Evaluating Workflow and Modeling Strategies of Pen Computing in the Beginning Architectural Design Studio

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Abstract. *This paper investigates the impact of Tablet PCs on the workflow in an undergraduate design studio. We examined how well the students adapted the Tablet PC into their day-to-day design work and evaluated the appropriateness of the Tablet PC as a common digital tool used in an architectural design studio. This research involved observation of student behavior during the semester and the conducting of a survey measuring various aspects of the students' use of the computers. A more specific goal was to compare the effectiveness of the pen versus the mouse as input devices for a three-dimensional modeling task in terms of both task time and strategies. Our assumption was that a change in input mode would affect the strategies and the performance. The results of a within-subjects, repeated-measures experiment carried out to elicit differences in input devices are discussed.*

Keywords. *Digital Design Education; Human-Computer Interaction; 3D Modeling; Pen Computing; Task Analysis*

Introduction

Architectural design can be seen as an iterative visual process that involves thinking and exploring in pictorial or symbolic abstractions. Even when a design solution occurs intuitively, it still must be evaluated against alternatives, critiqued and modified, making architectural design essentially a recursive 'propose-critique-modify' process (Chandrasekharan, 1990). One of the challenges beginning students face in the design process is visualizing their ideas (Porter, 1997). While the importance of sketching or "doodling" in this regard has never been underestimated as suggested by Goel (1995), computers have proved to be helpful particularly for three-dimensional visualization in the early design studio (Kalisperis and Pehlivanidou-Liakata, 1998). While one can choose from different paradigms for incorporating computers into the design process, as suggested by Gross and Do (1999), it is important not to overlook the relevance of sketching in the overall design process. As Herbert (1995) notes, most of the interactions between the handmade or traditional media and digital media are simple and single in that they are one-way and one-time. A familiar example is the scanning of conceptual sketches for use as underlay for three-dimensional CAD modeling or printing out a three-point perspective from modeling software for hand rendering. If, as Herbert (1995) points out, the interactions between traditional and digital media introduce new awareness in the creative process and thereby amplify designers' opportunities, this is an area ripe for exploration. Previous studies have measured design quality by the number of iterations of the design cycle (Kalisperis and Pehlivanidou-Liakata, 1998). We suggest here that by improving the efficiency of the interactions between the traditional sketch medium and the digital medium, more iterations of the design cycle can be achieved, and improved design quality would result.

Pen Computing and Architectural Design Studio

Pen computing, which relies on stylus and tablet as input devices, is currently generating intense interest, particularly among designers and architects. Pen computing helps to eliminate the interruption in workflow caused by the process of scanning and helps to overcome one of the main criticisms leveled against architectural computing: its rigidity in expressing a design idea, as opposed to the relative ease of the pencil-and-paper sketching. Though computer-aided design (CAD) has come a long way and is now embraced by professionals, much of its use is in the latter stages of the design process, particularly in creating high-end rendering or production of construction drawings. Pen computing offers the exciting possibility of combining the flexibility of pencil and paper with the representational complexity and realism of CAD applications. In sketching, there is little distance between thought and page, and the designer can capture creative ideas quickly and without difficulty, facilitating spontaneity. Based on the same logic, Tablet PCs should be one step further in taking advantage of the ability of digital technology to transfer ideas from inspiration to representation. Tablet PCs also have software tools that allow users to share, manage, and organize ideas. The mobility and flexibility of digital sketching are the key advantages over the common practice of starting a design on paper and then digitizing it later for manipulation.

In an academic environment, computers are often bound to a special studio or lab location, limiting their use by students as "electronic napkins" (after Gross and Do, 1996), which can record ideas whenever inspiration strikes. Because sketching or doodling is such an integral part of the design process, if it can only take place in a computer lab or studio, the making of architecture can become disjointed and limited. The separateness of the computer studio, locked and isolated, creates a lack of integration and loss of interaction between the students and faculty that exists in the traditional studio space. We introduced the portable Tablet PC-based studio as a solution to this problem. Each student was assigned a Tablet PC with all necessary CAD as well as image and video editing tools for the entire four-month semester. We evaluated the impact of the Tablet PC in the design studio based on our own observations and through a survey conducted towards the end of the semester.

Strategy and Three-dimensional modeling in CAD

The main advantage of using complex computer applications, such as a CAD tool, is that they have tremendous potential to quickly accomplish iterative tasks. With multiple approaches to accomplish a complex task, efficiency depends on the knowledge of alternate methods and the ability to choose the best one. This knowledge, referred to as strategic knowledge (Bhavnani and John, 1997) has been studied in diverse disciplines. Anderson (1990) defines strategic learning as the improvement arising out of people's optimization of problem solving for their specific domain. For the purposes of this study, we borrow Bhavnani and John's (1997, p. 94) definition that a strategy can be seen as a method of task decomposition that is non-obligatory and goal directed with the assumption that that a more efficient strategy improves performance. An operation in a three-dimensional CAD task is intended to change the three-dimensional world from one state to another. In the search of the goal, the set of all possible operations becomes the universe of possibilities that one explores. Mitchell (1990) compares this to a state-action tree, where the root node is the initial state, other nodes are possible states and the branches are possible operations. Thus, one can reach the goal state through different routes, which makes the choice of strategy critical for task performance. Other studies in the past have revealed that even highly experienced users often are not aware of the best route to take to achieve the goal state.

Two CAD strategies commonly used, according to Bhavnani and John (1996, 1997, 1998 and 2000) and Bhavnani, John and Fleming (1999), are Sequence-by-Operation and Detail-Aggregate-Manipulate (DAM). In the first approach, one draws each component of the basic shape as many times over as required. As opposed to this Sequence-by-Operation strategy, the easier way is to draw the elements of the repeated shape (Detail), group them together using an appropriate command (Aggregate) and create multiple copies (Manipulate). Another variation of the DAM strategy is the Aggregate–Drop-Modify (ADM) strategy, where the elements are selected, the exception is dropped and then modifications are made.

Fu and Gray (2004) have compared complex computer tools and investigated the reason that users have preferred strategies that are less efficient than recommended procedures. The main reasons for inefficient strategies included lack of knowledge or a preference for familiar, but less efficient strategies (Fu and Gray, 2004). The users are unaware of efficient strategies either because they were not made explicit enough by the system or because there is a weak causal relationship between method and the quality of the product. In the case of CAD, when compared to manual hand drafting, the quality of the final product is not dependent on the strategy and therefore, there is less motivation to choose the more efficient one. Bhavnani, John and Fleming (1999) point out that efficient strategies though known, are still not used if they are not seen as having value or when prior knowledge dominates performance. The above observations mirror the active user paradox composed of assimilation and production biases observed by Carroll and Rosson (1987).

Our initial experiences with CAD software using tablets suggested that the change in input mode might affect performance and choice of strategies. In the 1990s despite the use of large tablets in conjunction with commercial CAD software in leading professional design firms, the improvement in the overall workflow at the design stage was very limited. Though the pen was intended reduce the distance between the thought and the page, the tablet was still based on the logic of the grid, which acted as a constraint. The predefined process thus restricted the spontaneity associated with sketching. In this study, we were interested in seeing if this disconnect had any impact on task performance and whether it introduced any change in the choice of strategies.

Difference in task performance as a function of input device and strategies

An important objective of this study was to explore whether the user interface makes any difference in choice of strategies and the task time. The tablet/stylus input option parallels the traditional pencil-and-paper sketching with which the architects are at ease. Many consider sketching to be the ideal interface for architectural design, as opposed to the rigidity of keyboard and mouse for CAD. We were also interested in learning whether the tablet can be an appropriate interface for CAD software, even if the software is not specifically designed to take advantage of the tablet and stylus. One broader issue of importance is the strategies used to accomplish the 3d-modeling task. Studies by Bhavnani and John (1996, 1997, 1998 and 2000) have looked at the strategies used to accomplish 2d tasks in CAD. To the best of the authors' knowledge, there is no research report available on task performance and strategies for 3d modeling tasks in CAD. The added dimension increases the cognitive complexity and could potentially affect the choice of strategies and therefore the task performance.

GOMS as a tool for Task Analysis

Creating models of human behavior with the potential to predict task performance is useful in system design and evaluation. GOMS, an acronym for Goals, Operators, Methods and Selection rules, is an approach for a model-based evaluation of systems (Card, Moran and Newell, 1983). Goals, as the term suggests is simply what the user intends to do. Methods are the series of actions performed using the Operators (in the form of menu selections, button clicks, scroll bars, text entry etc.) to achieve the Goal (John, 2003). When more than one Method can be used to accomplish the goal, the Selection rules come into play. In most cases, the method involves sub-goals and as such it is hierarchical in its nature. GOMS analysis can be formalized and detailed to the extent where, task performance predictions using GOMS can be used as a substitute for empirical user testing (Kieras, 1997). Due to the formal nature of the task representation in a GOMS model, it can also be used for task analysis (Kieras, 2004). This quality of GOMS is utilized here to understand the strategies better.

Experiment

The study was carried out as a within-subjects repeated-measures experiment with 10 students (6 male, 4 female) between the ages of 19 and 21 (M = 19.5) from the Architecture Department at the Penn State University. Participants were asked to complete a 3d modeling task (see Figure 1) using a Tablet PC with both the two-button mouse and the stylus as the input options. All the participants used the same Tablet PC with the mouse, stylus, display, and input settings held constant across the subjects. The Tablet PC had a 1.79 GHz processor and a display resolution of 1024 by 768 pixels with on-screen actions output on a 19-inch monitor placed away from the subject and video recorded for later analysis.

In order to analyze the comparative efficiency of the strategy adopted by the subjects, comparisons were made to that of an expert user. Matt Holewnski from Form•Z was recruited for this purpose. The expert user was given the same task as the students and the process videotaped. The video was analyzed later to arrive at a detailed GOMS model and to ascertain task-time, to be used as a benchmark. The expert followed a detail-aggre-

Figure 1. Modeling task - From left to right: Layout plan, Final view, detail of single unit

gate-modify strategy for most subtasks.

Half the subjects were randomly selected to begin the task with the mouse option and the other half with the stylus option. All subjects began the experiment from the same starting point in an open Form•Z window. While the subject carried out the task, the investigator observed the subject from a distance. The task was repeated again using the second input option. This was done to ascertain if there was strategy improvement during the second trial. After completing the task using the second option, the subjects completed a questionnaire, which included open-ended items regarding the advantages and disadvantages of tablet/stylus option for Form•Z and Adobe Photoshop. We also included items on a Likert type scale from 1 to 10 measuring the appropriateness of the tablet for a variety of CAD and 2d graphic software. Other items measured general student computer usage for the semester and personal demographics.

Findings

Observations from GOMS and Hierarchical Task Analyses

One of the most interesting findings from the task breakdown from the GOMS analysis was the amount of time spent on manipulation of views. This highlights the importance of view manipulation in a 3d modeling task. The expert user spent approximately 27 percent of the overall productive task time performing view manipulations. Although the actual time taken for executing these commands may be very small, it is our guess that this time is also used for reflection, analysis, and laying out strategies for further development of the model. Another finding was that most of the modeling action happened with the mouse and most of the view manipulation action happened using the keyboard shortcut. Keyboard shortcuts were used almost always for view manipulations. This points to the advantage of traditional keyboard and mouse interface in improved task performance through bimanual input. This potential is not available in the tablet-stylus option.

The expert user, having created the basic block, proceeded by taking advantage of Form•Z's advanced tools, greatly reducing the number of steps needed to accomplish the goal. When completing a sub-task, in situations when the task was not quite perfect, the expert went ahead and completed it and then modified it, rather than retracing the steps. In terms of strategy, the expert used the DAM or ADM strategies and relied on advanced modeling tools, which cut down the number of steps drastically. The comparison in terms of strategy between the expert and novices in general is summarized in Table 1. It should be noted that

Task	Strategy of Expert	General Strategy of Novices
Basic block	• Create a pentagonal prism • Make copies for dormer & arches • Modify top corners to create hipped roof form	• Create rectangular block • Surfaces tools for creating roof
Dormers	• Scale copy made earlier for basic block to smaller size to create dormer • Multiple Copy to create 3 dormers	• Draw a rectangular and triangular prism • Union to create dormer • Copy for each dormer
Arches	• Scale copy saved earlier • Use advanced tools [Insert hole] to create the openings. Make copies. • Recede the outer arches into the building	• Create basic volume similar to dormer • Subtract cylinder and rectangular block to complete the opening • Create the deeper and shallow arches separately
Layout	• Detail – Aggregate – Modify	• Sequence by Operation

Table 1. Comparison of strategy of Novices to Expert strategy

there were some exceptions among novices when it came to certain subtasks and some students did not differ greatly from the expert. Also some of the students who used the stylus input option first, used more surface-modeling tools such as faces instead of solid-modeling tools, mimicking hand sketching where the emphasis is on delineating the surfaces or contours.

Since the students were all enrolled in a computer-based design studio and each had a Tablet PC for the semester, their total computer use was significantly high. The average use for course-related work was per week was 40.1 hours (S.D. = 15.32), most of which was devoted to Form•Z, which averaged 31.25 hours per week (S.D. = 13.81). Only 6.75 per cent (S.D. = 9.13) of the Form•Z use involved the utilized the stylus. Adobe Photoshop was another software used by all the subjects for academically related work, averaging 11.55 hours per week (S.D. = 10.5) of which approximately 51 percent [S.D. = 25.36] of the use involved the stylus. The items measuring perceived appropriateness of the tablet-stylus input for 3d software were averaged to create an "appropriateness index" for 3d software. A similar index was created for 2d software as well. The mean appropriateness of the tablet input for Form.•Z was 4.2 (S.D. = 1.93) and that for 3d modeling software in general was 4.61 (S.D. = 0.77). The mean appropriateness for Photoshop was 7.9 (S.D. = 1.91) and for 2d graphic software was 8.39 (S.D. = 1.60). This relates back to our earlier discussion that the predefined nature of the CAD tools inhibit the spontaneity, whereas with tools such as Photoshop, that is not an issue.

Video-recordings were used to arrive at the overall task time and observation of the strategy for each stage of the modeling task. Though the mean time for completing the 3d-task using the mouse option was lower at a mean of 1516.5 seconds (S.D. =776.63) against a mean of 1926.6 seconds (S.D. = 599.43) for the stylus option, this difference was not statistically significant ($p=0.15$). Since the p-value is far from acceptable significance level, one need not worry about the smaller sample here. The mean task times taken by subjects in both options were much higher than the task time of 642 seconds taken by the expert using the mouse option.The order in which the two input options were used was taken into account as a control variable in the experiment and was found to have a significant influence ($p=.009$) on the task time, with more efficient choice of strategies as well indicating an awareness of the efficiency of strategy previously employed.

The end of the semester discussion with the students and the open-ended responses to the

Advantages for Form•Z	Disadvantages for Form•Z
• Easier to model irregular shapes, contours and tracing overlays etc • Feels more free to move objects around • Easier to select & drag	• Switching between rendering modes • Keying in numbers for angles/lengths etc. • Rotation/zoom tools etc. not work well • Lack of precision • Keyboard shortcuts not available • Difficulty in double clicking, closing shapes • Opening/ Saving files
Advantages for Photoshop	**Disadvantages for Photoshop**
• Easy to sketch like pencil & paper • Easier than mouse, more natural • Similar to sketchbook	• Keyboard shortcuts • Select/deselect layers etc. difficult • Less precision • Opening Saving files

Table 2. Pen Computing implications for design workflow

General Areas that need improvement
• Switching of views, rendering style etc. • Some simple way of UNDO • Some way of using in conjunction with keyboard • Easier way to close polygons in Form•Z than triple clicks. • Improve zoom /view manipulation • More seamless way of inputting text information for specifying dimensions • Improve text input for dimensioning

Table 3. General Areas for Improvement for Tablet as an input for three-dimensional CAD software

survey clearly revealed that the Tablet PCs greatly improved the overall workflow in the design studio. Portability, elimination of need for scanning design sketches, and having all tools in one place were cited by students as improvements in workflow over regular computer-based studios. The key points from the student responses to the open ended questions regarding the advantages and disadvantages of tablet-stylus as an input device for Form•Z and Adobe Photoshop are summarized Table 2. Table 3 gives a quick summary of areas that need improvement

Discussion

While there are a number of small user-interface issues in use of Tablet PCs in digital design application, overall, they were seen as contributing positively to the workflow in the design studio. Though there was a difference in task time between the two input options, the result should be interpreted with caution for two reasons. One is that the difference was not statistically significant and the other is that the subjects had only limited experience with the tablet-stylus option. The more interesting findings are with regard to the strategy of the novices, especially their reliance on basic tools instead of the more advanced tools that could reduce the task time. These results call for a rethinking of the training strategies for novices as well as the need for the user interface to make the strategies underlying the use of a particular tool more explicit.

Another important observation is regarding the substantial time that users, both the expert and the novices, spent on view manipulations. The large amount of time and the frustrations expressed by the subjects for view manipulation subtasks suggest that this is an under-represented issue in input devices for 3d modeling software especially while using Tablet PCs. In sketching three dimensional views, the concept of view manipulations is absent, since a change of view implies creating a new view from scratch. Perhaps, one should seek a new metaphor for this action while using the tablet PCs. This study also revealed that it would be helpful for Tablet PCs to replicate bimanual input, such as using the mouse for modeling tasks and keyboard for view manipulation. As MacKenzie (2003) points out, our efforts in improving human-computer interaction should seek to tightly couple the hands, each complementing the task of the other.

The main limitation in this study was the fact that subjects were relatively novices with both modeling experience as well as in the use of the tablet PC. Future studies should include subjects with comparable experience in 3d modeling as well as in the use of tablet interface.

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