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DESIGN AND DEVELOPMENT OF 3D-CAD ENGINE

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Abstract: Civil infrastructure drawing data are normally generated by computer-aided design (CAD) software in the design phase, and are also frequently needed during the construction and maintenance phases. An environment would be provided in which 3D construction information can efficiently and smoothly be used throughout the project lifecycle. Then, a 3D-CAD engine should be developed and operated to create and modify 3D structure information, but Japan's CAD venders have not had a product of the 3D-CAD software. Therefore, the purpose of this research is to spread 3D-CAD rapidly and at low cost throughout the construction industry in Japan. To achieve this purpose, we designed and developed a 3D-CAD engine. Our research and development made progress step by step with the research, the outline design, the primary design, and the detailed design. To verify the designed algorithm, we developed a prototype. After this we developed a 3D-CAD engine, and also simple 3D-CAD software equipped with this engine.

1 INTRODUCTION

It is important for the construction industry in Japan to build an environment where 3D-CAD data are used for BIM, CALS/EC, and IT-based construction to improve productivity. The current use of 3D-CAD data in the industry is infrequent because a quality affordable 3D-CAD engine does not exist. 3D-CAD software use the kernel for modeling, which is expensive for Japanese construction CAD software companies to use their CAD software. Such a 3D-CAD engine must be designed and developed in order to enable low-cost use and quick implementation, leading to its deployment in various stages of the life cycle of construction projects.

The purpose of this project is to spread 3D-CAD rapidly and at low cost throughout the construction industry in Japan. To achieve this purpose, we designed and developed a 3D-CAD engine. Our research and development made progress step by step with the research (use cases, seeds, standards), the outline design (3D representation models, functional requirements), the primary design (3D data exchange specifications, user interface, user operation), and the detailed design (data model, algorithm, API functions). To verify the designed algorithm, we developed a prototype. After this we developed a 3D-CAD engine, and also simple 3D-CAD software equipped with this engine.

Using the 3D-CAD engine that we developed, we created 3D geometric shapes by parametric modeling. We also designed data structure in conformity with ISO10303 (STEP). In addition, settings of diverse attributes such as the time terms were realized. These are the contents of our research as follows: Outline of Kaiser Project in Kansai University, Design principle of 3D-CAD engine, Data structure in the 3D-CAD engine and its relationship with ISO, and Future expansion.

2 OUTLINE OF KAISER PROJECT IN KANSAI UNIVERSITY

The master plan of the project is shown in Figure 1. The project started from the fiscal 2008. As the product of research aid by Ministry of Land, Infrastructure, Transport and Tourism (MLIT), we prepared the investigation report and the primary design document. As the product of Kaiser Project in Kansai University, we prepared the outline design specification, the detailed design document, and the prototype. Finally, we developed the 3D-CAD engine and the simple 3D-CAD as the final product.

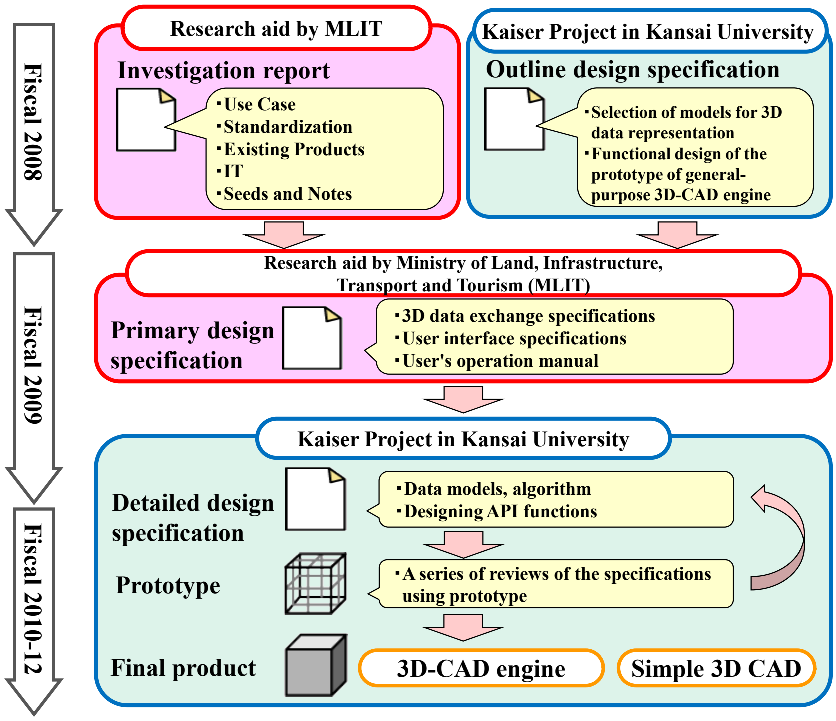

Figure 1: Master Plan of Project

An overview of the 3D-CAD engine is shown in Figure 2. At the center is a 3D model. The model is composed of a sketch, modeling operational histories, and 3D geometric shapes. Connecting them with each other allows a 3D model to be generated. A 3D model also maintains diverse attributes. At the bottom are application program interfaces, which provide various features for creating, editing, and operating a 3D model, as well as for processes including volume and surface area calculation. Moreover, using API for data conversion into drawing data, the data can be converted into the drawing data on the right. The data can also be converted into the exchange data on the left by converting in conformity with the 3D data exchange specification.

The organization of research of this project is shown in Figure 3. The project management office plays a central part. Participating members of the project include research institutes, IT vendors, trading companies, and CAD and GIS venders. The total amount of the fund is 100 million yen, offered by companies such as Mitsubishi Electric, as well as MLIT.

As to the operation of the project, we established the project management office, which is abbreviated to PMO. PMO plays a key role in the project operation as shown in Figure 4. Activities of PMO include the confirmation of budget execution, the order and inspection, the quality corrections in the project, the risk detection and direction of preventive measures, and the operation of progress meetings. Meetings were held 43 times over 4 years and a half in this project. Each time about 15 members attended the meeting, including CAD vendors, IT vendors, construction consultants, and university researchers.

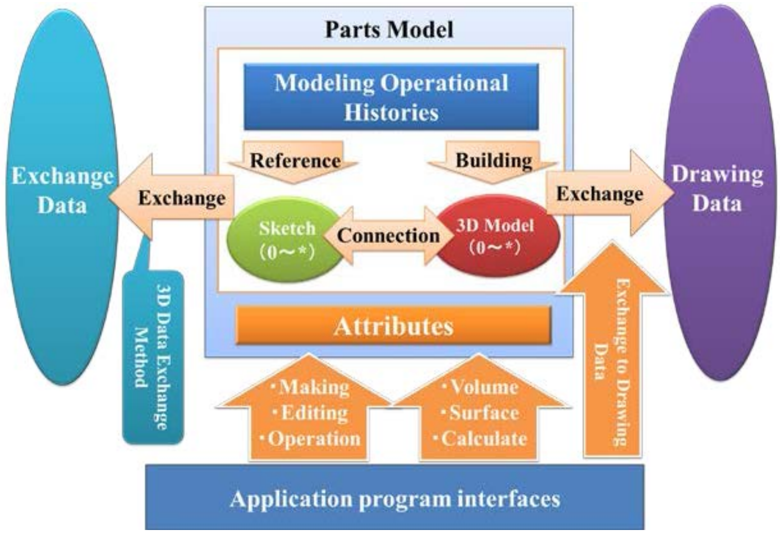

Figure 2: Overview of 3D-CAD Engine

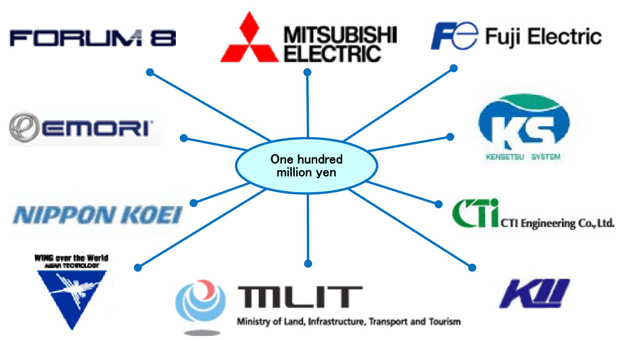

Figure 3: Organization of Research

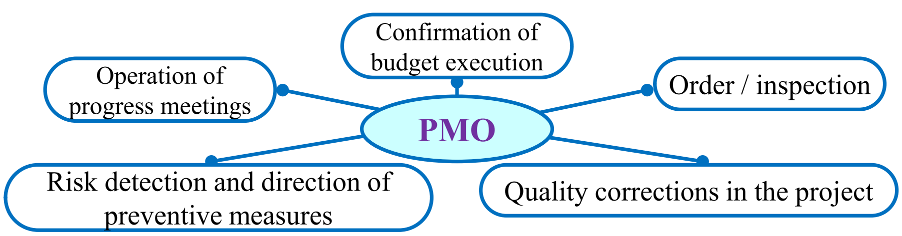

Figure 4: Operation of Project

3 DESIGN PRINCIPLE OF 3D-CAD ENGIN

3.1 Preconditions of Design Principle

As the preconditions of the design principle, we developed only 3D-CAD engine in this project. We also developed simple 3D-CAD software for verifying the 3D-CAD engine. Using the 3D-CAD engine that we developed, IT vendors and CAD vendors in Japan can develop domain CAD software, such as for roads, bridges, rivers etc.

3.2 Modeling Techniques

There are two kinds of 3D-CAD modeling: the direct modeling and the parametric modeling. The direct modeling directly creates and edits 3D geometric shapes to make drawings. It is easy to handle with its intuitive operation, but inefficient for making modifications. In contrast, the parametric modeling is a technique for defining the geometric shape of a model by setting variable parameters such as coordinate and size values to the model and giving values to the parameters. The parametric modeling is characterized by its easiness to edit because it allows the user to represent the design intent of a structure. The 3D-CAD engine developed in this project adopted parametric modeling. The CAD kernel is used for parametric modeling in commercial CAD software, which is expensive for Japanese CAD companies to use.

3.3 Basics of 3D Modeling

There are two basics of 3D modeling: the plane view drawing using sketches, and the 3D modeling based on plane view drawing. Regarding sketches, plane views are created to use as the foundation of CAD. In a plane view drawing in 3D-CAD, unlike 2D-CAD, it is not necessary to draw a plane view precisely since the length and angles of elements are determined by constraints later. After making plane view drawings, we go to the process of 3D modeling. As an example of 3D modeling, Fig.5 and 6 show some examples of creating a plane view drawing with sketches and 3D modeling with sweep.

3.3.1 Sketch

First of all, a sketch surface is made as shown in Figure 5. On the initial state of the sketch surface, a rectangle is created. Geometric constraints are applied to the rectangle to create a square. In this example, a square is created by constraining all lines to have the same length, and constraining all angles between the lines to be 90 degree.

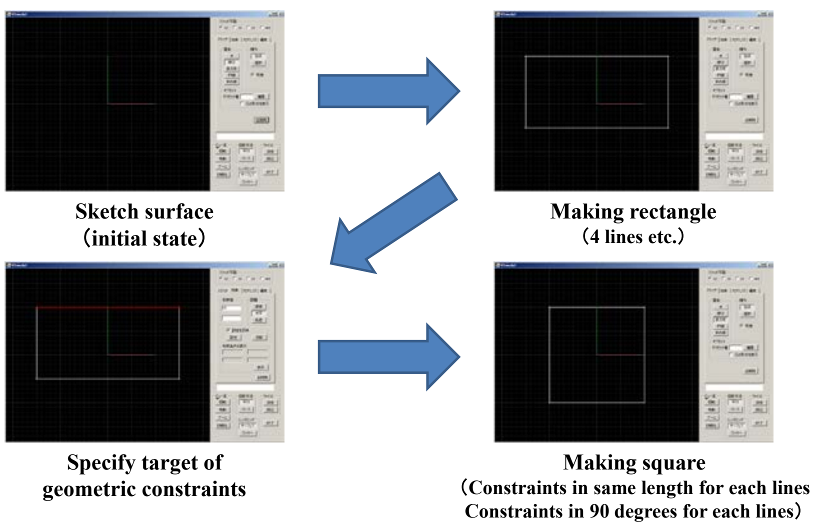

Figure 5: Sketch Surface

3.3.2 Sweep

A sweep action as shown in Figure 6 is applied to the square created with a sketch. To make a sweep action, a sweep line is created. A sweep line is created as a 3D geometric element. After this, a combination of a sweep plane and a sweep line is specified, and a sweep action is executed. Then a sweep model is generated based on the sweep surface and sweep line.

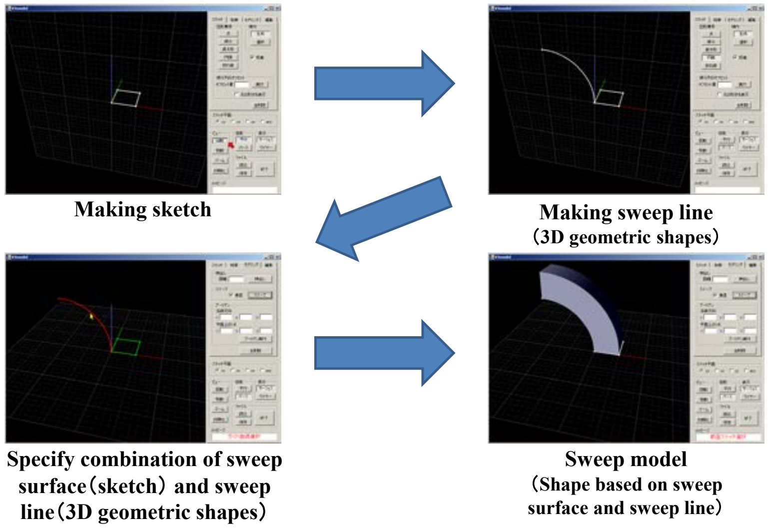

Figure 6: Sweep Action

3.3.3 Extrusion

As to the extrusion as shown in Figure 7, someone can create an extrusion model by extruding the sketch by the specified length.

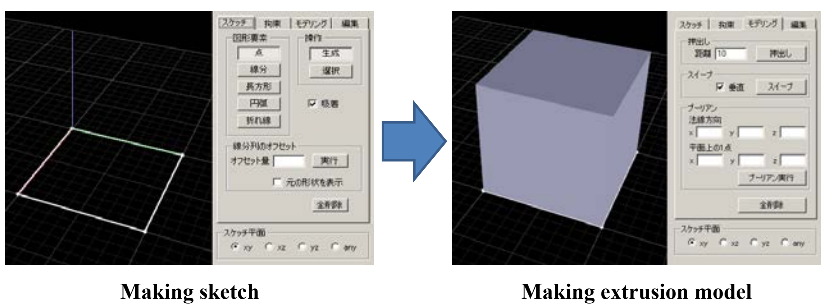

Figure 7: Extrusion

3.3.4 Chamfer

Figure 8 shows an example of the chamfer. After specifying the chamfer distance, the chamfer process is performed.

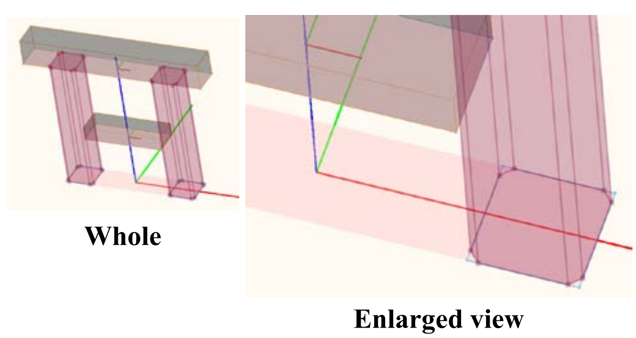

Figure 8: Chamfer

3.3.5 Fillet

Figure 9 shows an example of the fillet. This generates a round surface based on the specified radius.

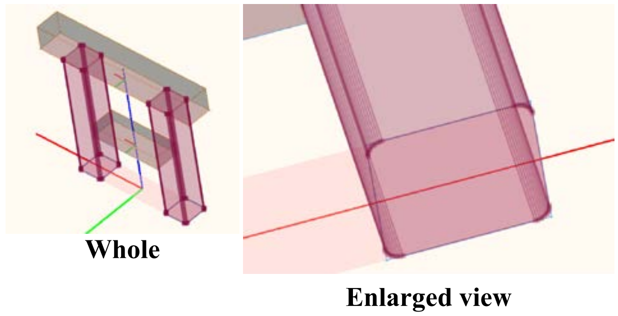

Figure 9: Fillet

3.3.6 Boolean

Figure 10 shows an example of using the boolean. A pipeline is connected to a pipeline to a manhole.

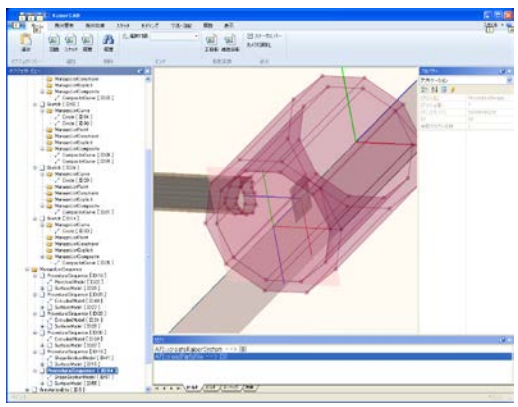

Figure 10: Boolean for Connecting Pipeline to Manhole

3.3.7 Example of Creating Alignment

Figure 11 shows an example of creating an alignment by using the sweep. An alignment model of road or railroad can be created by generating a cross-section using Sketch, and making a sweep action.

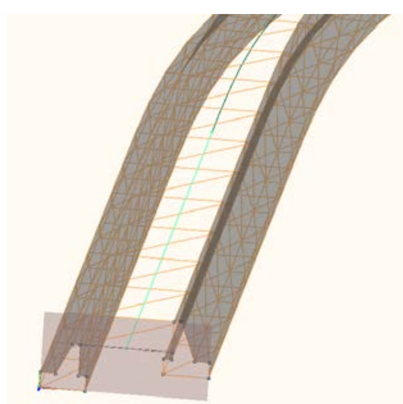

Figure 11: Example of Creating Road Alignments

4 DATA STRUCTURE IN 3D-CAD ENGINE AND ITS RELATIONSHIP WITH ISO

We explain the data structure in the 3D-CAD engine and its relationship with ISO.

4.1 Data Structure of 3D Model

Figure 12 is the data structure of a 3D model to be generated by the 3D-CAD engine. 3D models designed in Kaiser Project conform to ISO 10303, which is also called STEP. This figure shows elements of a 3D model and their corresponding parts in ISO 10303 that they conform to. Sketch conforms to Part 108, the modeling operational histories to Part 55 and Part 111, the 3D geometric shapes to AP 203 (ISO 10303-203. 1994) and Part 42, and the attributes to Part 41.

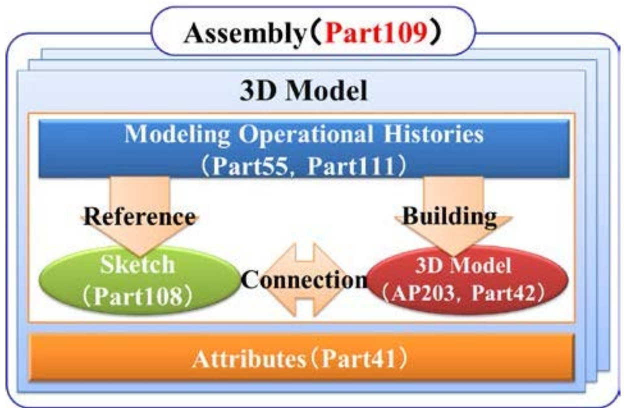

Figure 12: Data Structure of 3D-CAD Engine with ISO

4.1.1 Part 108

For the sketch, we adopted part 108 (ISO 10303-108. 2005.), which is about the parameterization and constraints for explicit geometric product models. Part 108 specifies the resource constructs for representing model parameters and constraints, together with the mechanisms necessary for associating them with geometric or other elements of models.

4.1.2 Part 55 and 111

For the modeling operational histories, we adopted Part 55 (ISO 10303-55. 2005.), which is about the procedural and hybrid representation, and Part 111 (ISO 10303-111. 2007.), which is about the elements for the procedural modeling of solid shapes. Part 55 specifies the representation of constructive operations use to build models, in other words, elements to record operational sequence. Part 111 specifies feature-based modeling commands, prescribing input parameters, output parameters, command specifications and so on.

4.1.3 AP203, Part 41 and 42

For the 3D geometric shapes, we adopted AP 203, which specifies the configuration controlled design. And Part 42 is referred to for geometric elements in AP 203. The conformance class, or CC, is CC4, which is the surface models with topology. For the attributes, we adopted Part 41, which specifies the fundamentals of product description and support.

4.1.4 Part 109

For the assembly, we adopted Part 109 (ISO 10303-109. 2004.), which is about the kinematic and geometric constraints for assembly models. Part 109 specifies the schemas for representing assembly feature relationship and for representing assembly constraints.

4.2 Assembly Process

Figure 13 shows the examples of the assembly process. For instance, a viaduct can be created easily by the assembly modeling, using data of the viaduct pier and the viaduct superstructure. Addition of the time attribute to 3D model, which is actually one of the features of the developed engine, enables the construction simulation to be performed.

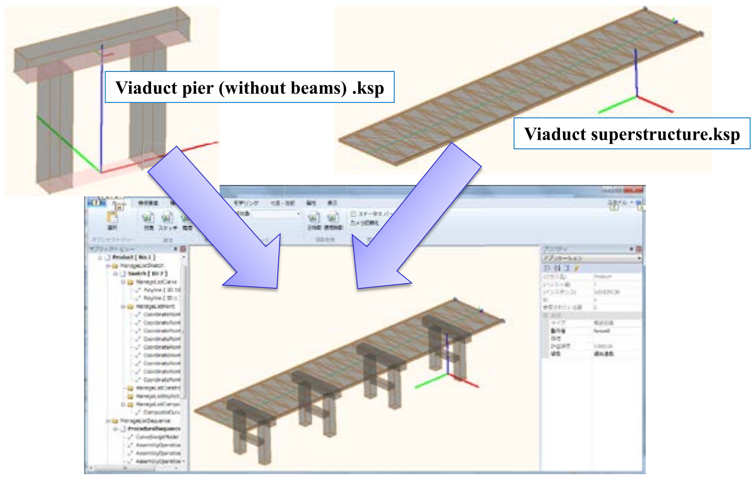

Figure 13: Assembly Process

4.3 Roads on Terrains with Point Cloud Data

Other functions of the engine include a function of reading the point cloud data. As Figure14 shows, this function makes it possible to read the point cloud data to generate a terrain, to create a road there, and to connect it with the viaduct created previously.

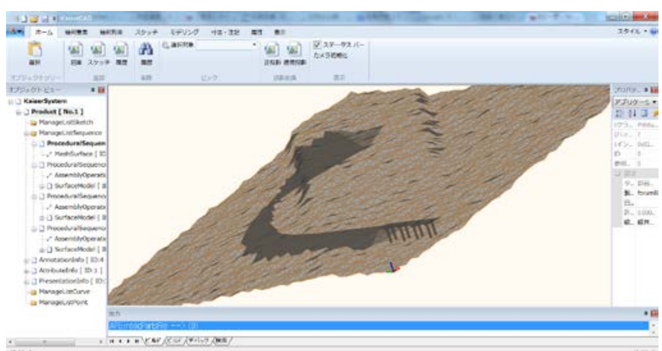

Figure 14: Creating Roads on Terrains with Point Cloud Data

5 FUTURE EXPANSION

5.1 Future Vision

We mention how to expand the project in the future.

5.1.1 Kensetsu System Co. Ltd.

One of the participating companies of the project, Kensetsu System Company draws its future vision like Figure 15. This company is planning to introduce the 3D-CAD engine into Dekispart and SiTECH 3D, both of which are the software products of Kensetsu System.

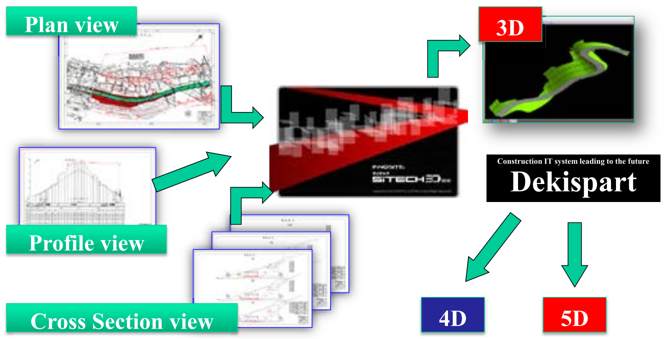

Figure 15: Future Vision of Kensetsu System Company

5.1.2 Forum 8 Co. Ltd.

Also one of the participating companies of the project as shown in Figure 16, Forum 8 Company is planning to realize efficient construction of 3D spaces by introducing 3D-CAD engine into different applications such as UC-win/Road, Engineer's Studio, and CAD for 3D bar arrangement.

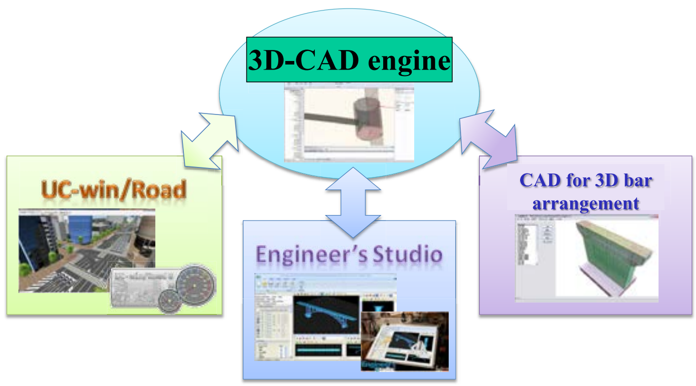

Figure 16: Future Vision of Forum 8 Company

5.2 Life Cycle Business using 3D information

The spread of 3D information by using the developed 3D-CAD engine is expected to contribute to the exchange, linking, sharing, and reuse of 3D information as shown in Figure 17. For example, using GIS data for Road database, engineers can make 3D evaluation with digital topographic maps. Using this, they can work out a design, and use the design data to perform structural modification or estimation. Then they can create execution data through the work progress control system and information-oriented construction, which they can add to GIS data. Finally they can deliver the GIS data to the road database. It is possible to realize such a cycle.

6 CONCLUSIONS

The project, which we have been working on for 5 years, started for the purpose of spreading 3D-CAD rapidly and at low cost throughout the construction industry in our country Japan. To achieve this purpose, we designed and developed a 3D-CAD engine. We also developed simple 3D-CAD software that implements an engine, for the purpose of verifying the 3D-CAD engine and its free provision to educational institutions. We expect that the 3D-CAD engine which we developed will be implemented in domain CAD software.

Under the policy of spreading the 3D-CAD engine, we are promoting its implementation in the domain CAD software of the participating companies in the project, as well as providing it free of charge to high schools, technical colleges, and universities all over the country. We are also considering its use in CIM, that is, construction information modeling. We believe that the life cycle realized by 3D models can contribute to productivity improvement for overall construction projects.

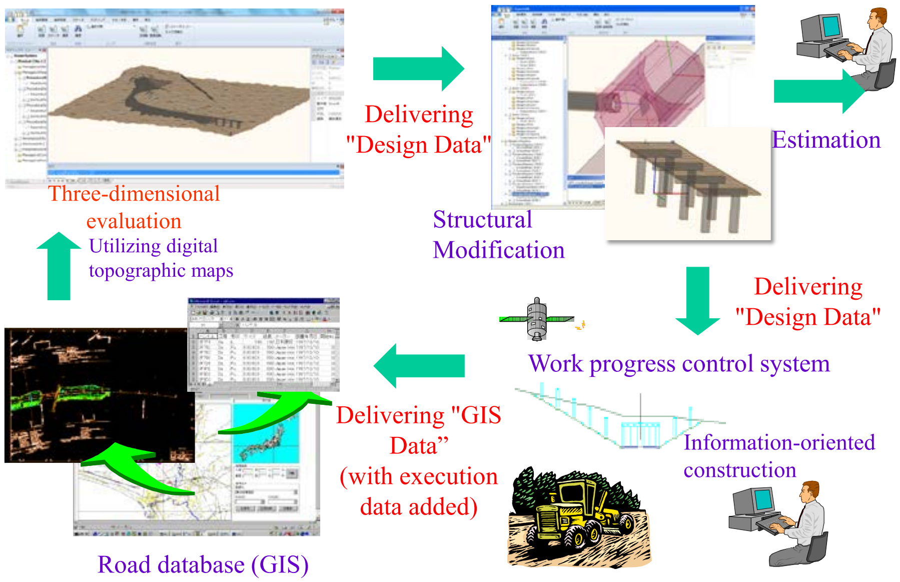

Figure 17: Exchange, Linking, Sharing, and Reuse of 3D Information

Acknowledgements

The name of the project is named after the athletic association of Kansai University, which is called "Kaisers". Since this is a big project of university-industry collaboration, we named it Kaiser Project.

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