The (Non) Relation between Efficiency and Choice of Computer tools in Design Modeling:
An Automated Protocol Analysis

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Abstract. There exists a fundamental belief among mainstream CAAD software developers that a designer's thought process is mainly driven towards achieving optimum efficiency. This paper argues that designers are not as much concerned with efficiency as much as protecting their personal preference for a certain method of object construction. Identifying and providing support to these methods - referred to here as 'methods-of-making,' is hence considered vital to how design efficiency is defined and how future CAAD tools are created. This hypothesis is empirically supported through a study conducted among 30 design students at the School of Architecture and Urban Planning, University of Wisconsin–Milwaukee.

Keywords. Computer tools, efficiency, design modeling, methods-of-making, preference

Introduction

Even with the popularity of digital tools in contemporary architectural practice, a fundamental difference exists in design styles between computer aids and human cognition. In this effect the question of increasing design productivity and the desire to achieve optimum efficiency have received considerable attention recently. However, design efficiency as defined by current software developers seems to be merely reduced to tool execution v/s time issues, much of this research is even unsupported and the results of which are at best 'proprietory' in nature. Literature on efficiency is hard to procure except for some corporate owned websites and a resistance to publish viable experimental procedures or results demonstrates the lack of thought on what design efficiency actually means. Software developers also use catch phrases such as 'ease-in-use,' 'intuitive experience' and 'powerful tool' as a market capturing strategy without really providing enough thought to the how architects really design. In fact no studies have even questioned whether designers really go about constructing objects based on a desire for achieving efficiency.

At the academic research level studies on CAAD efficiency is still at a nascent stage. Chia-Fen and Ku-Luna (1996) observed that task execution time among design students was highly correlated with the task execution times predicted by the AutoCAD keystroke level model. A more inclusive study by Bhavnani et al (1996) find that users tend to adopt suboptimal strategies and rely on a synthetic model containing of a mixture of manual and CAD methods. They argue that users have very little motivation to develop better strategies because a mixed model works - if not efficient. An argument is made to improve the lack of explicitly taught strategic knowledge in CAD. Indeed these studies have been conducted in the belief that productivity or efficiency is the most important aspect of architectural design process. However, no attention is provided to examine whether other issues exist which more are compelling in the interaction between designers and computers. These issues could range from design activity, styles of object construction, habit, experience, training and exposure to a particular tool, design context, design type, the nature of design problem and so on. While the causal effect of these issues are yet unknown, it is necessary to explore their effects.

Among the above mentioned issues, design activity in CAAD has been explored in some detail. Some of this activity include analysis/synthesis (McNeill et al,1999) and goal-driven/sensor-driven, (Tang and Gero,2000). While these studies suggest that a designer's thought process may not be guided by efficiency alone and that such activities have a role in object construction, they do not mention whether personal preference was a factor in terms of using particular methods, spending more time on certain activity or choosing certain CAAD tools. The current paper speculates that 'preference' may have a stronger effect on the choice of a design tool than previously known. Hence, the objective of this study is to understand the relative importance of two criteria: efficiency and personal preference for a certain method of object construction (referred to as method-of-making).

The specific hypotheses are (i) Null Hypothesis: Students construct objects by choosing digital tools mainly to achieve design efficiency (i.e. students select tools that are least time consuming and need the least effort). (ii) Alternative hypothesis: Students construct objects by choosing digital tools based on preferred method of object construction irrespective of the kind of object (i.e. students selects tools which they are most habituated to or are most comfortable with).

Methodology

The methodology used in this study is a concurrent automated protocol analysis. Such a concurrent protocol is conducted through observations during the design process and differ procedurally from retrospective protocols which are done after the process has been completed. Shortcomings exist in both these protocols. In the concurrent protocol explicit observations may not reveal implicit cognitive processes of designers and the researcher may not be able to accurately observe a designer's behavior over a long continuous period of time. Moreover, concurrent protocols involve intervention in terms of asking the designer to think aloud that may hamper the spontaneity of the design process. On the other hand, in the retrospective protocols participants retrieve data by recalling preceding cognitive processes and hence reveal information based on short term memory (STM) and partly based on long term memory (LTM). The characteristics of the human memory may seriously impair the results as details may be omitted or generated through logical reasoning rather than recall. To maintain spontaneity and at the same time objectivity of observation, an automated concurrent protocol in this study in which a protocol tracking software built in with the experiment automatically records each interaction between designer and computer. The computer generated protocol is generated through click counts and command types and analyzed after the experiment is conducted.

Experiment

The current study was conducted at the School of Architecture and Urban Planning, University of Wisconsin–Milwaukee. To ensure generalizability and empirical depth, a sample size of 30 was used. To control the effect of issues such as experience and training, a non random sample of first year level undergraduate students were selected. They have little or no prior design experience, are in the same design studio and have more or less no prior knowledge of digital modeling. To mitigate the affect of design context and instructional style the students were directed under a single studio instructor, who assigned them identical problems. Each of the three CAAD methods examined in this study (Aggregating, Carving and Extruding - defined later) received equal instruction time in order to minimize any bias towards one method or the other.

The students were asked to recreate a total of ten three-dimensional objects using the modeling system of MicroStation/TriForma version 08.00.02. The objects were labeled O01 to O10 reflecting the order in which the sessions were recorded and the students were labeled from s1 to s30, hereafter are referred to as the 'Operator.' The Operator was provided with an outline of a three dimensional platform in which the objects were to be situated. After each object was constructed, the researcher recorded the information regarding the Operator's keyboard clicks, mouse clicks and commands by the tracking software. This process took about thirty minutes to one hour for each Operator. At the end of the construction of ten objects the information was retrieved in a floppy disk and the data was coded. The coding is summarized in table 1

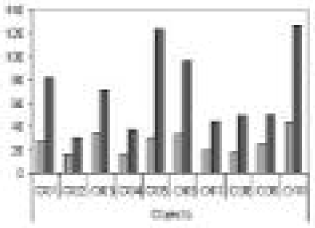
Findings

Relation between efficiency and choice of digital tools

The null hypothesis that students construct objects by choosing digital tools mainly to achieve design efficiency could be operationalized by assuming that the average Observed

Table 1: Coding for the protocol

Coding
CI = Click Count, represents the total keyed action taken by the Operator with keyboard and mouse. Every mouse click and every keystroke are included in this count.
AC = Action Categories, represent three types of model construction actions: Aggregating, Carving and Extruding. Each modeling tool in the Operator's palette of options is categorized as supporting one of these three Action Categories. These Action Categories can be used independently in the operation and are also mutually supportive.
A = Aggregating is a technique in which the Operator combines simple blocks to make a required object
C= Carving is a technique in which the Operator removes volume from a simple block to make a required object
E = Extruding is a technique in which the Operator makes a two-dimensional profile shape and then sweeps this profile through space to define a required object.
TC = Tool Count, represents the total number a tool from an Action Category is used to construct an object. There is a separate tool count for Aggregating, Carving and Extruding.
CA = Choice of Action, represents any Action Category that has a Tool Count of more than zero. For example, if two tools in the Action Category 'Aggregating' are activated during the construction of an object, the Tool Count for Aggregating would be two, and the Choice of Action is Positive for Aggregating. If the Operator activates tools from only one Action Category during the construction of an object, then the Choice of Action corresponds to the single Action Category with a positive Tool Count. If more than one Action Category contains a positive Tool Count for a particular object, then the choice of Action is considered indeterminate.
OE = Observed Efficiency is measured by the total click counts used by students to construct each object by comparing it to Optimal Efficiency.
OP = Optimal Efficiency represents the most direct route to each object and refers to fewest possible clicks needed to make each object. The Optimal Efficiency was determined by reference to the Operators Manual published by the Bentley Systems and by pre-testing an advanced user of the software.



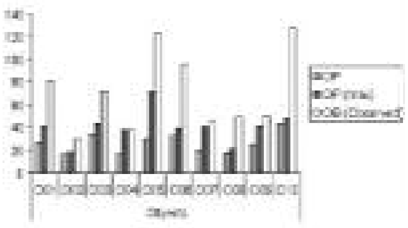


Fig 1:Bar chart showing comparison of Optimum and Observed Efficiency

Fig 2: Bar chart showing Observed Efficiency outside the range of min and max Optimum Efficiency

Efficiency (OB) will be correlated to Optimum Efficiency (OP) prescribed by the software. The closer OB is to OP the more likely that efficiency was a motive for the Choice of Action. Fig1 shows the comparison of Click Counts for Observed Efficiency (Mean) and Optimum efficiency. One can infer that OB is not correlated to OP, hence confirming that efficiency was not a motive for the Choice of Action. Hence the null hypothesis that students construct objects by choosing digital tools to achieve design efficiency can be rejected.

One can also observe from the bar chart that the correlation is minimum for some objects (O01, O02 O03, O05, O06 and O10) while for the rest there seems to be higher correlation. This difference could be attributed to the fact that there was a substantial difference in how students perceived complexity of the objects for different types of objects. However, in the research design the objects were selected in such a way that there would be minimum differences in their complexity. This could be evident by the minimum differences in the Optimum Efficiency across all types of objects (bar chart). Hence, the issue of complexity may not have played a predominant role.

If efficiency is not a motive for Choice of Action of digital tools, and complexity was not a motive either another possibility remains. The differences could be caused by 'ignorance' i.e. Operator could have been ignorant that a particular Optimum Efficiency existed for the respective Action Category. If he/she was aware of it he would have chosen the respective Action Category based on efficiency. One way to check for ignorance is by comparing Observed Efficiency (for each object) with the range of maximum and minimum Optimal Efficiency between the Action Categories (A, C and E). If the Observed Efficiency falls within this range, it is likely that ignorance was not a factor. If not, ignorance is likely to be a factor. It can be inferred from fig 2 that the Observed Click Count is well outside the range of minimum and maximum Optimum Efficiency.

Hence ignorance was a significant factor in the object construction process. However, even if there was no ignorance and the Optimum Efficiency of Action Categories were known by students the question remains whether students would still use efficiency as a central motive for choice of tools. While the bar chart reveals that they would not, however, there is some sort of congruence between Observed Efficiency (Mean) and Optimum Efficiency (max) i.e. the bar heights are almost parallel even if they are not equal. This could suggest that the students had some knowledge about the optimum efficiency although they did not choose the tools entirely based on it. This only shows that other compelling factors may have played a role in determining the choice of tools.

As discussed previously the Choice of Action does not have much correlation with efficiency, complexity (of objects) or ignorance. The alternative hypothesis could be that Operators construct objects by choosing digital tools based on a preferred method of object construction or methods-of-making irrespective of the kind of objects (i.e. students selects tools which they are most habituated to or are most comfortable with). This hypothesis could be examined by testing whether individual Operators use similar methods for all objects or whether different Operators use different methods for the same object.

Individual Operators predominantly use one set of Action Category over the other two

Fig 3 shows the Action Category for each Operator across all objects.

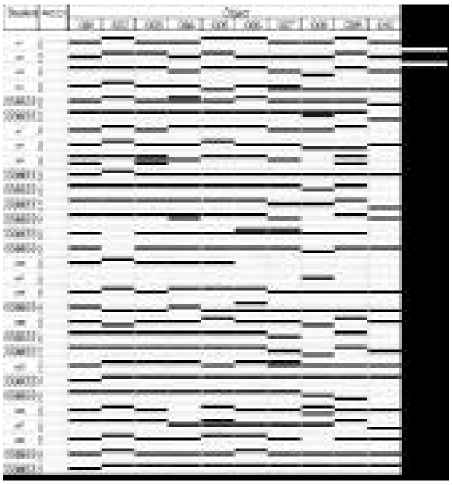


Fig 3:Protocol of Action Category for individual Operators The second

column shows the three action categories - aggregation, carving and extrusion (A,C,E) in that order. For each Operator, a thick horizontal line is drawn across all objects depending on what Action Categories were used for the respective objects. The shaded cells in the first column show those Operators who use one of the Action Category consistently (i.e. more than 75 percent of the time). The kind of Action Category is listed on the right hand side of the chart. 15 out of 30 Operators show clear consistency (10 use aggregation, 4 use carving and 1 uses extrusion. Out of the remaining 15, many show a preference to one Action Category, although not overwhelmingly. Hence one can infer that students prefer to use one set of Action Category over the other two and that preference plays a major role in the Choice of Action.

Operators as a group predominantly use one set of Action Category for a single object

To find out whether Operators tend to use one set of Action Category for a particular object a vertical analysis could be made (fig 4). The shad-

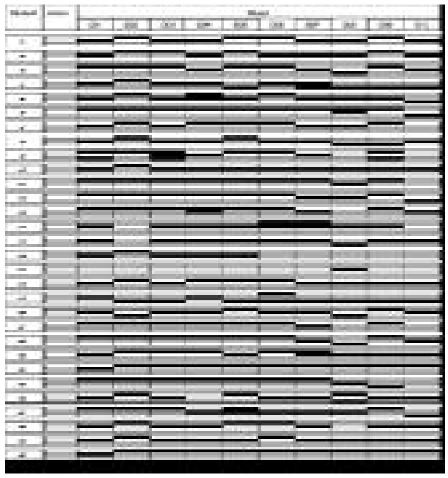


Fig 4: Protocol of Action Category for individual objects

ed cells in the first row

show those objects on which one set of Action Category was used consistently over the other two. The Action Categories are shown at the bottom. 6 objects are carved and 2 aggregated. For the remaining two no clear pattern is seen.

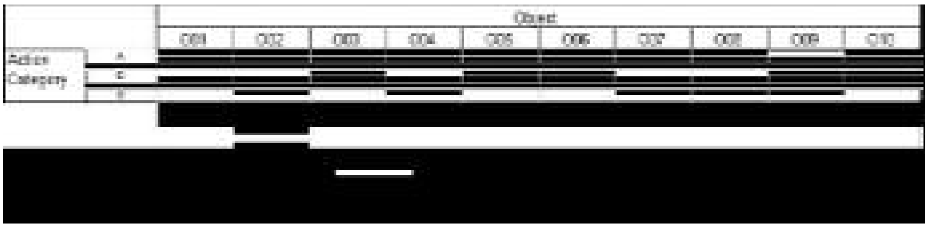


Fig 5: Observed and Optimum Action Category for all students across all objects

Hence one can infer that students prefer only one Action Category for a single object. However, for O04 and O07, the Choice of Action could have been driven by the tendency to achieve Optimum Efficiency. This is evident in comparing the Observed and Optimum Action Category as shown in the fig 5.

There will be no correlation between the sequence of Action Categories used by Operators to the sequence of Action Categories required for Optimum Efficiency across all objects

Chart 6 shows the sequence of Action Category for the average Observed Choice of Action and the Optimum Choice of Action across all objects. One can see that they correlate 3 times (O04, O07, O08) and do not correlate 7 times. This may not be sufficient enough to prove that there is no correlation between the Observed and the Optimum Action Category. However, this discrepancy could be due to the fact that the Action Category in the chart is taken as an Average Action Category for the entire student population. If one were to look at Action Category from the preceding two charts (chart 8 and 9) that it shows a high variation and is not normally distributed. In other words, the sequence of Observed and Optimum Action Categories may not correlate if the individual Action Categories were taken into account.

Conclusions

The findings of this preliminary study indicate that preference for a certain Action Category plays a role in the digital object construction than merely to accomplish Optimum Efficiency. This could be attributed to the fact that the ability to solve a design problem, besides other factors, depends on designer's personal problem solving approaches or method-of-making. Such method-of-making may be different from strategic knowledge of CAD usage (Bhavnani et al, 1996), generic design activity of analysis-synthesis (Mc Neill et al, 1999) or goal-driven/sensor-driven processes (Tang and Gero, 2000). Perhaps, the lack of understanding of these method-of-making could be one of the reasons why researchers have found no improvement in the performance of engineers and drafters using CAD system in comparison to non-CAD users. (Luczak, H.,1991; Majchrzak, A ,1990)

That personal problem solving strategies should be provided much attention, however, does not mean that every personal strategy needs to be accounted for. Design situations are varied and idiosyncratic that they cannot be understood in a definitive sense with the current methods of inquiry. However, it would be useful to acknowledge that architectural designers approach problems in a certain way (mainly based on individual style and habit) and these approaches may be different from how other disciplines approach it or how software developers envisage it.

The question is how one gets to discern these 'methods-of-making.' It would seem that one may have to look into design methods literature to get a better understanding of it. However, methods-of-making as referred in this study may not be accessible in design literature because they tend to occur at the level of interaction between designers and computers. In other words they occur at the level of 'theory-in-use' proposed by Argyris and Schon (1974). Theories in use are active decision making vehicles in the everyday world of practice and are different from 'espoused theories' (design principles, manifestos, normative theories etc.)i.e. Theories-in-use' help in translating espoused principles and values into explicit action. The congruence of theories-in-use and CAD strategic knowledge (Bhavnani et al,) may be an important criteria for generating a conducive interface for digital design.

It could also be useful to make a distinction between Optimal Efficiency and 'ease-in-use' as software developers tend to use these words synonymously. Just because students use fewer clicks may not mean that he/she is comfortable in using it. Neither does it mean that providing more powerful tools will resolve the problems faced in the usage of CAD tools. Shepard (1964) has observed that 'objective' optimality could be replaced by imposing subjective values for resolving conflicts so as to preserve the criterion of consistency with one's goals and values. The definition of optimality, as it is currently used in CAD literature, deals with a single criterion or goal while in the world of practice actual judgments and choices are typically based on multiple goals or criteria.

While personal problem solving strategies occur through habit, studies done by Sheerer (1963), suggest that habit could play both a negative and positive role. The negative role includes factors such as fixation, rigidity, resistance to change, tradition-orientation, fear of the unknown and so on. Positive habit, on the other hand, involves taking hints and cues that go beyond the information that is directly implied. Hence, CAAD tools need to be flexible in affording positive habits which become manifested as methods-of-making. It would be vital as to raise questions as to what makes designers use a certain tool or why certain tools are compatible to construct certain kinds of objects. Hence the focus of software development should be on determining what these methods-of-making are and how they are manifested in terms of preference for certain CAD tools. As this study has shown, students prefer certain tools for certain type of objects and sometimes use certain tool for any kind of objects.

In summary, at the core is a need to provide an effective interface to integrate CAD tools and design to suit the designer's personal problem solving strategies. Although CAD tools and design process have differing ends and objectives, one may not be able to expect total feasibility between the two. The best one could hope for are tools that have the ability to assist the design process cycle without overwhelming a designer's sense of order, flexible enough to allow for multiple usage, and of sufficient speed that maintains spontaneity and dynamism of design inquiry. Perhaps this may be a better measure of Optimum Efficiency in architectural design.

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