## REPLACEMENT AND TRANSFORMATION AS A KEY TO SCHEMATIC DESIGN THINKING

*3-D Modeling System which Supports Design Thinking*

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**Abstract.** This paper analyses a prototype of a 3D modeling system that can support schematic design development and begins starts with very abstract representation elaborates it step by step into a detailed representation. Using Mitchell's concept of a TOPDOWN system for 2D sketches as the basis, the authors proposed a design process model and a prototype that allows both bottom up additive processes in exploring the design frame and top down processes for the design refinement of each building element. Various utilities of replacing and transforming graphic objects as well as those that can control shapes and the location of those objects with construction lines have been proposed. The authors discussed possible use of the system and topics for future study by reviewing case studies.

### 1. Background and the purpose

Observing designersí sketches, one can easily see that the ìreplacing and transforming design elementsî operations are important in the development of a schematic design by beginning with a very abstract representation and elaborating it step by step, into a complete and detailed representation. Mitchell proposed TOPDOWN, a shell for use in developing a 2D CAD system(Mitchell *et al,* 1988). Some of his key ideas are control boxes or frames and graphic entities or objects that a designer defines in each frame. Once a user develops designs by subdividing frames and defining objects in each frame, a designer could explore design variations by simply translating frames or replacing objects. The relationship of the location of the objects is controlled with frames that describes hierarchical structures of the objects being designed. Monn also proposed a design tool that supports the operation that replaces 3d elements with those that have a different topology, but his system lacked a user interface that could transform the objects

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being designed in the frame provided(Monn, 1989).

The objective goal of this study is to develop a modeling system in a commercial CAD system that has similar utilities to those in TOPDOWN. The authors have also taken the following observations on the sketching studies of designers into account.

1) Schematic designs are generally developed in a top down fashion, but they often require a bottom up, or an additional process in some part of the design, such as the need to add frames.

2) Even when the total number of building elements needs to be changed, there will be some minor elements that need to be kept the same size.

3) Designers generally study various aspects of their design such as space planning, structure planning, or spatial design in a parallel fashion by manipulating representation models that are defined for the purpose in question.

4)As Branko found in his research on 2D sketches, construction lines(CL) or regulating lines have been frequently used to coordinate locations or shapes of objects in representation models(1997, Branko).

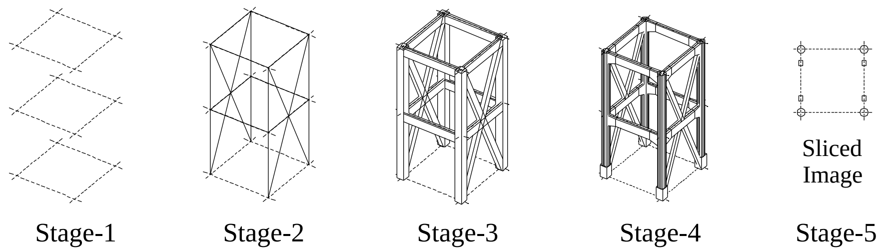


*Figure 1. Images of Objects used in Design Process of Structure*

| | Representation Model | Decision with Objects |
|---|---|---|
| Stage-1 | Construction Line | Guide Line for Location, Module |
| Stage-2 | Member Location Line | Location, Length, Connectives |
| Stage-3 | Primitive Frames | Location, Length, Connectives, Size or Volume of Members |
| Stage-4 | Custom Shapes | Location, Length, Connectives, Size or Volume of Members, Shapes of Members and Jointings |
| Stage-5 | Section Lines or 2D regions or 3D model | Reference to check conflicting |

*Figure 2. Relations between representation models and factors defined with objects*

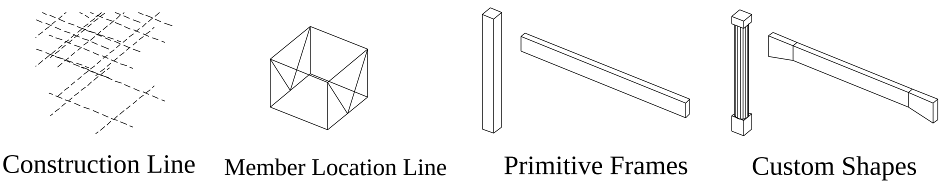


*Figure 3. Images of Representation Models in each Stages*

In this paper, the authors will discuss a model of the design process, the functional framework of the proposed system, and a prototype using 3-D modeling studies of building structure as an example.

## 2. A Model of the Design Development Process

The authors assumed the following five stages in 3-D modeling studies of a building structure. Fig 1 shows an example of 3-D graphic representations of a building structure that are designed in each stage. Fig 2 summarizes the relationship of graphic objects used to represent the design and the decisions that are described by those objects in each stage. Fig 3 illustrates an example of graphic representation models.

Stage 1 : description of design guidelines or regulations
Referring to space planning studies or policies for structural design, a designer locates construction lines (CL) as the design guide.
Stage 2 : defining the structural framework of building members
Using CLs as a guide, a designer defines the location and the length of building members, such as columns, beams, braces, or walls, with single lines that the authors call Member Location Lines (ML). MLs also represents how the defined members are connected.
Stage 3 : visualizing the rough size of a building structure
By replacing ML with a rough model using primitive shapes, such as rectangular or cylindrical solids, a designer tests the volumetric image of the design.
Stage 4 : refining shapes, detailed construction of elements, and their joining parts
By subdividing rough models and replacing each part with a detailed one, a designer can refine the shape of the building members and that of the joining parts.
Stage 5 : testing adaptability to other design requirements and adjusting the model
Soon after each stage from 2 to 4, a designer generally tests the adaptability of the model to the results from other design studies, such as space planning studies. In these tests, a designer often refer to a horizontally or vertically sliced image of the model. After the test, a designer adjusts the decisions translating CLs or MLs, or replacing or transforming the building elements that were defined in Stages 3 or 4. Figure 4

## 3. Specifications for System Development

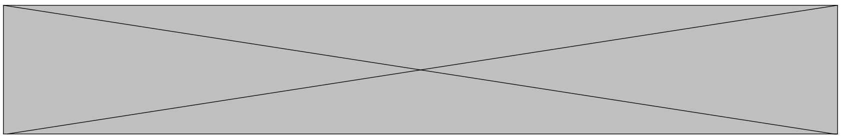

*Figure 4. A Design Process Model of Building Structure*

The authors proposed the following specifications in order to provide environment that is condusive to design studies, in particular to provide rapid transformation study at Stage 5 as well as to support easy replacement operations at Stages 3 and 4.

1) This system operates in a 3-d design world of a commercial CAD in which its standard commands can be used in the system.

2) A designer defines Construction Lines(CLs)first on a horizontal plane as defined in some part of  the design world that corresponds to the image of the plan.

3) There are two types of Member Location Lines(MLs) : ML that define the connecting of two intersections of CLs or MLs that are vertically defined on the plane at the intersection of CLs by separately defining their length.

4) Once a designer defines the location and length of structural members with  MLs, as well as when a designer translates CLs on a plane, the system automatically adjust the lengths and positions of all MLs that are connected to those CLs by keeping  the end of each ML that is connected to unchanged intersections from moving (Figure 5).

5) A designer can add a rectangular frame (FRAME) that represents the volume of

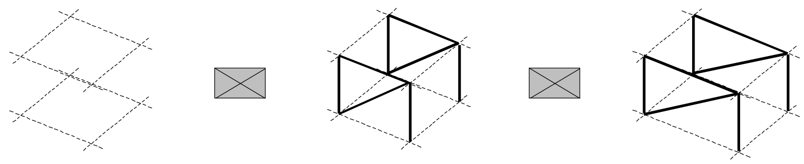


*Figure 5. Image of Adjusting Member Location Lines by moving Construction Lines*

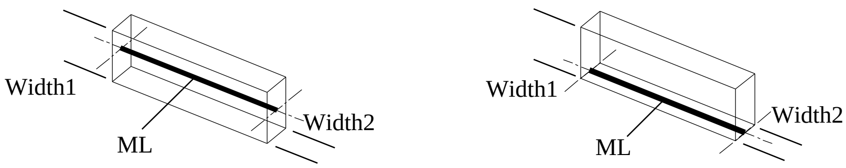


*Figure 6.  2 ways how to create FRAME*

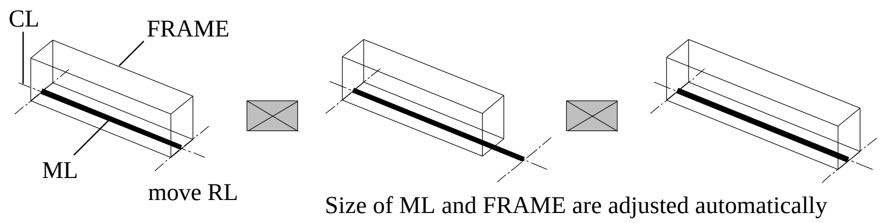


*Figure 7.  Image of Adjusting a ML and a FRAME by moving Construction Line*

structural members by simply defining the size of the sections (width 1 and 2). At this point in time there are two variations, in locating FRAMEs along a ML, as Figure 6 shows. It is also possible to rotate FRAMEs along a CL or a ML.

6) When the position and length of ML is changed, the system automatically adjusts the position and the length of the corresponding FRAMEs (Figure 7).

7) In order to model building members of detailed shapes, the system requires a user to define a sub-FRAME that overlapps a FRAME (Figure 8). Once a designer defines 3-D objects and place them in a sub-FRAME with a name, the system archives the 3D objects in the library (shape library) and, then, allows a designer to easily manipulate those objects as a part of the sub-FRAME.

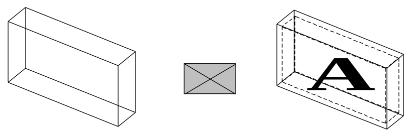


*Figure 8. Creating a sub-FRAME which have shape in a FRAME*

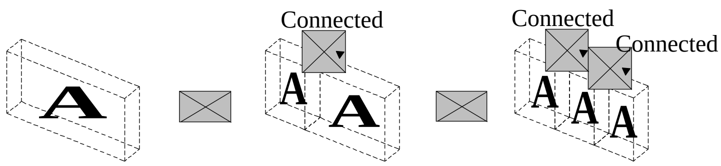


*Figure 9. Subdividing sub-FRAME*

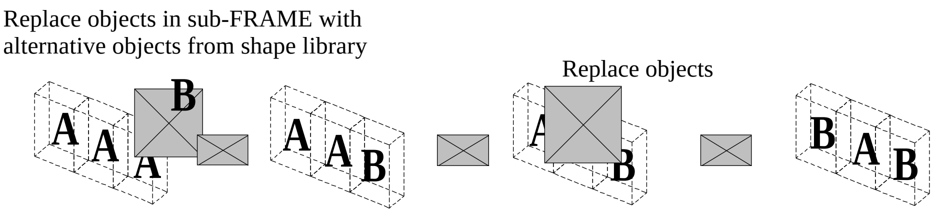


*Figure 10. Replacement Operations of shape in sub-FRAME*

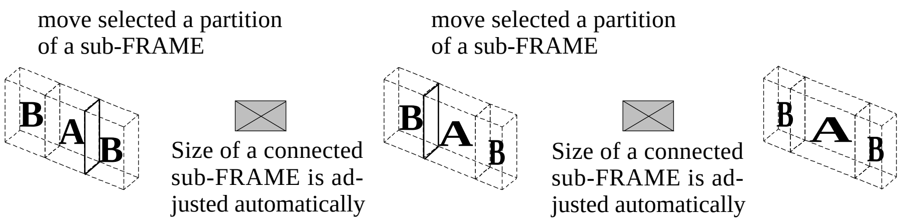


*Figure 11. Scaling sub-FRAMEs*

8) When the sub-FRAME is transformed, the system automatically transforms the shapes of the objects by keeping original relationship of every vertex of the objects to the sub-FRAME.
9) It is possible to define multiple sub-FRAMEs in any FRAME by dividing a sub-FRAME (Figure 9). The system also allows a designer to replace objects in a sub-FRAME with any objects in other sub-FRAMEs or those that are archived in the library (Figure 10).
10) Because sub-FRAMES in one FRAME are defined as connected, a designer could change the proportion of 3-D objects in a FRAME by translating the partition of the sub-FRAMES along its ML.(Figure 11)
11) The system can replace an un-subdivided sub-FRAME with any series of sub-divided sub-FRAMES.(Figure 12)
12) The system can fix the length of some of the sub-FRAMEs even when their total length is changed after the replacing operation or the transforming FRAME operation.(Figure 13, Figure 14)

## 4. The Prototype

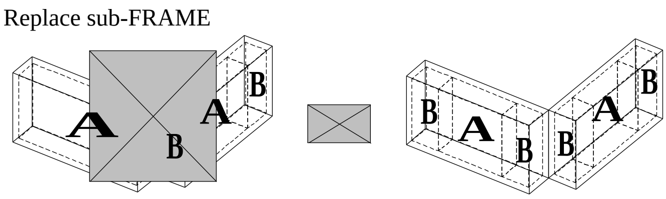


*Figure 12. Replacement Operations of sub-FRAMEs between two FRAMEs*

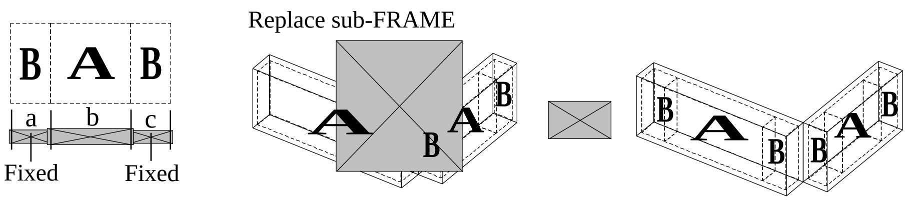


*Figure 13. Replacing sub-FRAMEs in condition that size of sub-FRAMEs are fixed*

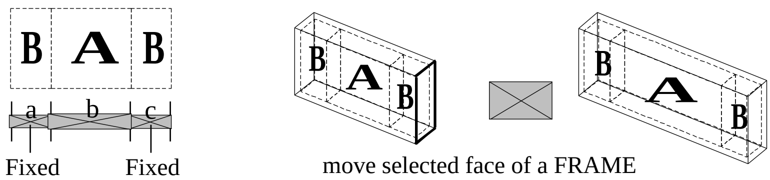


*Figure 14. Scaling a FRAME in condition that size of sub-FRAMEs are fixed*

The authors have developed a prototype for AutoCAD R14J for Windows by using AutoLISP. It uses the BLOCK utility and its data structure to control the attributes of entities in order to realize the proposed FRAMEs and sub-FRAME behaviors. As the system uses only utilities which are part of the standard AutoCAD R14 system, it is possible to use it on any platforms that AutoCAD R14J will operate on. Figure 15 shows the list of commands that were developed for this system and their functions. Figure 16 shows the sample processes that build a structural model with the system. The authors have not yet completed a sectioning utility that can be used in the Stage 5.

## 5. Case Study

We traced the design process of a project we had worked on previously design competition for the National Diet Library in Kansai-kan in order to test this system. Figure 17 illustrates some of the important stages of structure models. As the

| COMMAND | OPERATIONS |
|---|---|
| CL | Command to define a Construction Line(CL). |
| ML | Command to define a Member Location Line(ML). Clicking two intersection points of CLs. |
| FRM | Command to define the FRAME. Selecting MLs, then input two sectional sizes and select a CL or a ML to indicate the rotation of FRAMEs along |
| MKSUBFRM | Command to define a sub-FRAME that overlapp a FRAME. Select FRAMEs. |
| DIVSUBFRM | Command to divide a sub-FRAME. When selecting a sub-FRAME, the system sets connective data to subdivided sub-FRAMEs automatically. Data for connecting or Setting the size of a selected sub-FRAME are inherited by the divided sub-FRAMEs. |
| DEFSUBFRM | Command to archive 3-D objects in the shape library. Select the 3-D objects that were originally defined and the corresponding a sub-FRAME, then input a name for those 3-D objects. |
| FIX | Command to set the length of a sub-FRAME. Select a sub-FRAME, then select guidelines for indicating the directions in order to fix the length. |
| REPLACES | Command to replace objects in a sub-FRAME. Select a sub-FRAME which has objects that need to be replaced, then select another sub-FRAME which has alternative objects or insert them from shape library. |
| REPLACEF | Command to replace sub-FRAMEs in a FRAME. Select a FRAME which has sub-FRAMEs that need to be replaced, then select another FRAME which has alternative sub-FRAMEs. |
| CHDIR | Command to change the direction of objects in a sub-FRAME. |
| CLMV | Command to move CL(s). When moving CL(s), the location and the length of corresponding MLs, FRAMEs and objects in sub-FRAMEs are adjusted automatically. |
| CLRT | Command to rotate CL(s). When rotating CL(s), the location and the length of corresponding MLs, FRAMEs and the objects in the sub-FRAMEs are adjusted automatically. |

*Figure 15. The List of Commands for Developed System*

system worked effectively on a DOS/V machine that has a pentium 200MHz CPU, it is possible to use the system in the normal working environment of designers.

## 6. Evaluation of the System and Future Tasks

1) The proposed design process model which begins with abstract images of building structure such as Construction Lines and Member Location Lines and ends with detailed 3-D model appears to be useful in schematic design.
2) As the prototype has limited top-down operations that can design building members but has bottom up or additional process that can explore the total composition of a design image, this system is flexible enough to support a broad range of design studies.
3) The prototype showed that replacing utilities that are combined with size adjustment utilities could increase the speed of top down 3-D modeling studies when some members are used repetitively.
4) In particular utilities that can adjust total length of building elements and that allow a designer to specify sizes for some of their parts can be very useful.
5) Utilities that can transform a model of a building with a translation of Construction Lines and that is assumed to support the time-consuming task of adjusting 3-D models to the requirement are the result of design studies such as space planning.
6) In the next step, we are planning to develop a design environment in which a designer can manipulate different types of representation models simultaneously in one system, such as space planning or building bulk models, and in which a designer can adjust the design decisions that are made on different representation models.

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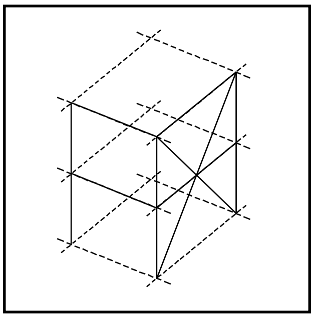
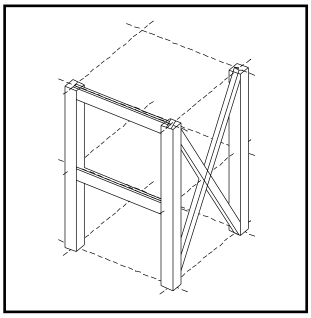
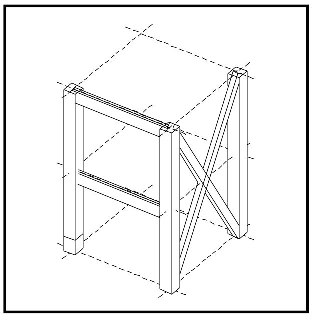


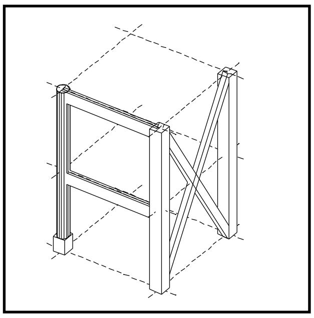
1) 1) Draw CLs and MLs by considering the structural conditions. (CLINE, MLINE) Each ML represents the location of columns, beams, or braces.



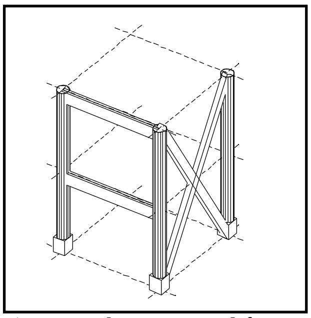
2) Locate the FRAMEs along the MLs.(FRM) All FRAMEs have surfaces as default conditions.



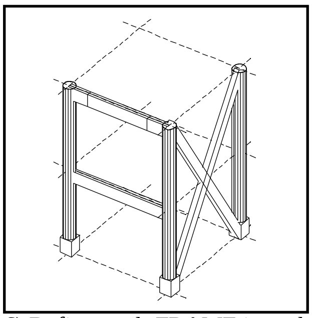
3) After defining a sub-FRAME in a FRAME (MKSUBFRM), divide it into two sub-FRAMEs.(DIVSUBFRM)



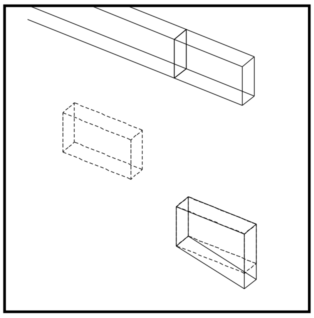
4) Replace a sub-FRAME with a cylinder model which is already archived in the shape library.(REPLACES)



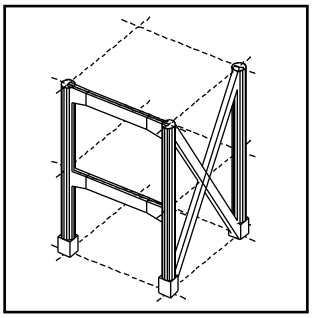
5) Using the command for replacing an object defined in a sub-FRAME, define the shapes of other two other vertical FRAMES. (REPLACEF)



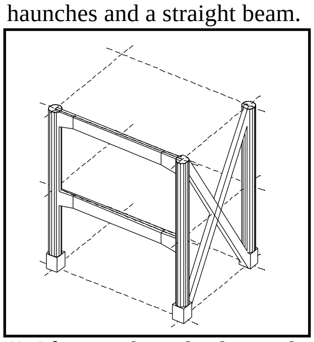
6) Define a sub-FRAME in each of the horizontal FRAMEs, then divide the sub-FRAME of the upper beams into 3 sub-FRAMEs that represent haunches and a straight beam.



7) Define the haunch model by referring to one of the sub-FRAMEs that is located at the end and archive it to in the shape library. (DEFSUBFRM)

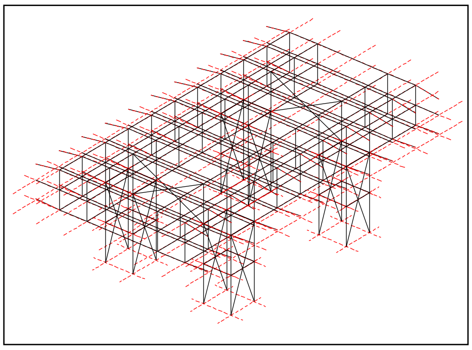


8) Using the replacing sub-FRAME command, locate a haunch model in the sub-FRAME that is located on the other side. Replace other sub-FRAMES with a set of sub-frames that has haunches and beams.

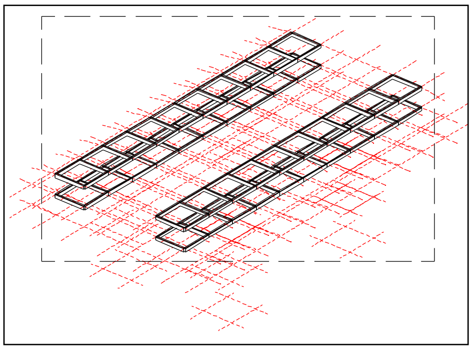


9) After attaching the data to the sub-FRAMEs that represent the haunches so that the length of haunch is set, the translation of CLs causes the size of the beams to increase while the length of haunces does not change. (CLMV)

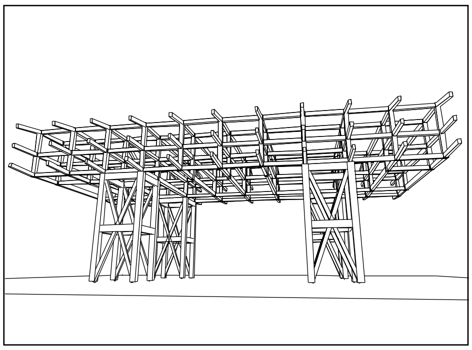
*Figure16. Sample Process that build a Structural Model with the System*



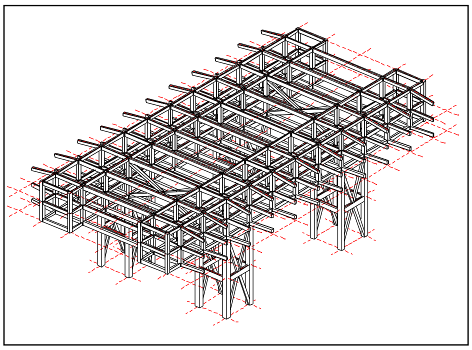
1) Draw MLs by space planning into account. By classifying layers of MLs based on the mean, a user can define FRAMEs on MLs in a layer at one time.



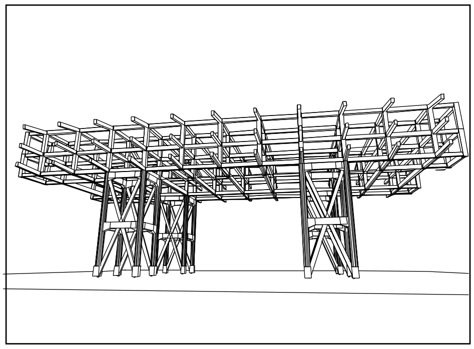
2) Display a layer for horizontal MLs. When selecting all MLs by window(dashed lines), input the size and rotation, and all FRAMEs can be located simultaneously.



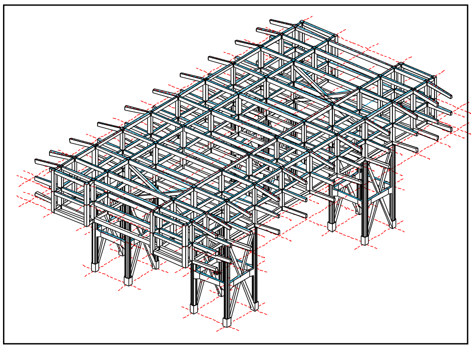
3) This figure shows the entire structure model from the perspective of the main entrance. Confirm the rough volume of the core.



4) Add two spans to both sides of the structure because the student in charge of space planning requested more floor area.



5) Members of the core are exposed by glass. Study custom shapes of the members of the core from architectural and structural factors.



6) Lengthen the spans of the core in order to locate stairs there, and then adjusting certain spans to finalize the design.

*Figure17. The Design Process that build a Structural Model with the System*