engineering proceedings

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Proceeding Paper

Application of Geospatial Data to Architectural Design Education †

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† Presented at the IEEE 5th Eurasia Conference on Biomedical Engineering, Healthcare and Sustainability, Tainan, Taiwan, 2–4 June 2023.

Abstract: The objective of this study is to incorporate varied geospatial data into CAD/BIM systems, which are now essential design tools for architects. Those geospatial data include digital information of topography, water features, roads and streets, existing buildings, and so on. Those data have been released by the government as public information, and their full utilization in actual design projects would be highly beneficial.

Keywords: geospatial data; architectural design; CAD; BIM; GIS

1. Background

In the current field of Architectural Design Education, a course of learning CAD (Computer Aided Design) is incorporated in the curriculum, and students are encouraged to use CAD for their design studies. Given the fact that the CAD system has widely been used in design firms, students need to improve their skills in using CAD in their school days. To meet with the desire of architects for the novelty in designs, the software as a design tool has evolved gradually since 1980s. Nowadays, architects can easily handle the complexity of geometric form such as solid objects and free curved surfaces.

Recently its evolution is observed in the design system called BIM (Building Information Modelling). There, such architectural components as column, wall, floor, roof, etc., are assembled within a virtual 3-dimensional space. They are 3D solid objects, and each object knows how to behave itself when it meets with the other components.

On the other hand, in the field of geography, valuable geospatial data have been prepared and provided by the government, so as to meet varied public needs. The extensive use of the Satellite Positioning and Navigating System has backed up this trend. In Japan, the Geospatial Information Authority (hereinafter GSI) started the distribution of "Fundamental Geospatial Data" in 2007 under the law of the "Basic Act on the Advancement of Utilizing Geospatial Information". Those data include topographic contour lines, water features, railways, streets and sidewalks, footprints of existing building, and so on. This set of information will give a tremendous advantage to architectural design studies. They are freely downloadable and cover the entire land space of Japan. Those data can be read and visualized on the software called GIS (Geographic Information System).

However, at this point, architects are not able to easily handle those valuable data in their design practices. Those geographic data are not transferrable among the systems of CAD, BIM, and GIS. From an architect's viewpoint, this prevents the full utilization of data related to an existing urban context for a specific design project.

For architectural design practices, those design tools need to be integrated so that a seamless dataflow between the systems is enabled. To examine the portability of data, a piece of land, approximately the surface area of 1000 m × 750 m adjacent to the campus of the Shizuoka Institute of Science and Technology, is chosen as a case study site.

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Citation: Sato, K. Application of Geospatial Data to Architectural Design Education. *Eng. Proc.* **2023**, *55*, 38. https://doi.org/10.3390/engproc2023055038

Academic Editors: Teen-Hang Meen, Kuei-Shu Hsu and Cheng-Fu Yang

Published: 30 November 2023

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In this study, AutoCAD 2024, Revit 2024 and QGIS 3.26 are used as basic design tools. Additionally, a series of Python and Lisp scripts are written and utilized for the data transfer from GIS to CAD. In the Python codes, the GeoPandas library is used for data analysis and to coordinate conversion between the global polar and the local orthogonal systems.

2. Site

The site for the case study is shown on the map and in the aerial photo below (Figures 1 and 2), which were visualized on QGIS (https://qgis.org). The specified land is located on a hilly terrain, and several settlements extend along the valleys. Geospatial data within the boundary, as shown in a red rectangle, are to be transferred to CAD systems. Both the map and the aerial photo are raster images on GIS at this stage, and vector data of varied features are needed for the development on CAD systems. The size of the bounding rectangle is 1000 m × 750 m. On QGIS, the CRS (Coordinate Reference System) of the image is set to Japan Plane Rectangular CS VIII, which covers the area over the Shizuoka Prefecture.

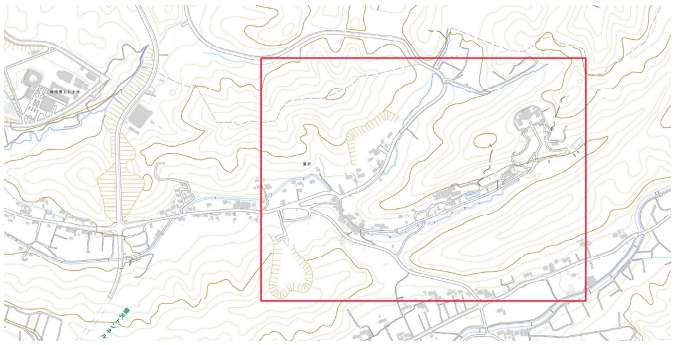


Figure 1. Site for case study/1000 m × 750 m.



Figure 2. Aerial photo and the bounding rectangle.

3. Fundamental Geospatial Data

Anyone can freely access and download the "Fundamental Geospatial Data" on the website of the Geospatial Information Authority (GSI). On the download page, "Fundamental Geospatial Data" or "Digital Elevation Model" can be chosen. Both data are used for this study. It is noteworthy that those digital data cover the entire land space of Japan.

Downloaded data are stored in a GML file format, which is a kind of text data containing the coordinates of longitude, latitude and altitude. This needs to be converted into Shape file format, which is commonly used in GIS systems. For this purpose, a short Python script is written using GeoPandas library. Pandas is a library for handling 2-dimensional tables like spread sheets, and GeoPandas is its extension to geospatial data. GeoPandas can read GML files and transform them into Shape files, while conducting coordinate conversions.

The image below (Figure 3) shows the Fundamental Geospatial Data of the area over Fukuroi city on QGIS. This set of geospatial data includes topographic contour lines, water features, railways, roads and streets, and existing buildings.

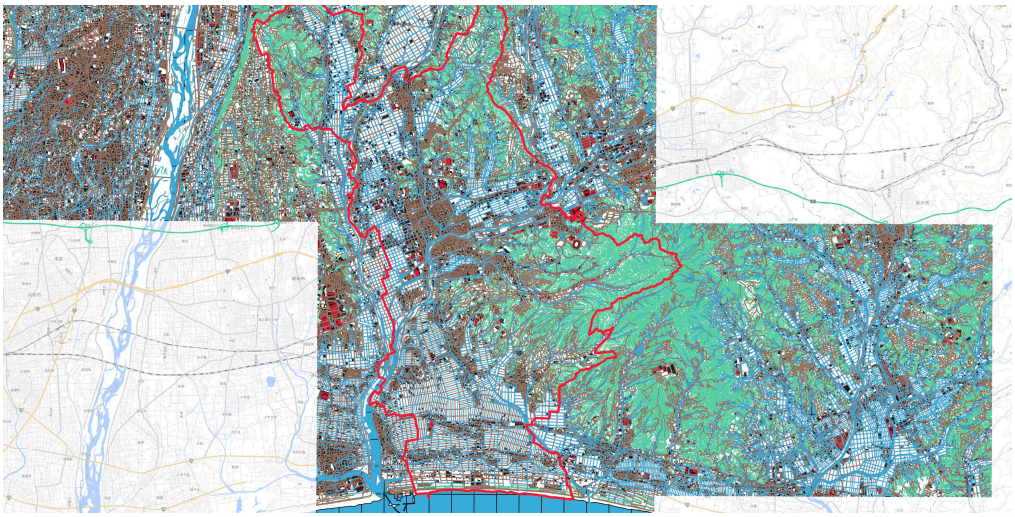


Figure 3. Fundamental Geospatial Data/Visualization on QGIS.

Now let us zoom into the specified land of 1000 m × 750 m for this case study (Figure 4). In this image, the map underlay is not displayed. The geospatial data of contour lines, water features, roads and buildings are all vectors consisting of coordinates of longitude and latitude. Converting those coordinate values into the local orthogonal system leads to the utilization of data in CAD and BIM systems. For this operation, we are reminded that the geospatial data are basically 2-dimensional. For instance, as for the contour data, the altitude is given as an attribute to the 2-dimensional point data.

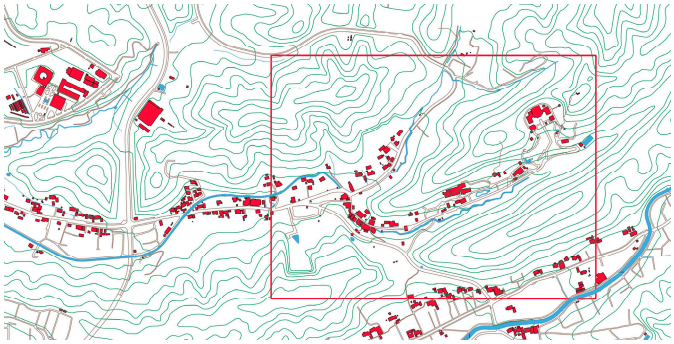


Figure 4. Zooming into the specified site.

In the following study, these contour data are not used because their vertical interval is set to 10 m. Instead, more precise information of the altitude is gained from the "Digital Elevation Model", and contour lines are calculated based on the altitude data on each point of the 5 m × 5 m mesh grid over the land. The accuracy of the data is reported to be less than 30 cm, and this figure is more than necessary for preliminary studies of a specific architectural design project.

4. Digital Elevation Model

The DEM (Digital Elevation Model) data are also downloadable from the website of GSI. The downloaded dataset is also stored in GML file format. However, it contains a list of three-dimensional point data and, therefore, GeoPandas cannot read the data. For reading and visualizing the data, one idea is to use a utility program called the Fundamental Geospatial Data Reader, which is provided by GSI. With that program, file conversion from GML format to a simple XYZ text format is possible. Another idea is to write a Python script to read GML files and output a simple CSV file, which contains a list of coordinates consisting of longitude, latitude, and altitude of points. The original dataset is huge, and another script for cropping data within the specified boundary is also needed.

So, data created in this way should be structured grid-data; however, the original data contain missing points over the water features. The dataset is discrete, and needs to be structured. For this, using Scipy library on Python, linear interpolation to the data is applied and a structured-grid dataset is achieved. Then, on the dense grid data, the calculation of contour lines is enabled with the help of ContourPy library.

5. Data Transfer to AutoCAD

In order to read geospatial data in AutoCAD [1], an intermediate data file is prepared. That file stores point data of the serially described x, y, and z coordinate values. To make this intermediate data file, a Python script is written. That script mainly works on two points: (1) the conversion of a coordinate reference system (from polar to orthogonal), and (2) the Boolean operation between objects ("features", in geospatial terms).

For CRS (Coordinate Reference System) conversion, GeoPandas library is used. More specifically, it works on the conversion from JGD2011 to JGD2011/Japan Plane Rectangular CS VIII. JGD2011 is the most common CRS in publications of GSI.

For cropping varied features within the rectangular boundary, Boolean operations are applied, which include such operations as union, subtract, and intersect between 2-dimensional geometric objects. A geospatial dataset comprises basically three object types: Point, LineString and Polygon. To work on those Boolean operations in Python codes, a library called Shapely is used.

Once this intermediate data file is created, then an application program to read and draw data in AutoCAD is needed. Historically, in AutoCAD, Lisp interpreter works as a man–machine interface for the system. Therefore, a Lisp script is written for reading geospatial data described in the intermediate files. There, the data types of Point, LineString, and Polygon are replaced with Point, Open Polyline and Closed Polyline of AutoCAD.

Thus, the geospatial data are imported to AutoCAD (Figures 5 and 6), which includes contour lines (3D Polyline), water features (2D Closed Polyline), roads (2D Polyline), and building footprints (2D Closed Polyline).

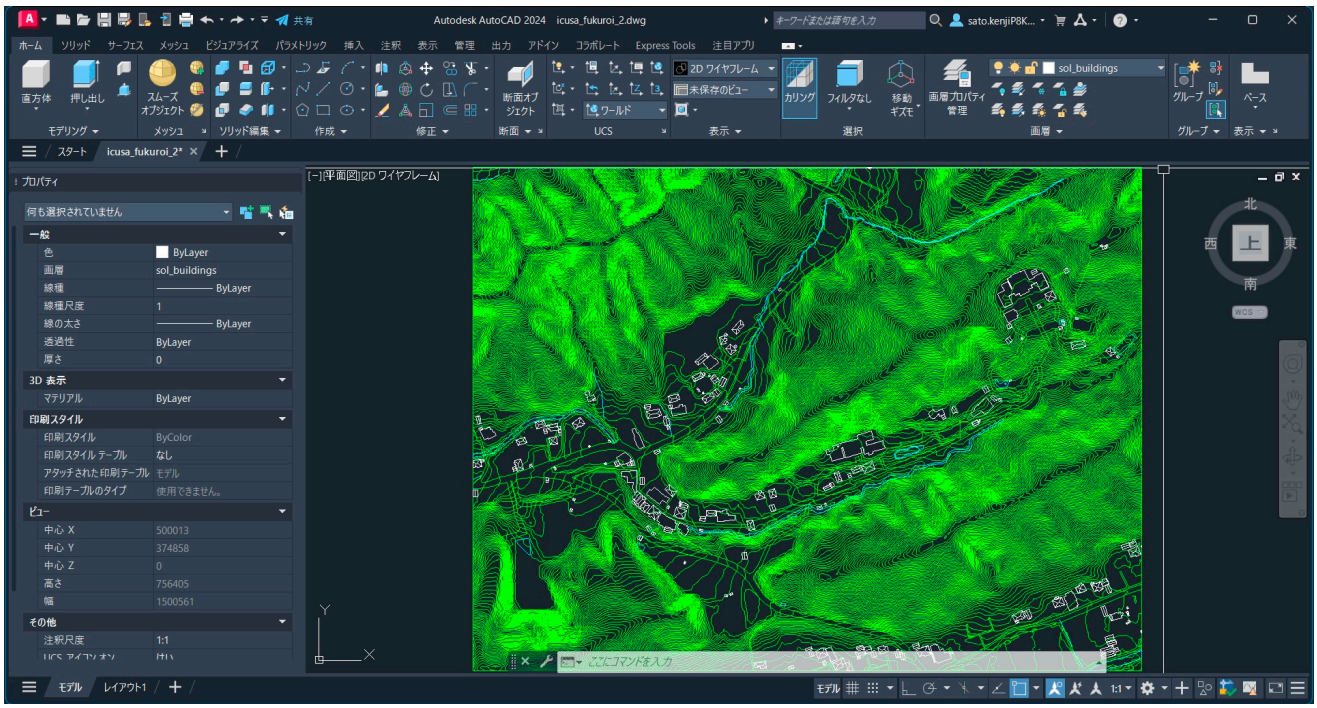


Figure 5. Visualization of data on AutoCAD/plan view.

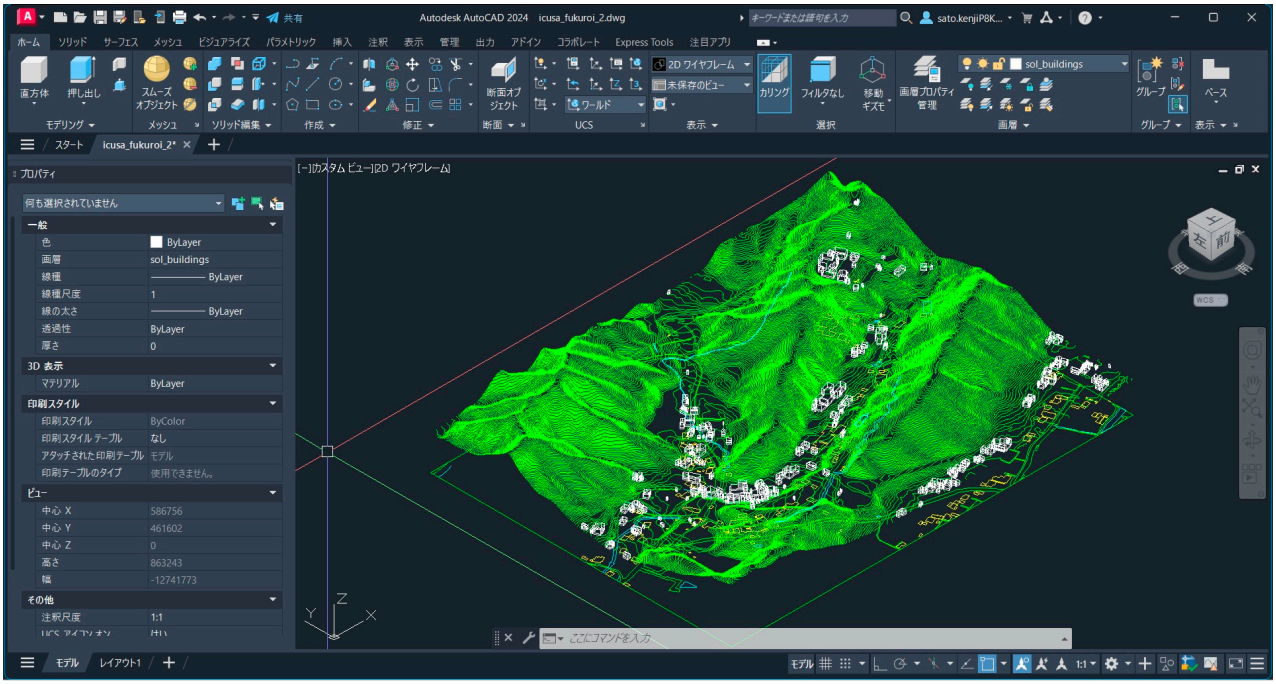


Figure 6. Visualization of data on AutoCAD/isometric view.

By extruding the drawn footprints, 3D building objects are created as 3D Solid. For this, building elevations need to be calculated beforehand. Since we already know the altitudes of every 5 m grid over the land, it is easy to calculate the elevation of each building. However, as for the height of the building, there is no information in the current Fundamental Geospatial Data. The profile of each building in the drawing does not represent its actual height. Knowing this limitation, the drawing still seems highly effective for architectural studies.

6. Development on Revit

On Revit, the topography of the land is generated by importing the grid data of altitude. The generated topographic object is called topo-solid in Revit (Figure 7). Regarding the roads and the water features, sub-regions on the topo-solid need to be specified.

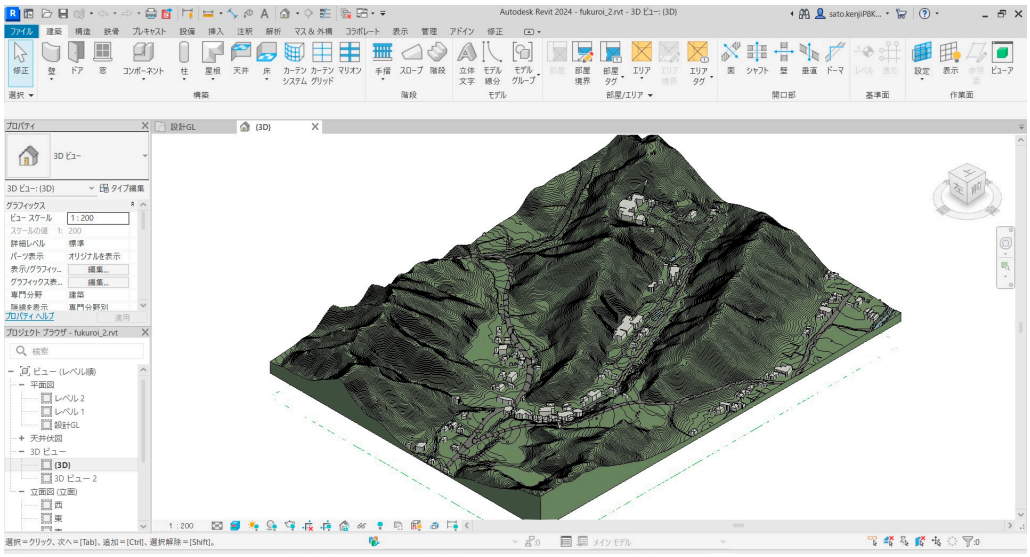


Figure 7. An environmental model of Revit/Topo-solid and sub-regions.

To create sub-regions, firstly AutoCAD data are imported, and the boundaries of each sub-region are traced. In Revit, this operation is called "sketching". In fact, this sketching is a time-consuming task, and another solution needs to be developed in the future. As for the buildings, they are imported from the AutoCAD data and converted into Mass objects of Revit.

On the surface of the topo-solid, you can easily place such landscape elements as natural trees, human profiles, and so on. Based on this environmental model, a specific site for a project can be set up as a sub-region on a topo-solid. Students will develop their design exercise on that project site.

7. Conclusions

The objective of this study has been to create an urban-scale model on CAD/BIM systems for architectural design on a specific site. By utilizing geospatial data, which are now available through public services, architects can extend their capability of handling the complexity of the real city.

The photograph below (Figure 8) is an example of a site model, which was made by students at a design studio for a certain project. That model is made with paper and styrofoam. Architects make such urban-scale models at the very beginning of the preliminary study for a project.

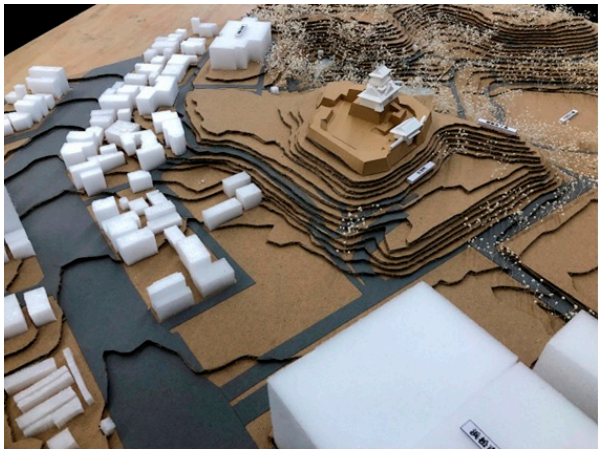


Figure 8. An example of a site model.

The aim of the study as so far carried out is to replace this real model with a virtual model on the computer. At this moment, the situation of data sharing between the CAD, BIM and GIS systems is inadequate. To read geospatial data, which basically comprise 2-dimensional geometric objects stored in the form of Shape file, and also to visualize the data on CAD/BIM systems, it is necessary to write a series of custom add-in programs at this stage. CAD, BIM and GIS systems are essentially the tools for manipulation of geometric objects and, therefore, integration of those tools is expected to be achieved soon.

Another subject to be resolved is related to the height, the shape, and the structure of existing buildings. At this moment, 2-dimensional information of existing buildings is provided in the "Fundamental Geospatial Data". When three-dimensional data of features are made available, our virtual model will become much closer to the real urban environment. It will definitely contribute to the design studies by architects.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The original GIS data were downloaded from the website of GSI https://www.gsi.go.jp/kiban (accessed on 15 May 2023). In this study, the following open-source

libraries were used: Pandas (https://pandas.pydata.org/), GeoPandas (https://geopandas.org/en/stable/), Shapely (https://pypi.org/project/shapely/), scipy.spatial (https://scipy.org/), ContourPy (https://pypi.org/project/contourpy/).

Conflicts of Interest: The author declares no conflict of interest.

Reference

1. Sato, K. *Learning AutoCAD for Architectural 2D and 3D Drawings*; Gakugei Shuppansha: Kyoto, Japan, 2021; Chapters 15 and 16; ISBN 978-4-7615-3270-3.

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