Schematic Design System for Flexible and Multi-Aspect Design Thinking

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A designer friendly CAD for schematic design is one of the important topics of CAD studies. There were attractive preceding studies aiming to develop a CAD that intended to enable designers to have flexible design thinking and interactively manipulate representation models. This paper has the same goals of study, but focuses on the needs to support flexible and multi-aspect design thinking. Though designers normally hope to elaborate on their ideas using separate sets of representation models suitable for respective studies, a present CAD that is designed to build a single set 3D model, has limited its ability as a tool for a schematic design. Assuming this as the base concept, authors have studied to develop a prototype of a schematic design system, customizing AutoCAD R14: Schematic Design System 98 (SDS98). It has convenient utilities both for building separate sets of representation models and for integrating and reconciling those models to build a single consolidate model. This paper discusses the common procedures of schematic design studies, necessary functional features for SDS, a case study of the system use, and finally, the advantages and the disadvantages of the proposed system.
Background and objectives of studies

A CAD for a schematic design, friendly to the way architects think of their designs, has long been an important topic of CAD studies. The Top-Down System that used the idea of parametric design and object substitution, is one of the preceding studies for a 2D system (Mitchell: 1983). Several commercial CADs have introduced "a kit of parametric 3D parts" approach to support the object-oriented 3D-design thinking. In recent years, Kolarevic (1997), discussing that the design tool needs an ability of interactive modeling and dynamic continuous manipulation of forms or objects being designed, proposed a drawing manipulation system, the "ReDraw." Kurman [1998] developed the "Sculptor," a 3D modeling tool that supports designers interactively transforming ideas or designs. Johansen [1998] presented a concept of "protean" that illustrates various suggestive features for design tools that could enable designers to work in a flexible, top-down manner with familiar elements of design thinking.

This paper has the same goals of studies, but focuses on the needs to support flexible and multi-aspect design thinking. In an early stage of schematic design, designers usually elaborate their ideas on different aspects separately, generally using separate sets of representation models of various types, suitable for respective studies. For example, they use 3D building bulk models for urban design studies, a series of plan drawings for space planning studies, and simple 3D models of building elements for structural design and spatial design studies. As the study advances, they, juxtaposing or overlapping these sets of models in their work space, gradually integrate design decisions, or reconcile conflicts found among them to build the final consolidated model of their design. Sometimes section drawings or some new models are produced to check the relationship among different models, or to transmit information from one model to others.

The present CAD has introduced a method to build a single set of 3D models to represent designs, for the purpose of making direct descriptions for the 3D world, as well as eliminating inconsistencies which are likely to happen among drawings. But the design method that uses a single set of 3D models seems to have prevented loose and flexible procedures of decision-making and design refinement, inevitable for schematic design processes. In other words, the conflict-free nature of the 3D model, in turn, made design thinking complicated and tasks difficult for designers, because they have to consider numerous subjects and often integrate conflicting decisions, during the modeling works.

It will be essential for a schematic design tool to provide both utilities to support building separate sets of representation models and to support integrating those models to build a single consolidated model. Assuming these as the base concept, authors have studied to develop a prototype of the schematic design systems, customizing AutoCAD R14: Schematic Design System '98 (SDS98). This paper discusses in the following sections, the common procedures of schematic design studies, functional features of the SDS, a case study of the system used, and finally, advantages and disadvantages of the proposed system.

Common features of the schematic design process

Though the process of schematic design might vary by projects and designers, it is still possible to observe common procedures and general features of works to be supported by design tools. Reviewing the processes of several design projects as well as sketches, drawings or models produced in those projects[11], authors summarized the following as guides to consider functional features of schematic design tools. We assumed that all works would be done on a single CAD system, even though they might practically be distributed to several network computers.

- Schematic design is a process to solve an ill-defined large set of problems. Designers usually start studies on some specific subjects, and then gradually increase the subject of studies[1]. Though there are no specific rules in the order of subjects they study, the building bulk design, the
space planning, and the physical structural design seem to be some of the common groups of subjects.

- They generally use many sets of representation models described in different styles that are convenient for subjects of studies. Considering that the 2D drawing and the 3D model have different features as a method of representation, a schematic design system needs to have utilities for handling the following types of representation models in one system. They include a series of sketches and plan drawings (space planning models), section drawings (section models), as well as 3D models (building bulk models and structural models).

- To support integrating the output of segmented studies and reconciling the conflicts remaining among representation models, the system needs to provide such utilities or working environments.

To observe separate representation models, as easily as a designer overlays or juxtaposes tracing papers and physical models on a desk.

To indicate discrepancy or contradictions remaining among separate representation models.

To exchange the part of models or the result of design decisions among representation models. Use of horizontal or vertical sections of a 3D model as a guide, to study space planning models or section models will be some of the examples.

To revise corresponding parts of separate representation models simultaneously.

- They generally follow a top-down style design process[2]. They will start design work, manipulating graphic symbols or simple geometric entities. As their design develops, they gradually attach them to various attributes of architectural objects, such as space units, space volumes, slabs, walls, or columns. Even in the case where they start a design by listing up required rooms or spaces, and then laying them out to gain a total image of the building shape, they generally use representation models of abstract forms, in an early stage, and then substitute with the model of concrete forms.

- They will frequently use the trial-and-error method to refine their designs: shape, size, or location of already defined models, or to reconcile conflicting needs[3]. It will be helpful if the system can adjust the size, shape, or the location of related elements, following some revision of part of the representation models.

- In a later stage of schematic design, they use the construction line as a guide to regulate the locations, shapes, or the size of spatial elements, or building elements, as well as to transmit design guidelines from one model to another[4]. Reducing the interval of construction lines is a common procedure for reducing the floor area that is unwillingly expanded during the design studies.
Basic concepts for the modeling environment of SDS'98

Assuming necessary features studied above, the authors' laboratory has studied several prototypes of schematic design systems, customizing AutoCAD R14J with AutoLISP (Morozumi'96, Shimokawa'96). The SDS'98 (Schematic Design System '98) is the latest version that integrates past studies (6). It has introduced a unique modeling environment in which designers could elaborate on their designs strategically, using four different types of representation models, such as the space planning model, the structural model, the building bulk model, and the section model, with the support of utilities to integrate those models. The SDS uses three different types of 2D and 3D study spaces hierarchically defined in the Machine Co-ordinate System (MCS). (Fig. 2)

Model Space (MS)

A cubic study space is used for building and manipulating 3D bulk models or 3D structural models. It also could be used as a model container that displays space planning models and section models at the 3D relative positions they were respectively defined. It is possible to define as many MSs as needed, at any part of the MCS. A rectangle frame displayed on the X-Y plane of the MCS and the label attached to the frame, represents its location. They will be used as a "handle" for clicking on designating active MSs, for modeling, changing visibility status of models in it, or changing the location of the MS in the CAD window. To define an MS, the user types in a command, label name, and clicks two opposite corners of rectangles on the X-Y plane of the MCS. Each MS has its local 3D coordinates that are parallel to the MCS, and its origin is located at one of the corners of the rectangle frame (7). There is no specific limit in the Z coordinates both above and below the X-Y plane (8).

Plan Face (PF)

There are horizontal planes for defining or modifying the space planning model (2D, 3D) of different floor levels, whose locations will be indi-
located with the rectangle frames with labels at the user-defined levels in the MS. They could also be used to extract horizontal section lines of 3D models at the level where those PFs are located, or at some distance higher than the respective levels. To define a PF, one is asked to make the corresponding MS active and type in the command, the label name, and the Z-coordinate where it will be located. In case several PFs will be defined at the constant pitch, there is a way to input the initial floor level, floor height, and the number of PFs needed. The frame and the label defined for each PF will be used as a handle to identify active PFs for various operations.

**Section Face (SF)**

There are vertical planes for defining or modifying the sectional model (2D), whose locations will be indicated with rectangle frames defined within the MS. They also could be used to extract vertical section lines of 3D models defined at the surface of the respective SF. To define a SF, a designer is asked to make the corresponding MS active, and type in the command, label name, and then click two different points on the X-Y plane of the MS which should contain its surface.

**Common features of study spaces: MS, PF, SF**

There are two important features for these study spaces. First, the system allows the user to translate a group of models freely to any position in the CAD window, by just dragging the frames that represent corresponding study spaces. It will help designers to compare different representation models or to analyze the spatial relationship of models, defined as the separate representation models. Because the system always controls the relationships of the local co-ordinates with the MCS, even when the study spaces are translated to any location of the MCS, a designer could manipulate models caring only about the local coordinates of the active study space.

Second, the study spaces can be used as folders of user-defined layers. Even when complicated models are shown on a display, and even when many study spaces are defined at the same time, one could easily select models by study space for various utility operations, such as to change visibility status, to copy operation among study areas, or to translate models in a display as described above. When one defines some layers on an active PF or SF in an MS, the system automatically attaches the name of the active MS and that of the active PF or SF as a prefix of the layer name. Once some models are copied from one study space to another, the system automatically generates corresponding layers with the new prefix.

**Utilities for defining and editing representation models**

**Utilities for space planning models**

- SDS uses three different line types in addition to normal line entities: they are the Boundary Line (BL) of space units, the Construction Line (CL), and the section line of 3D models defined at the intersection with the PF or the SF.
• Once a user types in the command and clicks any area closed by the line entities such as the BL or the CL, the system recognizes the areas as space units, and attaches the labels that indicate the size of the area and user defined name of the space. (Fig. 3-a-b) After this operation, line entities surrounding the space receive an attribute that they are interconnected lines of that space. There is another command to define a space across lines. SDS also has utilities to display the total area of defined spaces by the PF and by the MS.

• When a user rotates or translates some BLs, SDS adjusts the location and the length of the BL connected to them, keeping the other end of those BLs fixed. It also updates the indices of the area size. When a user rotates or translates some CLs, all the BLs located on those CLs will be automatically edited following the CL, which will result in the same arrangement in the indication of the area by the system as described above. (Fig.3-c)

• It is possible to start a design by defining a group of the space units, and assemble them side by side along some CLs or even adjust the size and shape of these space units, referring to the CL as a guide. (Fig. 3-a)

• The 3D objects that represent building elements such as the wall or row of columns can be attached to any BLs. 3D slab models can also be generated for any space unit with a special command. When the BL or CL is rotated or translated, SDS automatically adjusts the sizes, shapes and the positions of building elements attached to the BLs related to those. (Fig. 3-d)

• To support design refinement works, SDS has utilities to substitute building elements with other group of elements, automatically adjusting the proportion of replacing elements so that they will fit to the length of the designated BL.

**Utilities for building structural models**

• SDS uses the 3D objects of three different types that have special attributes. In addition to a set of the CLs, defined in an MS as guides for the structural modeling: the Member Location Line (ML), the FRAME and the Sub-FRAME, are represented by a rectangular parallel-epiped. The system assumes to use solid models for the FRAME and the Sub-FRAME, so that the system can extract section lines defined at the intersection with the PFs or the SFs.

• The ML, which is defined lying the intersections of the CLs, represents the location, and length of linear structural elements (Fig. 4-a). The FRAME, which is attached to an ML, represents the schematic volume of structural elements[12], and also functions as a blind box of a series of the Sub-FRAMES that represent linear structural elements of the specific shapes.

![Figure 4. Typical process of an elaborating structural model on an MS]( Diagram )
• SDS assumes that a user defines CLs for the structural models, copying the major CLs defined in the PF, or the SF of other MS, and locates a set of MLs by clicking intersections of those CLs so that they form a structural system. SDS could attach a FRAME and Sub-FRAME to a user defined section size to the designated MLs. (Fig. 4-c)

• It is possible to subdivide the Sub-FRAME along the ML, and substitute them one-by-one with structural elements of user defined shapes, as the design advances. (Fig. 4-c)

• Because SDS learns hierarchical relationships among those 3D objects, during the process of modeling, it automatically adjusts the size and location of the lower level elements when the upper level elements, such as CLs, FRAMES are edited. It is also possible to define the length of some Sub-FRAMES fixed, even when the length of ML, or FRAME is changed. (Fig. 4-c)

Procedures for defining building bulk models and sectional models

• SDS assumes that designers use solid models in defining building bulk models, so that the system could extract section lines defined at the intersection with the PFs or the SFs.

• At present, SDS asks designers to define or edit bulk models, using solid primitives and utilities for solid modeling, prepared by the Auto-CAD, such as extrusion or rotation of polygons and the Boolean operations among solid objects.

• SDS assumes to use section lines of 3D models defined at the intersection with the SF to define a section model, or to check the vertical relationships of 3D building elements.

• Once locating a SF to where a designer wants
to define a section model of some 3D models. SDS commands generate line entities that represent the edge of these models in the SF, which can be edited like normal editing commands. In generating section lines, the system automatically creates the new layers so that each edge line can be handled separately from others.

**Utilities for integrating and adjusting separate models**

SDS provides six utilities to support designers integrating and adjusting the models of various representation types defined in the separate study spaces.

**Juxtaposing or overlapping models of separate study spaces**

The system allows users to freely change the layouts of study spaces in the CAD window, by just dragging a frame that represents the corresponding study space. There is a command to overlap the clicked MSs to some other MSs, adjusting their coordinates. Another command gathers the PFs or the SFs at the original position in the MS.

**Extracting section lines of 3D models**

Utilities to extract section lines of 3D models defined at the intersection with PFs or SFs, will support designers in studying the spatial relationship of building elements carefully in the space planning model or the sectional model. (Fig. 6) Once the slab models are generated for each space unit, their section line will be extracted in a SF.

**Copying models among study spaces**

SDS supports a designer to copy any part of the models to other study spaces, when the designer wishes to integrate models or to transfer results of decisions made to separate study spaces. The possible combinations for copy operations are PF to PF, MS to MS, PF to MS, and SF to MS. Because the system knows the location of the local coordinates for each study space, selecting the part of models to be copied, simply clicking the frames of the destination study space, will locate copied models at the corresponding location in the study space. In case the destination is an MS, a vertical coordinate is kept in inserting models (Fig. 7), but it will be adjusted to
the surface level of the study spaces, when models are copied to SF.

**Checking discrepancy of models**

There is command to check discrepancies between the building bulk model and the space-planning model, performing the Boolean subtraction. To use this, it is necessary to overlap the MS of those two models, as well as to locate PFs at the original position of the MS. When a user designates the PFs and the 3D models to be examined, the system colors the part of the space planning models that sticks outside of the 3D models red, and the dented part inside the 3D models blue (Fig. 8). The size of blue or red areas will be indicated in the text window.

**Revising corresponding parts of models in separate PFs or MSs**

When the CLs are used to revise space planning models and/or structural models, an user could revise models defined in the separate PFs and MSs simultaneously. This utility can be used in both conditions that those study spaces are overlapped or juxtaposed.  (Fig. 9)

**Converting attributes of line entities**

There are three commands. The first command converts the section lines of 3D models into the CLs of the BLs. The second, converts the edge line of bulk models into the group of CLs for structural models, and the third attaches the CL to designated BLs. (Fig.-10)

**Case study**

Authors asked a graduate student to perform a library design with the system and observed his design process. He was given information about the site, a list of required spaces. The following figures illustrates some of the important stages of the design process in the chronological order.

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![Diagram](image.png)

**Figure 11. Design process of the student’s project (part-1)**

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**Basic Condition of the Project**

Site: Kanazawa City  
Site Area: 5,000m²  
Building Use: public library  
Functions: book storage, reading spaces, reference, meeting spaces, work-shops area, gallery, etc.  
Structure: two-storied SRC building  
Total Area: 2,700m² (tolerance: 10%)

**Step-1** He defined the MS and PF for the space planning model of a 1F plan. He started locating required space units represented with rectangles defined by BLs.
[Step 2] At first, mouse-dragging space units, he explored their possible grouping. Then, defining PEs for 1F & 2F and a drawing floor boundary assumed from the total area, he started zoning each floor described above.

[Step 3] Copying space units and joining them in the assumed floor boundary. He transformed shape of units to fit them, while keeping the area change at a minimum.

[Step 4] In the later stage, he juxtaposed the 1F of two floors so that he could consider the relationship of units located on separate floors.

[Step 5] He extended the space units represented with 2D lines to the expected floor height to study volumetric image. Defining new MSs, he defined first the image of the building bulk with a vault.

[Step 6] In comparison to the stacked space volume, the height of vault looked too large, he reduces the diameter of the vault model. He checked discrepancies of the bulk model and floor planning model with the check utility of S38.

[Step 7] He extracted horizontal section lines at the level of each PE, and converted them into Construction Lines (CLs) as guides to elaborate the floor plan in detail.

[Step 8] He added several CLs at 12am's module, and modified the shapes and the layout of the 2D space units, referring the CLs as guides. To secure the area required, he added spaces behind the vault.

[Step 9] Overlapping MSs for space planning models and building a bulk model, he added building bulk for the spaces added in Step 8.

Figure 11: Design process of the student's project (part 2)
Figure 11. Design process of the student's project (part 3)
Step-18 He defined another MS, in which he built a modeling of steel structures for the roofs.

Step-20 He juxtaposed those MS, and added RC columns & beams for a support at 2F level. Then translated the location of CL to adjust the front line of RC columns to a position in which the supports above touch the beams of the steel structure.

Step-19 He overlapped those two MS to study the relationship between the two structures. Observing sectional view image, he started exploring a support for the arched steel beams of the roof.

Step-21 He checked the image of designed supports. He also decided to insert braces between RC columns and extend the second floor beyond the row of supporting structures.

Step-22 He decided to remove RC columns for the second floor, then replaced rectangular FRAMES for braces with cylindrical objects using replacement utilities. Laying out several fittings, fixtures, and furniture, he generated the rendering image.

Figure 11. Design process of the student’s project (part-4)
Discussions

Possibility of practical use

As the system uses only standard utilities in the AutoCAD R14J, it can be used on any platform by just loading the developed programs. Though the student used a DOS/V machine with a Pentium 300MHz CPU and 128MB memory, he did not face any difficulties with operations during his studies. It could be used in the normal working environment of designers.

Multi-aspect design thinking

In the past projects, students faced difficulties when integrating or exchanging data among models studied for different aspects. The case studies showed that the system could effectively support the multi-aspect design thinking that inevitably uses numerous representation models for segmented subjects.

Data handling with the study spaces

Introduction of those study spaces provided quite a convenient environment for handling separate models in the CAD window, though a display of XGA or higher resolution would be expected to use the system effectively.

Role of 2D models

It is obvious that the 3D models provide a convenient environment for 3D design thinking, especially the perspective view image which supports sensuous evaluation of spaces well. It also became clear that the space planning models and the sectional models would be effectively used to analytically observe technical subjects of design. An integrated use of the 2D and the 3D representation models would enable designers to have comprehensive design thinking.

Utilities for integrating separate models

Developed utilities for copying, sectioning, and checking discrepancies seemed to be used effectively in understanding the relationship among models developed to study different subjects. It is requested that improvement of user interfaces and expansion of functions should be made.

Flexible, top-down design thinking

Various utilities for the space-planning model succeeded in supporting flexible, top-down design thinking. Those for the structural model also seemed to be used effectively, even though it could handle only the frame type structures. In the approach to transform models, especially models of separate groups, manipulating the CL seems to be effective for exploring alternatives.

Future tasks

Extending the system to support collaborative design, and developing utilities for building bulk models, are some of the major subjects assumed for future studies.

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Notes

[1] The process of two design competition projects of large public facilities done by the authors' laboratory were carefully analyzed. After reviewing 15 articles of the architecture magazine that introduced schematic design processes of 20 projects by 15 architects.

[2] "There is a limit in considering many disparate pieces of subjects at once. One will work segmenting complicated subjects and combining out of segmented works" (Johnson 98: p. 356).

[3] Mitchell (88) carefully discussed the top-down design process and the approach of substituting part of the models for design refinement. Johnson (98) also discussed these subjects. His "protean" has a similar approach of modeling, which is to attach attributes after exploring the formation of models.

[4] There are many studies on this feature such as
Kolarevic (97), Kurman (98), and Johnson (98).

Kolarevic (97) proposed a 2D sketching system in which models will be dynamically manipulated with the construction line.

The latest version was proposed in the doctoral dissertation of Mr. Shimokawa, accepted at the Kumamoto University in March, 1999. The title is "Development of Schematic Design System which Supports Adjustment Operations among Multiple Representation". It was written in Japanese.

After any MS is defined, typing in a label name and pointing to the location of the local origin in the MCS, are enough to define a new MS.

It is possible to model beyond the frame.

Though the system has the default values for the top and bottom limits of the frame, the user is able to change those limits.

For the situation where the corresponding layers exist, the system can insert models to those layers.

The detail of this utilities were presented in Shimokawa(98).

The system asks a designer to input two parameters for the section size.

References


Kolarevic, B., (1997): Relational Description of Shapes and Form Relation. Y. Liu & et. al (eds.), CAADRIA '97 (pp.29-39), Hsinchu, Taiwan


