

CRITIQUING FREEHAND SKETCHING

A Computational Tool for Design Evaluation

Abstract. Design Evaluator is a computational tool to support design reasoning. In this paper we describe how architects reason about spatial relations, functional concerns and 3D space with drawings. Design Evaluator is a freehand sketching environment that offers critiquing of circulation paths and arrangement of functions in a floor plan diagram. The critiques are presented in the forms of text, diagrammatic annotation and 3D VRML.

1. Introduction

1.1 ROLE OF DRAWING: MATERIAL FOR REFLECTIONS

Design studies researchers have identified the role of freehand design drawings (i.e. sketches and diagrams) as material that stimulates reflection in the early stage of design. Schön describes designing as ‘reflection-in-action’: designers go through the action of generating a design solution, evaluating it, reflecting on and changing it. He argues that drawing is essential as a tool in this reflecting process (Schön, 1985). Designers use drawings to externalize design ideas and then to develop their designs further. Through examining and interacting with the drawings, designers develop and modify their design ideas. Designers must see the visual image on the drawing (Goldschmidt, 1991) to make a decision, to add a new design idea, or to modify the design (Laseau, 1980). Schön argues that designers perform ‘seeing-moving-seeing cycles’ in designing. In this cycle, ‘seeing’ is the interpretation of a drawing that is composed of graphical symbols; it induces the designers to have a conversation with themselves about the design ideas that they have recorded in the drawing (Schön and Wiggins, 1992). This feedback initiates an action,

resulting in adding, moving, or removing design symbols in the drawing. Experiments show that people cannot remember all design information and reason about design alternatives without using external representations (Tversky, B., 1999). These representations (drawings) help people offload the burden of keeping all relevant information in short-term memory. Following this observation, we built the Design Evaluator, a design environment that offers critiquing annotations on drawings to facilitate design reflections. Design Evaluator offers critiques about functional issues and concerns about circulation path, adjacency requirements, as well as an interactive 3D visualization.

The rest of this paper is organized as follows. Section 2 describes related work. Section 3 is a scenario that illustrates how architects reason with their drawings. Section 4 describes Design Evaluator and Section 5 concludes with summary and discussion.

2. Related Work

Our project is based on two related premises. First, sketching is important in the creative design process. Second, freehand drawing system therefore is an appropriate tool to access design reasoning systems.

Computationally enhanced design tools can offer support for reasoning. In order to build a design environment supporting reasoning, especially in architecture area, we examined architectural concept sketches and observed that mainly employ three kinds of reasoning: spatial reasoning, functional reasoning and 3D visualization. Our Design Evaluator is therefore concerned about these three kinds of reasoning. Below we briefly review related work in these areas.

Systems that support spatial reasoning have been developed for design. Electronic Cocktail Napkin (Gross and Do, 1994) can recognize and interprets users' sketches. For example, if the user draws a stack of boxes or spiral, the system can recognize the diagram as a plan or elevation of Wright's Guggenheim museum.

The sKEA (Sketching Knowledge Entry Associate) system interprets sketches and the spatial relations in them to retrieve relevant information (Forbus and Usher, 2002). For example in a sketch, sKEA can match a rounded body of a cat to the rounded human torso. This matching capability can suggest possible placement locations for the limbs of a cat, close to the Design Evaluator project we present here. KID (Knowing-in-Design) (Nakakoji, 1993) and CRACK (A Critiquing Approach to Cooperative Kitchen Design) (Fisher and Morch, 1988) supports kitchen floor plan design with critiquing messages for problematic aspects such as a poorly

placed appliance or an incorrectly sized work triangle. The systems also offer successful kitchen layout examples for identified design tasks.

Several design systems provide critiques about functional behavior of recognized diagram symbols. For example, Critter (Kelly 1984) is a system for critiquing digital circuit designs. It provides critiques about behaviors such as unsatisfactory operating speed or power consumption. SketchIT (Stahovich, 1996) is a system for conceptual design of mechanical devices such as hook and pushrod. SketchIT identifies the parts and simulates the system's behavior to provide design feedback about function.

Several systems provide 3D visualization from 2D sketches. Teddy (Igarashi, 2000) enables a designer to quickly generate a three dimensional model from a sketch. Teddy generates three dimensional spherical objects with a polygonal mesh presentation that is useful, for example, for the early design stages of character animation (i.e. modeling a Teddy bear). VR Sketchpad (Do, 2001) enables quick creation of three dimensional space in VRML from a floor plan drawing. The project provides designers with a visualization tool to understand the relationships between the 2D plan view and its corresponding 3D space.

3. Reasoning with Sketches

3.1 VISUAL SYMBOLS: SPACES AND TEXT LABELS

Architects use visual symbols to represent their design ideas. For example, lines represent walls and a shape enclosed by lines defines a space. Labels often appear inside these enclosed shapes to denote functional assignments. These symbolic representations in drawings help designers to keep in mind the spatial arrangement is and what each space represents. Upon careful examination, one can identify designer's reasoning process in a design drawing. Drawings expose designers' reasoning, because they record their ideas and concerns on the drawings. For example, Graves describes that he sketches to record his observations and discoveries. His shorthanded notes and sketches are kept to be changed or combined with other version of sketches. He also argued that represented symbols are a kind of language to communicate with himself or others (Graves, 1977). Therefore we can understand architects' ideas and reasoning process from their sketches.

Figure 1 is an early design drawing by architect Steven Holl for the University of Iowa's Art and Art History Building. In this drawing he used lines and arrows to represent walls and visual access. He also wrote labels such as 'office', 'painting', 'history', 'class', 'court', and 'sculpture' to label these functional spaces. He wrote "main horizontal passages = meeting

places" with a yellow box as a legend, and drew the pedestrian circulation passage in yellow. Several double-headed arrows indicate visual access between the passage and the classrooms. A call-out arrow from the path is linked to the text of "see ongoing work along passage in court". These graphic symbols and text annotations indicate that the designer is concerned about the passageway between the court and the other classrooms (Figure 1).

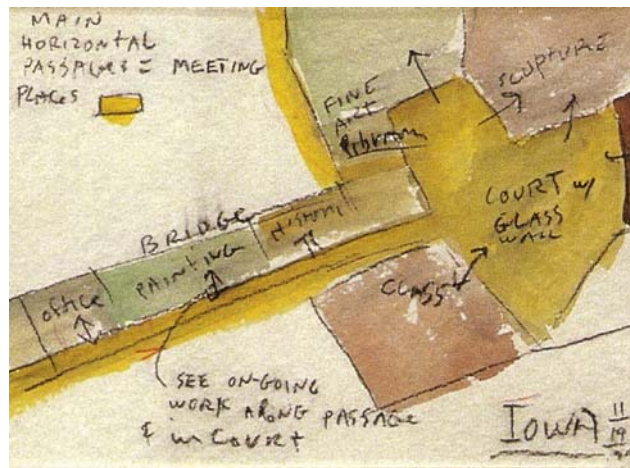


Figure 1. Visual symbols in Steven Holl's design drawings for the University of Iowa's Art and Art History Building include wall lines and text labeled spaces: The circulation path (passage way) is highlighted in yellow. Double-headed arrows indicate visual access. (Source: El Croquis, Holl, Steven, 2002)

3.2 SPATIAL CONCERNS

Architects see spatial relations such as connection and adjacency among spaces in their drawings. In the example (Figure 1), a 'court' (polygon space on the right) is connected with a sculpture room (top right) and a classroom (lower left). These spaces are clearly labeled 'sculpture' and 'class.' The architect has written, "w/ glass wall" below the functional label of 'court' to note a material choice. Arrows from the court to sculpture room represent concerns of visual access (i.e. where people can see the sculptures through the glass walls).

Architects also use the drawing as a medium to contemplate spatial arrangements. For example, Figure 2 shows a concept sketch in which the different colored shapes represent different functional spaces. The main school building with classrooms and a library is colored in dark red (top). The brown connecting rectangles represent a gallery building. The coloring of the spaces makes the focus and concerns more visible on the paper and

perhaps helps the designer to remember the idea or to communicate with others. Arrows from the main school building and his notes "limestone cliff views" represent his concerns of visual access/ views.

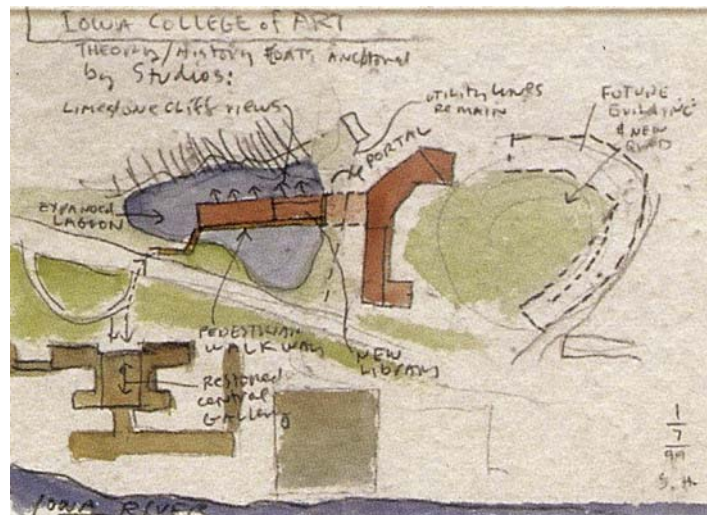


Figure 2. The different functional spaces are drawn in different colors in the concept sketch for the University of Iowa's Art and Art History Building (Source: El Croquis, Holl, 2002)

3.3 FUNCTIONAL CONCERNS

We can identify architects' concerns and decisions about functional arrangement of spaces and circulation from their design drawings. For example, in the plan for a small residence (Y House), Figure 3, Holl wrote 'MBR', 'BR', 'DR/K' and 'LR' as functional labels. The connecting linear shapes in yellow (center of the drawing) represent a continuous ramp. We can see that the designer drew a call-out line to label this as a "Y" ramp. The rectangle symbol next to the ramp represents a staircase. We suppose that this is a design for a two stories house, judging from symbols (stair and ramp) and text ("upper level" and "below"). In this drawing, the designer is concerned about the functional arrangements about the different floors. For example, on the top right, the architect wrote "BR below LR", a shorthand for the placement of a bedroom placed below the living room (at this level). On the lower part of the building, similar markings of 'MBR (master bedroom)' and 'BR (bedroom)' also appear on the drawing. Adjacent to the rooms there is an arrow with the text DR/K (Dinning room /Kitchen). Holl also circled his annotation of "2BR upper level" (lower left). This drawing shows that the designer was concerned about arrangements of functional

spaces and the spatial relationships such as horizontal or vertical adjacency between the rooms.

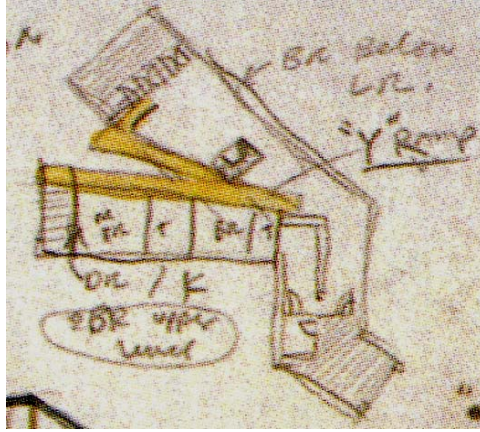


Figure 3. Text labels in the concept sketch for Y House indicate concerns about spatial arrangements of functional spaces. (Source: El Croquis, Holl, 2002)

Architects also consider the circulation paths in their design. For example, in Figure 4, the drawing has many graphical symbols such as lines and arrows. The lines represent wall partitions. The curvy arrows represent the circulation paths, which is evident in that the architect wrote the text “Freedom of Movement” at the upper left of the drawing. The presence of the many lines demonstrates the designer’s concern about people’s movement through the space.

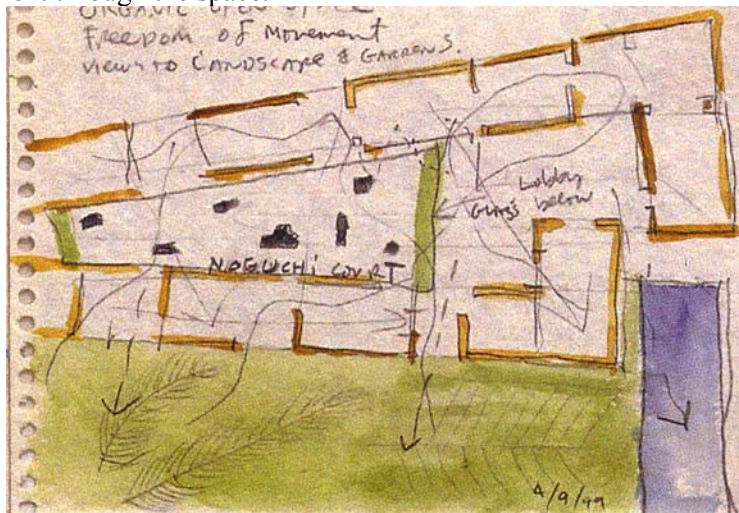


Figure 4. Circulation path concerns represented as curvy arrows in Holl’s concept sketch of the Nelson Atkin Museum of Art Expansion (Source: El Croquis, Holl, 2002)

3.4 3D VISUALIZATION

Architects use 3D perspective or isometric drawings during designing to reason about form and functional arrangements. Often these plan and 3D drawings appear on the same piece of tracing paper or pages in the same sketchbook. Figure 5-(a) shows a 3D drawing that appears right below the plan drawings of the Y House on the same page. This figure illustrates that the designer was concerned about the look and feel of the 3D form when he represented his design ideas in 2D drawings. Figure 5-(b) shows a bird's eye view of the plan sketch (left). One can see that the relations of rooms are illustrated clearly in this drawing by simply extruding the wall lines from the plan diagram. The circulation path here is also colored in yellow like the plan diagrams (Figure 5-(b) or Figure 1).

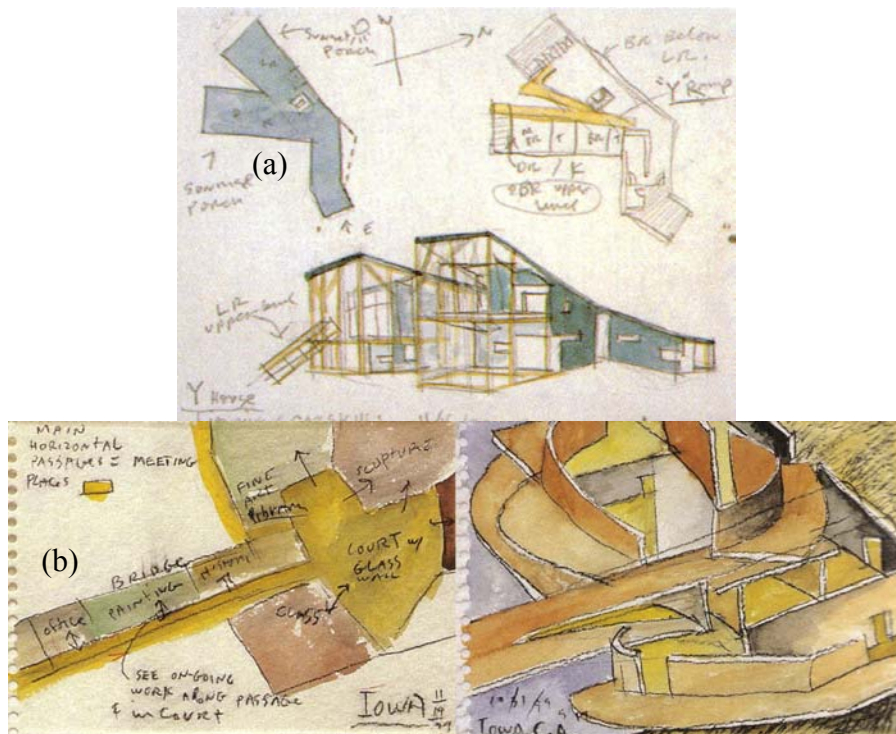


Figure 5. (a) Concept Sketch, Y House; (b) Concept Sketch, University of Iowa's Art and Art History Building (Source: El Croquis, Holl, 2002)

4. Computational Tool for Reasoning with Design Critiques

In the previous section, we saw how one architect recorded his concerns about spatial, functional relation and 3D visualizations in drawings. Our observations are as follows. He uses the visual symbols and shorthand notes for recording his design ideas and concerns. Holl reasons about the relation of neighboring rooms (Figure 1) as well as the whole arrangement with dividing larger functional spaces (Figure 2). Figures 3 and 4 show that he is concerned about functional relationship and circulation path. Using his drawing, he reasons about horizontal or vertical adjacency. For reasoning about the form and relationship of spaces, he used 3D perspective drawings.

To support architects' reasoning activities about spatial and functional relationships and 3D spaces in their design drawings, we built Design Evaluator as a proof-of-concept system. We incorporated these three issues into the Design Evaluator. The purpose of Design Evaluator is to support designer's reasoning process by providing design critiques.

In architectural design, one of the most complicated tasks is hospital design. In complex building design, designer's reasoning process gets more difficult. In this section we show Design Evaluator at work using examples from hospital designs. Like Figure 2, designer starts to sketch the large functional spaces (In Design Evaluator, we call this large functional space a zone). A hospital typically has three zones: Clinical zone, Nursing zone, and Support zone. The architect first specifies and draws the extent of these zones, then plans and draws several rooms such as ER, ICU, and ward. For this kind of designer's work, Design Evaluator provides a Zone checker. ER and ICU which verifies that ER is in the clinical zone and ward is in the nursing zone.

Arranging the rooms, the architect is concerned with circulation path and functional issues. As in Figure 3 and 4, the designer considers horizontal or vertical adjacency and circulation path. For helping this kind of reasoning, Design Evaluator provides a Path checker. The Path checker gives some design feedback. For example, ER and ICU should be adjacent, or a path must follow a specific sequence.

4.1. KNOWLEDGE CAPTURE FROM FREEHAND DIAGRAMS

Design Evaluator is a sketch drawing environment. The designer uses a stylus with a digitizing tablet to make freehand diagrams that represent spatial arrangement of rooms in a floor plan. Designers enter two types of data into their drawings: spatial diagrams and text labels. Spatial diagrams of drawn shapes are recognized as functional zones and rooms and their connections. Design Evaluator allows a designer to draw two kinds of

bubbles: zone and room. The designer uses a type-in box to input a text label for each room.

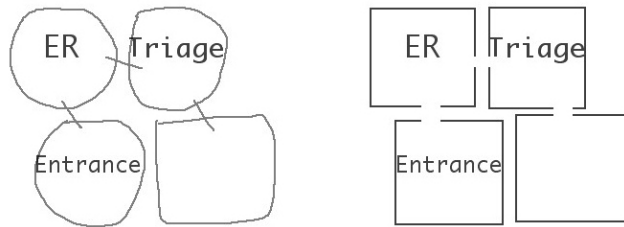


Figure 6. Sketched Diagrams: Design Evaluator provides two modes of drawing diagrams; sketched diagrams and rectified diagrams. In sketch mode, lines represent doors and in rectified mode, white space indicates doors.

The system also has two modes of display: sketch mode and rectified mode. The designer draws bubble diagrams to represent functional space such as entrance and triage (Figure 6 - left) and draws lines to connect bubbles to represent connections between functional spaces. The system can also display the space in a ‘rectified’ mode. In this mode, a freehand bubble will be converted to a rectangle shaped room and doorways are shown as open areas along the wall lines of the room (Figure 6 - right).

The Design Evaluator system captures information from the designer’s sketches. Recognized symbols (zones, rooms, and doors), text and spatial relationships are compared with stored *a-priori* design knowledge to generate critiques. Design Evaluator recognizes the spatial relationships in the diagram and generates a network representation of all the rooms and doors, and also generates all the set of possible paths through the floor plan.

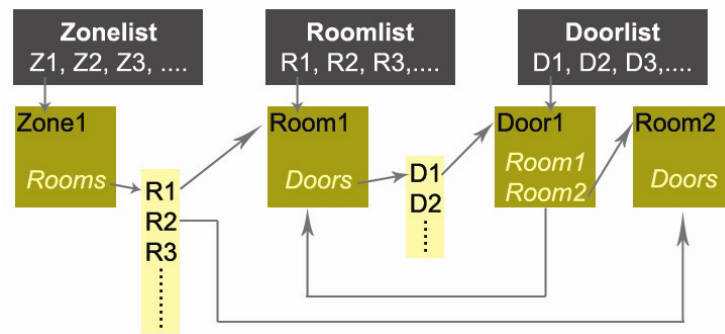


Figure 8. Relations of the Sketched Objects: Each zone has a list of its rooms and each room has a list of its doors. Each door knows which rooms it connects.

These sketched symbols are connected with each other in the database. Each zone object stores all rooms that are drawn in the zone and room object

stores zone object. In this way, the system represents zoning information from the diagram (Figure 8).

4.2. CRITIQUING

Design Evaluator works with two kinds of information: captured information from the drawing and design criteria as built-in rules. Design Evaluator has two checkers: a Path Checker and a Zone Checker. The Path Checker operates with two kinds of rules: 1) path sequence rules, and 2) room adjacency rules. The Zone Checker currently only has one kind of rule dealing with room placements in the appropriate zones.

The design criteria are categorized as *Zone Rules* and *Path Rules*. These rules are previously proposed by the designer to the DE system for determining that the proper placement of rooms and proper sequence of circulation for the rooms.

(1) Room Sequence Rule in the Path Checker

The Path Checker takes the form of an expression of:

(<Requirement> <room1> <room2> [<room3>])

This expression indicates that path sequence should follow room1– room2 – room3. For example, the following expression represents a required circulation sequence in a hospital design:

(MUST-PASS-THROUGH ENTRANCE TRIAGE ER)

The path from entrance to the ER must pass through the Triage area. This represents that the placements of functional spaces of ENTRANCE, TRIAGE AND EMERGENCY ROOM (ER) should follow a particular sequence of ENTRANCE – TRIAGE – ER. In other words, to access the ER, the circulation must pass through Triage. This requirement ensures that once patients are received from the entrance, they should be directed to Triage for treatment decisions before being sent to the ER.

(2) Adjacency Requirement in Path Checker

The Path Checker takes the form of an expression of:

(<Requirement> <room1> <room2>)

An adjacency requirement indicates that two rooms should be adjacent. For example, the following expression represents a required adjacency of two rooms in a hospital design.

(SHOULD-BE-ADJACENT ER ICU)

This requirement means Emergency room and Intensive care unit should be adjacent. If the delivered patient to ER is seriously ill, he should be directly moved into the ICU.

(3) Proper Room Placements in the Appropriate Zone in Zone Checker

The zone checker takes the form of an expression of:

(<Requirement> <Zone> (<Room> <Room> <Room> <Room>))

This expression indicates that all the (Rooms) should be in the given Zone. For example, the following expression represents a typical room placement requirement in hospital design.

(MUST-BE-IN CLINICAL-ZONE (ER TRIAGE CLINIC-FOR-OUTPATIENT DAYWARD...)).

Certain rooms should be placed in the clinical zone, because these rooms have the common character of clinical function.

Each rule is compared with the zone and room in the designer's sketch, and the paths that the system has derived. The Checkers compare the spatial arrangement of zones, rooms and paths with the rules. First, the Zone checker helps spatial reasoning to identify improper room placement in a zone. Although these seem simple to decide, in a design for a complicated building like a hospital, it is not uncommon to find poor placement of rooms. If the Zone checker discovers conflicts against rules, it shows the proper zone.

Secondly, the Path checker supports functional reasoning with two issues: to identify improper arrangement of path sequence between rooms and adjacency requirements. If the captured paths from sketched diagrams violate these path rules, the Path checker lets the designer know.

4.3 DISPLAYING CRITIQUES

Design Evaluator uses three methods to display the generated critiques: text messages, annotated drawings, and color coded 3D visualization. A critiquing is an effective way to stimulate designer's reflection, because it provides feedback for designers to improve their design, yet minimizes the increase in the designer's cognitive load. This section describes how the system gives critical feedback to the designer.

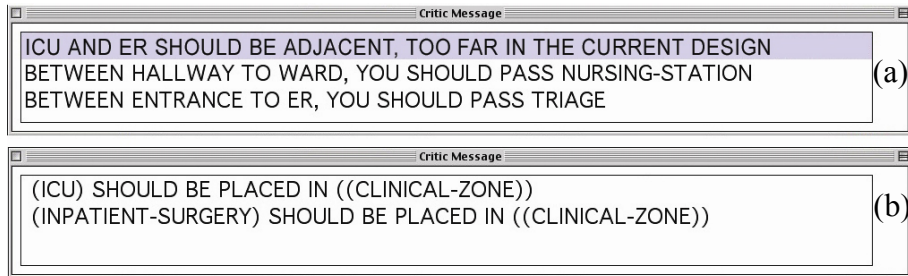


Figure 8. Text Critiques: (a) Path Checker critique messages display adjacency requirement (1st message) and proper sequence of rooms (2nd and 3rd messages), (b) Zone Checker critique messages signal problems with room placement.

4.3.1 Verbal Feedback

The system generates text messages in a special critique window, when the checkers find problems in the proposed design. Figure 8 shows an example of text critiques. The first message in Figure 8-(a) shows that “ICU AND ER SHOULD BE ADJACENT, TOO FAR IN THE CURRENT DESIGN”. The messages in the Figure 8-(b) are about zoning requirements.

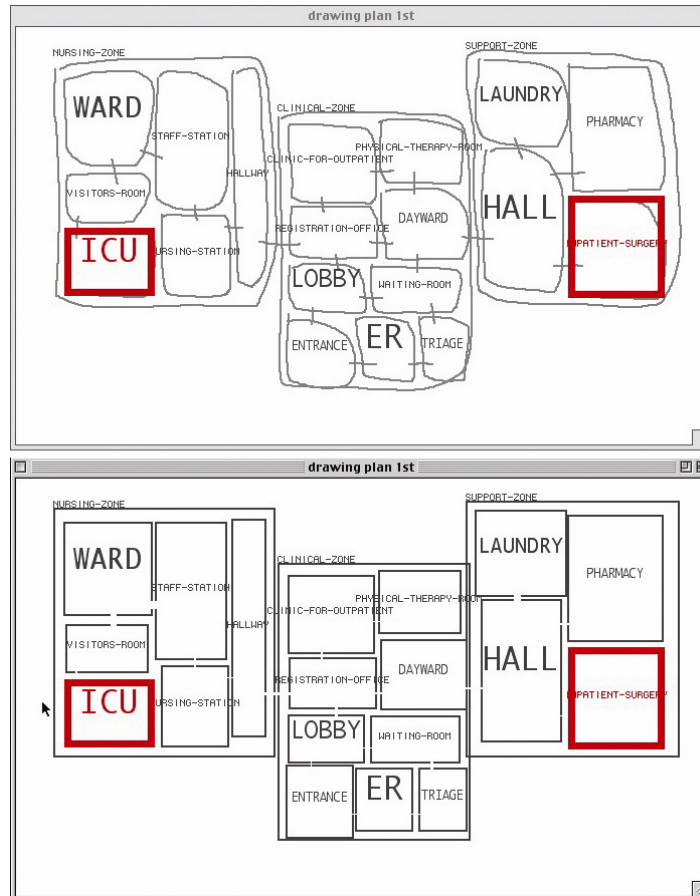


Figure 9. Zone Checker: Annotated Drawing of conflicts against zone rules: This annotation draws designer's attention to the placements of ICU and Inpatient-Surgery. (top- sketched input with critique annotation/ bottom – rectified display mode with critique annotation)

4.3.2 Visual Feedback

Each generated text critique message is connected with a drawing annotation. By drawing annotation we mean symbols added to the design drawing. For example, when a problem space is identified, the system will highlight that room boundary with thick wall lines (ICU and Inpatient-surgery in Figure 9). The Zone checker shows the designer the wrongly placed rooms by the highlighted thicker lines and also gives a text suggestion to move the rooms to another zone that has the proper character (Figure 9). The verbal and visual critiques are connected: if the user clicks on the first message in Figure 8, the Path checker shows the path from Ward to Hallway (Figure 10).

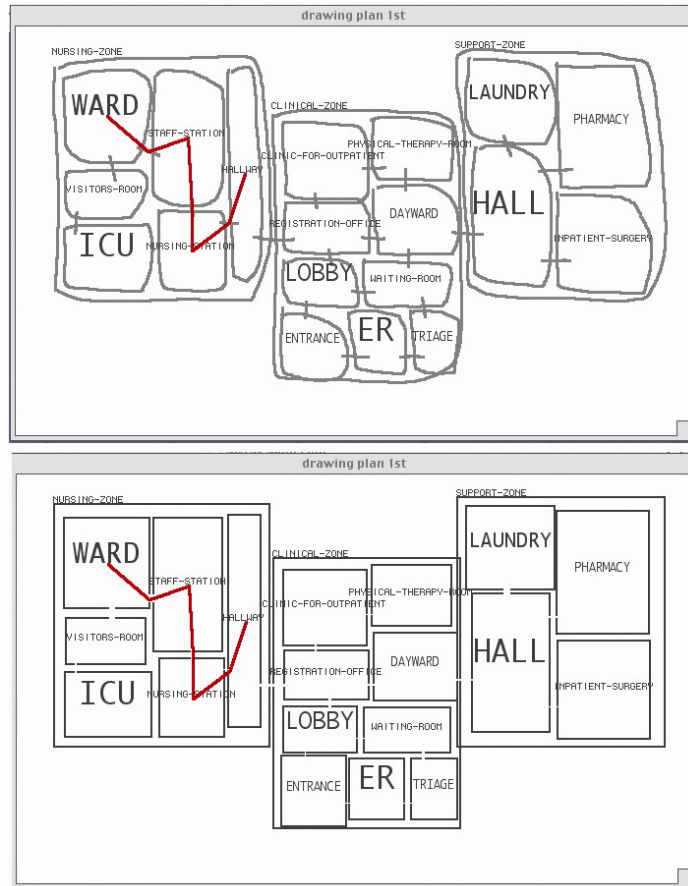


Figure 10. Path Checker: Annotated Drawing of conflicts against path rules

4.3.3 3D Visualization for 2D floor plan

The third method for providing design critiques is a 3D visualization of the space with VRML (Virtual Reality Modeling Language). The problematic placements of room are highlighted in the 3D space. Figure 11 shows the VRML model in the web browser, with highlighting to rooms indicate incorrectly placed rooms. A 3D model enables the designers to easily visualize the spatial relations in 3D and be able to “walk” inside the simulated space to further evaluate the spatial quality of the design.

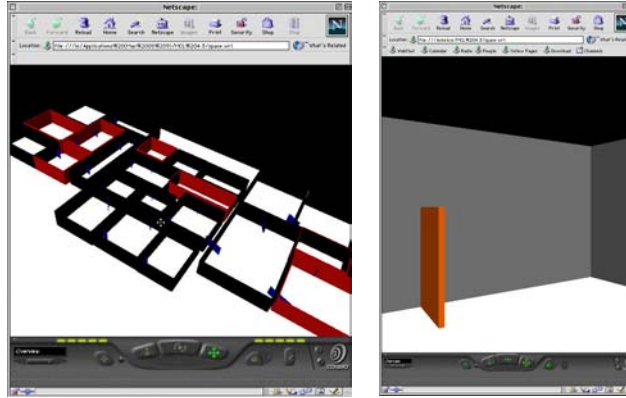


Figure 11. VRML mode generated from the floor plan for 3D Visualization and Walk-through

5. Discussion

Architects reason when they are making design drawings. As discussed above, architect Steven Holl drew graphical symbols to represent his design solutions. These symbols include lines and enclosures to represent functional spaces and text labeling for the rooms. Semantic information of drawing such as notations of design rationale also appeared on drawing apparently to remind himself of that information or to communicate it to others. We observed that architects reason about spatial relation, functional concerns and 3D space with their design drawings. We explored the potential of supporting these three categories of reasoning by implementing Design Evaluator, a sketch-based design critiquing system.

When the sketched diagrams violate the rules, Design Evaluator generates and annotated critiques. Knowledge in the system is represented as predefined rules that concern spatial relation, functional concerns and 3D space. Design Evaluator provides designers with text and visual design critiques. Through the visual critiques, designers may recognize potential problems. The designer might then try to solve those problems by moving rooms based on the provided critiques. In other words, Design Evaluator reminds designers of missing design information visually as well as semantically; these visual critiques might trigger new design alternatives. The critiquing helps to reason with his drawings any issues he might have overlooked.

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