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A Three-Dimensional CAD Engine: Implementing Parametric Modelling

S. Kubota[1], E. Kitagawa[2], K. Monobe[3], K. Nakamura[4] and S. Tanaka[5]
[1] Faculty of Software and Information Science, Iwate Prefectural University, Japan
[2] Faculty of Management Information, Hannan University, Japan
[3]Faculty of Project Design, Miyagi University, Japan
[4] Faculty of Information Technology and Social Sciences
Osaka University of Economics, Japan
[5] Faculty of Informatics, Kansai University, Japan

Abstract

Civil infrastructure is developed through an on-going process of planning, survey, design, construction, and maintenance, and drawings are created during each process. Drawing data is normally generated in the design phase using computer-aided design (CAD) software. Structure design intent, such as in CAD software functions, as well as model generation procedures are often expressed in CAD data. Such data is therefore also frequently needed during the construction and maintenance phases. Construction projects occur in a three-dimensional (3D) environment where integration of 3D data should lead to improved productivity, yet 3D CAD data that would be useful rarely exists. This paper proposes a 3D CAD engine for creating data that retains the design intent of civil infrastructure projects, based on a parametric modeling approach. Use of the proposed 3D CAD engine should benefit infrastructure projects, for example through adoption of parametric modeling, consideration of temporal information, and conformity to international standards. As a case study, 3D models of concrete structures are generated and software functionality is evaluated.

Keywords: three-dimensional computer-aided design, parametric modeling, product data model, STEP, ISO.

1 Introduction

Civil infrastructure is developed through an on-going process of planning, survey, design, construction, and maintenance, and retaining design knowledge and intent at each stage is an important aspect of civil infrastructure maintenance. Generating structure drawing data using computer-aided design (CAD) software during the design phase is one effective means toward that objective. Using CAD software functions and model generating procedures and operations helps to retain the design intent of construction engineers. An environment should be provided in which three-dimensional (3D) structure information can be efficiently and smoothly used throughout the project lifecycle [1, 2]. Presently, 2D drawing data are primarily used in the design and construction stages, and the use of 3D information has only recently started. A 3D CAD engine should be therefore be developed and operated to create and modify 3D shape information.

This paper proposes a three-dimensional CAD engine for creating and modifying 3D CAD data that retains the design intent of civil infrastructure projects, based on a parametric modeling approach. Use of the proposed 3D CAD engine should benefit infrastructure projects, for example through adoption of parametric modeling, consideration of temporal information, and conformity to international standards. As a case study, 3D models of concrete structures are generated and software functionality is evaluated.

2 Design concepts

In this section, a 3D CAD engine is proposed to create and modify 3D data retaining structure design intent. There are three design concepts required for retaining design intent and applying that information to international construction projects: the parametric modeling approach, data models based on international standards, and consideration of temporal attributes.

2.1 Parametric modeling approach

The 3D CAD engine is developed based on the parametric modeling approach. 3D models created according to current model functions have no means for design, and do not retain designer intents. Parametric modeling considers both the final geometric shapes and constraint conditions on those shapes, and can recreate 3D geometric shapes by processing constraint conditions and modeling operation histories. The proposed method adopts such features, storing procedural modeling operations and automatically generating final geometric structure shapes by reprocessing them. Shape definitions are also retained, and modeling operational histories and constraint conditions are applied to them.

Designs often change during the design and construction phases of civil infrastructure. Adopting parametric modeling, 3D model data incorporates modeling operational histories and thus the design intent of the construction engineers that generated the data. 3D model data can be regenerated by modifying 3D model parameters.

2.2 Data model based on international standards

Interoperability and compatibility are important when developing a platform for sharing civil infrastructure information. 3D information should therefore be standardized, based on accepted international standards. In international construction projects, ISO (International Organization for Standardization) or similar standards should be used. In Japan, the SCADEC exchange format—a 2D CAD data exchange format—is standardized through ISO 10303 Part 202 (also known as the "Standard for the exchange of product model data"). However, 3D information falls outside the scope of this CAD data standard. Instead, ISO 10303 Part 203 ("Configuration controlled design") standardizes the exchange and sharing of 3D information [3]. In this paper, ISO 10303 Part 203 is used for representing and exchanging data generated by the proposed 3D CAD engine. Sketch and constraint conditions in parametric modeling are based on ISO 10303 Part 108 ("Parameterization and constraints for explicit geometric product models") [4], modeling operational histories are based on Part 55 ("Procedural and hybrid representation") [5] and Part 111 ("Elements for the procedural modeling of solid shapes") [6], and assembly modeling is based on Part 109 ("Kinematic and geometric constraints for assembly models") [7].

2.3 Considering temporal attributes

It is necessary to accumulate information produced over the entire civil infrastructure lifecycle to analyze problems and solutions within a temporal sequence and to strategically and effectively maintain the infrastructure [8, 9]. Spatial and temporal information must be used to perform effective structure management. Information is generated over the civil infrastructure lifecycle, including spatial information such as geographical and positional attributes, and temporal information such as the time that a service opens and closes to the public [10, 11]. The proposed 3D CAD engine considers temporal attributes in addition to geometric information.

3 Development of the 3D CAD engine

3.1 Outline of the 3D CAD engine

The proposed 3D CAD engine is composed of a data model that manages data about each function and application program interface (API), which operate on functions and data as shown in Figure 1. APIs are utilized for CAD software domains such as roads, bridges, and dams. The 3D CAD engine's data model is composed of 3D geometric shape data, and manages 3D model data, sketches, modeling operational histories, attributes with temporal elements, and assembly data that manages data represented by assembly models.

3.2 System functions

3.2.1 Modeling functions

The 3D CAD engine defines modeling operations for basic shape creation and modification. Construction engineers can represent 3D shapes using sketches that describe the cross-sectional surface shape of 3D models, sketch constraint conditions, and modeling operational histories. The modeling methods of extrusion, rotation, sweep, ruled, mesh, and Boolean are implemented for basic shape creation. When modifying basic shapes, methods for corner chamfering, filleting, cutting, translation, rotation, and zoom are implemented. The 3D CAD engine records modeling operations in order as modeling operational histories. Parameter values are modified by construction engineers, and the modeling operational histories refer to sketch shapes.

Sketch functions define 2D geometric shapes on a plane. 2D geometric shapes such as lines, curves, circles, circular arcs, ellipses, parabolas, hyperbolas, NURBS curves, and clothoid curves are represented. Sketches can define geometric constraint conditions in horizontal, perpendicular, and angular directions. Assembly modeling functions allow assembly of multiple 3D geometric shapes into parts.

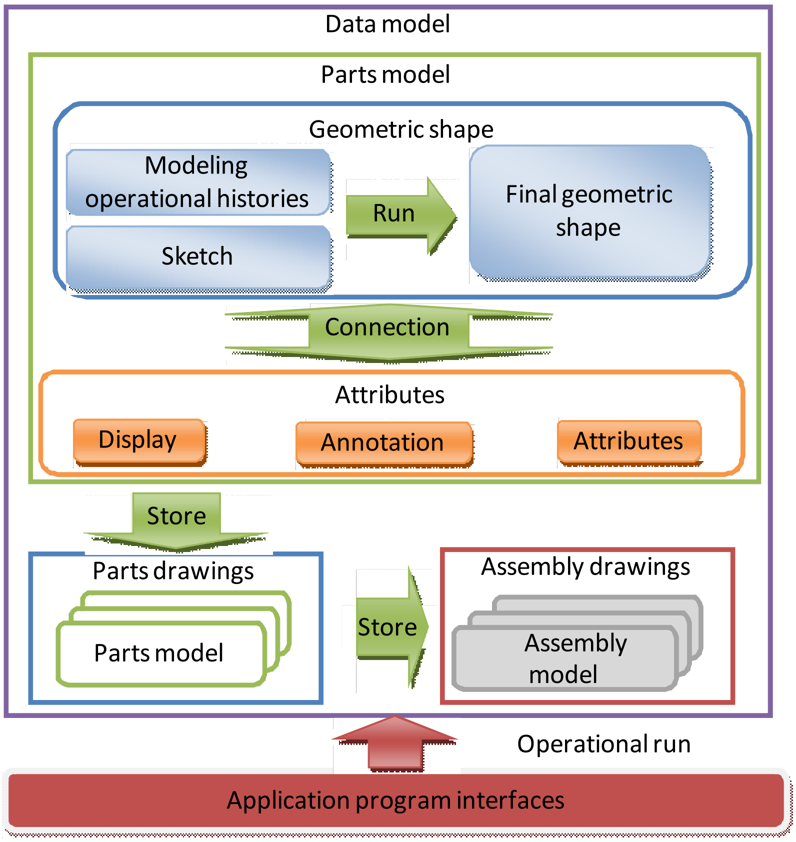

Figure 1: Outline of the 3D CAD engine.

3.2.2 Attributes information functions

Attribute information functions add attributes to 3D model data. The attributes are originally defined and added by 3D CAD engine users. 3D model data and attributes have a many-to-many relation. As mentioned above, the 3D CAD engine records temporal attributes. Table 1 shows the temporal elements of the proposed CAD engine. The 3D CAD engine also allows text annotation, markup, and layer, color, line type, and line width display attributes.

Elements	Contents
Generated time	Date and hour a structure was created
Deletion time	Date and hour a structure was deleted
Start time	Date and hour a place begins service
End time	Date and hour a place ends service

Table 1. Temporal elements.

3.3 Data model construction

3.3.1 Parametric modeling

3D data modeling operations are stored in a database based on ISO 10303. Figure 2 shows the exchanged data. The data model is based on Part 55 of ISO 10303. The "Procedural_shape_representation" entity of Part 55 is used to manage modeling operational histories, and the "Procedural_shape_representation_ sequence" entity is used to represent each operation. Figure 3 shows the proposed data model for parametric modeling.

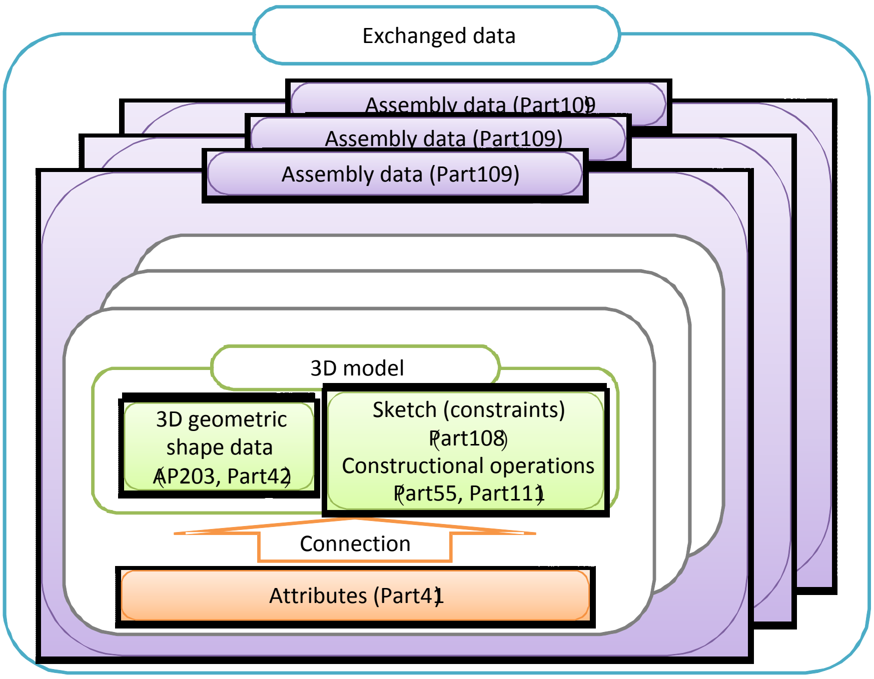

Figure 2: The 3D CAD engine data exchange format.

3.3.2 Sketches

The sketch data model has arbitrary plane, arranged geometric shape, and geometric constraint characteristics. Arbitrary planes and geometric shapes are represented based on Part 42 of ISO 10303, and geometric constraints are represented based on Part 108.

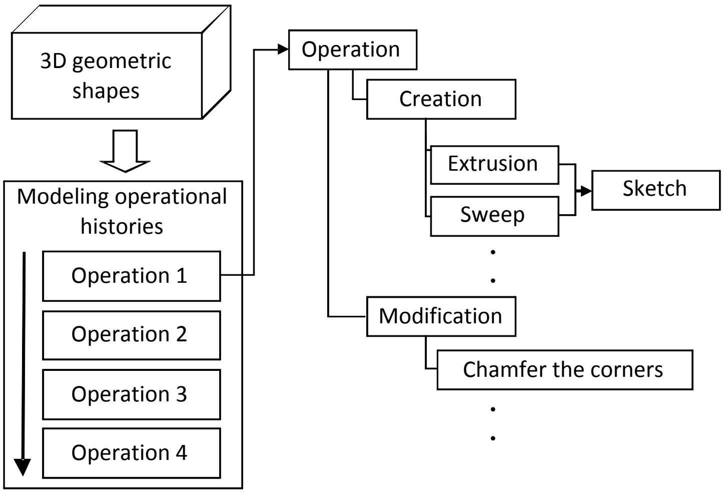

Figure 3: The parametric modeling data model.

3.3.3 Geometric shapes

The 3D CAD engine uses OpenGL to display 3D model data. OpenGL cannot describe circles or curved surfaces, which therefore must be divided into a triangulated irregular network (TIN). The geometric shape data model holds the 3D data represented by the TIN and previous 3D model data. 3D geometric shapes are constructed according to Part 203 of ISO 10303.

3.3.4 Assembly modeling

The assembly modeling data model is similar to parametric modeling in Part 55 of ISO 10303. The operations are based on Part 109. The data structure of the proposed 3D CAD engine is shown in Figure 4, based on the above discussion. All information in the 3D CAD engine is managed in the “Kaiser” package. The Kaiser package contains classes for managing system information, a “Utility” package composed of the classes defining common data structures for the 3D CAD engine, and a “Draw” package holding model data. The “Draw” package is composed of “Procedure,” “Sketch,” “Shape,” “GeometricItem,” “GeometricConstraint,” “Attribute,” “Annotation,” and “Presentation” packages.

3.4 Constraints evaluation algorithm

Construction engineers create sketches and input geometric constraint conditions using 3D CAD software based on the proposed engine. The function that determines the final geometric shapes by calculating the geometric constraint on shapes could be subject to geometric constraint problems. Figure 5 shows how such problems are resolved. The proposed method adopts a graph-solving algorithm for triangular shapes that transforms line segments and circular arcs created by the user into lines and circles according to the constraint conditions. The solver judges whether constraints are appropriate, and notifies users of under- and over-constraints.

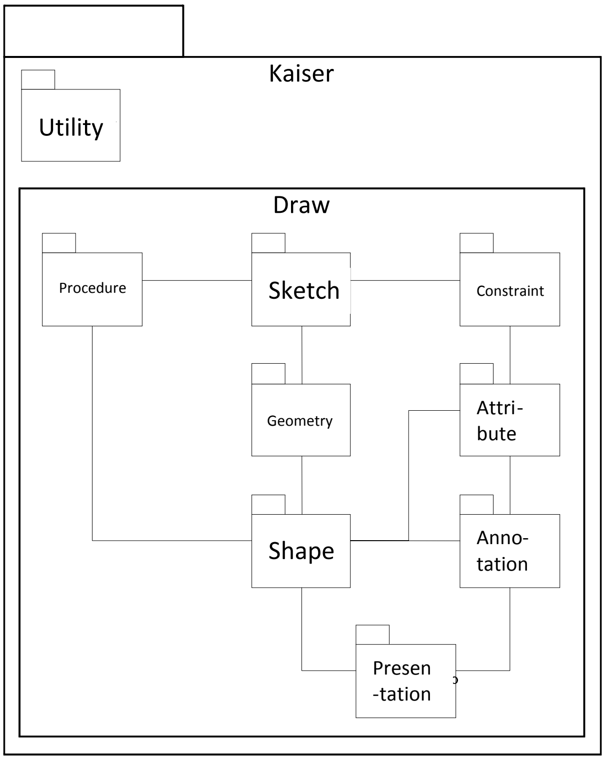

Figure 4: The parametric modeling data structure.

4 Prototype experiments

APIs in the 3D CAD engine and its prototype system were evaluated through construction of 3D models of a retaining wall, a prestressed concrete girder, and a gravity retaining wall, as shown in Figure 6. The developed prototype system included the functional requirements for sketching, model extrusion, sweeping, corner chamfering, filleting, and offsets. It was programmed in C++ and OpenGL 1.1 under the Visual Studio 2008 Service Pack 1 development environment. Experiment results indicate that modeling functions can create 3D model data by the proposed 3D CAD engine based on a parametric modeling approach.

5 Conclusions

In this paper, a 3D CAD engine was proposed for creating data that retains the design intent of civil infrastructure projects, based on a parametric modeling approach. Use of the proposed 3D CAD engine should benefit infrastructure projects, for example through adoption of parametric modelling, consideration of temporal information, and conformity to international standards. Case studies of 3D models for concrete structures were generated and the software functionality was evaluated.

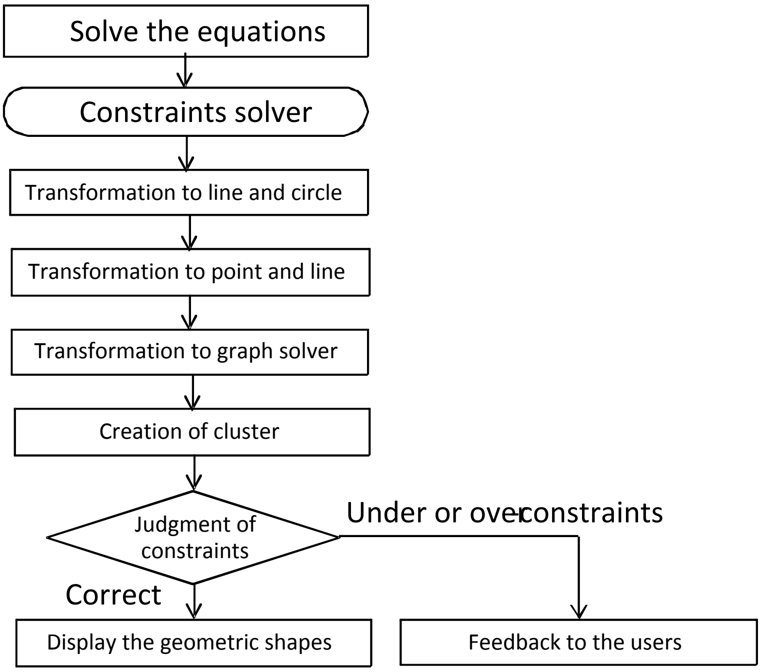

Figure 5: Solver flow for constraints evaluation.

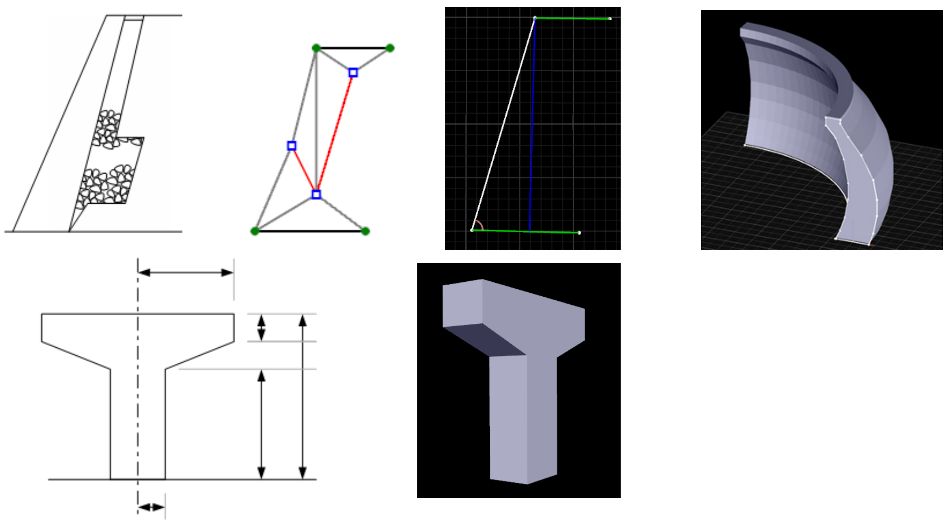

Figure 6: Retaining wall, prestressed concrete girder, and gravity type retaining wall models created using the prototype.

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