Chapter Five

Conclusion, Discussion, and Future Work

This chapter summarizes the thesis, discusses its findings and contributions, points out limitations of the current work, and also outlines directions for future research. The recognition and interpretation of drawing symbols for functional spaces in freehand sketches has been demonstrated to be a means to create 3-D model. However, still many extensions of this research deserve further consideration.

The chapter is divided into three sections. Section 5.1. is a summary of the thesis. Section 5.2. presents a discussion of the contribution and limitations of the current work. Section 5.3. discusses the future work, and finally Section 5.4.brings the thesis to a conclusion.

5.1. Summary of the Thesis

This thesis has introduced a symbol-based 3-D modeling tool that allows a designer to make freehand floor-plan drawings and draw symbols in order to explore the initial concepts of spatial layout. The program then converts those floor plans into 3-D models according to the use of symbols in the earliest stages of design process.

Chapter 2 and 3 reviewed the role of freehand drawings. Designers draw (diagrams and sketches) to explore ideas and solutions throughout the entire design process. By making drawings, designers have opportunities to re-examine and re-arrange the ideas originally appearing in mind and further re-develop and refine new ideas by modifying earlier ideas. Some fundamental features of freehand drawings are also discussed in Chapter 3.

Freehand drawings in the early design tend to be simple and rough, typically just consisting of a few simple elements. Designers use simple elements, such as lines or simple geometric polygons, to define space by either further dividing the entire floor plan into several individual rooms or enclosing individual spaces and then assembling all spaces to make a building.

Chapter 3 also discusses the use of drawing symbols in freehand sketches. Designers use different drawing symbols when thinking about different design concerns. By using symbols, designers assign "meanings" and give "characteristics" to every individual space. Different spaces have different characteristics. Designers use drawing symbols to identify different characteristics and functions. By recognizing drawing symbols, we can identify the characteristics of the space that those symbols refer to and further identify the architectural configuration of those spaces. Therefore, it is possible to create a 3-D modeling tool based on the recognition of drawing symbols in freehand sketches.

In Chapter 4, the computational implementation of a prototype modeling tool, the SpaceMaker, is described. The SpaceMaker is a 3-D digital modeling tool. It also can be conceived as a freehand drawing environment with a symbol recognition system, a 3-D model conversion system, and a model modification system. Designers input freehand drawing data by using a mouse or a stylus with a digitizing tablet. The data will then be categorized into three different types: exterior building boundary, interior partition walls, and drawing symbols. Each of three types of data will then be respectively handled by three independent recognition systems: Boundary Locator, Partition Locator, and Symbol Recognizer. The Symbol Recognizer also acts as a Space Locator. The Boundary Locator recognizes the first sketch envelope and identifies it as the boundary of a building. The Partition Locator recognizes the following sketch lines or bubbles and creates partition walls inside the boundary. The Symbol Recognizer (Space Locator) recognizes any drawn symbol and identifies both the location and the architectural configuration that the symbol represents. The Symbol Recognizer (Space Locator) then builds the space with pre-defined configuration at the corresponding location. The SpaceMaker also has a

Symbol Definition System that allows users to define a drawn symbol and pre-set the architectural configuration for that symbol. Moreover, some Modification Tools also have been introduced. Users can modify the converted 3-D model by either moving any one of partition walls to change the spatial layout or varying the characteristic of any partition wall to adjust the degree of enclosure of a space. And finally, a VRML translator module in the SpaceMaker converts 2-D freehand sketches into 3-D models by outputting standard VRML format files that any VRML enabled web-browser can read and display.

5.2. Discussion

5.2.1. Contribution of this Thesis

This thesis has developed a prototype 3-D modeling tool, the SpaceMaker, for early schematic architectural design. The computational implementation is based on studies of the features of freehand drawings and the use of drawing symbols in freehand floor-plan sketches.

The thesis reveals that it is possible to quickly build 3-D models in the early phases of design process by making freehand floor-plan sketches and integrating designer-defined drawing symbols into freehand sketches, and finally having the modeling tool recognize the features of freehand drawings and pre-defined symbols. By enabling users to employ a pen-based interface to explore the space layout and input spatial data into a computer, the SpaceMaker enables designers to work with spatial components of a design without specifying their precise internal structure. In other words, the SpaceMaker permits postponing decisions about detailed specification and allows proposed configurations to be replaced by more precise decisions later throughout the design process. Using the SpaceMaker, designers can arrange the spatial layout based on the fundamental characteristics of space, and quickly experience the space in 3-D. On the other hand, the

SpaceMaker also enables designers to modify and add more precise details into the model later in the design process. For example, as described in Chapter 4, the SpaceMaker allows designers to give a wall an opening with any shape to change the characteristic of this architectural component.

Because designers can explore the spatial layout without worrying about specific details such as exact shapes, dimensions, windows, and doors when using the SpaceMaker to build 3-D models, designers can mainly focus on the "void" space instead of "solid" architectural elements. People usually make freehand drawings or further make simple massing models when they start designing. In the same way, the SpaceMaker can be conceived as a digitizing sketch board and a digital 3-D model maker. You think of the space first, and the boundary conditions that are most suitable to the space, and then think of the configuration of solid elements that come together with the space, and finally draw a symbol to represent this space. So, to make a model, you only draw a bubble or several lines to decide approximate shapes and size of spaces and also label the spaces with symbols, and finally a set of elements, defined by yourself in advance, will appear together on the screen to construct the model. You make space by thinking of space. That is the reason why we need the SpaceMaker.

5.2.2. Limitations of the Current Work

A crucial characteristic of early conceptual freehand drawings is that they indicate not only a designer's decisions but also the associated degrees of ambiguity, imprecision, and abstraction. Typically, designers draw formless or blob-like shapes that could be interpreted in one of several ways in their freehand sketches to represent a temporary solution. By keeping drawings ambiguous and abstract, the early conceptual design can remain flexible and allow any later modifications and adjustments.

SpaceMaker tries to embed ambiguity and flexibility into its modeling environment. That is why the SpaceMaker allows users to input drawing data by sketching with a pen to take advantage of the imprecision and abstraction of freehand drawings. However, currently the SpaceMaker only supports a one-to-one conversion between 2-D freehand sketches and 3-D computerized models. Although designers still can flexibly explore the alternatives of spatial configuration by making 2-D sketches, they only get one 3-D interpretation of each sketch. One-to-many relations of sketch to model could certainly enhance SpaceMaker's flexibility. In addition, another limitation, related to one-to-one-conversion, has to do with recognizing freehand sketching input. Currently the SpaceMaker perceives the whole world as an all-parallel-or-perpendicular world. SpaceMaker only returns designers a simple rectangle when they input a freeform envelope no matter how complex its shape. For example, when a user draws a freeform envelope, shown in Figure 5.1 (a), the SpaceMaker will return a smallest rectangle that fully contains the entire envelope. However, this translation may not exactly be the designer's original intention, which should be a smaller rectangle shown in Figure 5.1 (b).

Figure 5.1, A misunderstood recognition may occur due to the
ambiguity of freehand stroke.

Here is another example. An intended-L-shaped envelope will still be recognized as a rectangle, shown in Figure 5.2 (a). However, it may really be an L-shaped space as the designer initially intended, shown in Figure 5.2 (b).
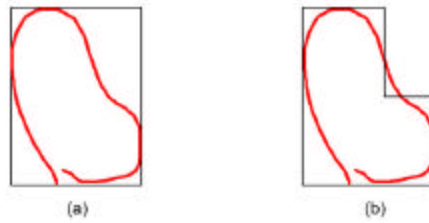
Figure 5.2, A freehand-stroke may be interpreted into different results.

This single-result recognition certainly weakens and obstructs the flexibility of graphic thinking. Therefore, a multi-result recognition mechanism of freehand sketching input should be implemented into the drawing environment. Furthermore, it will be possible to also create a one-to-many conversion modeling environment by implementing the multi-direction recognition mechanism. When a user enters a freehand sketch floor plan, the SpaceMaker will be able to respond with multiple models with similar but different configurations instead of a single model.

Currently, SpaceMaker only converts a single floor plan and creates a 3-D model by simply extruding the third dimension in Z-axis from the floor plan. The conversion is based on the assumption that all walls are vertical. For most architecture, the assumption may be correct. However, providing designers the ability to also modify space in section can enhance the flexibility of using the SpaceMaker. Although currently designers can adjust the height of a space when defining its symbol, SpaceMaker's modification tools work only in plan. In addition, allowing the SpaceMaker to deal with multi-floor space will be another way to broaden SpaceMaker's capability. This will also allow designers to walk through the virtual space not only horizontally but also vertically through VRML-enabled web-browser.

While the SpaceMaker supports a convenient paper-like modeling environment for designers easily creating 3-D models, there is still another limitation due to the computational implementation. The recognition systems currently support only single-stroke recognition. They require users to accomplish each single task, such as enclosing a building boundary, partitioning the floor, and inserting a symbol, within only one single

stroke input. For example, a designer must draw the letter "B", using one single stroke to write the letter, shown in Figure 5.3 (a). However, people's natural handwriting may need two strokes to complete a letter "B", shown in Figure 5.3 (b).
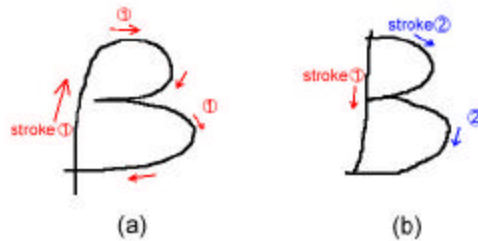

Figure 5.3, A symbol can be drawn in different ways.

(a)   a letter B done in one single stroke, (b) two strokes.

Therefore, the recognition systems may need to extend the recognition capability to multi-stroke input. Allowing multi-stroke input will enhance the convenience of using the SpaceMaker and broaden the range of symbol configurations. By using multi-stroke inputs, designers will be able to draw all necessary partition walls or bubbles to layout the spatial arrangement before the SpaceMaker starts the recognition and conversion tasks. In addition, the symbol recognition is currently based on the low level recognition that only compares the similarity of shapes for each single stroke. However, if the SpaceMaker is able to support the multi-stroke input, the symbol recognition system should take into account the spatial relationships between all drawn elements for a drawing symbol. For example, the current recognition system may not be able to identify the difference between two symbols that both have one circle and one rectangle, shown in Figure 5.4, based only on the similarity of shapes. The spatial configuration must also be taken into account in order to recognize the difference.
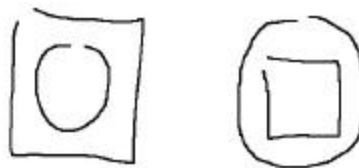

Figure 5.4, The spatial configuration must also be taken into account in order to recognize the difference between these two symbols that both have one circle and one rectangle.

5.3. Future Work

While this thesis has demonstrated the potential of efficiently creating 3-D models by converting 2-D freehand drawings, many opportunities for extending the scope of this thesis remain. This section presents some of these directions.

One-to-Many Conversion

Modeling conversion based on one-to-many relations of sketching to modeling can certainly enhance the degree of flexibility of using the SpaceMaker. By using the proposed one-to-many conversion mechanism, designers will be able to view a set of different models with similar configurations due to the ambiguity of designer's freehand sketching inputs. Then designers can pick one model that best matches the designer's initial design intention and further modify the design.

Multi-Direction Recognition

A multi-direction recognition mechanism of freehand sketching input should be implemented into the drawing environment. Due to the imprecision and ambiguity of freehand strokes, the current one-directional recognition mechanism may not be able to exactly identify the designer's initial intention. A multi-direction recognition mechanism for freehand sketching input will return several similar results, which all potentially match the sketching input, for one single freehand stroke. It will then be possible to also create a one-to-many conversion modeling environment by implementing the multi-direction recognition mechanism.

Multi-Floor Layout

Enabling the SpaceMaker to deal with multi-floor space will be another potential way to broaden its limitations, and this will also make it possible that designers can walk through the virtual space not only horizontally but also vertically using a VRML-enabled web-browser.

Precise Symbol Definition

Currently, designers may choose from only three different types of architectural elements, a solid wall, a colonnade with three columns, and an empty wall, to define a symbol. In order to enhance the flexibility and broaden the limitation of the SpaceMaker, more choices of architectural elements with different configurations should be implemented into the symbol definition system. For example, the number of columns should be adjustable for any given colonnade.

Multi-Stroke Input and High-Level Context Recognition

Enabling designers to use multi-stroke inputs to layout the entire floor plan or to arrange the spatial configuration for drawing symbols will enhance the convenience of using the SpaceMaker. Besides, the SpaceMaker should also support the high-level context recognition in order to broaden the range of symbol configurations.

Database and Data-Retrieval

By using the SpaceMaker, we can quickly build a 3-D model by applying symbols into freehand floor plan sketches. The program records not just a 3-D model but also the original floor plan sketch that actually contains the information of "spatial hierarchy and spatial order" for that 3-D model. If we can also make the program convert a floor plan sketch into a diagram (bubble diagram) that shows the "spatial order" of that sketch, each 3-D model will have not only the sketch floor plan but also an "index" of spatial information according to functions. We can then use those indexes for searching for a model we need. An index diagram (bubble diagram) can be seen as a key for searching and retrieving some pre-stored floor plans with similar spatial relationship in a pre-set database. Inturn we can view spaces in 3-D by converting floor plan into 3-D models. Figure 5.5 shows that a complete database of the SpaceMaker will contain three types of data: 3-D model, 2-D freehand floor plan, and an index diagram.
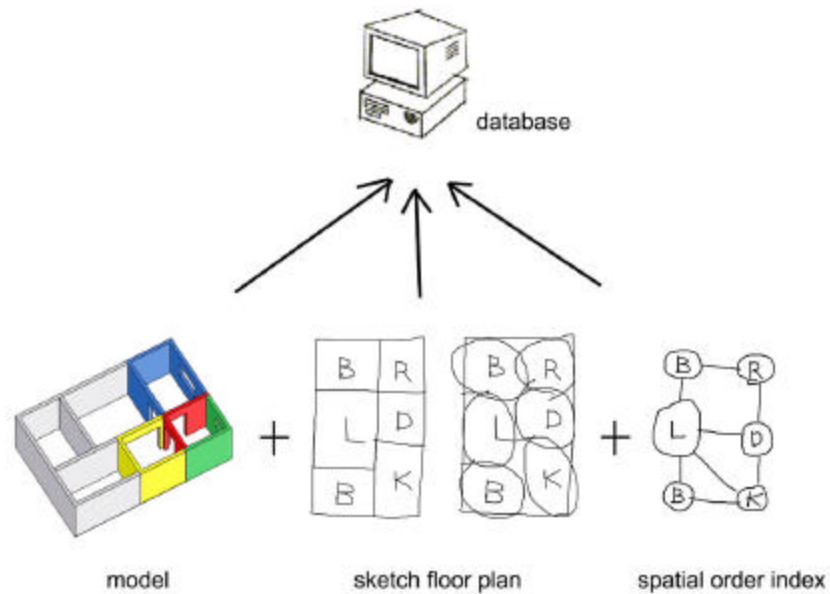
Figure 5.5, A complete database will contain three types of data: 3-D model,
2-D freehand floor plan, and an index diagram.

5.4. Conclusion

SpaceMaker is a prototype of a 3-D modeling tool that aims to enhance the decision-
making process of spatial configuration for an architectural design by creating 3-D virtual
space and providing designers 3-D spatial information during the early phases of
designing. Meanwhile, the SpaceMaker represents my intention to look at a different
direction for establishing a 3-D modeling environment that is truly suitable to early
conceptual design for the architectural field. We are the designers. We know what we
need to make computers be better assistants and in-turn make ourselves generate better
design solutions. In fact, we already have a powerful means to establish a better design
environment on ours own, and that is our knowledge of architectural design.