Digital Modeling in Design Foundation Coursework: An Exploratory Study of the Effectiveness of Conceptual Design Software

Stan Guidera and D. Scot MacPherson

Abstract

This paper presents the results of a study that was conducted to identify and document student perceptions of the effectiveness of computer modeling software introduced in a design foundations course that had previously utilized only conventional manually-produced representation techniques. Rather than attempt to utilize a production-oriented CAD program, this exploratory study investigated the use of alternative software applications developed by vendors specifically to function as conceptual design tools. The study was structured to identify areas of future investigation related to student perceptions of the effectiveness of the software in facilitating design exploration, the effectiveness and ease of use of various application features, and the extent to which prior CAD coursework was related to the perceived effectiveness of the software on design outcomes.

Introduction

The pervasiveness of computing in architectural practice poses challenges for design educators as faculty attempt to address the demands from practicing professionals for graduates who have greater competencies with digital technologies (Mitgang, 1999). The role of computing in architectural practice has evolved to CAD's becoming a baseline requirement for clients (Green, 2002). However, the emphasis of design education on developing design skills and promoting conceptual exploration has given rise to an ongoing debate among educators about the role of CAD and related digital tools in design curriculums. Further, it has been argued that the mandate of architectural education is to cultivate skills in life-long learning and that practice is where students develop technical knowledge (Karloff, 1996).

For educators attempting to integrate digital media in design courses, the criteria for selecting appropriate applications and tools for meeting course objectives is primarily subjective. More important, the literature on this topic commonly focuses on the success of students when using digital applications in design projects from the instructor's perspective, rather than from the novice designer's point of view. Therefore, research conducted to identify the extent to which students found software effective in the design process can provide insight into how digital design tools are best utilized by novice designers and assist design faculty in selecting appropriate digital applications to support intended course outcomes . In order to develop a basis for making such decisions, a study was conducted to begin to establish a knowledge base that could help identify and document student perceptions of the effectiveness of a software application.

To explore the use of an alternative to production-oriented CAD programs, this study was structured to investigate software applications developed specifically to function as conceptual design tools in introductory design courses. The study focused on student's perception related to the software effectiveness in facilitating design exploration, the effectiveness and ease of use of various application features, and the extent to which prior CAD skills were related to the perceived effectiveness of the software on design outcomes. Given the emphasis of these applications on ease of use, issues related to the influence of prior CAD skills on students perceptions were of particular interest.

All participants in the study were architecture majors enrolled in the second class of a two-course sequence covering concepts related to architectural representation and design foundations. Activities associated with the study took place during the final project of the course. The students were provided a project brief; they were required to use manual drawing and physical modeling in parallel with computer modeling using software developed for conceptual design in the development of their individual design solutions. Data was gathered using an instructor-developed survey administered at the end of the course. Instructor observation and statistical analysis of the survey data were used to develop an initial assessment of the perceived effectiveness of the software among students in the course.

Literature Review

Conceptual Design Processes and the Limitations of CAD

Sketching has traditionally been an integral activity in conceptual design. The importance of the sketch in the design process has been attributed to both its role in the iterative actions associated with conceptual design as well as to the contribution of ambiguity. Laseau (2000) discussed the importance of sketching as a means of facilitating "graphic thinking" in the design process, stating that graphic thinking facilitated a "communication loop" between the paper, the eye, the hand, and the brain, and that the potential of graphic thinking lies in the continuous cycling of information (p. 8). Goel (1995) referred to the sketch as a non-notational symbol system that promotes cognitive shifts from one proposed conceptual idea to other alternative concepts, a process he referred to as *lateral transformation*. He stated that "the general claim is that lateral transformations need to occur during the preliminary phase of design problem solving and that the density and ambiguity of the symbol system of sketching facilitate these cognitive operations" (p. 194) and cited the role of ambiguity in promoting lateral transformations or shifts between alternative concepts and solutions.

The visually ambiguous features of a sketch have been associated with the cognitive processes needed for design exploration. Won (2001) argued that during the drawing process designers demonstrate a "seeing behavior," in which they will concentrate on the figural properties of a , thus enabling the designer to "see the image as something else" (p. 324). Similarly, Suwa and Tversky (1997) proposed that sketches enable designers to "see unanticipated relations and features that suggest ways to refine and revise ideas" (p. 386).

In architectural design, CAD (computer-aided drafting or design) has become a primary medium for the development of construction drawings in professional practice. However, the inherent emphasis of CAD on precision has "accentuated the divide between explicit and implicit information" (Johnson, 1998). The pen or pencil sketch has retained its prominence as a design tool because it is exploratory rather than absolute, because it is inherently ambiguous, and because the degree to which the information it conveys is implied and subjective. Chastain, Kalay, and Peri (2002) argued that CAD is inherently unambiguous because its representations are explicit rather than implicit and therefore it is inappropriate for early stages of the design in which much of the effort is focused on conceptual characteristics.

The lack of ambiguity in computer-generated representations has lead to the view that computer applications are ineffective as design tools in the early stages of the design process where the priority is creativity (Van Elsas & Veergeest, 1998; Leglise, 1995; Suwa & Tvurskey, 1997). Jonson (2002) proposed that the strength of the freehand sketch lies in its economy of means (low cost) and immediacy (single-tool interface). He argued that a sketch carries less redundancy than a final drawing, stating that "when a sketch represents more than one possible interpretation, it could be seen as an explorative tool" (p. 248). This position directly contrasts with the purpose of a drafted image which has the intent of promoting the acceptance of a specific interpretationOutput generated with CAD applications is similarly viewed as lacking the ambiguity necessary to effectively promote the multiple interpretations and visual shifts in perception associated with design exploration in design processes (Won, 2001).

According to Bilda and Demirken (2003), CAD software works primarily on a "draw then modify" principle. From their research, they concluded that designers were more effective in using time, conceiving the problem, producing alternate solutions, and perceiving visual-spatial features and the organizational relations of a design in traditional rather than digital media during conceptual design. Other researchers have concluded that these limitations extend to other disciplines. In a study to investigate the comparison between traditional media and digital media among novice graphic designers, Stones and Cassidy (2007) concluded that working on a computer "seems not to be as effective, both in terms of fluency and variety, as drawing the form on paper" (p. 70).

The limitations of CAD in conceptual design also have been linked to the interface used. Designers typically use a mouse, a keyboard, and a 2D screen to interact with CAD systems. According to Ye, Campbell, Page, and Badni (2006), "the need to design and deploy new computer interfaces for the CAD system is evident, especially in support of conceptual design" (p.78).

3D Modeling and Digital Sketching Tools

According to Abdelhameed (2004), exploring design ideas through either two-dimensional or three-dimensional forms is the basis of design exploration and visual thinking during the design process. Whereas traditional media relied largely on sketching, 2D representations, and physical models for design exploration, computer-modeling tools have greatly expanded the ability of designers to develop 2D and 3D representations. For example, Simondetti (2002) investigated the implications of introducing computer-generated physical modeling in the early stages of the design process. He studied a design process that integrated sketching, computer modeling, and computer-generated physical modeling. According to Simondetti, this recursive process provided the following advantages: (1) understanding kinetic design, (2) understanding design involving complex geometry, and (3) understanding design at the interface with the human body.

Re-conceptualizing the Design Process to Optimize Digital Tools

Some researchers have suggested that the use of digital tools in conceptual design involves re-conceptualizing the design process itself in a way in which design with digital tools is perceived as involving an inherently different process. Abdelhameed (2004) argued that computing has "changed from being just a tool for drawing to being a medium through and by design which design is performed and solutions are generated" (p. 485). Bilda and Demirken (2003) proposed that "while digital media seems inconvenient for the conceptual design phase, this situation depends on the designer's designing habits" as well as limitations of the software (p. 49). Therefore, the argument that digital design tools are inappropriate for conceptual design may be reframed as an argument that the traditional design processes are mismatched to the digital media environment.

This re-conceptualization is reflected in arguments that propose that digital technologies be conceived as a design medium rather than a design tool. Oxman (2006) proposed that "interaction with computational design media requires of the designer a different form of input and level of formalization" and that "these distinctions between paper-based interaction with representations and digital interactions are significant both cognitively and theoretically" (p. 243). Sequin (2001) stated that the computer enabled artists to "to tackle structures of a level of complexity that clearly exceeded what an unassisted human could hope to achieve in the conceptual design phase as well as in the actual implementation of the final shape" (p. 345). He proposed that there was a "general trend to make computer based environments not simply a (still quite imperfect) emulation of real physical artist's tools, but to exploit some unique and novel services that only a computer can offer" (p. 347).

Conceptual Digital Design Environments

Conceptual design processes differ from other design phases such as design development and production, and typical digital design applications do not provide adequate support for all phases (Schodeck, Becthold, Griggs, Koa, & Steinberg, 2005). Effective conceptual design in a digital environment must rely on quick feedback from (digital) sketches, 3D modeling, and visualization. Conceptual modeling environments developed specifically for early design phases are "stand alone" sketching programs, geometric modelers, and renderers with an emphasis on initial shape generation that "employ line elements to facilitate the transition from traditional hand sketching to digital modeling" and often utilize interactive tablets for input in a manner similar to sketching on paper (Schodeck, Becthold, Griggs, Koa, & Steinberg, 2005, p. 193).According to Schodeck, Becthold, Griggs, Koa, & Steinberg (2005), "these environments must be simple to learn, easy to use, and not impose limits" (p. 192), This approach is consistent with proposals that suggest that conceptual digital design environments should emulate or parallel manual sketching (Bilda & Demirkan, 2003; Jonson, 2002).

Summary

The literature suggests that digital design tools that were developed specifically for conceptual design may provide substantive benefits over attempts to utilize conventional CAD in early design phases. In addition to ease of use and learning, stand-alone sketching programs provide the benefits of a nontraditional medium for design exploration supported by parallels with more traditional media. Consequently, this study was developed to investigate how a conceptual digital design application could be utilized by novice designers in an academic setting.

Methodology

As an exploratory study, the research methodology was structured to document student perceptions of the effectiveness of conceptual design software effectiveness in a design foundations course and also to investigate approaches to conducting the research and analysis. The study was structured to address the following research questions:

1. Does CAD experience influence the perceived effectiveness and use of the software? The null hypothesis for research question one was that prior CAD experience does not influence the perceived effectiveness and use of the software.

2. To what extent was the use of this software application perceived to influence the design process? The null hypothesis for research question two was that \the software was not perceived to influence the design process.

3. What software tools/features/operations were perceived as effective and/or easy to use?

Research Design

The research design for this study was structured to utilize a mixed methodology; quantitative data collected with a survey instrument was supported by supplemental data collection by the class instructor in the form of instructor observations and logs. It was the intention of the researchers that the instructor's observations would be used to provide insights into the survey responses and analysis of the quantitative data collected with the survey instrument.

Population & Sample

The study participants were students enrolled in the second course of the two-course architectural representation and design foundations sequence of the four-year Bachelor of Science program at a public university. This required class was offered once per academic year, open only to second-year architecture majors. The study population was a convenience sample; therefore, there was no attempt to randomly select participants from a larger group as the students were selected based on their enrollment in a specific course which would have required prior coursework involving manual drawings and physical models. This decision was based on the conclusion that students had to some extent developed skills with design concepts, composition, drafting, and model building, which would provide a reference for their perception of the software effectiveness. Additionally, the course typically included a mixture of students with CAD skills and those without, therefore providing the potential for responding to the research question related to the influence of CAD experience.

Instrumentation

A survey was developed by the researchers to collect data related to the research questions. .Instructor's observations were documented during the duration of the class activity. The survey utilized a series of Likert questions which documented the participants' experiences using the software in the study activities. However, it should be noted that the instrument was not pilot tested nor were reliability checks conducted for the Likert items. The questions were used to collect data on the participants' CAD experience, and the influence of CAD skills in learning and using the software. The questions also were used to collect data on the participants' perceived effectiveness of specific software features, tools, and operations, as well on the participants' perceptions of the ease of use of various features and operations. Additional questions were used to collect data on the participants' perceptions of the influence that this software had on their design process, and of the effectiveness of the software as a design and communication tool.

The majority of the survey questions were based on a five-point rating scale. For questions intended to collect data on perceived effectiveness, the responses were "very effective" (5), "effective" (4), "neutral" (3), "ineffective" (2), and "very ineffective" (1). For questions intended to collect data on perceived ease-of-use, the responses were "very easy" (5), "easy" (4), "neutral" (3), "difficult" (2), and "very difficult" (1). Data was also collected for these categories with questions requiring a response of "strongly agree" (5), "agree" (4), "neutral" (3), "disagree" (2), or "strongly disagree" (1).

Statistical Analyses

Statistical analyses were employed to answer the research questions for the study. The use of Likert-style questions limited the quantitative analysis to tests appropriate for ordinal data. To test for significant ratings above or below neutral, a single-sample t test with a test value of 3.00 was used to analyze the mean of the responses to each question. The confidence interval used for all tests and analysis was .95 (a =.05).

Nonparametric correlation tests were used to analyze responses for all variables. Despite the inherent limitations associated with the use of nonparametric tests with the small size of the study population and assumption that the data was normally distributed, it was anticipated that cross-tab and correlation test could provide additional insight into the t-test results. Additionally, analysis using crosstab and correlation tests in the exploratory study could assist in evaluating the structure of the survey questions and identifying minimum study population sizes required for further research.

For analysis of CAD experience and skill level three primary variables were used. First, the participants were asked to identify the number of CAD courses they had taken in both high school and college. This provided a measure that was to some degree objective. Second, they were asked to indicate their perception of their CAD proficiency using a Likert-item with a ranking of very proficient, proficient, moderate, minimal, or no experience. Lastly, the participants were also asked to indicate the extent to which they perceived their CAD skills to be useful in using the software on a Likert scale ranging from 1, not at all useful, to 5, very useful. Students with no prior CAD skills were excluded from the statistical analysis.

To determine the extent that the software was perceived to influence the design process, the survey included questions which asked the participants to rate the extent to which they perceived the use of the software had a positive effect on design outcomes and had a positive effect on design communication. Participants were also asked to rate the extent they perceived that the use of the software influenced their use of forms in the model and to rate the extent to which they believed they were able to create all the forms they intended to use in their model.

To determine the perceived effectiveness of specific software features and operations, participants were asked to rate the effectiveness of the software relative to a variety of features and operations, including:

1. The use of the workspace and grid snap
2. The use of object handles or grips to reshape or resize an object
3. The use of object handles or grips to reposition an object
4. The ability to add shadows to the display
5. The ability to change to plan or elevation views

The ratings ranged from very effective (5), to very ineffective (1), with a rating of 3 indicating neutral. An additional response of "I did not use this feature" was also provided. These responses were excluded from the data analysis. Other operations were similarly rated for ease of use using a five-point ranking of five for "very easy" to one for "very difficult," with a ranking of 3 indicating neutral. The operations were:

1. Creating rectangular/box-shaped volumes
2. Creating curvilinear-shaped objects
3. Creating objects with accurate and/or specific dimensions
4. Using the grid tools to create objects at specific locations
5. Using the grid tools to create objects with specific dimension
6. Accurately re-positioning objects and forms in space
7. Accurately placing/positioning objects and forms relative to other objects and/or forms
8. Accurately placing/positioning objects at varying elevations or heights.

Additionally, other operations were rated for perceived effectiveness using a five-point ranking of five for "strongly agree" that the operation was effective to one for "strongly disagree" that the operation was effective, with a ranking of three indicating neutral. The operations were:

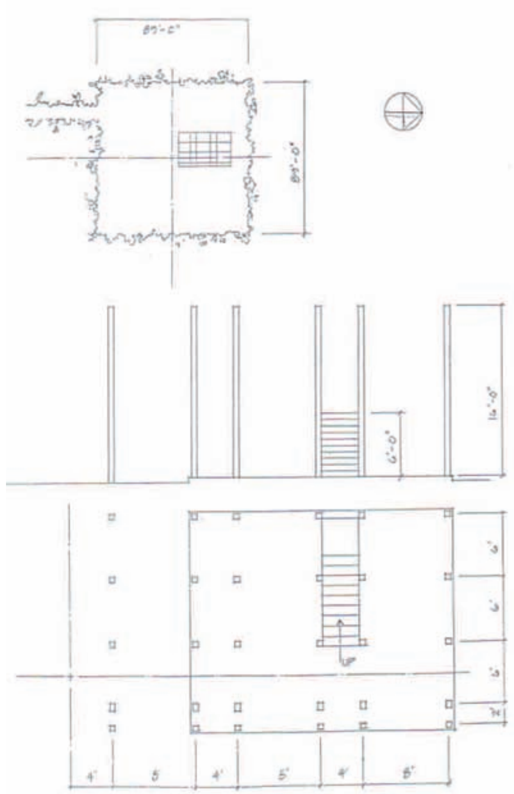
1. Interface/commands facilitated precise positioning/placement of objects.
2. Interface/commands facilitated precise re-positioning/movement of objects.

Data Collection Procedures

The researchers utilized a design project in a second-year, first-semester design foundations course as the source for data collection related to the research questions. The project was selected because it had sufficient duration to enable the faculty to allocate time to introducing the software as part of the course activities. The project brief required students to design a structure that "was enclosed but not enclosed" within a predefined context that included a pre-existing slab and column grid located in a flat rectangular open space surrounded on all four sides with dense trees. This was intended to provide the students with a pre-existing ordering system (the column grid) and a well-defined site perimeter (the wooded perimeter). The pre-existing components were to be integrated into their design (Figure 1).

Initial class activities were directed towards exploring responses to the project brief and included manual sketching and development of physical models. As the students continued to use sketching and physical modeling, class time was allocated to introduce them to Autodesk's Architectural Studio software, a conceptual design application that included a variety of 3-dimensional modeling tools. The software modeling tools included the capability to create 3D shapes using primitive objects such as cubes, spheres, and cylinders, and objects that could be created using free-form spline-based sketching tools. The software included a grid-snap feature (workspace grid) and the capability to easily create a user-defined grid on object-surfaces. The interface incorporated references to conventional drawing and drafting media and techniques. The drawing tools included both free-hand sketching emulation as well as basic 2D geometry commands used to create lines and

Figure 1. Study Project Handout



shapes such as arcs and rectangles. This enabled students to utilize practices that had been promoted in class, including techniques such as overlaying layers of tracing paper and icon-based drawing tools with a functionality that at least to some extent paralleled pencil and felt markers used in the course. The use of interface elements that parallel conventional design representation techniques and processes is aligned with the parameters for digital conceptual design applications proposed by Bilda and Demirkan (2003). All students used identical computers configured with a mouse as the input device.

Two software training sessions were conducted over the duration of the assignment. During and after the initial session, students were required to work with the software independently of the course project in order to produce freeform compositions which incorporated both rectangular and curvilinear forms. After the second session, the students were asked to experiment by re-creating their course projects and developing them further using the software tools. For their final project submission, students were instructed they could utilize images generated from the computer model to supplement to their physical models and manually drafted documentation.

The Survey was administered at the end of the primary design activities for the project, but prior to the student's final presentation. This enabled students to have sufficient experience with the software to provide informed responses to the questions on software features as well as their overall experience in using the application as a design tool. Although the survey was administered during class time, students were informed that participation in the study was voluntary.

Supplemental data was collected using logs or journals of the instructors' observations during training sessions and also during nonstructured studio activities. These writings primarily focused on documenting commonly used features, commonly used command or software operation sequences, and aspects of software operations that students found to be more time-consuming or difficult.

Findings

Assumptions and Limitations

Because of the small study population size, the extent to which the findings can be generalized is inherently limited, and, since the study was structured around the operation and features of one software application, the generalization of conclusions to other applications is limited as well. It should be noted that any conclusions related to non parametric tests conducted on responses associated with prior CAD skills, an area of interest in this study, was further limited because students with no prior CAD skills were excluded from the statistical analysis, further reducing the sample size.

The study population was also a convenience sample in that the students were selected in terms based on their status as novice designers in the architecture program at a specific institution, and their access to labs with the required software installed. Therefore, it could not be assured that this sample was an accurate representation of some larger group or population. Additionally, the use of Likert-scale questions assumed that data was normally distributed and that all participants utilized a similar interpretation of the available categories and terminologies when responding to the questions. It was also assumed that there was only limited influence of the Hawthorne effect (Brannigan & Zwerman, 2001), which assumes that responses to the survey items were influenced by participation in the study. Lastly, as the instructor's observations were intended to be supplemental to the primary data collection using the survey instrument, these observations were assumed to be anecdotal in the absence of a data-collection structure which supported more rigorous qualitative analysis.

Figure 2. Initial Experimentation (1st Session): Perspective and Plan View

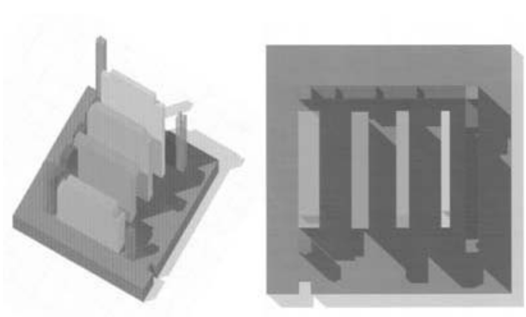
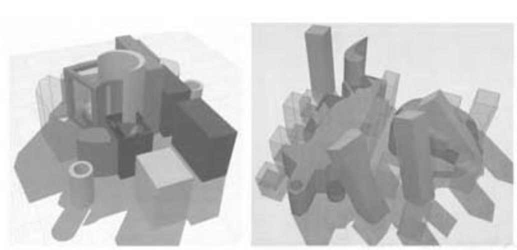


Figure 3. Software Experimentation (2nd Session)



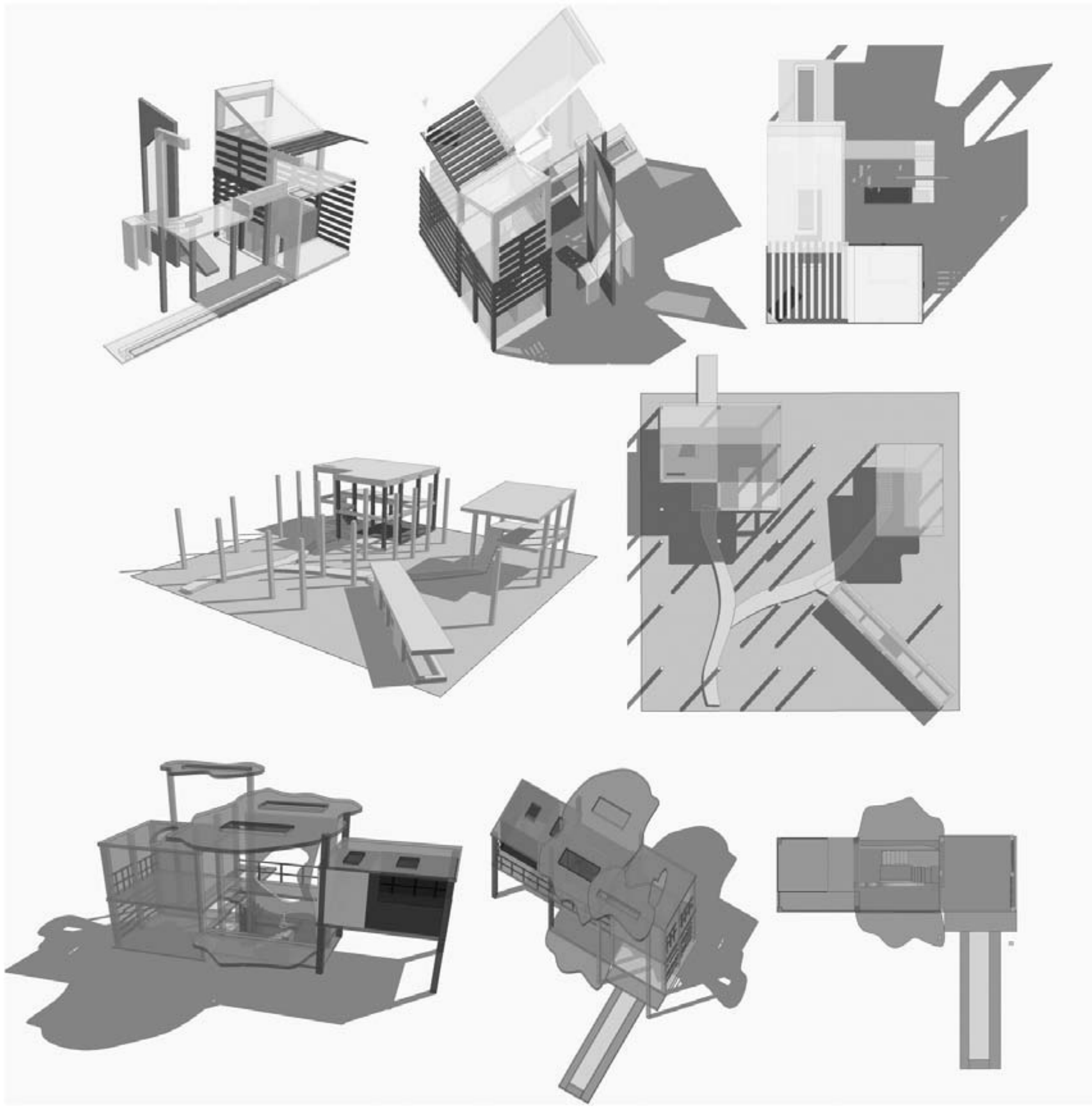
Instructor Observations

All participants in the study appeared to be able to navigate the menu selections and create basic geometry with little difficulty. The primary modeling approach was to place objects, initially using only rectangular-shaped volumes, using the default predefined object height (10 units) and then manipulate the geometry to the desired height, as well as length and width. In the initial explorations, students primarily utilized manipulations of height in the z direction with very limited manipulation of geometry off-axis relative to x, y, and z axis (Figure 2). Students appeared to utilize the ability to switch between orthographic and perspective views and also to utilize shadows and the ability to manipulate object transparency. Some students had difficulty with the zoom features when experimenting with "field of view" options. Students would "get stuck" in perspective view after incorrectly performing zoom operations that produced a very wide field of view, resulting in a distorted on-screen view of their geometry. The students did not utilize software features that paralleled manual drafting, including the sketching tools such as multiple pens for variations in line weight and style. Additionally, no students were observed using sketch overlays. During the second training session more experimentation with curved forms and off-axis geometry was observed (Figure 3). The use of the ground plane grid and grid-snap tools increased, as did attempts to use more precision in creating 3D geometry, a factor largely associated with attempts to begin to use the software to build a computer model of their project. For the final project submission, most students included supplemental computer images when presenting their work. It was noted that nearly all submissions incorporated shadows and included plan or elevation views in the output (Figure 4).

Data Analysis

A total of 24 students were in the class, and 23 participants completed the survey (N = 23). 15 participants (65.2%) indicated they previously had taken at least one CAD class. Of these, seven (30.4%) had taken one class, three had taken two classes, and one had taken three or more classes. The participants self-identified skill level was documented as follows: seven indicated that they had no CAD skills, four

Figure 4. Final Project submissions.



indicated their CAD skills were minimal, 10 indicated their CAD skills were moderate, and one indicated proficiency with CAD. These results indicate consistency between reported CAD skills and number of CAD courses. One participant did not respond to these two questions, but did submit the survey and respond to the other questions on the survey. These responses are documented in Table 1 and Table 2.

One sample t-tests yielded several statistically significant results. T-test's for the variables rating overall ease-of-use and overall ability to learn the software found a positive mean difference of .64 (p = .002) and 1.05 (p = .000) respectively. For specific tools and features, statistically significant ratings were found for the effectiveness of workspace grid settings (p = .000), the effectiveness of handles or grip effectiveness to re-size objects (p =.000), the effectiveness of handles or grip to re-position objects (p = .000), the ability to rotate objects (p = .001), , the ability to add shadows (p = .000), the ability to change to plan or elevation views (p = .000), and creating rectangular volumes (p = .000). T-tests found that mean difference of the rating for the perception that the software influenced the forms used in the participants designs was also significant at the .01 level (p = .000). Additionally, no significant mean difference for the perception that the participants were able to create all the forms they needed (p = .576),

Table 1 Respondent CAD Class Experience (N = 23)

No prior CAD classes	One prior CAD class	Two prior CAD classes	Three or more prior CAD classes	No Response
7	11	3	1	1

Table 2 Respondent CAD skill self-assessment (N = 23)

No CAD skills	CAD skills: Minimal	CAD skills: Moderate	CAD skills: Proficient	No Response
7	**4**	**10**	**1**	**1**

suggesting a largely neutral rating for this variable. Features and operations that generally related to accuracy and precision were found to be not significant or in some cases to have negative mean differences, indicating an unfavorable rating.

Although the small study population limited the interpretation of the results of nonparametric tests, the analysis were conducted in an attempt to identify areas in which both the study and the survey instrument could be improved. Cross-tab analysis of the responses yielded statistically significant relationships between the perceived usefulness of previous CAD skills and the ease-of-use of the software to modify objects to specific dimensions (-.505, p = .002), and ease-of-use of the grid tools to create objects with specific dimensions (-.359, p = .036). A significant relationship was found between perceived CAD skill level and ease-of-use of the software to create curved forms (.419, p = .035). Similarly, analysis using bivariate correlations (Kendall tau b) yielded a significant negative correlation between the perceived usefulness of previous CAD skills and the ease-of-use of the software to modify objects to specific dimensions (-.505, p = .016), and a positive correlation for ease-of-use of the software to create curved forms (.419, p = .047). Bi-variate correlation analysis yielded a significant negative correlation between number of CAD classes and the ease of use of the software in placement and positioning objects (-.588, p = .014).

Cross-tab analysis yielded statistically significant relationships between perceptions that the software had a positive effect on design outcomes and perceived overall software ease-of-use (.463, p = .006), the effectiveness of the software for facilitating students in creating forms and shapes needed for their designs (.518, p = .009), and the effectiveness of the software for communicating their design (.452, p = .030). Bivariate correlation analysis found statistically significant relationships between perceptions that the software was positive for communicating their final project (.452, p = .024), and the effectiveness of the software tools and operations for creating all the forms they intended for their design (.518, p = .010). When considering specific tools and features/operations, bivariate correlations were found between perceptions that the software had a positive effect on design outcomes and workspace and grid setting features (.523, p = .009), the effectiveness of object-handles or grips to re-size objects (.678, p = .001), the effectiveness of the interface and commands for precision in object placement/positioning (.435, p = .026), and the effectiveness of the interface and commands for precision in object relocation/re-positioning (.631, p = .001).

Conclusions and Recommendations

Analysis of the responses suggested for this group of students CAD skills, did not appear to have a positive influence on the use and operation of the software, thus resulting in the null hypothesis for research question one not being rejected. It could be assumed that for these students' experience using CAD software, which would typically include commands that employed a high degree of accuracy and precision, was not easily translated to the modeling tasks using this type of application. Therefore, the data and observations in this exploratory study suggested that CAD skills may not be essential to the introduction of this type of application in this course and that the introduction earlier in the curriculum, at which time several students may have not had any CAD training or experience, may actually be favorable. Such a conclusion cannot be generalized to other students or curriculum because of the use of a convenience sample and a small study population in this exploratory study.

The responses suggested participants seemed to view the software positively influencing the project design and communication, thus rejecting the null hypothesis for research question two. Even though it is necessary to consider the limitations of nonparametric tests in the context of this study, the positive correlations found between the perception that the software had a positive effect on design and the perceived ability to create all forms needed for the design indicated this study population likely perceived the software most effective were those who were most successful at developing the competencies they needed to model their projects.

The students' responses suggest that the software was to some extent perceived as easy to use and learn, as indicated by the ratings for these variables. However, these exploratory findings also suggested that on the whole the students were neutral in their rating of their ability to develop the required competencies; anthey also may have believed the software did influence their designs. The data does suggest that the participants found certain tools and features more effective than others. For example, the survey responses and the instructor's observations suggested that the novice designers in this course with no CAD experience had the greatest difficulty in creating computer models with precise dimensions and in creating curvilinear forms. Arguably, since creating curvilinear forms involves more complicated processes than creating rectilinear forms, it could be assumed that curved forms required greater technical competencies because this is the single variable where the positive influence of CAD skills was most evident. This result suggests that for inexperienced students faculty may still find it necessary for allocation of time to learning activities specifically associated with dimensional precision and more complex object modeling tasks are recommended in order to minimize the extent these features would be perceived as obstacles to design exploration.

Inventory of recommended features

The combination of the data sources, classroom observations, and student comments suggested that some 3D modeling tools and features were perceived to be either more effective or easier to use than others. Additionally, the extent of use of several tools and features also suggested preferences among the participants.. Therefore, the study suggests that educators considering integrating digital modeling tools should consider applications that include the features described in the following paragraphs:

Direct Geometry Manipulation

The data indicated that the novice designers in the study preferred to directly manipulate the geometry, as evidenced by the statistically significant effectiveness ratings for the operation of handles and grips. This was supported by instructors' observations, specifically in relation to the commonly observed technique of first creating an object and then modifying and manipulating the object to the desired dimension and location.

Grid Tools

The data also indicated that grid tools on both objects and workplace were utilized and considered effective. It is likely that the grid-snap tools provided a means by which students could create and align objects with precision without relying on typing in specific coordinates. However, it should be noted that although not statistically significant, correlation tests found negative correlation between perceived CAD skills, number of CAD classes, and the perceived usefulness of CAD skills and ratings for all questions related to effectiveness of the grid and workspace tools. Though the study did not document perceptions of the effectiveness and ease-of-use of coordinate entry, alternative methods of placement and manipulation may be considered an important feature.

Orthographic Views

It was observed that the ability to easily change between perspective and orthographic views was utilized extensively by the participants. This feature was also used for generating output at various stages during the assignment. One-sample t-tests found the mean difference of the rating for the effectiveness of the ability to change to orthographic views was significant at the .01 level ($p = .000$). The data also suggested an association between the perceived effectiveness of this feature and the ability to learn to use the software (.455, $p = .006$). While the combination of observation, output, and data analysis suggested that this feature is effective, utilizing orthographic views in a digital design tool can also serve to make connections with related coursework and course activities that employ drafting techniques and other similar terminology.

Shadow Display

The data suggested that the display-shadow option was widely utilized in the assignment for output generated during the training sessions and for display of the participant's solutions to the design problem. One-sample t-tests found the mean difference of the rating for the effectiveness of the ability to use shadows was significant at the .01 level ($p = .000$). The perceived effectiveness of the ability to use shadows was significantly correlated with perceived ability to learn the software (.360. $p = .025$) and with the perceived effectiveness of the software in accurately placing objects at varying elevations

(.555, p = .000). The study did not yield any data that suggested an explanation and no assumptions can be directly inferred from the documentation. However, given the extensive use of shadows observed suggested that this feature was utilized to an extent that it may be an important option in any application used in a design course.

Survey Instrument and Methodology Modifications

The results of this exploratory study suggest several adjustments in methodology and in the survey instrument. In future studies a minimum study population size of approximately 48 would be more appropriate in order to assure minimum cell counts required for many nonparametric tests. Along with the increased population size, analysis should also include distribution tests to determine the extent to which assumptions of normal distributions can be made to more effectively support any interpretations and conclusions. Analysis of responses that used t-tests should also be expanded. Since a one-sample median test allows for testing to determine if a sample median differs significantly from a hypothesized value, future studies should consider median t-tests in addition to mean t-tests in order to more effectively support conclusions.

Several recommendations for modifications to the survey instrument arose from the analysis related to the nonparametric statistical analysis used in this study. Most of these modifications were related to the size of the study population. For nonparametric tests, restructuring the Likert questions from five items to three would more likely yield tests results that met the minimum number of responses required in future studies with small populations. Additionally, the instrument used in this exploratory study was structured to collect data using t-tests and nonparametric tests. Questions should be restructured to collect data that can be more clearly associated with a specific statistical test associated with a specific research question rather than attempting to the somewhat uniform approach to all research questions and tests that was employed in this study. Lastly, since the role of CAD experience was an area of interest in this study, in future studies the instrument should be modified to collect additional demographic data related to prior CAD experience in order to provide a more thorough description of the participants' skill sets. In larger studies, this change could assist in identifying similarities, differences, and subcategories among the students with CAD experience in order to draw more informed conclusions related to comparisons between students with CAD experience and those without.

Areas for Further Research

The study findings suggest that digital design tools can be integrated in such courses without CAD skills or related technical knowledge as a prerequisite, and that these applications can serve to facilitate design exploration and communication for novice designers. However, additional empirical research into the perceived effectiveness of conceptual design software in design foundations courses is necessary to substantiate the findings of this exploratory study. The initial analysis provides insight into the influence of some of the variables that could affect student performance and success in meeting intended studio learning outcomes. Specifically, investigations with larger populations that compare alternative software applications could assist faculty in identifying the features in common among the applications that proved to be perceived as most effective by users. Expanding the investigation to include multiple disciplines may provide insight into the fields and areas of study in which these applications held potential for enhancing outcomes. Additionally, given the data and the instructors' observations, the findings related to use of features such as direct geometry manipulation suggest investigations of the role of alternative input devices may be appropriate as well in order to identify ways faculty could optimize digital conceptual design tools in academic environments.

Dr. Stan G. Guidera is an Architect and Associate Professor in the Department of Architecture & Environmental Design at Bowling Green State University, Ohio, and a member of Alpha Gamma Chapter of Epsilon Pi Tau.

Scot McPherson is a Lecturer in the Department of Architecture and Environmental Design at Bowling Green State University, Ohio.

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