Development of a Prototype System of Three Dimensional Geologic Modeling for Providing Geologic Information using Web-GIS

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Abstract

The purpose of the present study is to develop a three dimensional geologic modeling system on Web-GIS and to define the basic elements of the model for providing geologic information accurately and effectively. The prototype system has been developed to perform acquisition of geologic data, construction of models, and visualization of the modeling results on Web. The base system of the prototype is constructed by the integration of a mapping engine, Web-GIS client, GIS and relational database using typical FOSS4G (Free and Open Source Software for Geoinformatics) products. The main system for the geologic modeling is composed of nine functional modules. The basic elements of the three dimensional geologic model have been defined according to the arrangement of data flow of this modeling system. Further, this system has been established by the subsurface modeling using real borehole data from the Western Osaka Plain in Japan.

1. Introduction

In recent times, mankind has been facing many problems such as environmental pollution, natural disasters and radioactive wastes, etc. Mitigation and prevention of natural disasters and proper disposal of radioactive wastes require careful consideration of the natural geological setup. Proper management of these problems requires a good knowledge of geology around those areas. For this it becomes important to provide geologic information accurately and effectively. Three dimensional geologic models are generated from the geological analysis of fundamental field data and the knowledge of the geologist. These models provide vital geologic information on any area under consideration However, the quantity and quality of the basic data, theory and assumption of geological process are not known to the user of geologic models. Therefore, it is important to actively provide the information of the basic elements for geologic modeling in addition to the actual geologic model. This information enables the user to evaluate accuracy, resolution and reliability of the geologic models. Information used for constructing the three dimensional (3D) geological map can be provided as a logical model. For this purpose, the basic theory for 3D modeling as a surface model has been developed (Shiono et al., 1994, 1998). The methodology and algorithms implemented for visualization of geologic model have been developed using the Open Source GRASS GIS environment (Masumoto et al., 1997, 2004). Further, with the aim of providing an easy to use interface and also to provide remote access possibly from field sites, an online Spatial Information System for Geologic Modeling (SISGeM) incorporating the algorithms and methods used in the standalone system has been developed (Raghavan et al., 2000 and Nemoto et al., 2003). However, the SISGeM is unable to perform the function for sharing and distributed processing of the information due to the lack of support for geospatial standards and interoperability in the system. The Open Geospatial Consortium (OGC) Web Processing Service (WPS) standard (Open Geospatial Consortium, 2007) enables implementation of algorithms for 3D geological modeling in an interoperable Web-GIS framework. In this paper, we present a prototype system for 3D geologic modeling to perform acquisition of the field survey data, construction of the models and visualization of the results entirely in Web-GIS application. The Web-GIS is based on the previous research quoted in the paragraph above. The basic workflow of the 3D geologic model has been defined to provide geologic information based on surface interpolation and logical modeling.

2. System Configuration and Function

The Prototype system for 3D geologic modeling has been constructed as Web-GIS application with nine functional modules.

2.1 Base System

The base system for 3D geologic modeling is constructed by the integration of Web-GIS Mapping engine, Web-GIS client, GIS and relational database to support the various functions and the use of WPS standard for interoperable geoprocessing using the FOSS4G products (Ninsawat et al., 2008 and Masumoto et al., 2008). The software configuration of this base system is shown in Table 1. These GIS application software and libraries are supported by OSGeo Foundation (The Open Source Geospatial Foundation)

Table 1: Software configuration of the base system

System	Name
Operating System	Mandriva Linux
Mapping Engine	MapServer
Web-GIS Client	OpenLayers
GIS	GRASS GIS
DataBase	PostgreSQL/PostGIS

2.2 Modules for Geologic Modeling

The main system of the geologic modeling is composed of nine functional modules. There are seven functional modules ranging from the accumulation of the field survey data to the construction of three dimensional models. In addition to these modules, there are two functional modules that enable sharing, providing and visualizing of all the data in standard format of Web and Web-GIS. Figure 1 shows the relationship of the nine modules and the data flow of the system. The outlines of the final objective for these functional modules are as follows.

Data Acquisition Module: This module imports various basic data files such as the filed survey data, the borehole data, and the elevation data from offline or an online database into the relational database module of the system.

Stratigraphic Correlation Module: This module supports stratigraphic correlation of the geologic data establishing the stratigraphic classification and geologic structure on Web-GIS. The results of the correlation and stratigraphy are stored into the database (Sakurai et al., 2008).

Classify and Arrange Module: This module performs the classification and rearrangement of the basic data according to the established stratigraphy using an inference engine. Also, this module checks the consistency of the results logically and generates the location data and the event sequence (Iwamura et al., 2008, 2012).

Logical Modeling Module: This module creates the event sequence and the logical model of geologic structure. It also arranges the data set for the estimation of the geologic boundary. The logical model showing the hierarchical relationship between the boundary surfaces and geologic units can be automatically generated based on the event sequence and knowledge of geologic structures.

Surface Estimation Module: This module estimates the geologic boundary from the data set arranged by the logical modeling module using bi-cubic spline function (Nonogaki et al., 2008). These surfaces including the parameter for estimation are stored in the database.

Geologic Function Module: This module defines the geologic function that expresses the rule to assign the unique geologic unit to every point in the objective 3D space. Three dimensional geologic models are constructed virtually by implementing the geologic function from the boundary surfaces of geologic units and the logical model of geologic structure.

Database Management Module: This module manages all data in the relational database. The basic data, the results of stratigraphic correlation, the event sequence, and the logical model of geologic structure, estimated surfaces, and the parameters of surface estimation can be queried and updated on-demand from each module.

Visualization Module: This module exports the data and the model to the appropriate data format for 2 or 3D visualization. For 3D visualization, VRML format is used for Web browser plug-in viewer (e.g.: Cortona3D), and GRASS format is supported as an auxiliary method for Nviz visualization tool of GRASS GIS. Further, this module creates the 2D geological profiles along the straight line between arbitrary two points.

Standardization Module: This module transfers the data and the elements of the model using OGC standards for Web-GIS. WMS and WFS define the raster images and the vector features are used for the geologic elements.

Presently, this prototype system for 3D geologic modeling is complete and provides all the basic functions. Further improvements would be focused on improving interface and documentation for production use.

3. Basic Elements of Three Dimensional Geologic Models

The spatial distribution and the relation of geological units are expressed in a 3D geologic model based on the fundamental field data and the knowledge of the geology. The flow of the geologic information for the construction process of the 3D geologic model is shown in Figure 1. These information can be arranged according to the following items.

Observed Data: Data from the field survey (e.g. location, attitude, attribute, lithofacies, and relationship, etc.) and the data from analyzing (e.g. dating, fossil, rock properties, geophysical prospecting, and geochemical, etc.).

Inferred Information: Information of the geologic units (e.g. correlation, stratigraphy and structure, etc.)

Logical Model: The event sequence, and the logical model of geologic structure.

Boundary Surfaces: The geometrical shapes of boundary surfaces including data and parameters for estimation.

Construction Method: The theory, process and the method of analysis used for modeling including the boundary surface estimation method.

These data can be classified into quantitative and qualitative data. The information of the geologic units is inferred from observed data. The event sequence shows the geological history. The logical model of geologic structure expresses the logical relationship between geologic units and boundary surfaces.

The above items are the basic elements of a 3D geologic model. There are many issues to be solved in the information of geologic model, such as the problems of objectivity, reproducibility, renewability, extensibility, compatibility, flexibility and versatility. These problems can be solved by the providing the basic elements used to construct the 3D geologic model.

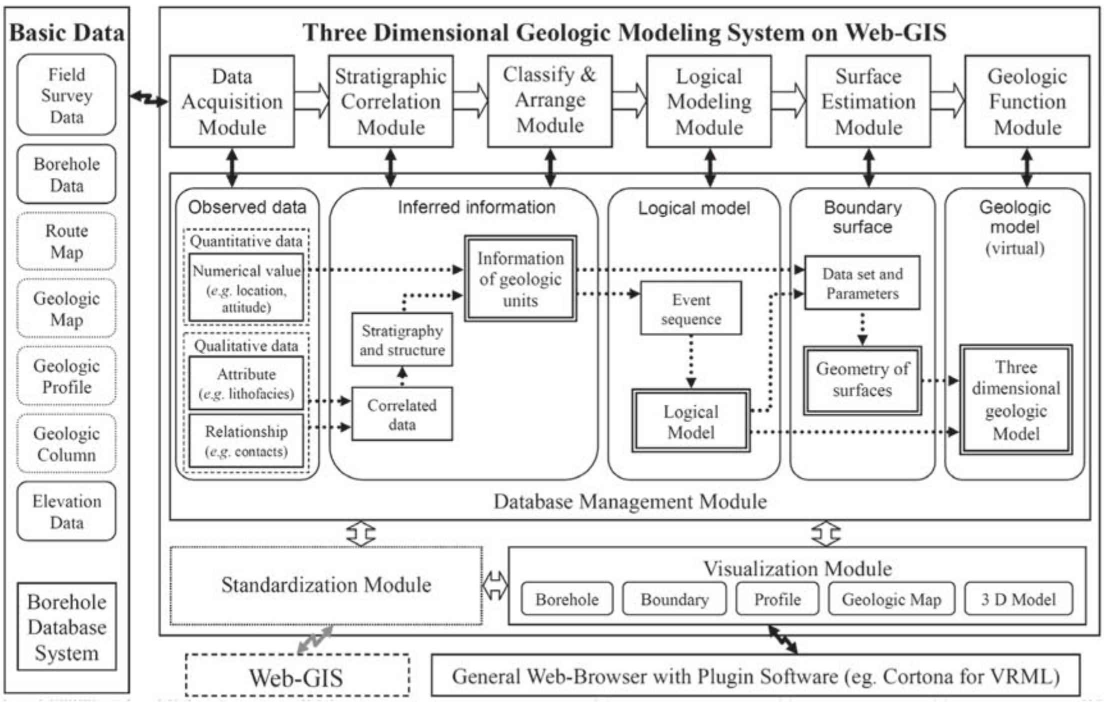

Figure 1: Relationships of the modules and data flow of the 3D geologic modeling system on Web-GIS

4. Examples

The subsurface model of the Western Osaka Plain has been constructed using the modeling system developed in this research. This model is meant only to verify function of the modules and flow of the information for 3D geologic modeling. Figures 2, 3 and 4 show the sample images of the 'modeling system view window'. Figure 2(a) shows the location of borehole sites on a general map. Figure 2(b) shows the drawing line of profile using draw line function to select boreholes for the stratigraphic correlation. The work window of the stratigraphic correlation module is shown in Figure 3. Figure 3(a) shows the selected borehole logs and Figure 3(b) shows expanded image of borehole log. Each borehole log shows geological description (lithology and fossil content) and the Standard Penetration Test N-Value (also known as N-Value). In this work window, the lithofacies correlation can be carried out by choosing geologic units that bear correlation (Sakurai et al., 2008). Figure 4 shows the logical model of geologic structure created by the logical modeling module. This logical model shows the relationship between eight boundary surfaces and nine geologic units including open space α. Examples of visualization of geologic model and the borehole data are shown in Figure 5, 6 and 7. Figure 5 shows the geological profiles on the 'modeling system view window' without plug-in software. Figure 6 shows the various VRML screenshots using Cortona3D viewer plug-in for Web browser. Figure 7 shows the boundary surfaces and profile using Nviz of GRASS GIS. The arbitrary geologic profiles can be created directly in real time by the Nviz function.

(a)
(b)

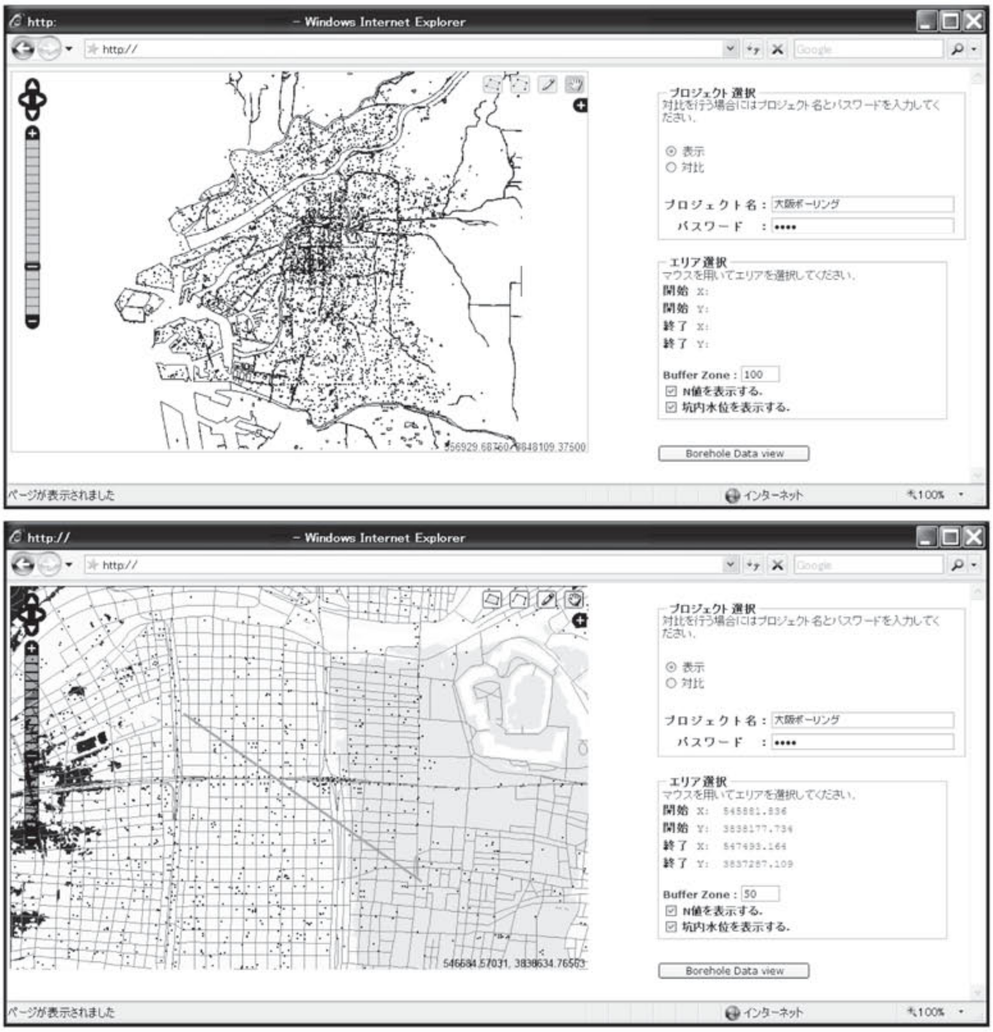

Figure 2: Example images of the three dimensional geologic modeling system. (a) Points of borehole site on general map, and (b) line of profile for the stratigraphic correlation

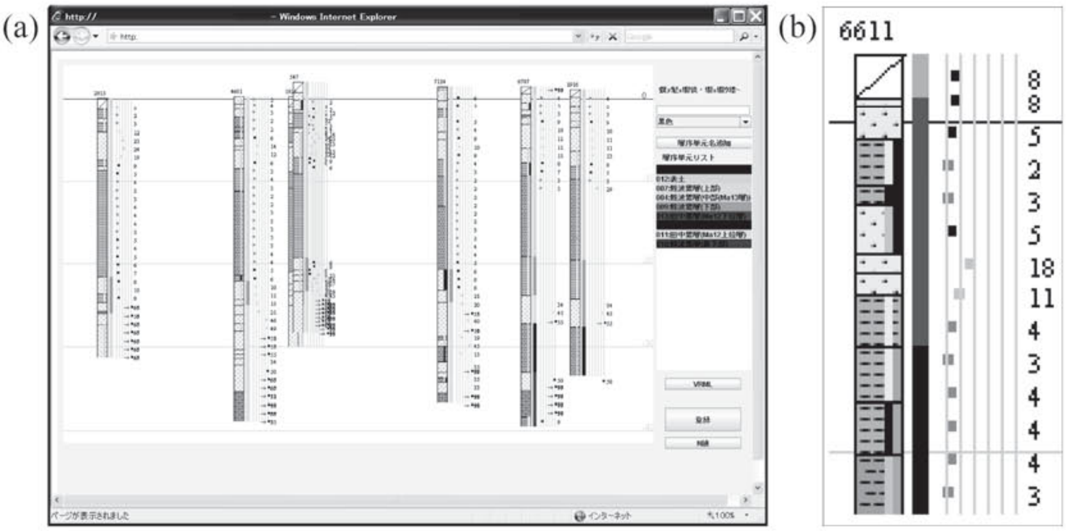

Figure 3: Example image of the stratigraphic correlation module. (a) Borehole logs with lithofacies correlation results, and (b) expanded image of the borehole log

	S1	S2	S3	S4	S5	S6	S7	S8
b1	−		−				−	−
b2	+	−	−				−	−
b3	+	+	−				−	−
b4			+	−			−	−
b5			+	+	−		−	−
b6			+	+	+	−	−	−
b7			+	+	+	+	−	−
b8							+	−
α								+

Figure 4: Example image of the logical model of geologic structure

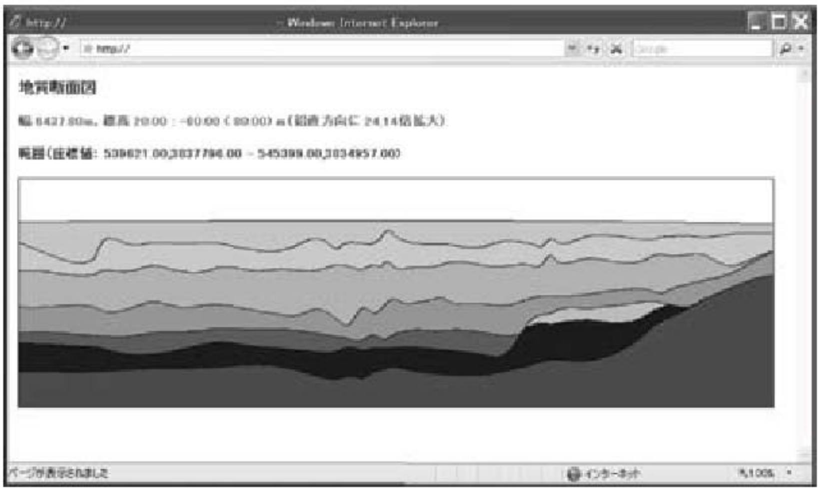

Figure 5: Example image of geological profile on Web browser without plug-in software

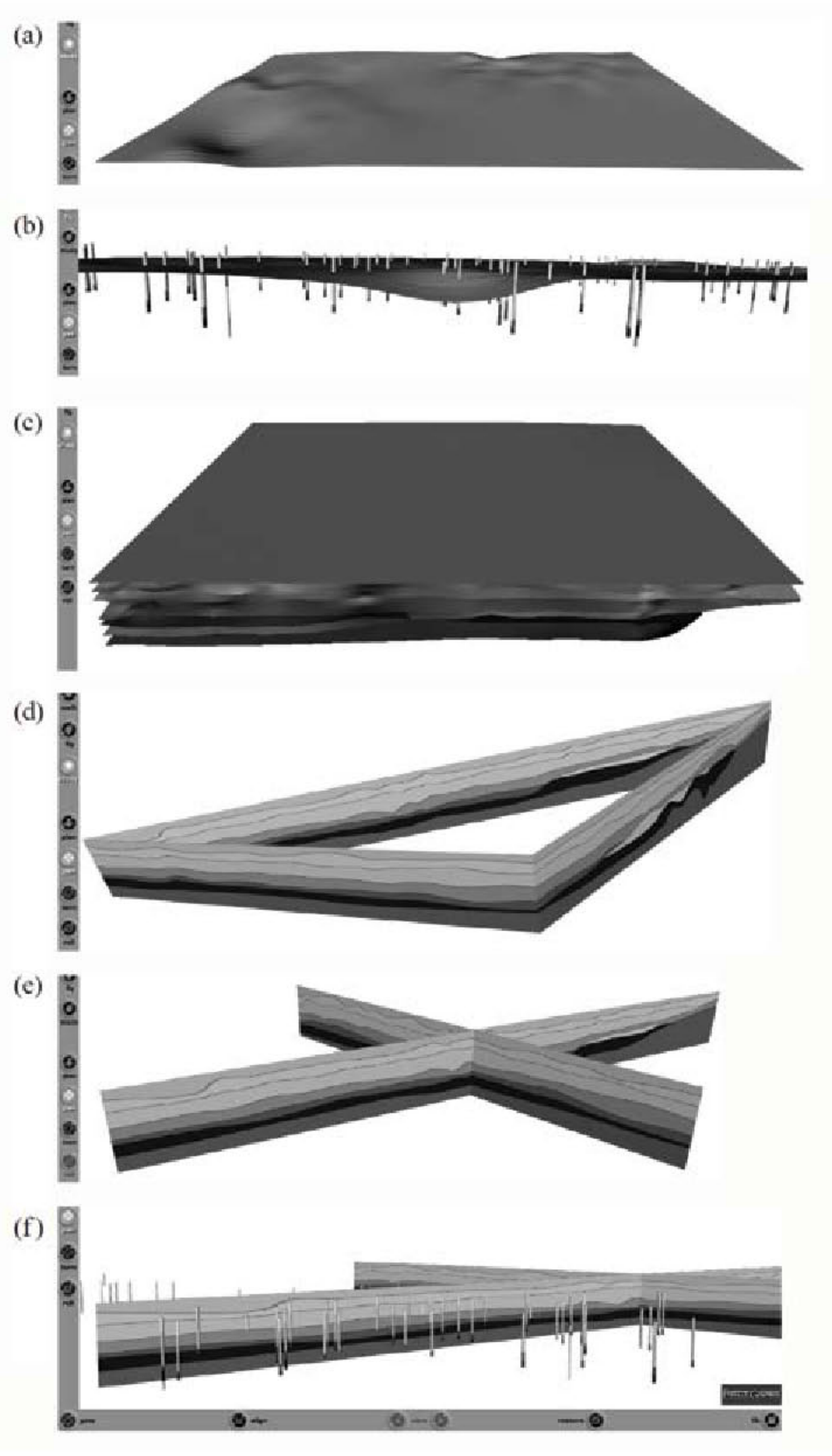

Figure 6: Example images of the model on Web browser using VRML viewer (Cortona3D). (a) Geologic boundary surface, (b) geologic boundary surface with borehole data, (c) geological model, (d) geologic profiles, (e) cross geologic profiles, and (f) profiles with borehole data

Figure 7: Boundary surfaces and profile of the model using Nviz of GRASS GIS

5. Discussion and Conclusions

The basic elements of the 3D geologic model and the prototype of the modeling system for providing the 3D geological information were presented The basic elements are very important to support effective utilization, provide better understanding and enhance reliability for the users of geologic model. Recently, GeoSciML which is an application schema, specified a set of feature-type and supporting structure for geological information (Sen and Duffy, 2005 and Fusejima and Bandibas, 2008). The basic elements of 3D geologic model developed in the present research will be made compatible with the structural information provided by the GeoSciML schema. There are some limitations on the present prototype system. The limitation can be discussed as two issues. The first issue is solvable problem such as the data management for faulted structure and the standardization of the model, and the second issue that does not have an easy solution about dealing with overhang and overfold geologic structure. In case of a fault, the true side of the fault of a layer separated by a fault cannot be defined automatically. To create such faulted 3D model in the present system, layers that are displaced by faults must be treated as two different layers. This problem can be solved by the using the algorithm based on the theory of faulted structure modeling by Yonezawa et al., (2005). Relating to the standardization, there is no standardized format for geologic model. In the near feature, it is necessary to define a world standard format for sharing and practical use of geologic model information. The structure of overhang and overfold cannot be processed by this system. This problem is essentially the weak point, and can not be solved immediately. This is because, in the case of these structures, two or more different elevation height values which are not expressible as a raster data, are present at the same location. Some new theories, algorithms and techniques related with 3D geologic modeling have been developed such as Web-based surface fitting system (Nonogaki et al., 2010, 2012) and the 3D direct visualizing using OpenGL API. For practical use, further development and improvement of this modeling system is necessary by incorporating the above enhancements.

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