On the Strategic Integration of Sketching and Parametric Modeling in Conceptual Design

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Architects perform problem-solving tasks while designing through various externalization modes. Among the architectural community sketching is associated with conceptual design, and parametric modeling is seen as a tool for detailed design development. However, parametric modeling is increasingly being used for exploring design concepts.

We propose that sketching and parametric modeling can be integrated strategically as alternate externalization modes to support problem solving in conceptual design. With sketching, architects are able to externalize their ideas quickly and effortlessly, as the flexible structure of sketching provokes multiple interpretations through continuous reflection. With parametric modeling, architects must define a set of parameters and rule-based constraints. By modeling design objects as parametric, multiple design variations can be generated, modified, and evaluated.

In this paper we describe an efficient process of problem-solving by studying the strategic use of sketching and parametric modeling in conceptual design. We conduct an experiment to explore the processes involved in both modes. Digital sketching is recorded by the Logitech io2 personal digital pen, and parametric modeling using Digital Project software is recorded by screen video capturing software, followed by a retrospective analysis. The ACADIA 2007 competition brief is used as the design task.

INTRODUCTION

Architects perform problem-solving tasks while designing through a variety of externalization modes (Goel 1995). Through freehand sketching, diagrams, manipulation of physical artifacts, three- dimensional computer modeling, and other representations, they externalize their concepts in early phases of design to develop their different moves and actions through further reflection (Schön 1983).

In the computer aided design discipline, many attempts have been made to augment problem-solving task structures in design (Chandrasekaran 1990). We understand design problem-solving as a complex activity involving a number of subtasks and a potential number of methods and tools available for representing each subtask. In this paper, we examine freehand sketching and parametric modeling as two tools that architects often use in professional practice to represent such subtasks.

Some studies have shown, however, that the knowledge of design tasks together with the knowledge of the tools necessary to carry out such tasks is not quite sufficient for an efficient design problem-solving process (Bhavnani and John 2000). These studies argue that some strategies have to be adopted in order to achieve such efficiency. We propose that sketching and parametric modeling can be integrated strategically as two alternate externalization modes to support problem-solving in early phases of conceptual design. Through investigating how architects use both tools alternately while designing, and exploring the underlying reasoning process, we study the strategic integration of sketching and parametric modeling in conceptual design.

We build on efforts in architectural research that apply protocol analysis to the design process from a problem-solving perspective (Eastman 1970; Akin 1986) and others that study human cognitive behavior within problem-solving contexts (Kirwan and Ainsworth 1993). We begin our discussion with an observation of problem-solving and task-structuring processes in both sketching and parametric modeling. We look at previous efforts in this discipline, and identify unsolved issues, focusing on the strategic integration of sketching and parametric modeling in conceptual design. We then describe our protocol experiment that observes how architects engage in problem-solving and task structuring activities using sketching and parametric modeling.

1. THE NEED FOR INTEGRATION OF SKETCHING AND PARAMETRIC MODELING

It is assumed among the architectural community that sketching is mainly associated with conceptual design (Goldschmidt 1991). With sketching, architects are able to externalize their ideas quickly and effortlessly, as the flexible structure of sketching provokes multiple interpretations through continuous reflection (Schön 1983). It is understood that sketching eases the process of externalizing early concepts but requires an additional successor tool to take design to next level of detail. In the field of architectecture, building information modeling (BIM) applications, used initially for detailed design development, are increasingly being used for exploring design concepts (Khemlani 2006). BIM incorporates parametric modeling as a powerful tool for visualization and analysis. With parametric modeling, architects must define a set of parameters and rule-based constraints. By modeling design objects as parametric, multiple design variations can be generated, modified, and evaluated (Aish et al. 2005; Anderl et al. 1996). Because of these additional functionalities, the parametric modeling interface in applications such as Digital Project is very complex, adding a cognitive load to the designer as he or she engages in design problem-solving.

The focus of this study is to integrate sketching and parametric modeling to describe an efficient process of problem-solving in conceptual design; a process achieved through integrating both the ease of explicit externalization and representation embedded in the sketching process, and the formalization of design concepts through testing and evaluation using parametric modeling tools.

2. EXPANDING THE MODEL OF STRATEGIC COMPUTER APPLICATION USAGES

Bhavnani and John identify "an intermediate layer of knowledge" between the overall task and the use of computational tools to achieve the task (Figure 1). Though task decomposition, the authors demonstrate how expert users perform less operations to achieve the same tasks as novices (Bhavnani& John 2000). Within this layer of knowledge, they describe three "aggregation strategies" that differentiate expert users of computer applications from novices because they can reduce the time it takes to accomplish a task, and also reduce the number of errors. In essence, the strategies are based on maximizing the "iterative power of the computer." Their model for complex computer applications focuses on efficiency and error reduction when performing repetitive tasks in 2-D CAD, spreadsheet applications, and word processing, providing strategies with wide applicability. One important observation is that strategies "may require additional cognitive costs" and therefore would not be efficient. We believe that complex applications such as Digital Project require more time in planning how to achieve a design task.

By expanding the intermediate layer of knowledge in

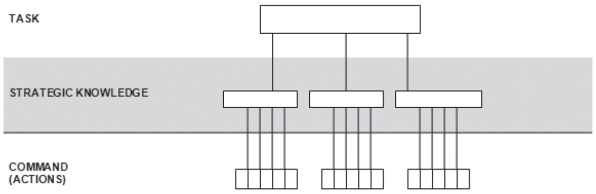

FIGURE 1 Authors' interpretation of the Model of Strategic Use of Complex Computer Systems after Bhavnani & John, 2000

Bhavnani's model of aggregation strategies (Bhavnani et al. 2000), we study the strategic integration of sketching and parametric modeling to describe an efficient process of problem-solving in conceptual design. We propose that architects undergo two different thinking processes while sketching and constructing models using parametric tools, and that both processes are essential during conceptual design. Our goal is to search for a space of integration between both modes of externalization, instead of adopting other external tools, to describe an efficient process of problem-solving in conceptual design.

3. PROTOCOL OF SKETCHING AND PARAMETRIC MODELING

We conduct a protocol study to explore in depth the sequence of tasks involved in conceptual design, alternating between sketching and parametric modeling. We observe five graduate students (A, B, C, D and E) in separate design sessions. Each session lasts approximately one hour. Digital sketching is recorded by the Logitech io2 personal digital pen, and parametric modeling using Digital Project is recorded by screen video capturing software. Video tape recording and a retrospective analysis of each session provided supplementary data.

Graduate students with similar background in sketching and parametric modeling were selected for this study. All students had undergraduate architecture degrees, which we assume includes design education and sketching expertise. All were graduate students in Design Computing, having just completed an introductory course in Digital Project. Among the students, A did not have professional experience, but was a teaching assistant for the Digital Project course. Among those with professional experience, C and E had worked in design competitions, B had extensive professional experience in construction and cost estimation, and D was a teaching assistant in another parametric modeling software. E had been a teaching assistant for free-hand drawing.

The ACADIA 2007 competition brief was used as the design task. The competition called for the renova-

Time	Mod. Time	Mode	Action	Type of action
	24:47	Sketching	Task	Assigning space of performance theater in SKETCH 2—labeling it /writing down text
	25:05	Sketching	Task	Specifying small spaces in performance theater—hatching
	25:07	Sketching	Transition	Thinking over SKETCH 2 & 3
	25:21	Sketching	Task	Specifying detailed space of theater
	25:30	Sketching	Task	Emphasizing spaces in SKETCH 3
	26:00	Parametric	Interruption	
	27:40	Parametric	Task	Creating a parametric "sketch" in Digital Project
32:26	28:22	Parametric	Task	Setting up tools
33:18	29:14	Parametric	Task	Undoing sketch, making a plane in GEOMETRICAL SET 1
33:45	29:41	Parametric	Task	Making GEOMETRICAL SET 2
33:52	29:48	Parametric	Task	Creating a parametric "sketch"
34:00	29:56	Parametric	Task	Creating a rectangle

FIGURE 2 Sample Segment of the Protocol Transcript for Subject A

tion of an existing waterfront building to house the New Media School in Halifax. The brief provided a programmatic break-down for the project including area and height requirements. Site photographs, a site plan, and a building section were also provided. The brief included a description of the building's structure, column grid, and bay spacing, which was an important constraint in the design. As part of our study, students were asked to develop a preliminary massing scheme incorporating a parametric relationship between the length of the building and the area of the performance theater.

Each session consisted of a 15-minute introduction to the design task, and a 45-minute design session, followed by a retrospective, where the students were asked to describe their approach to the design problem and their sequence of design action. The students were provided with a digital pen and notebook as the sketching tool, and a computer with an open Digital Project file as the parametric tool. The students were instructed to use both tools alternately. Students were free to switch between tools in whatever sequence they required to accomplish their design task. This freedom of alternating between tools was an essential part of our study. It allowed us to capture individual strategies of tool integration, and the corresponding sequence of externalization modes.

4. RESULTS FROM PROTOCOL

After reading the brief, each subject's actions were recorded using a video camera, the digital pen, and a screen capture to record actions in parametric modeling. The recordings were transcribed and segmented as sequence of sub-tasks (Figure 2).

- A spent 26 minutes sketching. The first task in sketching was to layout the structural grid in plan. He located the main programmatic spaces in the two levels of the building. In the parametric modeling environment, he executed the same sequence of actions. He created guidelines for the building's structural grid and rectangles for the programmatic spaces. Then he proceeded to extrude the areas. An analysis of tasks and transitions for subject A are illustrated in Figure 4.
- B spent a long time calculating areas, detailing the layout in plan, which reflected his professional background in cost estimation. He alternated multiple times between sketching and the parametric tool. After allocating the areas, he drew an axonometric showing vertical circulation and massing. After testing the areas in the parametric tool, he then drew the plans with the sketching tool.
- C opened the AutoCAD application to see the site plan and drew two rectangles for 3 minutes. He proceeded to sketch for approximately 20 minutes. The first task in sketching was to layout the structural grid and the main spaces in plan. He alternated between sketching plans and sections, labeling the areas. Then he switched to the parametric tool and extruded rectangular volumes for the first floor massing.
- D first looked at the provided site photos. He then spent 8 minutes sketching, tracing over the section of the building. He asked if he had to use the actual building, and was explicit about reshaping and utilizing part of the existing structure. In the parametric tool, he developed a section profile, extruded it, and made an array.
- E spent 5 minutes sketching. Before he started drawing, he asked about the orientation and approach to the building. In his sketch, he laid the structural grid in section using a ruler, and located the main functions. He was explicit about changes in the ground plane, the form and orientation of masses, and the expression of the building as a design metaphor. In the parametric modeling tool (Figure 3), he created the structural grid in section. He continued to draw the main volumes in section. He applied color and transparency to each volume.

5. DISCUSSION–STRATEGIES AND TRANSITIONS

In our experiment, none of the subjects completed the design task in the assigned duration. All subjects said they had completed between 5 and 20% of the task of developing the parametric model. In general, subjects sketched first, and then developed a parametric model. B was the only subject who alternated frequently between the two tools. Two of the subjects, however, expressed that if they were to continue the design task, they would have alternated between sketching and parametric modeling. Subjects C and D mentioned how restricting the parametric tool was. C felt limited by certain features such as automatically assigned constraints, and preferred assigning them manually in an easy to use interface. D preferred a tool that integrated more sketching functionalities within the parametric environment.

5.1. STRATEGIES AND TRANSITIONS

The design task is decomposed into a sequence of subtasks. This sequencing is a design strategy to achieve the task efficiently. Each design subtask is further decomposed into a sequence of tool tasks, or tool strategies, to achieve a particular design sub-task. Tool tasks are decomposed into a sequence of external actions (Figure 5). Tool strategies involve the sequence of sketching actions or parametric modeling commands to achieve

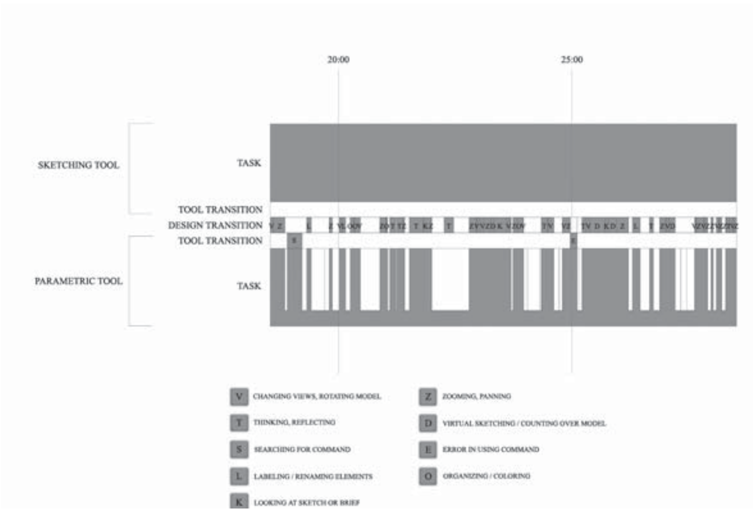

FIGURE 3 Detail of the Analysis of Subject E

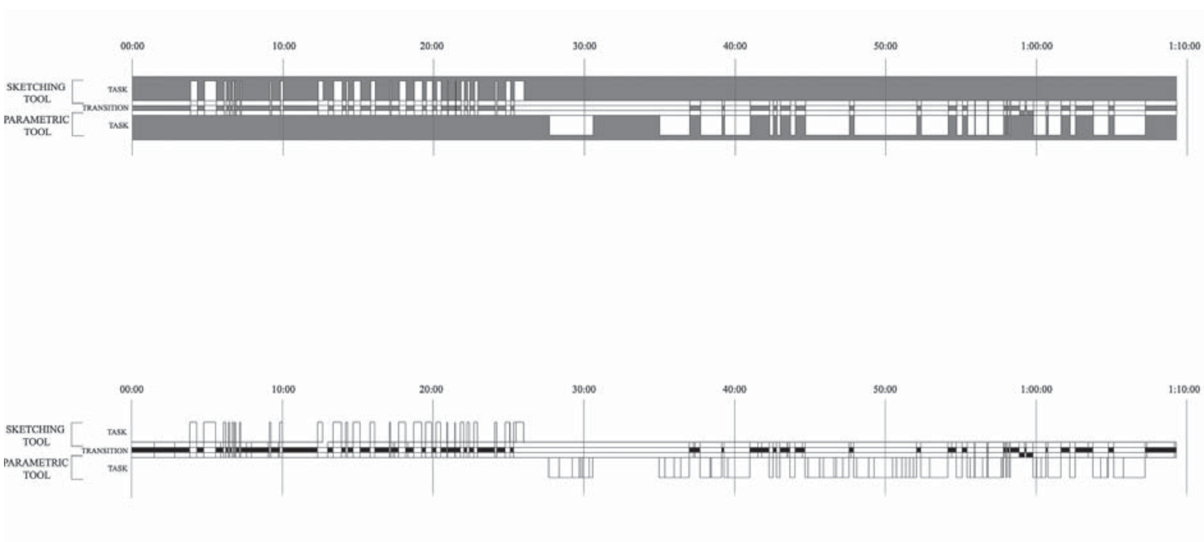

FIGURE 4 Task and Transition Analysis of Subject A

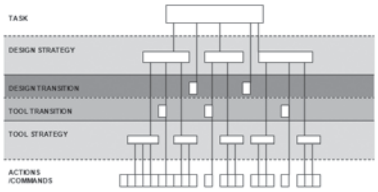

FIGURE 5 Strategies and Transitions: The Expanded Intermediate Layer of Knowledge

a design subtask.

Transitions in the design strategy and the tool strategy help the designer assess the efficiency of the design process, move to the next task, or revaluate the strategy. Design transition is a moment of reflection, during a tool task, or between tool tasks, to verify, evaluate, or modify the solution for the design subtask. Tool transition includes tool actions that facilitate the subtask, such as making a poché in sketching, or labeling objects in parametric modeling.

In this experiment, we expand the intermediate layer of knowledge discussed earlier, to describe the strategic integration of sketching and parametric modeling in conceptual design. We introduce two types of strategic knowledge: design strategy and tool strategy; and two levels of transitions: design transition and tool transition (Figure 5). By design strategy, we refer to the decomposition of design tasks into a sequence of subtasks, in a way that facilitates the completion of a high level task through breaking it down to a set of "executable" design operations. A design strategy can include decomposing a space planning task into the subtasks of calculating areas of the required spaces, organizing spaces, generating circulation paths… etc. By tool strategy, we refer to the sequence of actions or commands specific to the tool used in order to achieve a specific design subtask in an efficient manner. A tool strategy in the sketching environment can include choosing which design view to draw (e.g. plan, section or 3-D view), or specifying certain elements to sketch in order to extract information relevant to the task, or to carry on to the modeling environment. In the parametric environment, a tool strategy can include selecting an efficient sequence of commands to define a pad or body part, extrude, etc.

By a design transition, we refer to a moment of reflection or thinking during a task or between tasks, carried out to verify, evaluate, or modify solutions for design subtasks. In the sketching environment, continuous stops to look at the sketch or design brief, emphasizing sketched strokes, hatching areas, are all considered as design transitions. In the parametric environment, design transitions include zooming, panning, virtual sketching over the model, changing views, rotating the model, and coloring, labeling, and organizing elements in the model. By a tool transition, we refer to an interval of time, during a task or between tasks, consumed in managing restrictions caused by the specific tool in hand, thus this depends on the user's level of expertise in working with a specific tool. Tool transitions can include searching for the most suitable or efficient command to execute for the given task, or encountering certain errors in executing a command and redoing it using another path of execution. In this sense, less tool transitions indicate a higher level of expertise and control over the used tool.

5.2. THE DESIGN-PRODUCE STRATEGY AND THE PROPOSE-VERIFY/MODIFY STRATEGY

For the purpose of this experiment, we focus on two test subjects demonstrating two different strategies for integrating sketching and parametric modeling; subject A and subject E. From the transition analysis for subject A, we observed short one or two second-intervals of command selection, indicating precise decisions. The sequence of actions in constructing the digital model demonstrated aggregation strategies as defined in Bhavnani's model of tool use expertise. The transitions we observed, such as labeling part bodies, zooming out and reframing the model in the screen, indicated completion of a task. Subject A used sketching to design and parametric modeling to produce the design generated in sketching mode. We refer to this approach for integrating sketching and parametric modeling as a *Design-Produce* strategy. In this strategy, there is a clear distinction and segregation in the use of the two tools.

Subject E had the longest period of internal reflection before he started sketching. He used the sketching tool to propose a preliminary design scheme, and then he used the parametric tool for continuous verification and modification. From the design transition analysis, we observed multiple transitions. Design transitions such as zooming, panning, changing views, labeling, virtual sketching over the model to trace notions of masses and circulation, indicated that he was continuously using the parametric tool to design rather than implement. We also observed multiple interruptions in performing tasks including searching for commands and menus. His sequence of actions indicated less expertise and efficiency using the interface. We refer to this approach as a *Propose-Verify/Modify* strategy. This is a more integrated approach in which the design process evolves incrementally through preliminary design proposal and continuous verification and modification through the capabilities of evaluation and testing embedded in the parametric modeling environment.

Future studies would extend the protocol analysis for further confirmation of our hypothesis that designers would alternate between tools. A line of investigation would be to study in more depth the task and transition decomposition processes involved in both sketching and parametric modeling. Another parallel line of investigation would be to explore the opportunities of integration and alternation between the two tools through identifying a multitude of integration strategies.

CONCLUSION

When performing a design task, designers develop strategies that integrate the sequencing of design tasks and the sequencing of tool task to solve the design problem. Ours study looks beyond 2-D CAD, at the integration of two externalization modes: sketching and parametric modeling. We study the strategic integration of sketching and parametric modeling as two externalization modes for design problem-solving in conceptual design. We expand the intermediate layer of knowledge between tasks and actions by including these two externalization modes, transitions between the levels of tasks, and strategies for achieving those subtasks. We identify two types of transitions: tool transitions and design transitions; and two types of strategies: tool strategies and design strategies.

The strategic integration of sketching and parametric modeling is dependant on the level of expertise in the use of these tools to externalize and test design ideas for design problem-solving. We have a better understanding of efficiency of usage, as both the time it takes to perform a design task by strategic sequencing of tasks, and the tool selection to achieve a design subtask. We conclude that the integration of sketching parametric modeling in conceptual design yields two possible strategies, *Design-Produce* and *Propose-Verify/Modify*, for an efficient process of problem-solving in conceptual design.

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