.5) defined as a Japan-specific ADE. Furthermore, land use and disaster risk information are described in CityGML (Akaboshi et al., 2020).

3D city models and digital twins in the CityGML format have been distributed across more than 40 cities in Europe and the United States (representative areas include Helsinki, Berlin, and Dublin), with LOD1–LOD2 data actively used for urban planning and future simulations. Case studies such as the development of a method to simulate flooding and building damage after heavy rainfall using the generated 3DCMs are also increasing (Jang et al., 2021). Notably, CityGML has the characteristics of an intermediate format; therefore, a converter is required for visualization in the GIS, with converters such as FME and CityGML-tools utilized in many use cases.

PLATEAU is unique because it is unified rather than provided by separate data sites for each local government, as evaluated in previous studies on international comparisons of 3DCMs (Lei et al., 2023). In addition, although this study focused on building data, urban planning maps, hazard maps, LOD1 data for roads and topography, and aerial photo data, they were organized in a unified manner. Furthermore, in terms of data visualization (i.e., the FOSS4G-based web viewer described in Section 4), the formats (FGDB, GeoJSON, GeoTiFF) for handling data directly from data portals in a desktop GIS, 3DTiles and MVT formats were applied to web map applications. In addition, because modeling tools are becoming more common, certain regions also provide data converted to FBX and OBJ formats, which can be rapidly manipulated in modeling applications, such as Blender and Unity. The Software Development Kit (SDK) for Unreal Engine and Unity released under an MIT license in 2022.

3.2 PLATEAU building data coverage

In the following sections, we primarily describe the LOD1 building data in PLATEAU, noting that most of the survey data (aerial photos and building surveys) used to create LOD1 are modeled based on information recorded between 2019 and 2021 and are not consistent over time. For the selected cities in PLATEAU, the tabulated results (as of March 2023) show 150 cities (35,704 sq. km; avg. 233.45 sq. km), representing approximately 11% of the total of 1747 cities nationwide. The residential population of developed cities was found to be 49,782,246, approximately 40% of Japan's total population. The building box model (LOD1) included 18,309,883 objects (avg. 120,750 objects) or approximately 55% of the total coverage area of 19,592 sq. km (Table 1).

The city with the highest coverage of LOD1 data was the entire central Tokyo area (23 wards) (1,768,252 objects; 100%), and even large cities with a population of 500,000 or more covered approximately half of the area, primarily in urban planning areas. The amount of OSM building data (as of 2020) for the same area was also extracted using QGIS based on "Planet.osm" data and tabulated for each city. Consequently, the number of OSM buildings in the cities covered by PLATEAU was 5,666,066 objects, approximately 31% of the total number of buildings maintained in LOD1. Therefore, the cities covered by PLATEAU had more detailed building data than the OSM data.

Category	Unit	> 500,000 pop. Cities	> 200,000 pop. Cities	Tokyo's 23 Wards	General Cities	Total
Selected Cities	cities	17	26	23	84	150
Total Population	2020 pop.	24,574,264	9,116,039	9,733,276	6,358,667	49,782,246
City Areas	sq. km	10,392	9,226	623	15,463	35,704
OSM Buildings	objects	2,896,476	916,057	731,374	1,122,159	5,666,066
Buildings LOD1	sq. km	4,830	4,886	623	9,254	19,593
	objects	7,776,703	4,691,285	1,768,252	4,073,643	18,309,883
Buildings LOD2	sq. km	71	80	23	133	307
	objects	181,978	161,884	31,082	222,712	597,656

Table 1. Summary of 3DCM data in PLATEAU cities.

Figure 1 shows a scatter plot of the development status of each city, with the population on the horizontal axis and the number of LOD1 building objects on the vertical axis. The size of the circle represents the number of OSM building data points for the same city using a proportional symbol (objects; OSM: objects); for instance, Nagoya City (LOD1: 723,639 objects; OSM: 293,216 objects). Yokohama City has the largest population among the target cities other than Tokyo, and 3DCMs were developed for the entire city area. Consequently, LOD:882,007 objects were compared with OSM:690,984 objects. Among the municipalities with only a part of their urban area covered, Sapporo (LOD1: 647,149 objects; OSM: 285,391 objects) and Kyoto (LOD1: 520,136 objects; OSM: 409,894 objects) are notable in terms of the number of buildings. Considering that LOD1 data exist for many large cities with limited OSM data, these open data can be used for OSM in the future.

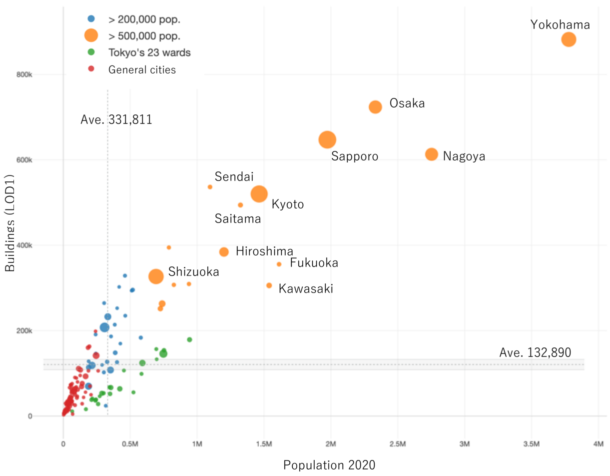

Figure 1. Distribution of population size and number of buildings in PLATEAU cities

Furthermore, maintaining the data as LOD2 to use roof shapes and building exterior images (textures) for detailed landscape simulation is important. As shown in Table 1, the total developed area is 299.3 sq. km (with 597,656 objects), 0.8% of the total urban area, and this is more developed in regional cities with a population of less than 200,000 than in large cities. In these areas, there is a rising trend in the exploration of direct 3DCM applications that cannot be achieved by large-scale data development alone, for instances, through visualization services to intuitively understand disaster risk and vertical evacuation and automated driving services using data such as shopping arcades and vegetation.

3.3 Comparison of PLATEAU and OSM building in Tokyo

To compare the spatial distribution trends of building data from LOD1 of PLATEAU and OSM, the number of buildings was counted in 23 wards of central Tokyo (Seto, 2022), where the coverage of both data was high. The numbers of objects for each building dataset in the entire area were 731,374 objects for OSM and 1,768,252 objects for PLATEAU. If the number of objects in PLATEAU is considered the total, the number of buildings in OSM is approximately 40% (Figure 2).

Next, to compare microscopic spatial units, the number of units in each building data was tabulated for each of the 3,190 city blocks, and the percentage of OSM data with PLATEAU data as the population was calculated (Figure 3). The results indicated that 1548 city blocks had less than 50% OSM data. However, in 502 (approximately 15.7%) city blocks, the OSM data exceeded the LOD1 data, with most located around the Tokyo Station or in the western part of the city (Suginami Ward). As a factor in this discrepancy, a historical analysis of the timestamps and versions of the OSM building data (approximately 80,000 objects) not available in PLATEAU revealed that most data were created more than 2 years before the LOD1 data and have never been updated. Therefore, LOD1 data with an update history older than 2020 may need to be replaced to keep the data updated, even in areas with relatively suitable coverage of OSM data.

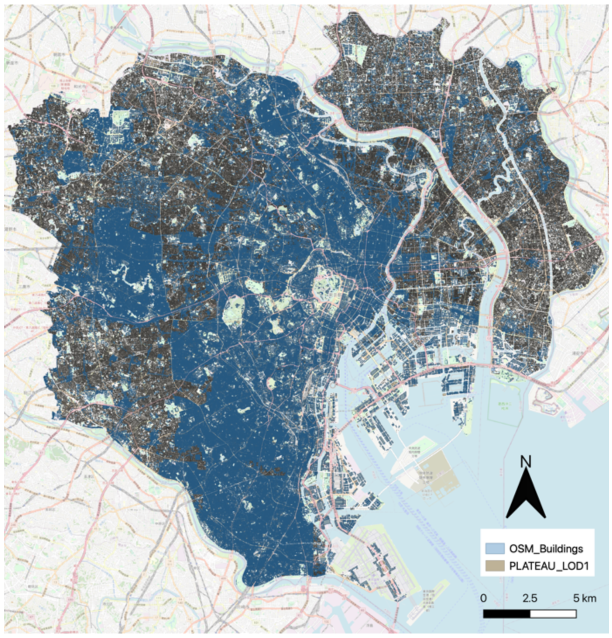

Figure 2. Overview of PLATEAU LOD1 and OSM building data distribution.

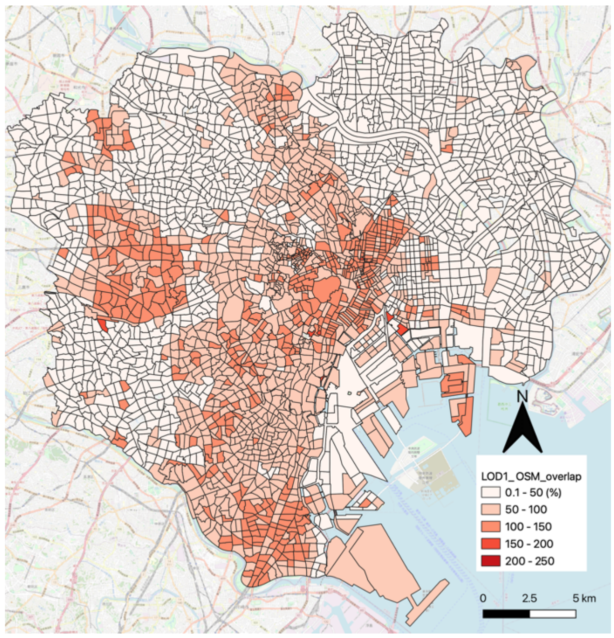

Figure 3. Distribution rates of OSM per LOD1 buildings.

Another feature of PLATEAU is that attributes related to building height are entered in all data; we extracted the OSM data that contained the "height" or "building:levels" attribute (27,499 objects) and calculated their percentage in LOD1 data (Figure 4).

The results revealed that the number of city blocks with height data in the OSM data was limited to specific areas around the Tokyo Station and waterfront. Therefore, it is expected that LOD1 data, which are open data of high quality in terms of shape and attribute data, may be useful for improving OSM.

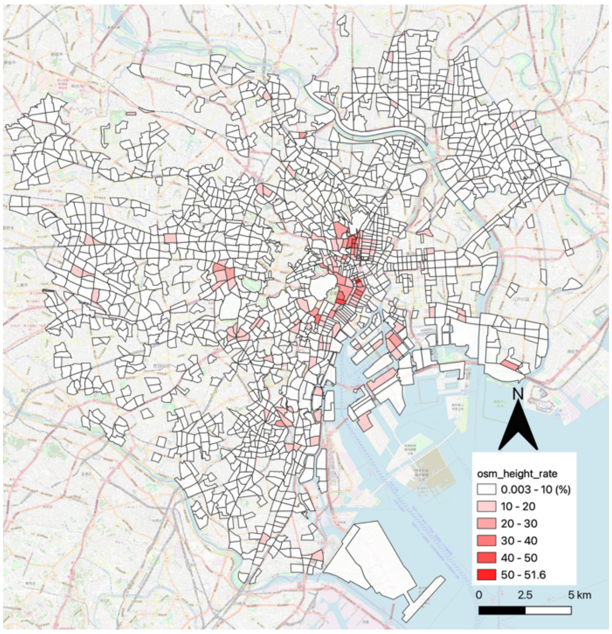

Figure 4. Distribution rates of OSM buildings that include height attributes by districts.

4. DEVELOPMENT OF PLATEAU VIEW BY FOSS4G

Although open data are important, many end users have difficulty viewing 3D city models in a GIS. In addition, many operations by Japanese local governments are conducted in environments where the terminals used are inferior. Therefore, from the beginning of the project, it was necessary to provide a common viewer who could browse various data in a web browser and an editor in the local government who oversaw data maintenance. Users who do not have GIS software or related applications to visualize 3DCMs, PLATEAU VIEW, based on FOSS4G, will be released in 2021, with the v2.0 construction environment currently in place.
https://github.com/Project-PLATEAU/PLATEAU-VIEW-2.0

The architecture of the viewer—a WebGIS platform called "Re:Earth" (Eukarya, 2023)—is shown in Figure 5; this platform can natively support 3D tiles and CZML animations because it is based on CesiumJS. Furthermore, one of the main features of this platform is that it has plug-ins using WebAssembly, which allows for easy functional extensions and Contents Management System (CMS) features, such as data management and an editor, which were not possible with previous viewers based on TerriaJS. In fact, v2.0 has a CMS that manages various data and an editor that allows viewer customization without coding; v2.0 is hosted by Terraform, which is based on the Google Cloud Platform.

Figure 6 shows the data hosting process. TerriaJS, the first PLATEAU View v1.0, only had a viewer function, complicating the execution of content management without coding. The newly developed 'Re:Earth CMS' therefore allows local government officials and data creators who are not web engineers to upload 3DCMs themselves, subject them to quality checks by MLIT officials, customize the viewer, and publish the data. This CMS is a major architectural advance in that it also facilitates integration with other platforms such as FME and PLATEAU SDKs for data format conversion.

Based on the open data philosophy of Project PLATEAU, a number of these demonstration environments are available in an open guidebook under CC-BY 4.0 and a repository on GitHub under an Apache-2.0 license and can be reproduced (Figure 7).

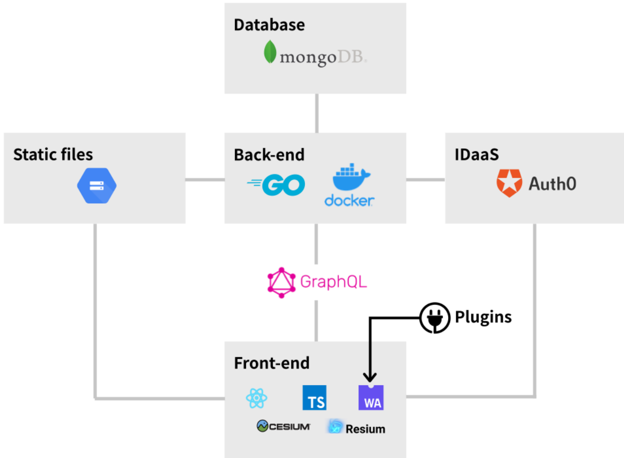

Figure 5. PLATEAU VIEW 2.0 architecture.

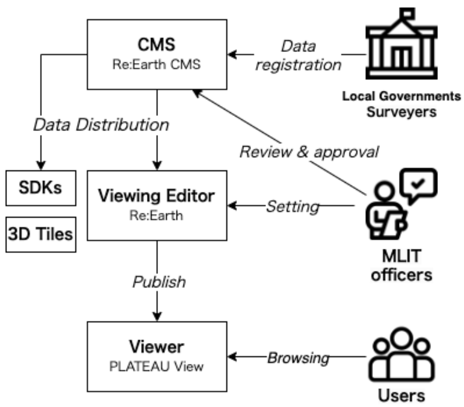

Figure 6. Data hosting flow of Project PLATEAU.

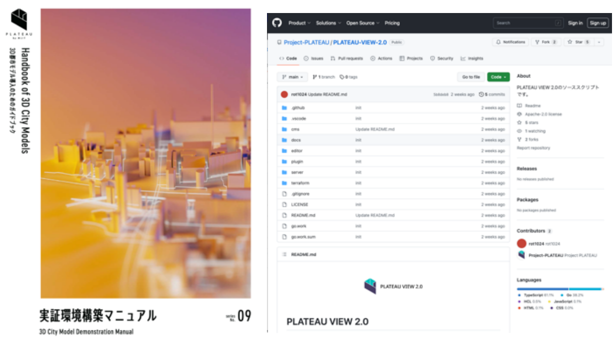

Figure 7. Handbook of constructing demonstration environment.

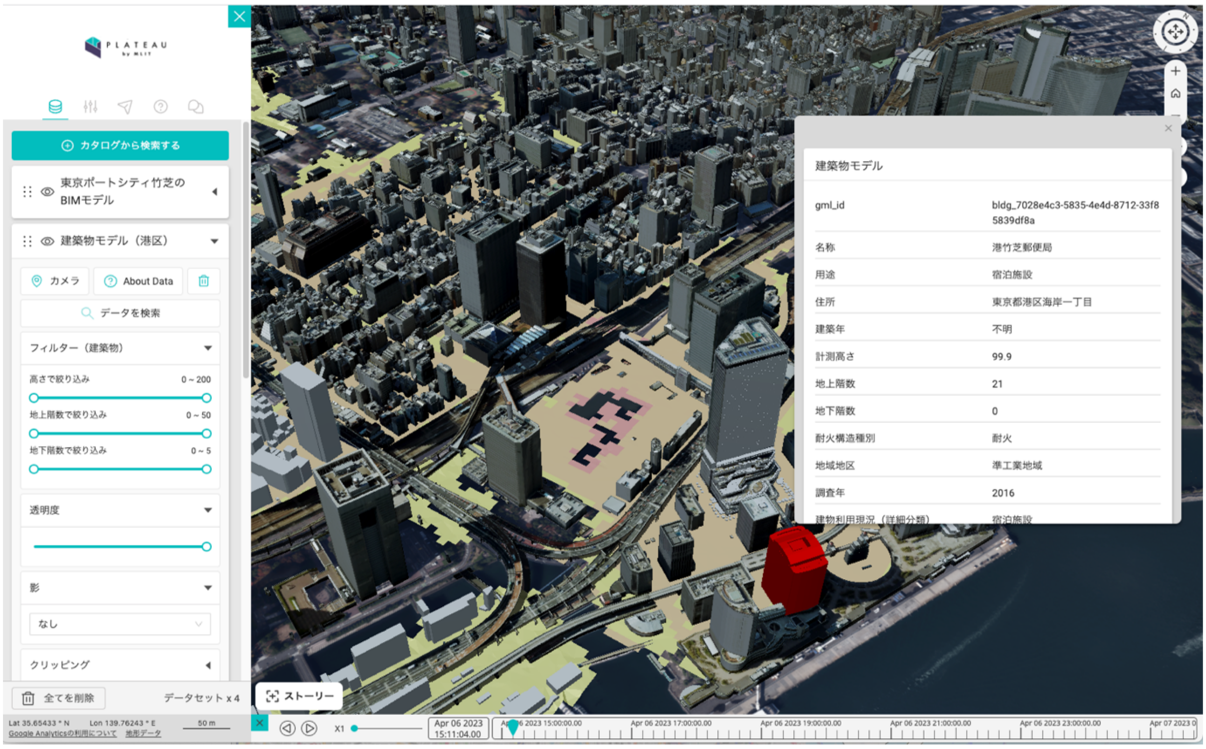

Figure 8. Web interface of PLATEAU VIEW v2.0 in Tokyo.

Without building an environment, the viewer on the official site (https://plateauview.mlit.go.jp/) also has various functions: in addition to displaying 3DCMs, it can be customized with a combination of multiple geospatial data, including assumed data on floods and earthquakes. The 3D map can be customized by combining multiple types of geospatial information, including the display of 3DCMs as well as flood and earthquake prediction data and real-time bus location data every 10 s in Tokyo. For example, Figure 8 shows the PLATEAU data for central Tokyo, where attributes such as structure, year of construction, height, and use can be reviewed for each building. The ground surface is color coded by inundation depth based on a river flooding simulation. These color-coded data on building attributes (such as year of construction, structure, and use) can be viewed in detail by clicking on them, allowing their direct use as a tool for considering land use from a three-dimensional bird's eye view. Figure 9 shows an example of a fused display of underground city structures and underground structure data in Sapporo, where the red polygon in the center represents the shape of the underground city ceiling.

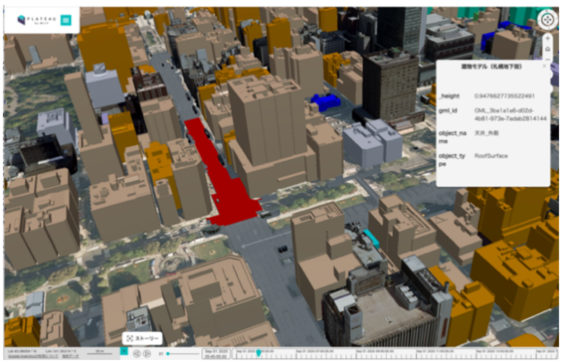

Figure 9. Visualization of structural data in the underground streets of Sapporo on PLATEAU VIEW 2.0.

5. TRENDS OF USE-CASE PROJECTS USING PLATEAU DATA AND FOSS4G TOOLS

In this section, we analyze the project, focusing primarily on using the developed data. With the rapid progress in 3D data related to urban planning, such as building data, in the cities of Japan with various population sizes, expanding the areas in which these data can be used is important for urban planning, disaster prevention, and infrastructure management, which are important issues in Japan. Therefore, PLATEAU will conduct 57 demonstration projects in 2022 on an experimental basis in partnership with private companies and local governments, with 40 of these projects conducted in specific regions to develop use cases.

Table 2 shows the status of the use-case development. The most common theme was disaster simulation, with nine developed use cases. Moreover, this most common theme (disaster simulation (nine projects)) was followed by urban planning (seven projects) and AR/VR (six projects). Nineteen projects were developed, approximately half of which were OSS on GitHub, with urban planning being the most common (six projects). The tools used in the demonstrations included CesiumJS (TerriaJS) and PostGIS for demonstrations, QGIS and R (ArcGIS was used in some projects) for simulations in local environments, and AR/VR tools. Many projects use Unity, which is proprietary but widely used. As shown in the list, many projects combined FOSS4G tools with PLATEAU data; however, simulation and advanced analysis required conversion from the resource data, CityGML, while many cases used proprietary FME.

Furthermore, highly accurate geospatial information, such as 3DCMs, is actively used for citizen participation and collaboration.

id	field	project title	tools	area	github	lang
uc22-015	AR/VR	XR Technology Utilization for Citizen Engagement in City Planning	Blender Unity CesiumJS QGIS PostGIS ARCore	local	×	-
uc22-016	AR/VR	Interfacing AR and Metaverse Platforms in Cities	ARCore Unity Strapi	local	×	-
uc22-019	AR/VR	Area Management via Digital Twin Technology	3dsmax ArchiCAD Creator UnrealEngine Ruby React	local	×	-
uc22-031	AR/VR	Education Tool for City Planning	Blender Rhinocerous Twinmotion	local	×	-
uc22-043	Autonomous Car	VPS Utilization in Localization of Autonomous Vehicles	VPS ADENU	local	×	-
uc22-006	Autonomous (UAV)	Assistance system for UAV infrared inspections of outer wall	Shade3D GIMP	local	×	-
uc22-039	Data Management	Plug-in sharing platform for 3D City Model	Re:Earth	city	×	-
uc22-009	Disaster Simulation	elaborated flooding simulation using 3D City Models	ArcGIS CesiumJS TerriaJS	local	×	-
uc22-010	Disaster Simulation	simulation of the quantity of disaster waste generating	QGIS	large city	○	Python
uc22-014	Disaster Simulation	Landslide Management System with 3D data	CesiumJS ARCore LAStools CloudCompare	local	×	-
uc22-017	Disaster Simulation	Security equipment installation planning support tool	ArcGIS	local	×	-
uc22-018	Disaster Simulation	Development of a Plug-in System to Support Community Disaster Management	CesiumJS	local	○	JavaScript
uc22-027	Disaster Simulation	Snow Risk Management Support Tool	OpenFOAM ParaView QGIS Unity Blender	local	○	C++
uc22-030	Disaster Simulation	Digital transformation of area management for disaster prevention	CesiumJS Unreal Engine Rhinocerous Blender Revit	local	○	C++
uc22-039	Disaster Simulation	Simulation system of evacuation behavior (by car or foot) during floods	R CesiumJS	local	○	JavaScript
uc22-041	Disaster Simulation	Development of a Flood Risk Management Application via WebGIS Technology	CesiumJS PostGIS ARCore Unity ArcGIS	local	○	JavaScript
uc22-013	Environment Modeling	Carbon Neutrality Policy Promotion Support System	QGIS FZKViewer	city	○	C++
uc22-021	Environment Modeling	Estimation of Wall Solar Power Potential	VC Publisher FZK Viewer	local	×	-
uc22-032	Environment Modeling	Regional Energy Management Assistance System	QGIS	local	×	-
uc22-036	Environment Modeling	Heat island simulation	scSTREAM	local	×	-
uc22-037	Environment Modeling	Climate Change Impact Simulation by Using 3D City Model	Altair CFD	city	×	-
uc22-038	Facility Management	Base station location planning using private 5G radio wave simulation	Altair CFD	local	×	-
uc22-003	Urban Modeling	Floor-Area-Ratio 3D visualization simulation system	ArcGIS CesiumJS Babylon.js	local	○	TypeScript
uc22-020	Urban Modeling	Methodology on Urban Structure Simulation	ArcGIS Pro QGIS R	city	○	Python
uc22-023	Urban Modeling	System of Pedestrian Traffic Simulation	QGIS Unity	local	○	Python
uc22-042	Urban Modeling	Urban Policy Simulations Linked with the City OS	CesiumJS FIWARE GAUSS iRIC Wind perfect	city	×	-
uc22-011	Urban Planning	Gamification Methodology for Community Building with Citizen Engagement	Cities:Skyline s Mapbox	local	×	-
uc22-012	Urban Planning	DX of development permission	CesiumJS TerriaJS GeoServer PostGIS	city	○	TypeScript
uc22-022	Urban Planning	Development of Wellness Application to Encourage Walking	CesiumJS PostGIS pgRouting turf.js	local	×	-
uc22-028	Urban Planning	Development of Area Management Dashboard	CesiumJS TerriaJS GeoServer PostGIS pgrouting	local	○	Clojure
uc22-035	Urban Planning	Development of an immersive urban planning tool using XR technology	Next.js AR.js Three.js Unity OpenCV	local	○	JavaScript
uc22-040	Urban Planning	Smart Planning Methods for Walkable Design	QGIS Shade3D GAUSS	local	○	Python
uc22-045	Urban Planning	Landscape planning support tools	Unity	local	○	Unity

Table 2. List of use case development projects in Project PLATEAU 2022.

Although only a few examples of direct use for citizen participation have been reported, XR technology is utilized for citizen engagement in urban planning (UC22-015), the Development of an Immersive Urban Planning Tool (UC22-015), and the Development of an Immersive Urban Planning Tool using XR technology (UC22-035). Case study UC22-015 used the PLATEAU and XR technologies in a workshop to discuss the redevelopment of public spaces in a suburban area of Tokyo. Ten workshops were held in-person and online with citizen participation, and four proposals were compiled. In this initiative, the workshops used VR glasses and AR applications to discuss future concepts based on the data collected during fieldwork in real space (Figure 10). The results were again input as data into the virtual space and visualized to share spatial characteristics with those who did not attend the workshop. These results are also posted on PLATEAU VIEW 2.0 as use-case examples (Figure 11). Preserving the results of community development activities, such as digital archives, is also important from a data commons perspective.

Figure 10. Participatory workshops using XR technology with PLATEAU datasets. (Provided by HoloLab Inc.)

Figure 11. Workshop data archives and future town planning proposals in PLATEAU VIEW 2.0. (Provided by HoloLab Inc.)

6. CONCLUSIONS

This study aimed to summarize and review PLATEAU's data development, demonstration, and open-sourcing efforts. In Japan, the development of 3DCMs has been accomplished on a one-off basis in each city, but an important feature of this project has been the development of an environment that can be used as digital commons by establishing common specifications and standard formats for use in a digital twin. Standardization and allowing data access based on CityGML have enabled large-scale data development on a global scale. Additionally, data maintenance techniques and visualizations were developed by FOSS4G and documented under open licenses and OSS. In addition, thematic demonstrations were conducted in more than 40 local areas. The tools developed were released under OSS in approximately half of the projects, which are expected to involve a wide range of technology actors.

The user interface of PLATEAU View is easier to use and enables smooth viewing of 3DCMs; however, these tools may still require advanced spatial knowledge and GIS skills in certain cases. Therefore, to broaden participation and use, PLATEAU must become more user centric and encourage sharing tools, use cases, and data to expand its user base. A system in which designers, using civic tech and game engines, who are not directly involved in urban planning can assist public-sector planners with their technical questions is important and expected in future use-case projects. In addition, as the need for 3DCMs increases beyond urban planning applications, increasing incentives for further data coverage and continuous data updating by local governments, which are most likely to use 3DCMs in practice, should continue to be carefully discussed.

Given the above, the challenges of this project include obtaining an open digital community with nationwide coverage, ensuring continuous updating 3DCM data, improving literacy and usability design that allows non-specialists and administrators to easily use the data, and sharing tools and case studies.

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APPENDIX

CityGML data from the PLATEAU project are available under the CC-BY 4.0, ODC BY, and ODbL licenses at the official CKAN data portal. (in Japanese):
https://www.geospatial.jp/ckan/dataset/plateau.

In addition, the PLATEAU building data (1,768,252 objects) and OSM building data (731,374 objects) for the 23 wards of Tokyo used in the analysis in Section 3.3 were spatially aggregated into administrative ward data. The dataset is available on the Github repository:
https://github.com/tossetolab/plateau-osm-aggregation.