A Component-based Approach for Generation of 3 Dimensional CAD Models Using a Construction MODEL Component Database

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Abstract

In recent years, three-dimensional visualization technologies have been researched and applied for aiding the operations of design, planning, construction, etc. in construction engineering. A three-dimensional (3D) CAD model of a targeted facility or construction project is a requirement. Due to the uniqueness and custom features of construction products, their 3D models usually have to be built based on basic geometric modeling elements from scratch. Generally, this is a time-consuming and labor-intensive process. In addition, the reusability of built 3D models is low. For improving efficiency in building 3D models and reusability of built 3D models, this research proposes a component-based approach for generation of 3D models using a construction model component database. A construction model component database is developed to store and provide 3D models of construction components, such as materials and equipments, to be queried and retrieved for generating global 3D models in construction engineering. A management interface of the database is developed for inserting and editing construction component models. A model building interface which utilizes the database for generating global 3D models based on search, selection, and then setting operation is also developed. The data format of 3D component models in the database is X3D for interoperability. Base on the proposed approach, 3D CAD models can be built more efficiently by instancing existing components in the database. In addition, built models can be decomposed into component models to be stored in the database for being reused.

Keywords: database; Visualization; 3D model; CAD; Virtual Construction.

1. Introduction

Recent years have seen the introduction of 3D CAD to the design, planning and execution phases of civil engineering projects. In the design phase, constructing a 3D model allows planners to visualize the entire project, and helps them to quickly find and resolve design conflicts. A 3D model can also help ensure that complex procedures fully conform to stated design principles. If each stage of construction is represented in turn, the three-dimensional model becomes a four-dimensional animation of the construction process. This animation can give the engineer the experience of seeing the construction process before it ever happens. McKinney and Fischer (1998) suggest that this process can overcome the problems of traditional, two-dimensional plans. Clayton et al. (2002) also think that virtual sites based on 3D models can help understanding of the engineering situation.

3D models can also be extended for virtual testing and performance prediction. They can be used to test flood prevention systems in reservoirs, or predict building structure performance during earthquakes. For example, Chen and Hsieh (2008) propose constructing 3D models complete with information on materials, stress, etc., then using XML transformations to integrate them with commercial analysis software. These applications are a unique function of 3D CAD, and cannot be replicated using traditional 2D designs.

However, the products used in construction are highly specialized and customized, so 3D modeling has always been a labor- and time-intensive process. Once developed, a model generally cannot be used on more than one project. 3D modeling is also expensive, so despite its advantages, it is not yet a standard procedure in the construction industry. This paper proposes establishing a database of reusable components for 3D models, which would allow for modular construction. This database would cut modeling time, costs and labor.

2. Research Objective

Buildings and bridges, the products created by the construction industry, are generally unique. They are designed to meet specific needs, and the constraints that the site environment places on each construction will be different. Therefore it is current practice in the industry to develop each 3D model from scratch. Appropriate software is selected based on the design requirements, and the specific features of the design are input by engineers. There is currently no widely applicable mechanism for reducing the investment of time and labor in setting up a 3D model. Once developed, the majority of models cannot be re-used.

If a model could be decomposed into components, and those components could be reused in the development of other models, it would save a lot of time that is currently wasted on building similar models anew each time. This paper proposes two innovations: (a) a database of 3D model components which can be put together in a modular fashion; and (b) a development process that uses these components to construct full 3D models. The development process involves three phases. (1) The user searches the database for components that meet the project requirements. (2) The desired components are selected and pieced together in a 3D environment. (3) The properties of the components are adjusted as necessary. The steps are repeated as often as necessary until the selected components fit together as a single model that meets the project design requirements. The process is illustrated in Figure 1.

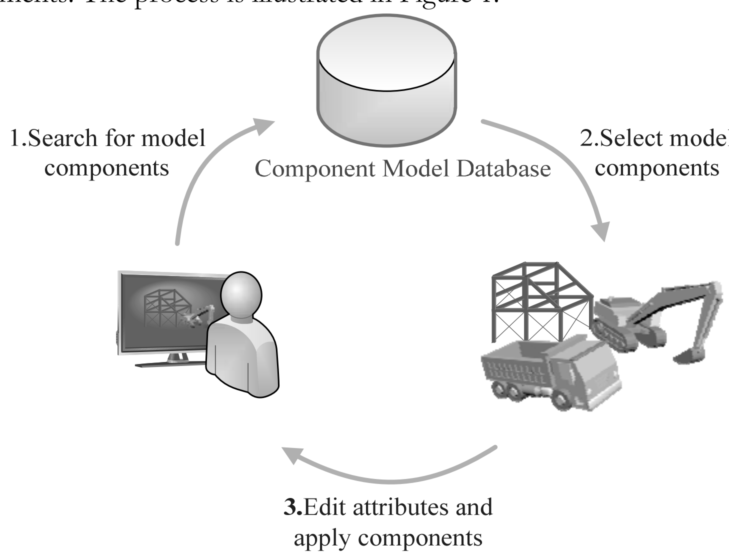

Figure 1. Model development process

3. Format

The components are of three basic types: personnel, equipment systems, and materials. They are defined by their geometric properties.

It is desirable that the format for components should be an open standard, not a proprietary format linked to a certain software. If the database can be searched and added to from any software platform, it will have greater potential for fast development. Therefore, the royalty-free, open X3D standard was chosen as the format. X3D is a new XML-based format developed out of VRML. It features a rich system of tags, is highly extensible, and is very compatible with web applications. In future most 3D design software will support X3D.

4. System Elements

The system needs to provide a database of components; a database management module; model construction module; and a format converter.

4.1. Database Management Module

User input will be necessary if the database is to supply an accurate, varied and complete range of components. Users will add to and enrich the components stored, increasing the flexibility and utility of the system. The system must therefore include a mechanism for user management and maintenance of the database. Necessary maintenance operations include adding new components, deleting components, and editing component features. Users must also be able to manage component classes. The system management mechanisms and functions are illustrated in Figure 2.

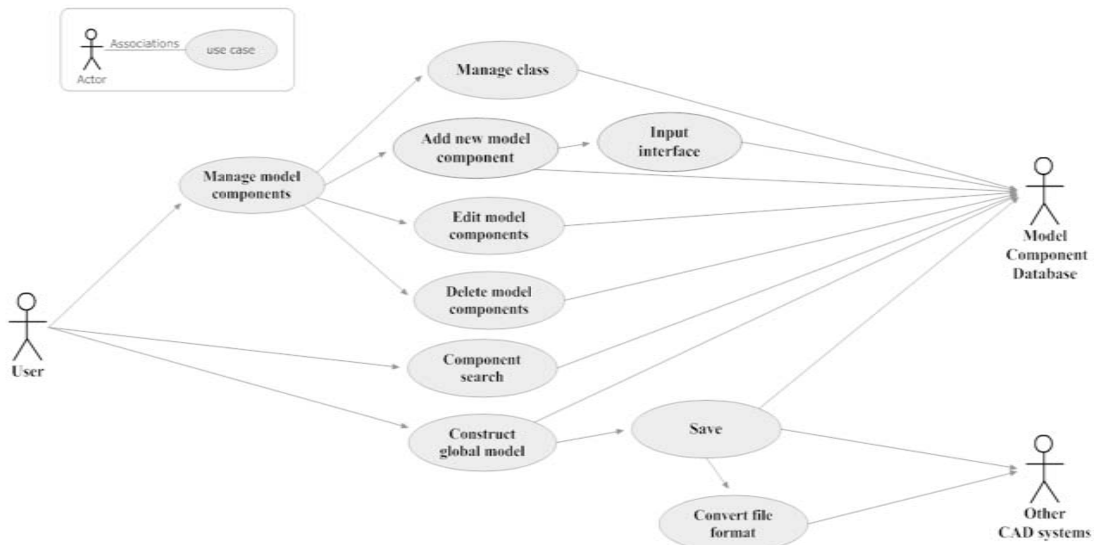

Figure 2. Model component database management system

There will be three ways in which a new component can be entered into the system. (1) Components can be input using the component management module. (2) If a component is already in X3D, the user import it directly. (3) If a component is in an incompatible format, it can be converted through by the format conversion module, and then imported. (See Figure 3).

4.2. Model Construction Module

The system needs a design interface through which users can assemble components into a final structure. This interface must include user-friendly 3D movement and perspective control, and flexible settings for the 3D environment. Most importantly, it must be easy to find suitable components and to apply them in the environment. The search function must be effective enough that there can be a seamless transfer of the user's design concept into the model. It is the combination of the design interface and the component database that will allow for a dramatic rise in efficiency in 3D modeling.

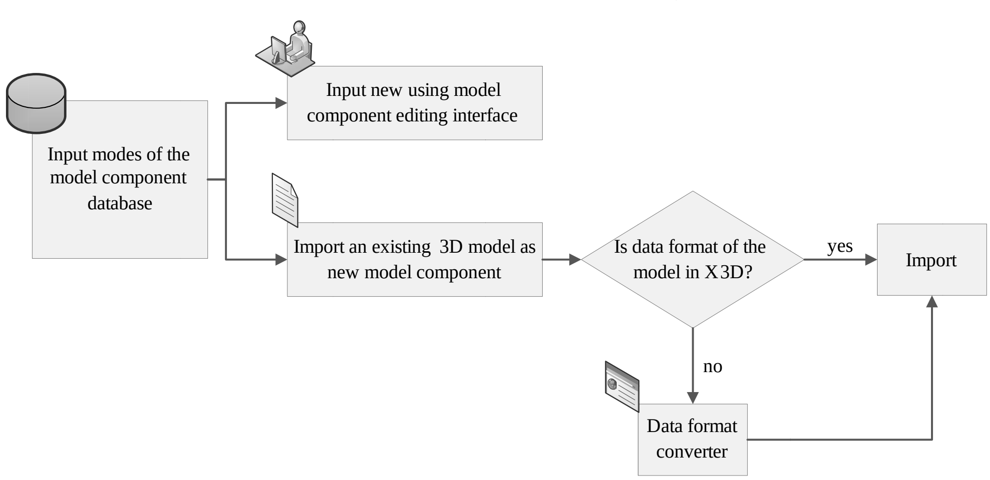

Figure 3. Adding model components to the database

4.3. Format Converter

The decision to base the database on an open standard means that the system will be interoperable with other CAD software systems. The X3D format is based on XML, and it is therefore possible to use XML to automatically convert to other formats. For the purposes of this study, the format converter will be tested by converting X3D components to VRML.

5. Development of the System

The structure of the system is shown in Figure 4. Its major components are the component database and three interfaces: the database management module; the model construction module; and the format converter. The database is online, so that all users can access it through the Internet. Users can also add to the components in the database, making it more powerful and useful. Because it is an open platform, any software will be able to access the database. Even a web browser equipped with the necessary plug-ins would also be able to view components.

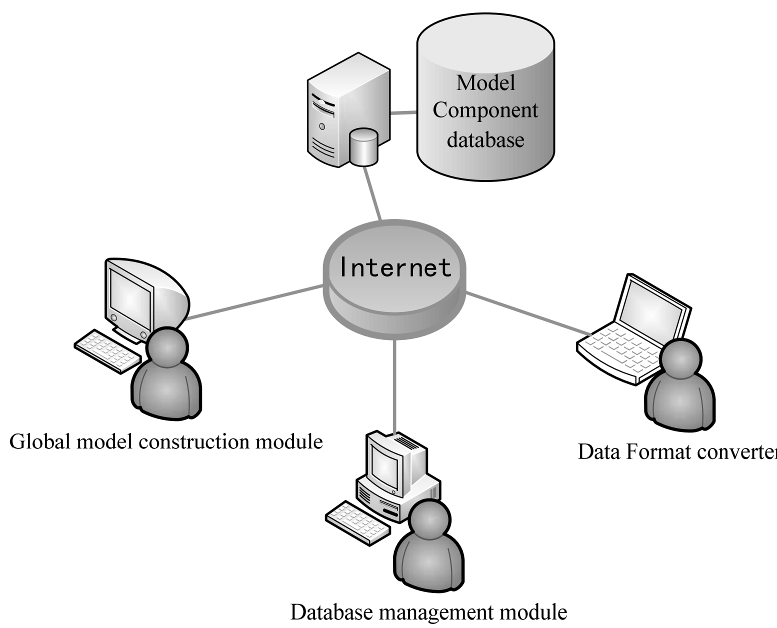

Figure 4. System architecture

5.1. Database Design

Database design must satisfy user demands; for this system, there must be powerful search functions to allow users to quickly find the components they need. Therefore for each component, several basic properties must be entered: component name, author, brief description, small image. Each component will also belong to one or more user-defined classes. For example, a user can define a jib crane as belonging to the class crane, construction machinery, large machinery, etc. Multiple classes allow users to define components in more than one mode, making them easier for other users to find. Users can also define extra properties for components, such as component dimensions. Figure 5 shows the information structure of components in the database.

5.2. X3D DOM Design

X3D documents are composed of nodes and fields. Nodes describe the form and function of a model, fields record the properties of nodes.

In order to allow for direct access to information in the X3D format, the system uses the X3D document object model (DOM). It is object-oriented in terms of accessing X3D documents, meaning the system can directly access data in the documents in runtime.

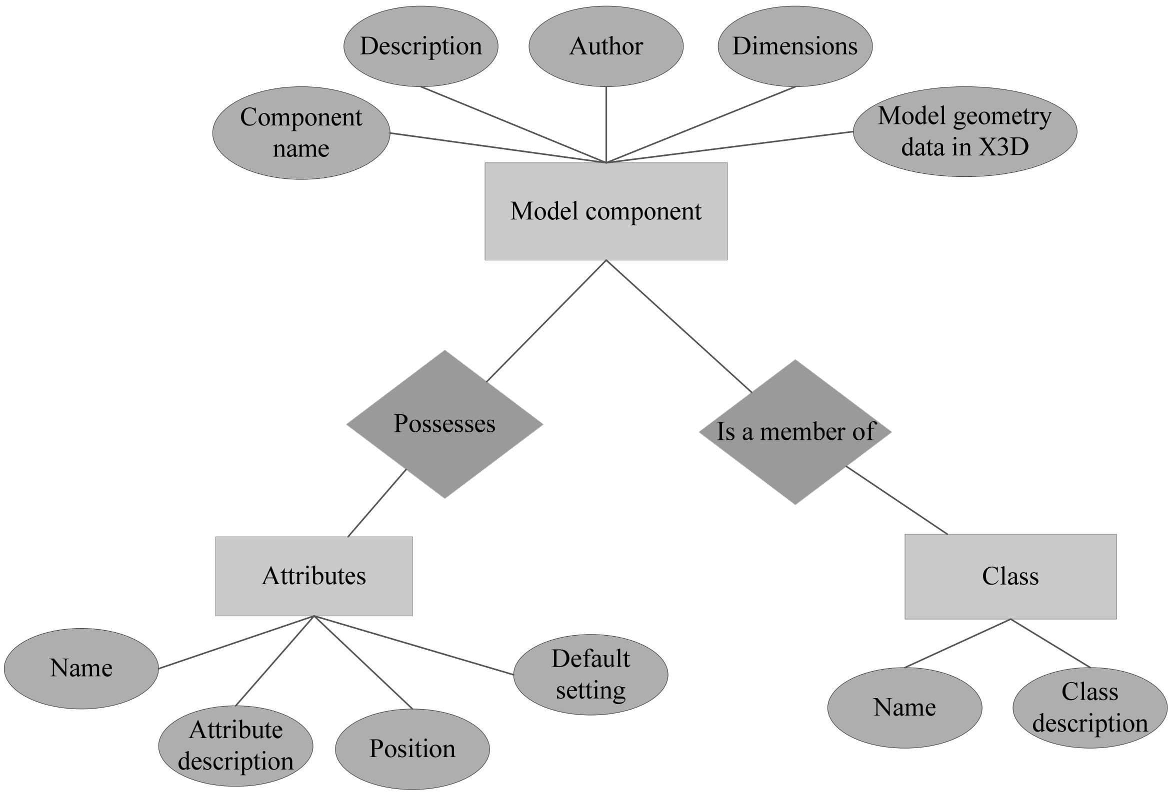

Figure 5. Database schemas

5.3 System Interfaces

5.3.1 Component and class management

The system presents all components in list form, and users can also select the components they want to manage by class. Selecting a component will bring up all of the information for that component (name, description, author, etc.) and a preview. At this point, users can edit or delete the component.

Users can also select Manage classes. The system will then list all classes, and which components belong to them. The user can choose to edit or delete a class, and can also create new classes.

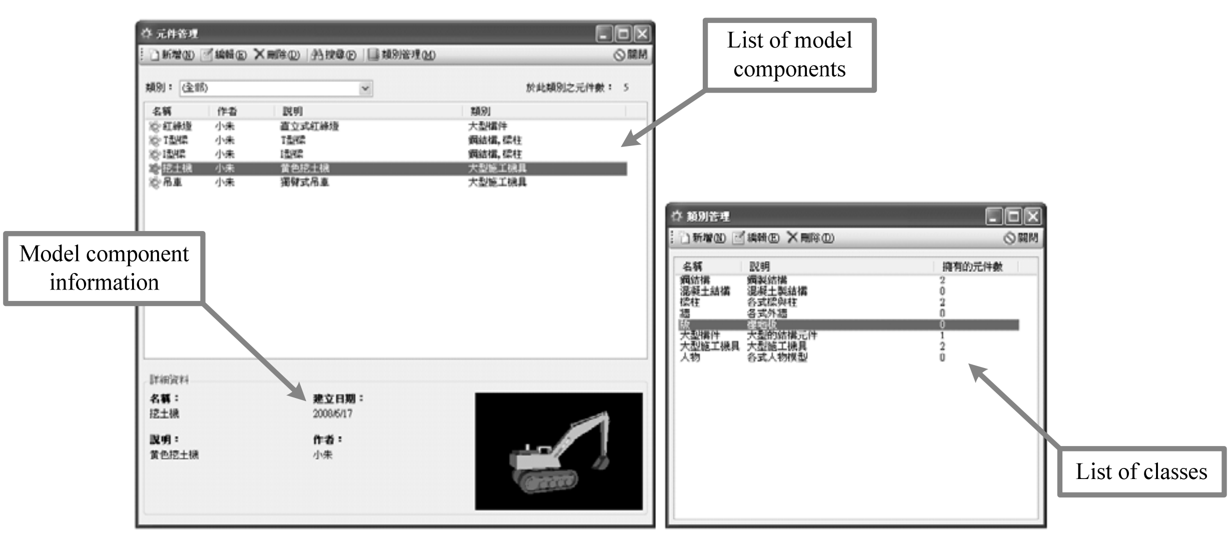

Figure 6. Interfaces for managing model component s and classes

5.3.2 Adding, deleting and editing components

When a user adds a component, they enter the X3D code in the component window. The preview window shows the component as it is entered. The system can recognize the X3D format, and indicates when incorrect code is entered. Users can also select Import X3D file, and import any X3D file as a component.

The X3D community has suggested some conversion tools for other common 3D formats (e.g. 3DMax). 3D models in other formats can thus be converted into X3D and imported.

When the X3D code has been entered for a component, a description and basic properties must be entered for the reference of other users. Properties will also make the component searchable. Basic properties include the name of the component, a description, the name of the author, etc. The component must also be assigned to one or more classes. When this information has been entered, the new component is formally accepted into the system.

Users can also edit existing components by selecting Edit. The edit interface is identical to the component input interface.

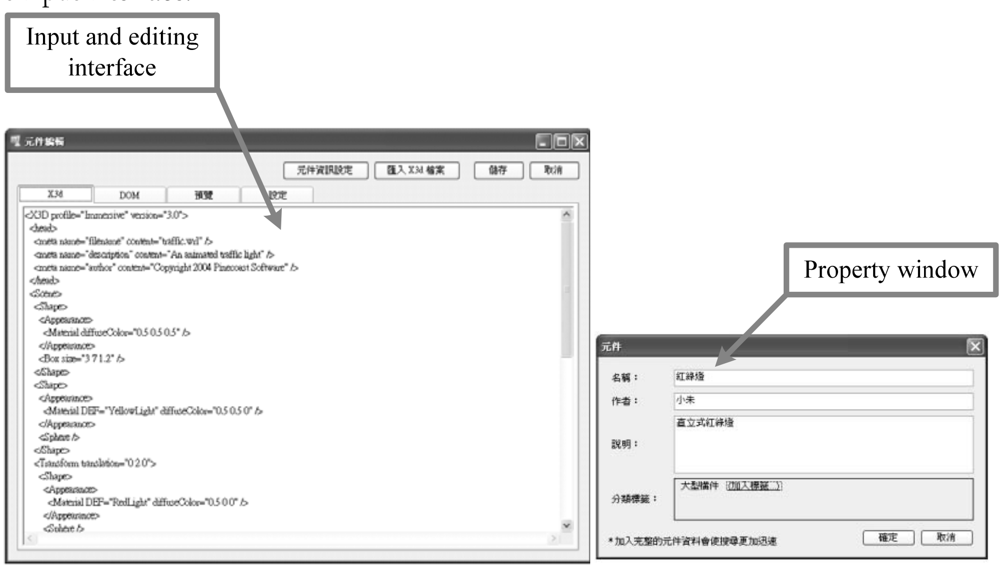

Figure 7. Interfaces for inputting and editing model components

5.3.3 Search

Users need to find components quickly and efficiently when constructing a model. The system allows searches in three modes. (1) Keyword search. The system goes through the database component by component, and all components with information that match the search keywords are listed. For example, if the user searches component names for the search term “wall”, then components named “concrete wall”, “brick wall”, “boundary wall” will all appear in the search results. (2) Class search. Users can search for all components within one or more classes, without entering search terms. (3) Complex search. Users can set multiple search conditions, using both classes and keywords. For example, it would be possible to search for components by author “John Smith” in the classes “construction” and “architectural components”.

These search modes should allow users to find the components they need quickly and efficiently. The list of search results includes a preview of the components, to help users decide which components to select.

5.3.4 Model construction

The process of developing a full 3D model is one of continually setting search parameters, selecting components (by double clicking them) and adding them to the environment. In the environment, users simply click and drag the components into position. They can also use the properties window to alter the properties of the components (size, orientation, etc.). When properties have been set, multiple copies of the altered component can be made, without having to set properties for each copy. Users can also alter the environment as necessary, setting background, lighting, ground conditions, size, etc.

When sufficient components have been added and the model is complete, the user can choose to save it as a separate X3D file, or can save it back to the database as a new component. After saving, the user can continue to edit the file.

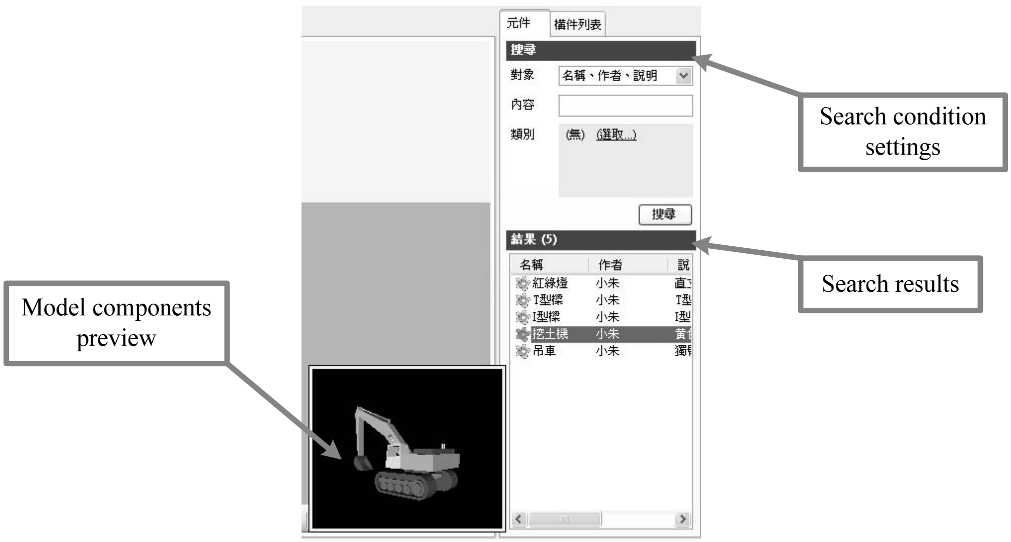

Figure 8. Search interface

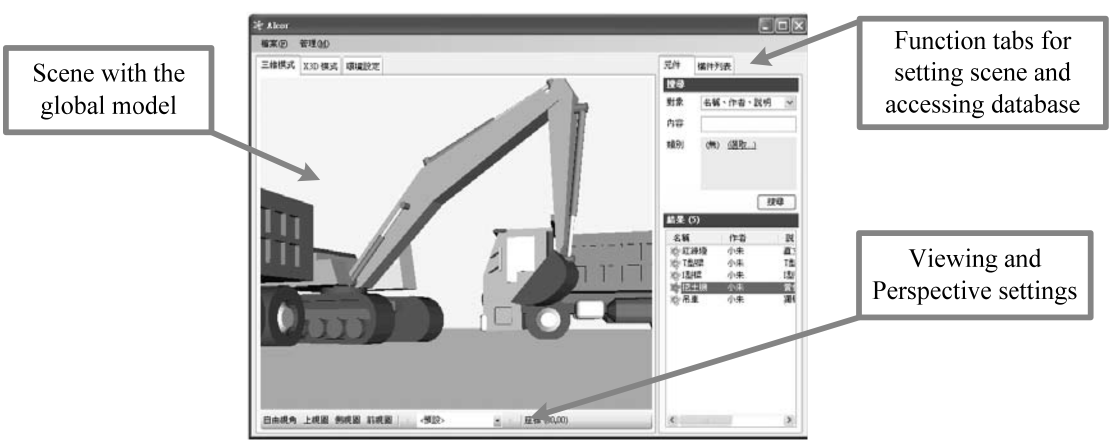

Figure 9. Model construction interface

6. Conclusion

In this paper a new system is proposed for developing three-dimensional models for engineering projects. The system is based on a database of 3D components, with separate modules for model construction and for database maintenance. Using this system, users will be able to construct 3D models more quickly and efficiently. Completed models can be viewed and edited on any software which supports the open X3D standard.

Users also have the option of adding to the component database, allowing future developers to reuse their components. Using preexisting components can reduce the time spent creating a model, and thus increases efficient use of human resources.

There are two major differences between the system proposed here and those already available. The first is the database of 3D components. Using powerful search tools, users are able to quickly and accurately locate suitable components, and apply them in a 3D model. Users also have the option of editing and adding to the database, increasing its power and flexibility. Second, the system uses the X3D open standard rather than a proprietary standard. Most systems or software will support X3D, and it can be converted automatically for those that do not. This means that the database will be accessible to users of almost any system.

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