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Comparing SESAME and Sketching on Paper for Conceptual 3D Design

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Abstract

In the early stages of design, several concepts are usually generated to explore the possibilities. This paper investigates how well a computer-based system can support design thinking. SESAME is a novel 3D design system that aims to support creativity during the explorative phase of the design process. We report an evaluation comparing SESAME to paper sketching for early design exploration in an urban design scenario. Through the user evaluation, we illustrate how important it is to support essential properties of traditional sketching, such as rapid creation/modification, emergent shapes, and tolerance to ambiguity. Additionally, we show that a 3D system can indeed facilitate form exploration at the early stages of design thinking.

Categories and Subject Descriptors (according to ACM CCS): H.5.2 [User Interface]: Evaluation/methodology, Prototyping.

1. Introduction

In the early stages of the design process, a designer iteratively evaluates multiple solutions to explore the design space. Traditionally, this has been done by sketching on paper. However, design practices such as architecture are becoming exclusively digital and collaborative in terms of the exchange of ideas over digital networks. Therefore, it would be beneficial to support sketching in computer-based systems. Conventional CAD systems are not very well suited for this process as they force the user to think about details and the underlying geometry.

In the field of design research, some researchers have conducted empirical studies of the design process that sought to identify the important properties design tools should possess [SPG98, BD03, MRB03]. This work was usually based on observations of designers' behavior during a conceptual session, and they studied sessions aided by sketching on paper or a conventional CAD system.

In addition, user evaluations were perfomed on several prototype design systems. These studies were generally either based on evaluation of the final designs created via a research prototype [TKN*03] or a subjective judgment by expert designers after a short term experience using the prototype system [DIJ95, BK03, VA02]. The main shortcoming of these studies is that they fail to analyze in detail how the designers used the system and hence did not identify which parts of these systems supported the design goals and which did not.

The above implies that it is beneficial to evaluate a system not only by investigating the output, but also by analyzing the user behavior in the process. In particular, this will better highlight the advantages and disadvantages of the system. This paper demonstrates a user evaluation that performs such an analysis on SESAME. The SESAME (Sketch, Extrude, Sculpt, and Manipulate Easily) system was developed to support the creativity of designers during 3D conceptual design [Oh05]. It is based on a drawing and extrusion interface. In addition, the system provides novel manipulation techniques for object motion [OS05] and grouping. To assess how well SESAME supports the early phases of design process, we conducted an evaluation to compare it with sketching on paper.

2. Related Work

We first present an overview of other systems targeted at 3D conceptual design, then list 3D systems that were evaluated with user studies and finally look at the structured design process analysis.

2.1 Conceptual Design Systems

One class of systems for conceptual design creates 3D models by interpreting a sketch. The general problem with this approach is that it can deal only with a subset of all possible objects [VMS04] (this paper also reviews this issue).

Another approach is gesture-based interfaces, where users create 3D objects using a set of predefined gestures. SKETCH [ZHH96] is one of the main examples, but a disadvantage of this system is that the types of created objects are limited by the “vocabulary” of the gesture interface and the need to train users on them. The SKETCH’s user interface was adapted in Sketch-N-Make [BZF*98], which was developed for designing and manufacturing machined metal and plastic prismatic parts. This system provides an example of how the result of a conceptual session can be transformed into a production step.

Teddy [IMT99] extended this gesture-based approach to free-form objects. Chateau [IH01] also utilizes a gesture interface, but uses suggestion engines to aid the user. These engines suggest possible scene configurations based on common design conventions such as symmetry or parallelism. But this approach consumes a substantial amount of screen-space.

In Virtual Lego [OS04], people can create complex Lego models efficiently using intelligent manipulation techniques. However, the scene can be built only out of rectangular blocks, which is a very coarse medium.

SketchUp™ (http://www.sketchup.com) is a system targeted at architectural design and uses push-pull techniques to facilitate scene creation. It provides a simple user interface to quickly build 3D structures. One drawback of this system is that it sometimes requires the user to manipulate polygons, which can be cumbersome during rapid design exploration.

2.2 Evaluations of Conceptual Design Systems

Vries and Achten [VA02] tested their system, DDDoolz, with architecture design students. The evaluation method was to let students use the system in course projects and then collected opinions from them. Dijk [Dij95] conducted an unstructured user evaluation of their system, FSD (Fast Shape Designer). There, the designers were exposed to the system for one day and then encouraged to make comments about the system to the experimenter. Tano et *al.* [TKN*03] compared their system, Godzilla, with sketching on paper for car exterior design. The number of solutions as well as design ratings were measured to judge the success of the system. However, they failed to show how designers worked with the system and what led to the difficulties during the design sessions with their system.

2.3 Structured Design Process Analysis

There have been many studies to identify the mental operations that occur during the design process, especially for sketching. Goel [Goe95] analyzed sketches of designers and demonstrated that designers conduct lateral and vertical transformation in each sketch during the design process. Lateral transformation is the movement from one idea to a (slightly) different idea while vertical transformation is the movement from one idea to a more detailed and exacting version of the same idea. He demonstrated that lateral transformations occur a lot more frequently in early stages of design process compared to later stages.

Suwa *et al.* [SPG98] presented a coding scheme to decompose design process into four action categories: physical, perceptual, functional, and conceptual. For each category, detailed user actions are defined, such as a drawing action in the physical category or an action of judging the aesthetics of a design in the conceptual category. This coding scheme is very useful to identify the role of sketching in conceptual design.

Bilda [BD03] applied the above-mentioned coding scheme to compare paper sketching with a conventional computer system. He showed that existing computer systems require much more cognitive effort in operating the system interface than the cognitive effort put into the design problem.

Meniru *et al*. [MRB03] used a detailed coding scheme to analyze sketchers’ actions and produced a list of requirements for computer tools to support the early architectural design process.

From the above work, we can see that it is possible to analyze the properties of a design tool by analyzing the actions of designers according to a structured action coding scheme. In this paper, we present an adaptation of such a coding scheme to analyze the usability of a prototype 3D design system.

3. SESAME: System Overview

Figure 1 shows the user interface of SESAME. The system is composed of a main window and a tool palette on the right side.

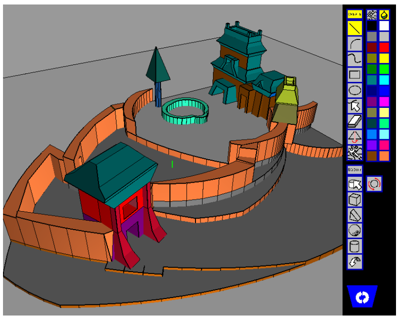

Figure 1: *User Interface of SESAME*

The system provides a drawing and extrusion interface to create and modify scenes. Users can draw lines, curves, or free-form drawings on any surface in the scene. A suggestion interface helps with drawing parallel or perpendicular lines. The system automatically detects closed contours whenever the user draws a line. Each closed contour can be extruded by the user into the third dimension by dragging with the right mouse button (Figure 2a,b). Dragging outwards extrudes a new volume (Figure 2b,c) while dragging inwards sculpts the existing volume (Figure 2d,e,f).

In addition, SESAME provides an intuitive object movement scheme without axis-widgets (handles). This allows the user to drag any object across the surfaces of the scene while keeping it in contact with the nearest surface. Details of this technique and an evaluation comparing it with axis-widgets are presented in [OS05]. The evaluation showed that our technique is significantly more efficient for novice users. Also, the system provides a hierarchical grouping scheme based on contact information computed by a collision detection algorithm [Oh04].

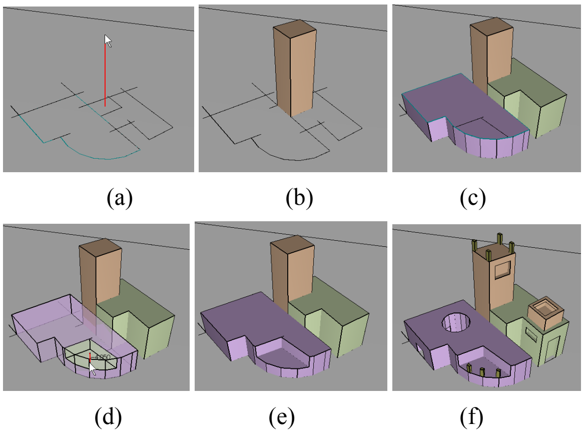

Figure 2: *Extrusion interface in SESAME*

Overall, the user interface of SESAME was designed to facilitate fast structural modification of a scene during the early design process, since this capability has been identified in the literature as important (e.g. lateral transformations [Goe95]).

SESAME is comparable to SKETCH [ZHH96] or SketchUp™ as all of these systems support extrusion of closed contours in one way or another. However, in SKETCH, there are many different gestures, with the potential for misrecognition and the need to remember the gestures. Also, designing with gestures requires a clear idea about what a design should look like, which is often ambiguous during the early formative stages of design thinking The biggest difference between SketchUp and SESAME is that SESAME is based on solids, while SketchUp is based on polygons. However, the manipulation of individual polygons, edges and vertices of a solid object can be counterproductive during the early design phases as these low-level primitives can distract from the main design exploration.

4. Objectives of the User Study

The main objectives of our studies were to answer the following questions:

1) Does SESAME allow users to produce conceptual design solutions in a reasonable amount of time?
2) Does SESAME support the exploration of different design solutions?
3) Does SESAME support creativity during design?
4) Does SESAME provide a reasonable range of modeling operations?

5. Task

The task was chosen from a set of urban design problems. In this task, participants were asked to undertake a preliminary building massing and form study typical of that performed at the start of the design process. The goal was to produce possible design solution(s) for commercial and residential space on the Goodwill property (a charitable organization) shown in Figure 3.

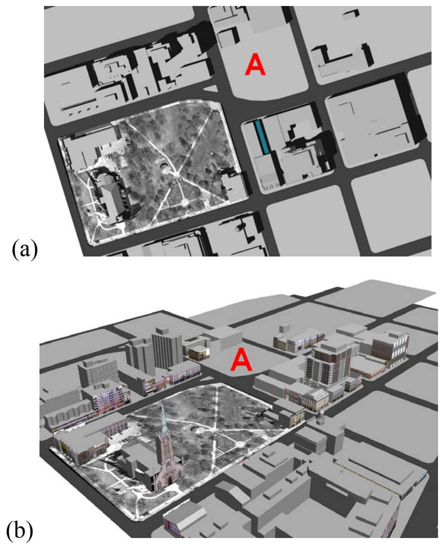

Figure 3: *The design task. (a) Top view and (b) oblique view of a city. 'A' indicates the site of the new building.*

6. Comparison with Sketching on Paper

Even though a comparison between sketching and SESAME is desirable, the two methods are perceived to be considerably different by most designers, which makes a direct comparison challenging. The biggest difference is that sketching produces 2D drawings on paper, while SESAME and other computer systems produce a 3D computer representation. This fact indirectly supports the perception that sketching is a problem-solving tool and CAD systems are tools to visualize concrete geometric forms.

Therefore, rather than comparing the two methods directly, it may be more meaningful to investigate the potential roles of SESAME during the early design process relative to the role of sketching on paper.

6.1 Subjects

Six participants were recruited from the set of Master's students in Architecture and Landscape Architecture at the University of Toronto (one male and five females, age 20-35).

Participants had professional and academic experience in architecture or urban landscape design ranging from three years to seven years (avg.4.9 yrs). They rated their sketching skills between average and excellent. None of the participants had used SESAME beforehand.

6.2 Procedure

The test session was composed of an introduction session, a SESAME training session, two task sessions, and a qualitative evaluation session. After the introduction, the written description of the design problem was presented to participants. The time for reading the description was not included in the task time. The order of the two systems was counterbalanced to address learning effects. The experimenter trained participants with SESAME for thirty minutes, immediately before the design session with SESAME. Since we assumed the design task to be rapid prototyping for early design and because it is subjective to judge whether a design is finished or not, each task session time was limited to thirty minutes. However, participants had a choice to stop the task when they felt that their design was finished. In the paper sketching session, the top and perspective views (Figure 3) were provided as base drawings. Pencils and erasers were provided and participants brought tracing paper for the evaluation. All those task sessions were video recorded for later analysis.

After the task sessions, participants filled out a questionnaire and discussed the system with the experimenter.

To highlight some of the effects in this user study, we sorted our users so that the first three users (#1, #2, #3) conducted the sketching session first and the other three conducted the SESAME session first.

6.3 Measurements

6.3.1 Design quality

The goal of the evaluation was to judge if a participant could produce a reasonably valid result (Q.1 in section 4) and be creative (Q.3 in section 4).

To evaluate the results for each participant quality, creativity, practicality, and overall quality were rated. These ratings were performed by one of the authors of this paper, who is the leader of a design studio and has many years of experience in urban design. Ratings ranged from 0 to 10. The creativity was measured to judge if a design was inventive and expressive. The practicality measure aimed to judge if a design was buildable and fulfilled the design requirements. The overall rating provided a balanced judgment between creative exploration and reality.

6.3.2 Analysis of paper sketching tasks

The characterization of the sketching was performed by looking for changes between different sketches of the model. This is based on the general observation that designers draw multiple sketches to produce a solution. The difference between sketches usually represents the progress in a design process, such as consideration on different design problems, trials of alternative forms, or refinement of a solution. Schon and Wiggins [SW92] called this kind of progress "*moves*". In this analysis, *moves* were counted by comparing the difference between subsequent sketches. In addition, the number of solutions was counted relative to the drawing that seemed to be the final solution.

6.3.3 Analysis of SESAME tasks

The goals of this analysis were to evaluate if a participant could explore design problems well enough (Q.2 in section 4) and to determine if SESAME effectively supports modeling (Q.4 in section 4).

Table 1: *Categories of modeling operation*

Operation category	Code	Operation
Navigation	N	Navigation for better view of the model, assessment of a scene, or walk-through.
2D Drawing	D	2D drawing activities, e.g. drawing, selecting, or editing 2D.
3D Creation	C	Add 3D primitives, extrude 2D contours, clone existing ones.
Modification	O	Sculpt or extrude to change shape.
Manipulation	A	Resize, extrude to resize, rotate, move, or remove.
Material	T	Apply or change texture or color.
Miscellaneous	I	Any activities that are not directly related to changing the geometry.

The characteristics of the design tasks were examined by decomposing them into unit modeling operations as shown in Table 1. Due to space limitations, this is only an abbreviated version of the full table presented in [Oh05].

The modeling operations were enumerated by observing the video-taped user sessions several times. Using this scheme, we also counted "failed" operations to check if designers could perform their desired operation well enough. We determined an operation to have failed whenever the user encountered unexpected results due to user interface problems.

6.3.4 Considered types of design problems

The types of design problems that are considered by designers were derived from users' statements and modeling activities recorded in the video of the design sessions.

6.3.5 Users' opinions

At the end of the test, we conducted a free form discussion with participants to identify problems and characteristics of the systems.

6.4 Results

6.4.1 Design quality

Several example results are presented in Figure 4. There was no significant difference between SESAME and paper sketching in terms of creativity, practicality, and overall quality.

Table 2 shows the ratings on qualities of design solutions for each user. The designs that created from SESAME-first session users were rated higher than those from the sketching-first session users in terms of creativity and rated slightly lower in terms of practicality. The possible explanations will follow later in the subsections through the analysis of design tasks.

Table 2: *Design quality rating*

	Creativity		Practicality		Overall	
	SESAME	sketch	SESAME	sketch	SESAME	sketch
#1,2,3	2,5,5	3,5,7	4,9,5	5,9,3	3,7,5	4,7,5
#4,5,6	4,7,10	8,7,8	4,5,2	5,5,2	4,6,8	6,6,6
Avg.	5.5	6.39	4.83	4.83	5.5	5.67

6.4.2 Analysis of paper sketching tasks

Table 3 shows a summary of the paper-based design tasks. In general, participants changed sketches to draw from a different viewpoint, to consider the form in terms of a different aspect of the design program, to produce an alternative solution, or to generate a more refined drawing.

Most of the designers started the sketching session from the plan view (Figure 3a), tracing aspects of the environment to gain a better understanding of the area. Then, they sketched the plan view of the building on top of the traced environment. Later, they developed 3D forms of buildings by drawing extrusion lines on the plan view or by drawing on perspective views. Hatching strokes were frequently used to express the patterns of windows or surrounding environment. Some users sketched to express subjective attributes of buildings by changing parameters of the perspective projection.

Table 3: *Sketch analysis results*

	#1	#2	#3	#4	#5	#6	Avg.
Sketches	5	3	7	6	2	5	4.67
Solutions	1	1	1	4	1	1	1.5
"Moves"	3	2	4	4	1	4	3

There was not much difference in attitude towards the task among users who sketched first (user #1,2,3). They tried to understand the design problem and produced one initial design solution.

However, users who used SESAME in the first session exhibited various behaviors in the sketching session, since they gained some understanding of the design problem in the SESAME session. User #4 produced several design variants, user #5 reproduced the previous idea, and user #6 produced many sketches to reflect on the design solution that was created in the initial SESAME session. This implies that the sort of understanding SESAME provided was different from sketching. That is, the last three users gained a better understanding of the design problem in terms of scale through SESAME. This helped some users to make further progress on the design in the second sketching session. As a result, this group of users produced

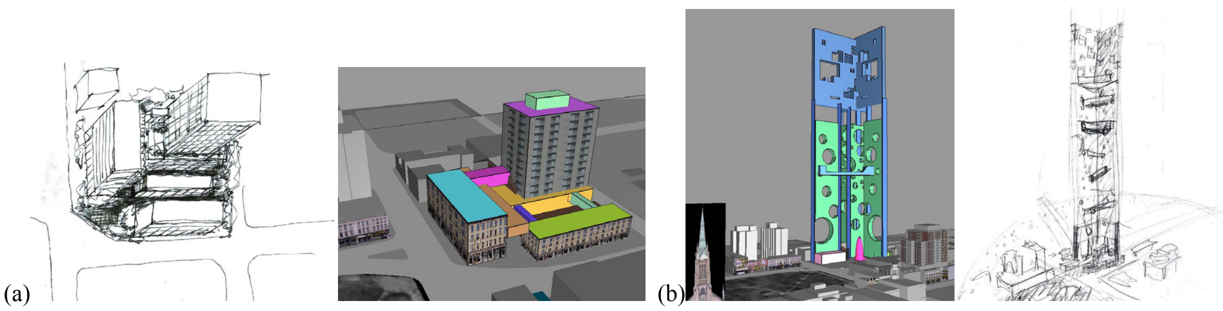

Figure 4: *Design results from (a) user #2 (b) user #6. Left column is from the first design session and the right column is from the second design session.*

designs that are rated higher in terms of creativity as shown in section 6.4.1.

6.4.3 Analysis of SESAME tasks

Table 4 shows the total number of operations and the number of failures for each operation. Overall, users performed a lot more drawing operations (D, 32%) than other operations.

We decided that an operation had failed whenever the user encountered unexpected results due to user interface problems. Overall, 4.1% of all operations failed. 65% of the failures were in the drawing (D) actions. This was due to an implementation problem in selecting the current drawing surface, which manifested whenever the user clicked directly on an edge of the scene. This sometimes resulted in unexpected drawing outcomes, as the system did not always resolve the corresponding ambiguity correctly.

Table 4: *Total number of operations and failures.*

	N	D	C	O	A	T	I
Total	81	188	105	73	90	5	15
Failure	0	15	6	1	0	0	0

In SESAME, people first started with navigating the background scene to understand the environment. This task roughly corresponded to the tracing task in the sketching session. Then, they sketched the plan of new buildings, then extruded into the third dimension, as they did in sketching sessions. Then, they developed their designs further by changing the position or size of buildings, or changed forms by sculpting.

One interesting observation was that users who sketched first showed less interest in elaborating forms in the latter SESAME session than those who used SESAME first. People who used SESAME initially made more use of modification operations. That is, the group of users who used SESAME first, performed three times more modification operations (avg.3.33 times for user #1,2,3 vs. avg.20.67 times for user #4,5,6). Modifications included carving of shapes to create details on building, such as entrances and windows, as well as the modification of overall shapes. The difference between the groups was significant (t_2=0.56, $p\approx$0.05).

Sketch-first session users stated that SESAME was basically used to reproduce one of the ideas from the sketching session, i.e. mainly using it in the typical role of a CAD system. Another possible interpretation to this result is that the first tool (whether it is sketching or SESAME) to generate a basic concept governed the way the design was produced in the second system. Since sketching does not provide sculpting operations easily, the designers who sketched first did not try to do it frequently in the second SESAME sessions. Meanwhile, first SESAME session users activated this operation more often, since they were not "prejudiced" by the sketching session.

However, we need to consider these statistical results with caution due to the small number of subjects. There was no other significant difference between the two groups. Figure 5 illustrates the percentages of modeling operations by category for successful operations.

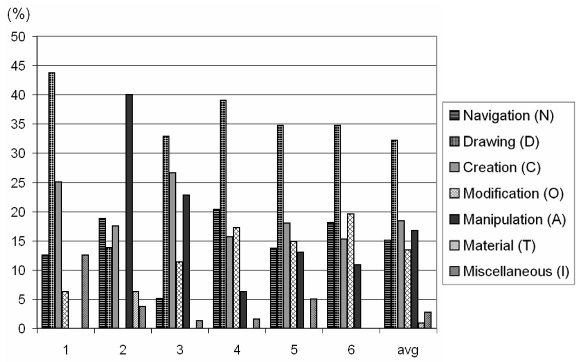

Figure 5: *Percentage of operation categories by user*

6.4.4 Considered types of design problems

Overall, the problems considered in sketching had a tendency to be more abstract than those in SESAME. This is most probably because sketching is performed in 2D and context is provided for through a single fixed viewpoint at each sketch. Some examples of problems that were considered in this process were: use of land area and buildings, lighting conditions, and functional connections with the existing area.

In SESAME sessions, people usually experimented with the form of the new building(s), after spending some initial time investigating the environment. In their exploration, the models were frequently compared with the surrounding area. Aspects considered here were the fit and scale of structures into the environment, the effect of the new building on the landscape from various viewpoints, and the look of the building from an eye-level view.

6.4.5 Users' opinions

As mentioned before, sketching with pen and paper is generally accepted as a primary problem solving tool for designers. The tendency to use sketching for this purpose was especially strong when users felt confident in sketching. Subjects who did the sketching session first seemed to use SESAME only as a conventional visualization tool. User #2 in this group mentioned that SESAME could be used to bridge the gap between an initial concept sketch and a later detailed design with conventional CAD tools.

In contrast, subjects who used SESAME before the sketching session mentioned that the system helped them to reflect on the problems in 3D and to understand the scale of objects better. This shows that SESAME can be used before sketching sessions to help the user produce initial ideas. User #6 stated that SESAME is "playful" and thus facilitates experimentation with unexpected forms rather than the conventional forms that are most often used. For that user, the unconventional forms possible with SESAME resulted in many design questions and many of those questions were investigated in the following sketching session.

6.5 Comparison of SESAME with Paper Sketching

6.5.1 Similarities

First, the most dominant operation in SESAME was 2D drawing. The 2D drawing interface allowed first time users to create a meaningful solution after a short training time. Users could sketch an initial idea similar to conventional sketching on paper.

Second, it was frequently observed that SESAME users sketched rough shapes of objects and then moved to describing additional details of the model. One of the known advantages of sketching is that it supports various levels of abstraction. In the general design process aided by sketching, people often consider the overall idea first and then move into a specific area later. This kind of behavior was also observed in many SESAME sessions. For example, one user first created several big boxes, while designating a function for each. Then the user changed the shapes of the boxes to elaborate the form.

Third, some designers made use of emergent shapes [Gro01]. While designers are sketching, unexpected contours emerge out of the experimental strokes, which leads to creative design exploration. Some users drew lines in random directions in SESAME to generate various shapes of contours and then extruded or carved them to create 3D forms.

6.5.2 Differences

First, designers showed a tendency to consider abstract design problems in sketching, while they experimented more with form in SESAME. The fixed viewpoint of 2D sketching seemed to condition users to consider a single design issue in one sketch. By changing sketches they could move to test different aspects of the design problem. This feature seemed to help designers solve design problems in a structured way. Currently, SESAME does not support this kind of multi-solution view interface. We think this is an interesting future research topic. On the other hand, SESAME users experimented more with forms and they frequently considered their designs relative to the context of the surrounding environment. This is due to the fact that a change of a form appears in 3D and this directly affects the neighboring environment.

Second, sketching provides the freedom to express subjective feeling about a design, while SESAME can only provide impersonal views of the model. In sketching sessions, some designers added trees or symbols of people to express the mood (or impression) of a new building. Furthermore, they sometimes manipulated the parameters of perspective locally to place emphasis on a part of the building. In SESAME, such control of the representation is currently not possible.

6.6 Roles of SESAME

Summarizing the results of the evaluations, possible roles for SESAME for conceptual design can be stated as follows: 1) a tool to initially examine design problems, 2) a tool for form exploration during the early design process, and 3) a tool for the elaboration on a design solution before final detailing sessions. Those roles can be mapped to each phase of early design processes as shown in Figure 6.

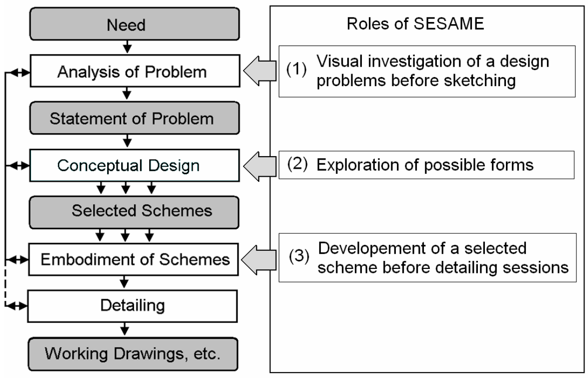

Figure 6: *Design process and potential roles of SESAME*

7. Conclusion and Future Work

We have presented a 3D conceptual design system, called SESAME. A user study was conducted to analyze the properties and potential roles of SESAME in the early design process. We observed that the drawing interface and solid modeling scheme helped designers to be creative while using our system. The results suggest that the system can aid in the overall design process.

In the future, we hope to incorporate the positive properties for problem solving that sketching supported in this study and were observed to be suboptimal in SESAME. To be able to replace sketching with the computer system in early design phases, it will be necessary to incorporate the properties of sketching as a problem-solving tool. We observed that sketching assists designers to focus on a single design issue in any one sketch. Also, sketching makes it simple to compare between different sketch sections. Through this, designers seemed to be able to manage design problem-solving process effectively.

In addition, we want to extend the system to allow for more free-form design activities and make the drawing interface more flexible, e.g. by allowing contours to span multiple surfaces.

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