Improvement of three-dimensionalization method of roads and railroads in 3D Digital Japan Basic Map

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Abstract

Toward the realization of the Digital Twin, nationwide 3D maps are being developed in many countries around the world. As a fundamental map covering the whole land of Japan, the Geospatial Information Authority of Japan (GSI) maintains the map called the Digital Japan Basic Map. The Digital Japan Basic Map has been prepared as 2D map information. Due to Cabinet Decisions made on 2023, GSI is required to implement 3D mapping across the whole country by FY2028. In this report, we describe the implement of 3D map in Japan, issues and improvement in three-dimensionalization method for roads and railroads, verification using MMS data, and supposed future directions.

1. Introduction

1.1 Background

Digital twin is a technology that replicates physical environments or systems in a virtual space, enabling real-time monitoring, analysis, and predictions. A critical component for creating an accurate and functional digital twin is the availability of high-quality spatial data, with 3D maps serving as a key enabler. 3D maps describe not only 2D position coordinates but also information about the shape, size, and structure of objects within a particular environment, including topography, buildings, roads, and other infrastructure.

Toward the realization of the digital twin, nationwide 3D maps are being developed in many countries around the world (Biljecki et al., 2015; Lei et al., 2023), such as Netherlands (Stoter et al., 2012), Switzerland (Stoter et al., 2016; Federal Office of Topography swisstopo, 2024), and Singapore (Soon and Khoo, 2017). In Japan, efforts to realize the digital twin are accelerating as well, and the Geospatial Information Authority of Japan (GSI), the national mapping agency of Japan, is advancing efforts to extend the Digital Japan Basic Map (Map Information) into a 3D map of the entire country by the fiscal year 2028. The development of 3D map under a unified national standard is expected to contribute to the creation of new value by making more advanced analysis possible and expanding the range of utilization of information.

1.2 Digital Japan Basic Map (Map Information)

Before explaining the implementation of 3D map, we address conventional 2D map information, the Digital Japan Basic Map (Map Information).

The Digital Japan Basic Map (Map Information) serves as the basis for all maps of Japan and is produced as a digital format map information with a standardized schema that covers the whole country (Hasegawa and Ishiyama, 2013). It includes the Fundamental Geospatial Data, that is a standard for determining the positions of geospatial information in digital maps as provided for in the Basic Act on the Advancement of Utilizing Geospatial Information (Act No.63 of 2007), and true position and high-precision geospatial information position of which matches with the position of the former. Positional accuracy of the map information is equal to or more than 1:2500 in urban areas and 1:25000 or more for other areas.

The map information consists of nine subpackages including annotations, boundaries, traffic facilities, buildings, structures, water areas, land use, topography, and accompanying information (Figure 1). Among them, the traffic facilities subpackage especially includes Road Edge as well as Road Centerline and Railroad Track Centerline class. Road Centerline and Railroad Track Centerline classes have various attributes such as type and state that can determine whether they are "normal sections", "bridge / elevated sections", "tunnels", or otherwise. Road Centerline class also have an attribute that indicate road width.

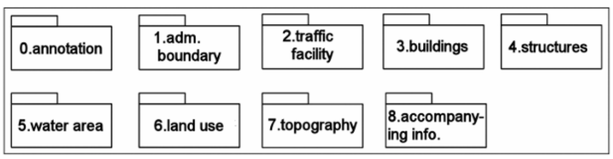

Figure 1. Subpackages of the Digital Japan Basic Map (Map Information) (Hasegawa and Ishiyama, 2013).

The Digital Japan Basic Map has been designated as one of the Public Basic Information Database in the Basic Act on the Formation of a Digital Society (Act No.35 of 2021), which is a database containing especially fundamental information for society, which has increased the need to continually maintain and update it.

1.3 Policy Framework for 3D Mapping Implementation

The Digital Japan Basic Map has been prepared as 2D map information. However, in order to realize a digital society, it is necessary to prepare the fundamental national map in 3D and maintain it by quickly reflecting the changes in the country in the 3D map information. Against this background, Cabinet Decisions were made on the "Priority plan for the realization of a digital society" on June 9th, 2023 and the "Follow-up on the Growth Strategy, etc." on June 16th, 2023, which require GSI to implement 3D mapping across the whole country by FY2028.

1.4 Related work in Japan

One of the leading examples of 3D mapping in Japan is "Project PLATEAU", which has been promoted since 2020 under the initiative of the City Bureau of the Ministry of Land, Infrastructure, Transport and Tourism (MLIT), Japan (Seto et al., 2023; MLIT, 2025a). In Project PLATEAU, 3D city models are being developed based on basic urban planning maps produced by local governments, and various applications of the models are explored. As of May 2025, deliverables of the project for more than 200 cities nationwide have been provided in the CityGML format and publicly available as open 3D city models.

In our project, we adopted a 3D modelling method compatible with Project PLATEAU, aiming for mutual utilization between our results and the 3D city models provided by Project PLATEAU. Project PLATEAU provides standard product specifications for buildings, roads, and railroads, which corresponds to LOD 0-3 in the CityGML, and standard work procedures for developing them (MLIT, 2025b).

1.5 Structure of this report

This report is structured as follows, shown in Figure 2. Section 2 outlines the method of three-dimensionalization and the development of the initial version of the tool to develop 3D map. Section 3 presents the major issues and the improvement of the initial tool to resolve these issues. Section 4 details verification of the prototype data with the data acquired by the Mobile Mapping System (MMS) and the data correction method using the MMS data as well. Section 5 describes the prototype data released in March 2025. Finally, Section 6 offers our conclusions and future directions.

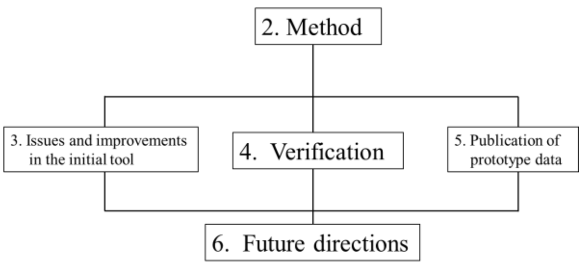

Figure 2. Structure of this report.

2. Method

2.1 Schematic diagram of 3D mapping in this work

To efficiently implement a nationwide 3D map, it is essential to avoid new measurements as much as possible and to utilize existing measurements with simple methods of 3D mapping. Therefore, GSI attempted to create a 3D map by extrusion from 2D footprints, which is one of the most well-known and simple way of 3D mapping (Biljecki et al., 2015).

We used the conventional Digital Japan Basic Map (Map Information) as 2D footprints, and point cloud data acquired through aerial photogrammetry or airborne LiDAR and grid data represented in Digital Elevation Model (DEM) format as elevation data. Also, we selected buildings, roads (Road Centerlines), and railroads (Railroad Track Centerlines) as the main target geographic features for 3D mapping. Figure 3 shows a schematic diagram of the concept of adding height information to polygons of buildings and line strings of Road Centerlines and Railroad Track Centerlines.

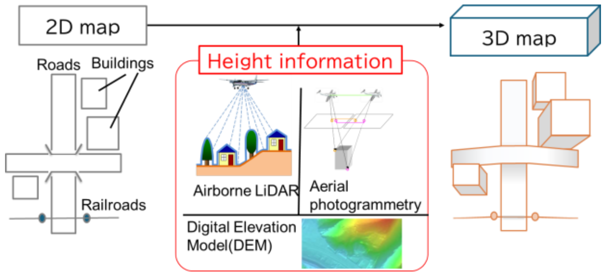

Figure 3. Schematic diagram of 3D mapping.

2.2 3D mapping methods of roads and railroads

In this report, we focus on roads and railroads. We describe the details of adding height information to roads and railroads in this work as follows.

For roads and railroads, we adopted a 3D mapping method by adding height information to the 2D coordinates (latitude and longitude) for each of vertices that constitute the Road Centerlines and Railroad Track Centerlines of the 2D map data, respectively (Figure 4).

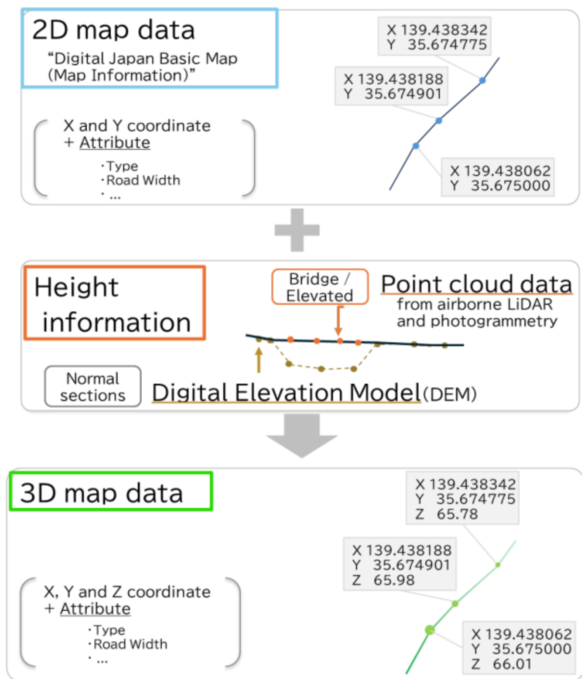

Figure 4. 3D mapping methods of roads and railroads.

Since most of the roads and railroads are located on the ground surface, height information was basically assigned from DEM, which corresponds to the elevation of the ground surface. On the other hand, structures such as bridges are located above the ground, so their types were identified by the Feature Type Code attribute of the Digital Japan Basic Map (Map Information), and height information was assigned from point cloud data that reflected the height of structures on the surface. In particular, for roads and railroads where the Feature Type Code is "bridge / elevated", the elevation values of the vertices of road and railroad centerlines were assigned from TIN generated from the point cloud data within a certain distance around vertices, and for other roads and railroads, the elevation values of the vertices

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of centerlines were assigned from the nearest grid data or TIN generated from the ground data.

2.3 Development of the initial version of 3D mapping tool

Based on the methods described above, we developed an initial version of tool in FY2023 to automatically create 3D map data by adding height information to centerlines. The tool was written in Python and each computational process for handling geospatial information was implemented using libraries such as PostGIS and PDAL based on the database management system PostgreSQL.

This initial tool was created to identify issues with the primitive 3D mapping methods mentioned above and to refine procedures.

3. Issues and improvements in the initial tool

Although the initial tool developed in FY2023 had achieved efficient 3D conversion of map data to some extent, detailed examination of each object revealed some unnatural aspects of the 3D shape. Each of these issues is described below.

3.1 Issues in the initial tool

3.1.1 Discontinuous elevation values at vertices with different source data:
As shown in Figure 5(A), the elevation values of the centerlines at the edges of the bridge / elevated sections obtained from point cloud data are generally different from the elevation values in DEM, so there is a discontinuity in elevation values at the point where the normal section meets the bridge / elevated section.

3.1.2 Influence of structures above the road / railroad surface:
To obtain accurate elevation values at locations such as bridges, where elevation values are given from point cloud data rather than DEM, it is necessary to use only point cloud data that measures the road / railroad surface. However, the actual point cloud data contains measurement points on superstructures of bridge, such as trass, power system, and overhead wire, and on vegetation on the road surface. Due to these effects, the centerlines of bridge or elevated structure sometimes had unnatural slopes, as shown in Figure 5(B).

3.1.3 Issues when DEM and road / railroad surface do not match:
Figure 5(C) and (D) illustrate the issue when DEM and road / railroad surface do not match. If there is an underpass that passes under the road / railroad which does not meet the criteria to be acquired as a bridge / elevated section, this section of road / railroad centerlines has an attribute of a normal section, and so the elevation value is assigned from DEM. Under these conditions, and also if DEM represents the elevation value of underpass below the road rather than the road surface, and the vertex of the upper road / railroad centerline is located at such a position, the centerline had a V-shaped concavity as shown in Figure 5(C). On the other hand, if there is a long tunnel in a mountainous area, DEM does not show the elevation value in the tunnel, so the vertices in the tunnel got the elevation values of the ground surface, as shown in Figure 5(D).

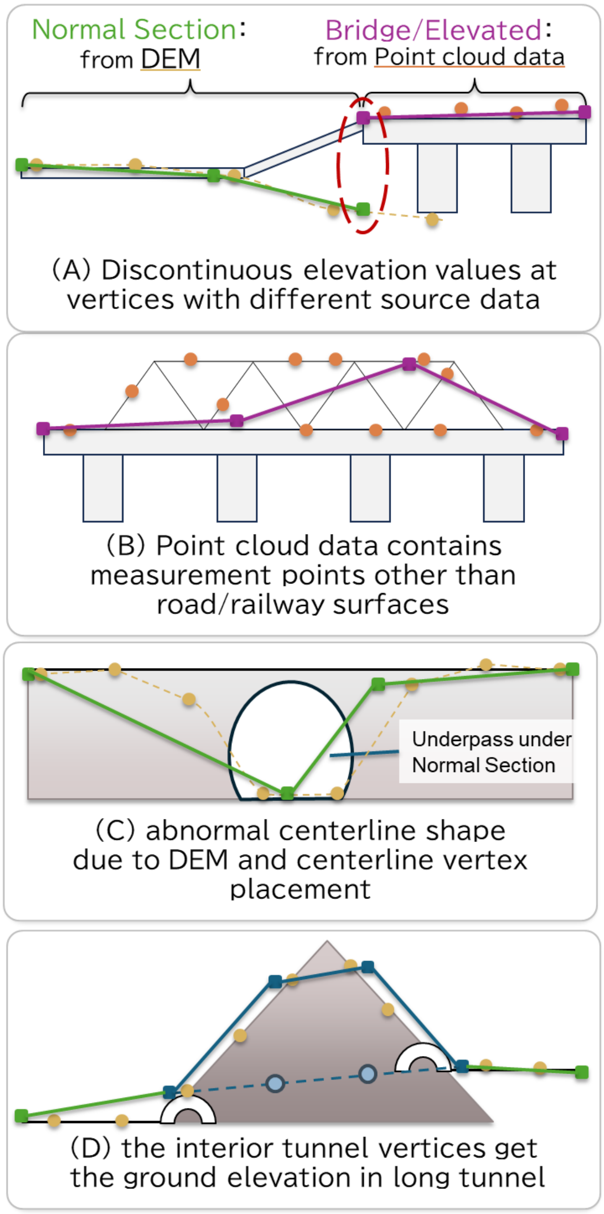

Figure 5. Unnatural aspects of the 3D shape with the initial tool.

3.2 Improvement of the initial tool

To tackle with these issues, the initial tool was modified in FY2024 to improve operability and expand calculation functions. This chapter describes the major modifications made to the initial tool.

3.2.1 Correction of discontinuous elevation values at vertices with different source data:
To address the issue in Figure 5(A) of discontinuities in elevation values at points of contact between bridges or elevated structures and other points due to differences in the source data, the modified tool has a function to correct the elevation values at the vertices of discontinuous sections to match the elevation values at the vertices of the connecting bridges or elevated structures. On the other hand, this correction sometimes resulted in steep slopes and unnatural irregularities around the connection points.

3.2.2 Influence of structures above the road / railroad surface:

To solve the issues of unnatural gradients caused by structures on the road / railroad and DEMs that do not match the road / railroad surface shown in Figure 5(A) – (D), we considered that it would be effective to calculate the gradient values of the centerline based on the assigned elevation values and detect the locations of steep gradients that could not exist in reality. We therefore added to the initial tool a function that calculates the slope of each segment of the centerline and the amount of change in the slope at each vertex (the difference between the slopes of the two segments connected to the vertex) and then detects abnormal locations when the absolute value of the slope or the change in slope is greater than a threshold value.

The threshold values of the absolute value of the slope and the change in slope were initially set with reference to the Road Structure Ordinance and other regulations, which specify the desirable longitudinal gradient of the road according to the design speed from the viewpoint of safety and smoothness of vehicle traffic.

In addition to the detection of abnormal slope and slope change value, the initial tool has been modified to extract the intersection of the centerline and the waterline and the points where elevation values could not be assigned, and to provide a function to check the status of the assignment of elevation values. It is also possible to directly modify the elevation values of such points in the modified tool based on extrapolation and interpolation from adjacent vertices or cross-sectional view of the centerline.

3.2.3 Change in method for acquiring elevation values for bridge / elevated sections and its surroundings:
Aiming to correct the discontinuity in Figure 5(A) and reduce the occurrence of 3D shape defects in the centerline caused by measurement points other than the road / railroad surface in Figure 5(B), we implemented a method of acquiring the median of elevation value of the point cloud data in the buffer created from the centerline as the elevation value of the bridge / elevated sections and its surroundings. Figure 6 shows the outline of new acquisition method compared with the initial tool.

In the initial tool, the elevation values on the centerline of bridge / elevated sections were obtained using TINs generated from point cloud data within a certain distance from the vertices. In this case, if any of the three points from point cloud data that make up the triangle including the vertex had an outlier that was measured off the road / railroad surface, the outlier had a significant effect on the elevation value assigned to the vertex. In the modified tool, the search area of the point cloud data was expanded to the area of buffer polygons in the width and extension directions of the centerline, and attention was paid to the feature that the median value is less susceptible to outliers. In addition, in order to smooth elevation changes around bridge / elevated sections, three segments of normal sections connecting to bridge / elevated sections were also included in the buffer polygons.

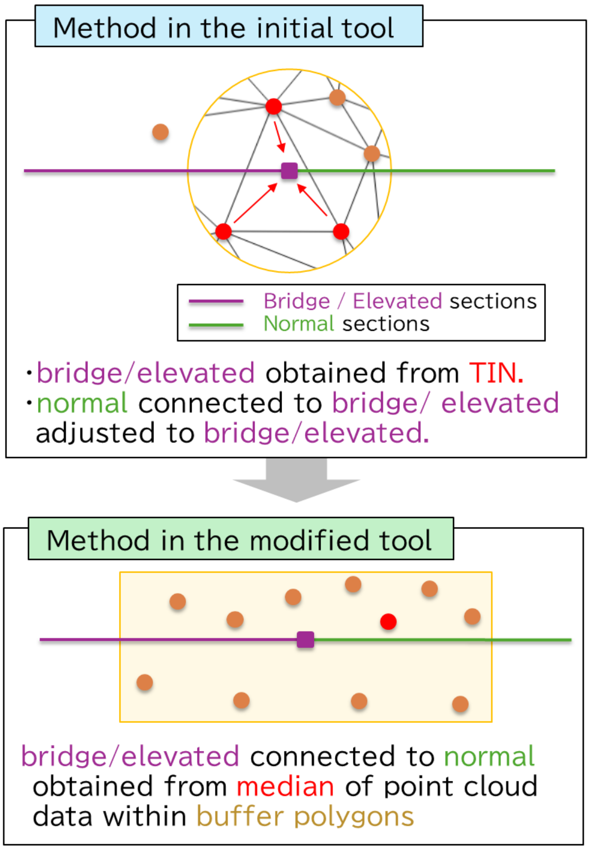

Figure 6. Outline of new acquisition method compared with the initial tool.

3.2.4 Verification of change in method for acquiring elevation values for bridge / elevated sections:
To verify this new acquisition method, a cross-sectional view of a section (A - A' in Figure 7) of the Shonan Monorail (bridge / elevated sections of railroad) in Kamakura City, Kanagawa Prefecture, created by the initial tool and the modified tool, is shown in Figure 7. Both tools used 3D point cloud data measured in 2021 provided by the Reforestation Division, Green Policy Department, Environment and Agriculture Bureau, Kanagawa Prefecture.

The grey dots in Figure 7 are the automatically calculated cross-sectional elevations from the point cloud data, including points from interpolation of the track surface and the ground surface. The initial tool (shown in green line in Figure 7) did not capture much of the track surface elevation of the monorail with a narrow track width, because it was greatly affected by the points measured on the lower ground surface. By contrast, the modified tool (shown in red line in Figure 7) illustrates a significant improvement in elevation acquisition of Railroad Track Centerlines. The sharp drop in elevation that occurs in some areas in the modified tool can be corrected using the methods described in Section 3.2.2.

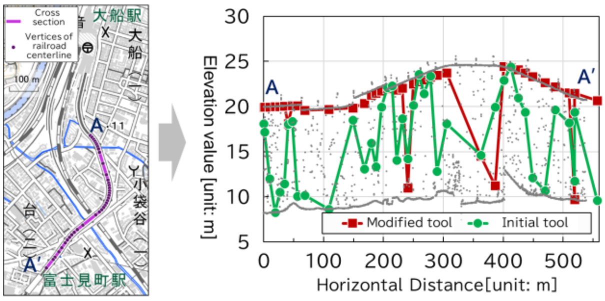

Figure 7. Comparison of elevation values for Railroad Track Centerlines obtained with the initial tool and the modified tool (height magnification of cross section: 15x).

4. Verification of elevation values

4.1 Overview of Verification

As of FY2023, it was not sufficiently verified whether the elevation values automatically assigned by the initial tool were consistent with the actual landforms or not, and what the direct causes of the defects in the 3D shapes as shown in Figure 5 were. Therefore, in parallel with the improvement of the initial tool, we conducted the verification of the initial tool by comparing 3D map data created by the tool with the 3D point cloud data acquired by the Mobile Mapping System (MMS), which is a vehicle-mounted survey system that combines LiDAR and high-resolution cameras to capture precise 3D spatial data while in motion. This section describes the verification method and its results.

4.2 Verification Methods

In order to verify the elevation values assigned to road centerlines, we examined elevation values included in the road map data provided on a trial basis by the Road Bureau of the Ministry of Land, Infrastructure, Transport and Tourism to see if they could be used for comparison with the initial tool and for data correction.

Figure 8 shows an enlarged view of a part of the road map data acquired by MMS. Since the road map data was obtained separately for the inbound and outbound lanes, data for verification was created by substituting the elevation values of the road map data into the road centerlines in the following manner and then compared with the data created by the initial tool.

1) Generate a perpendicular line from the vertex of the road centerline to the width direction (Blue line in Figure 8).
2) Obtain the intersection point (Yellow square) where the perpendicular line and road map data intersect.
3) Obtain the elevation value of the intersection point by linear interpolation from the elevation values of the vertices of the road map data (Red circle), according to the distance.
4) Obtain the elevation value of the vertices of the road centerline (Green circle) from an inverse distance weighted (IDW) average of two intersection points.

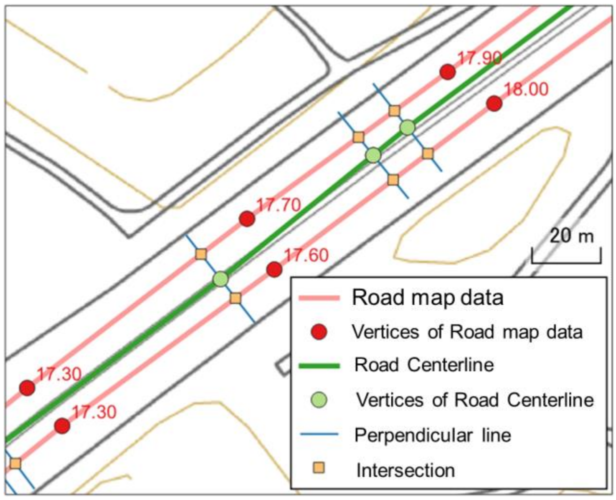

Figure 8. Method for assigning elevation values to the road centerlines from the road map data with elevation values obtained by MMS.

4.3 Results

Figure 9 shows the output of the initial tool and the result of assigning elevation values from the road map data using the method described in Section 4.2 for the section for which verification data was created. In the section for which cross-sectional maps were created, issues such as the one shown in Figure 5(C) occurred frequently at the intersection with the underpass that passes under the highway.

It was found that this issue could be effectively solved by obtaining elevation values from the road map data. On the other hand, looking at the cross sections in Figure 9, the elevation values for the sections where the issue in Figure 5(C) did not occur were generally consistent. For all sections for which verification data was generated, the number of vertices excluding the overlap of connection points between separate lines was 137, and the difference in elevation values (values obtained with the initial tool minus values from the road map data) was calculated. The 25 points (about 18%) with the absolute value of the difference of 1 m or more were excluded from verification in consistency of the elevation data, because they were considered as errors due to the issue shown in Figure 5(C). The remaining 112 points had a mean of +0.24 m and a standard deviation of 0.21 m. Therefore, it can be said that the elevation values obtained by the initial tool are consistent with the actual values measured by MMS in most part of this section. In the future, we are planning to make the above process of obtaining elevation values more automated, so that the MMS measured values included in the road map data can be used for the development of 3D road centerlines at other locations as well.

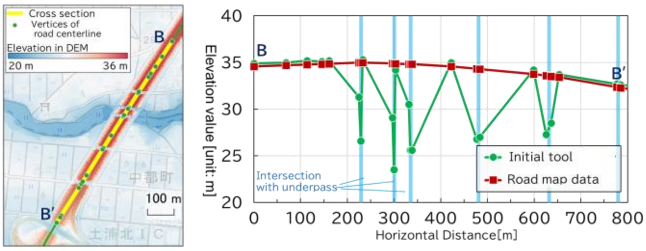

Figure 9. Comparison of elevation values obtained from the initial tool and the road map data (height magnification of cross section: 20x).

5. Publication of prototype data

We released the prototype data for the 3D map on March 26, 2025. This prototype data (Figure 10) was not efficiently modified by the modified tool described above but rather was manually modified from the results automatically processed by the initial tool prior to the modifications.

In FY2025, we plan to conduct hearings with academics, experts and others based on this data, improve the specifications and maintenance method of the 3D map based on the results of these surveys and studies, and begin providing the data sequentially.

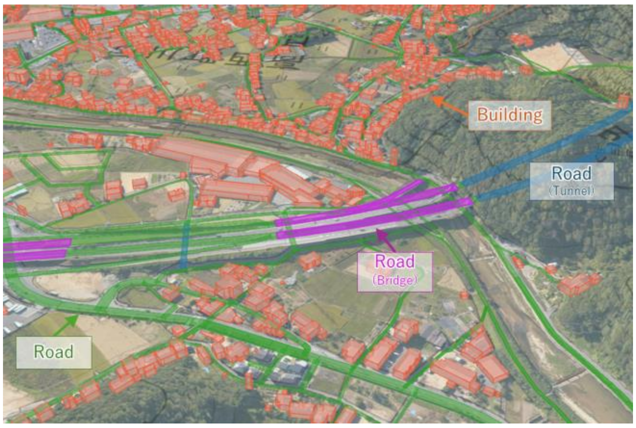

Figure 10. Image of prototype data for 3D map. The road surface is generated and displayed with the road width attribute from the road centerline.

6. Summary and Future direction

In this report, we outlined the method of three-dimensionalization, the development of the initial version of the tool to develop 3D map, the major present issues and the improvement of the initial tool, the verification and data correction with the data acquired by the MMS, and ongoing release of the prototype data in 2025.

The efforts for three-dimensionalization of maps have just begun, and there remains various issues and considerations, including maintenance methods that effectively utilize existing 3D data such as PLATEAU, updating methods after creation, and data specifications. We will continue efforts to achieve the goal of implement of the entire national 3D map by FY2028.

Acknowledgements

In this paper, the airborne LiDAR data conducted by municipalities and administrative organization and collected by GSI, and the 3D point cloud data provided as open data by the Reforestation Division, Green Policy Department, Environment and Agriculture Bureau, Kanagawa Prefecture were used to adding height information. We would like to thank the 3D Geoinfo community for providing open data.

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