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Assessing the use of digital sketching and conceptual design software in first-year architectural design studio

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Computer aided design software has supplanted traditional drafting in architectural practice as well as in most related design and engineering disciplines. However, both educators as well as many design practitioners continue to rely on traditional sketching during conceptual design. This has been attributed to the perception that CAD applications are ineffective as a medium for design exploration and that CAD has been perceived as a medium intended for production that is difficult to use in the early stages of the design process where the priority is creativity rather than precision [1, 2, 3].

New applications intended to function specifically for digital sketching and conceptual design environment are now available. While the potential for conceptual design software to provide a link between conceptual design stages of the design process and the CAD applications used for production documents may be particularly relevant for professionals, it is increasingly relevant to educators as well. Criticism directed towards architecture schools for failing to provide sufficient technical education and preparation for the realities of practice [4] is reflected in the ongoing reliance of many architecture educators on traditional media. However, arguments that computers have the potential to radically alter the process of architectural design and that digital-based design will replace traditional modes of architectural design [5] suggest that conceptual design software may provide an opportunity for educators to address this criticism and enhance student preparation for practice.

Sketching and the Design Process

The relationship between sketching and conceptual design has been attributed to characteristics and activities associated with both the creation and interpretation of sketches. Jonson [6] proposed that the strength of the freehand sketch lies in its economy of means (low cost), immediacy (single tool interface), and ease of low-level correction and revision. Additionally, 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" which directly contrasts with the purpose of a drafted image which has the intent of promoting the acceptance of a specific interpretation (p. 248). According to Chastain, Kalay, and Peri [7], sketches are "semantically open". They proposed that "the abstraction inherent in a design sketch serves to aid the analogous reasoning used early in the design task"

(p. 240) and that "a design task is abstract; typically conceptual; it is more concerned with exploration than with describing a solution and implies more than it defines" (p. 239).

A key characteristic of sketches that promotes the abstraction and re-interpretation is the ambiguity inherent in manually-created conceptual drawings. Sketches and freehand vignettes created in conceptual design are intentionally ambiguous, a key characteristic that fosters cognitive processes needed for exploration. Won [8] proposed that during the drawing process designers demonstrate a "seeing behavior" in which they will concentrate on the figural properties of a sketch. He stated that as a result the designer may "see the image as something else" (p. 324) and added that the shift of 'seeing' to 'seeing as' stimulates imaging. Similarly, Suwa and Tversky [9] proposed that as designers inspect sketches "they see unanticipated relations and features that suggest ways to refine and revise ideas" (p. 386).

Goel [10] proposed that sketching 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/or solutions. These positions suggest that the function of the sketch in design is to provide a mechanism for the active cycling of ideas rather than to merely document them. Laseau [11] referred to this process as graphic thinking that promotes a "continuous cycling of information-laden images from paper to eye to brain to hand and back to paper".

Ambiguity associated with sketching arises from multiple factors. Variations in the width and precision influence are among the characteristics that influence interpretation of sketched markings. Inherently, the markings that make up a sketch are imprecise: width and texture of the lines vary in width and the edges vary in definition. It is the lack of specificity that contrasts sketch markings with conventional CAD markings. Preliminary sketches using traditional media consist of strokes that are rough in contrast to the "concrete" character of computer drawn lines [8]. Arguably, CAD applications have been limited in providing tools that meet these parameters. AutoCAD includes a sketch command that attempts to emulate the looseness of freehand drawing. However, this command produces a series of lines that produces images with a limited degree of the ambiguity that is required for multiple interpretations associated with effective use of sketching. Scanning sketches and using raster-to-vector conversion software to convert scanned sketches to vector data compatible with CAD applications provides another option for integrating preliminary conceptual drawings with CAD. However, this process lacks both immediacy and low-level interaction of sketching and is limited in the extent to which it supports a cyclical design process that produces lateral transformations.

Van Elsas and Vergeest [2] suggested that 3-dimensional modeling for conceptual design could provide an alternative to sketching. Applications such as Autodesk's Architectural Desktop are examples of commercially available software that facilitates a workflow process that starts with conceptual mass modeling tools used to create 3D shapes that can be developed into a detailed computer model that is then used to generating production documents. While most CAD applications provide 3D visualization capabilities, studies have found that experienced designers often do not utilize these features. This has been attributed to the more developed ability of experienced designers to think and visualize in three dimensions as well to the influence of design habits developed over the course of their education and careers which lead them to rely more on 2-dimensional representations [12].

Despite the ubiquitous presence of CAD technology, designers continue to find aspects of traditional sketch media that contribute to conceptual thinking lacking in CAD interfaces and ultimately in the representations produced with CAD, either on screen or in printed form. As noted previously, the ineffectiveness of digital media in conceptual design has been attributed to characteristics of the markings as well. However, digital media has not been flexible enough to facilitate "doodling" or diagramming [12]. Additionally computer-based conceptual design practices should also to some extent emulate or parallel manual sketching [6, 12] rather than CAD practices. According to Bilda and Demirkan [12] in addition to providing tools for diagrammatic representations, conceptual design software should offer tools to emulate other manual sketching actions such as a semi-transparent copying activity analogous to tracing paper.

Therefore, three conditions are necessary in order for conceptual design with digital tools to be effective. First, they must to some extent function in a way that is parallel or analogous to the processes and practices associated with traditional conceptual design. Secondly, the shapes and line-work created with the digital tools must have the capability of being perceived as indeterminate and ambiguous. Lastly, they must address at least two of the strengths of free hand sketching proposed by Jonson [6] : immediacy (single tool interface) and ease of low-level correction and revision, in order to facilitate the cycling of ideas.

Many applications that have been marketed as design or "sketch" tools actually functioned more as low-cost entry-level CAD programs rather than as a design tool as implied in their name. In contrast, new applications such as Sketchpad and Architectural Studio have been developed as stand-alone applications with features and interfaces that attempt to facilitate ease of use by designers lacking CAD skills. In addition to freehand sketching tools, these applications also incorporate 2D geometry commands for creating shapes such as lines, arcs, and rectangles as well as three dimensional modeling capabilities. More importantly, the transition from traditional media and representation techniques to digital media may be further enhanced by the ways in which these applications utilize references to conventional drawing media.

Case study

In order to assess the potential for utilizing conceptual design software in academic coursework, faculty teaching an introductory architectural design and drafting course conducted a study intended to assess the perceived effectiveness of the software. The content of the course covered manual drafting techniques and conventions, taught through a sequence of orthographic drawing exercises. The exercises were followed by a design project structured to require students to synthesize course material as well as to introduce them to design problems and the design process. The academic majors declared by students enrolled in the course included architecture, interior design, construction, education, and mechanical design.

The course instructors selected Autodesk Architectural Studio software for the study. The instructors determined it's features met the three conditions identified as necessary for conceptual design software to be effective. These features included drawing tools that emulated, both with icons and operation, those associated with traditional sketching such as pencils, markers, and techniques such as overlaying layers of tracing paper (figure 1). It was anticipated that these features could enable students to more effectively utilize manual drafting practices that had been promoted in class. The sketching and drawings tools emulated the wide variety of conventional marking devices typically used in manual sketching and the drawing tools included both freehand sketching emulation as well as basic 2D geometry commands used to easily create shapes such as lines, arcs, and rectangles. Additionally, the 3-dimensional modeling tools afforded an opportunity for at least limited observations of the utilization of digital modeling tools by novice designers.

Study Methodology

The study utilized a mixed methodology combining both qualitative and quantitative data collection techniques and was divided into two distinct components. The activities in the first phase took place in a single session. The participants were asked to use the computer sketching and modeling tools for tasks that paralleled those in a class exercise they had completed earlier in the course using traditional media. In the original class exercise, students were required to design a composition with a fixed number of cubic shapes, document the design with orthographic drawings, and build a physical model. The exercise emphasized the use of sketches during the design process. In the study exercise, students were required to develop a new solution to the same problem using the software sketch tools to develop their designs, the 2D geometry drawing tools to create orthographic drawings, and 3D modeling tools to create a computer model.

The use of software features and tools was monitored and documented. After completing the required tasks, the students were asked to respond to a series of open-ended questions regarding their perceptions of the software's features, tools, and ease of use. In addition to using the student responses to gain insight into what components of the software were perceived to be most effective, issues raised in the first phase of the study were used to refine the survey questions used to collect data for quantitative analysis in the second phase of the study.

Phase-two of the study required a different group of students to utilize the software during the preliminary phase of the design studio project and took place over three two-hour class sessions. They were also required to use the 3D modeling tools to create images to be used in a presentation of their final design solution. Their progress was monitored and documented. Upon completion of the modeling activities, a survey designed to assess the student's perceptions regarding the effectiveness of the software in comparison with traditional media was administered. The survey was used to gather demographic data that included academic major as well as the number of manual drafting courses participants had taken in high school and college, including the course in which they were currently enrolled. Similarly, participants were asked to identify the number of CAD courses they had taken in high school and college and to indicate if they had experience using CAD software to create 3D models. The survey also asked students to categorize the extent of their freehand sketching experience on a scale of none, minimal, moderate or extensive and to categorize their perception of their proficiency with CAD software on a scale of none, low, moderate, and high. The data related to CAD experience was added as a result of comments made by students in the first phase of the study.

A series of nine likert-scale questions were used to collect data on the participant's experiences using the software in the study activities. The questions asked students to indicate their perceptions relative to four factors: the overall ease of use of the software, the extent to which the software operation was analogous to manual drafting practices they had learned, the effectiveness of the sketching tools, and the effectiveness of the 3D modeling tools. Four questions specifically addressed participant's perceptions of the effectiveness of the 3D modeling features relative to physical modeling tasks, asking them to rate the ease of use of the software 3D modeling relative to building physical models and to rate the effectiveness of the computer model relative to physical models in helping them understand their design. The responses to these likert-scale questions were strongly agree, agree, neutral, disagree, and strongly disagree. A ninth likert-scale question, developed in response to the activities in the first phase of the study, asked students to rate their perceptions of the effectiveness of the software sketching tools relative to sketching manually in developing their designs. The responses to these likert-scale questions were: considerably more effective, more effective, neutral, less effect, and considerably less effective. Lastly, after completing the survey, students were asked to provide a brief narrative that described their overall experience in both learning and using the software, and to identify the features they found most useful. The responses to this question were used to gain insight into the results of the quantitative analysis.

The limited size of the study and the data collected using likert-scale questions limited the quantitative analysis to tests appropriate for ordinal data. Descriptive statistics were used to determine frequency distributions. Non-parametric correlation tests using Spearman's Rho were used to analyze likert-scale responses relative to the demographic data and course-experience questions. One-way Analysis of Variance was used to test for between-group differences. A confidence interval of .95 was used in all tests. The software used for data analysis was SPSS version10.

Phase One Observations

The data collected in the first phase of the study were primarily qualitative. The instructors noted the comments made by the participants as they learned to use the software. Instructors also documented their observations of how the software was used in the exercises. Additionally, the responses to open ended questions posed to the participants at the end of the study session were documented.

While monitoring student activities during the study session, the instructor observations noted that the students appeared to have no difficulties in using the freehand sketching tools. However, it was also noted that the participants utilized the 2D geometry drawings tools more than the sketch tools even during conceptual design. This observation led to the revision of one of the survey questions to specifically ask participants about their perceived effectiveness of the software sketching tools relative to manual sketching.

The responses to questions posed to the students after the session activities were completed were consistent. The participants described the software as easy to use and rated the software as somewhat more effective" than manual sketching. The participants also indicated that the 3D modeling features were easy to use. A student who had no previous CAD experience referred to the user-friendliness of the software and stated "the software was surprisingly easy to use" which further indicated that it would be appropriate for students with either limited or no CAD experience to use the software in the design-project phase of the study.

However, another student with CAD experience also responded that the software was easy to use but suggested that the lack of precision relative to CAD applications and the inability to manipulate multiple objects was an obstacle to the use of the software in more advanced classes. Based on these comments, the survey instrument was modified to collect additional data on the participant's CAD experience by asking those who had experience with CAD to rate their CAD proficiency and if they had used CAD for 3D modeling. It was anticipated that analysis of the likert-scale questions relative to the additional data would provide greater insight into the influence of CAD skills on perceptions of the software's effectiveness.

Phase 2 Observations

All students completed the digital sketch and modeling assignment and went on to complete the project (Figure 2). There were no negative classroom observations regarding ease of use of the software. However, even though the students were given two specific tasks to complete (create a sketch of their proposal using digital sketch software and then test their design proposal using the modeling tools), there were two common trends observed in the way in which students utilized the features of the software as they progressed through the computer segment of the assignment. First, it was noted that there was only limited use of the freehand drawing tools and that students preferred to use the geometric drawing tools instead. The students utilized these tools diagrammatically rather than as a means to attempt to develop representations resembling plans and often used multiple colors and variations in line thickness (Figure 3). This indicated that the drawing tools were used at least to some extent for conceptualization. While no clear conclusions can be drawn from these observations, it is possible that the limited use of digital sketching could be attributed to the student's general lack of sketching experience. It also possible that the use of a mouse as an input device was more conducive to using geometry rather than freehand line work. Second, nearly all students appeared to move from sketching to modeling after only limited time working in 2D. Since images of the computer model were a required component for the final presentation, it is possible that students perceived that learning and using the modeling was more important than the sketching tools. However, this also may be attributed to a greater interest among the students in working with the 3D modeling tools.

Of the 18 students enrolled in the course, eleven chose to participate in the study. Of these, four were majoring in architecture, three in interior design, and two in construction management. The remaining two respondents were majoring in education and mechanical design. Four participants (36.4%) indicated they had at least moderate sketching experience while six (54.5%) indicated they had minimal sketching experience. One student (9.1%) indicated they had no prior sketching experience. Four indicated they had taken at least two manual drafting courses, including the one in which they were currently enrolled, and two indicated they had taken three or more. Five listed that their manual drafting experience was limited to their current course. The combination of these data with the course observations further indicates that limited sketching and drawing experience may have influenced the use of the software sketching tools.

The extent of the participants' CAD experience was greater than anticipated. Six participants indicated they had previous experience with CAD software and had taken CAD courses. Three indicated they had taken one CAD class and three respondents indicated they had taken at least three CAD classes. Of these six participants, four indicated they had used CAD for 3D modeling. However, only two of the students with CAD experience described their CAD proficiency as high while two described their proficiency as moderate and two described it as minimal.

One-way Analysis of Variance tests found no significant between-group differences relative to any demographic data, including academic field, and the responses to the likert-scale questions, although it is likely the results were influenced by the small sample size relative to the number of categories. In contrast, frequency distributions and statistical analysis of the responses to the nine likert-scale questions produced results that were somewhat more conclusive. Seven students (63.6%) indicated that the software was easy to use and two (18.2%) responded neutrally. However, two others (18.2%) indicated the software was not easy to use. When asked if the software functioned in ways similar to manual drafting, six respondents (54.5%) agreed and two (18.2%) strongly agreed that the software operations were analogous to the practices used in manual drafting. However, one (9.1%) disagreed and two (18.2%) were neutral in their assessment. Seven respondents (63.7%) either agreed or strongly agreed that the software sketching tools were effective. However two (18.2%) disagreed and one (9.1%) was neutral. Similarly, seven respondents (63.7%) either agreed or strongly agreed that the 3D modeling tools were effective. As with the sketching tools, two (18.2%) disagreed and one (9.1%) was neutral. These data suggested that learning the application's features was not an obstacle for the participants and suggested that it could be utilized for course tasks and activities.

The distributions also indicated that the number of participants rating the software features as easy to use was relatively proportionate to the frequencies for effectiveness of the software features. This was supported by statistical analysis of the likert-scale questions relating to ease of use and perceived effectiveness of the software tools. Non-parametric correlation tests using Spearman's Rho found a significant positive correlation between the participants' rating of the ease of use of the software and the perceived effectiveness of the software sketching tools (.603, p=.049) and the perceived effectiveness of the software 3D modeling features (.691, p=.018). The significance of these relationships indicated that ease of use was an influential factor in the participant's perceptions of the effectiveness of the software's features.

However, when asked to evaluate the effectiveness of the software sketching tools during design development for the final project, only three (27.3%) rated the software as either more effective or considerably more effective than manual sketching. The majority of the participants (seven, 63.6%) were neutral in their assessment and one participant (9.1%) felt that the software sketch tools were less effective. Additionally, while the responses were not statistically significant, correlation tests using Spearman's Rho found a negative correlation between the ratings for this question and ratings for ease of use. These data were at least some extent inconsistent with the frequency distributions for the ratings for ease of use and effectiveness. It is possible that while the software tools were perceived to be effective and easy to use, the participants had difficulty in applying the tools to a specific task.

The statistical analysis did indicate that CAD experience influenced the perceptions of the effectiveness of the software. There was a significant positive correlation between the perceived effectiveness of the software's sketching tools and the participant's rating of their CAD proficiency (.762, p=.006), the number of CAD classes taken (.780, p=.005), number of CAD courses participants had taken and perceived effectiveness of the software's 3D features (.895, p=.000). In contrast, it should be noted that although there was a positive correlation between the perceived effectiveness of the software's sketching tools and the participants rating of their sketching experience, the correlation was not statistically significant. Therefore, CAD experience had a stronger influence on the perception of effectiveness.

Interestingly, while there was a significant positive correlation (.772, p=.005) between the number of CAD courses participants had taken and the perceived effectiveness of the software's sketching tools, there was a significant negative correlation (-.656, p=.028) between the number of CAD courses participants had taken and the responses to the question asking to indicate whether the software functioned in a way that was analogous to manual drafting. These findings indicated that, while participants with more CAD experience perceived the software sketching tools to be effective, this did not translate to a perception that the software operation effectively paralleled manual drafting.

Analysis of the use and perceptions of the 3D tools was also influenced by CAD experience. A positive correlation was found between 3D CAD experience and perceived effectiveness of the software's 3D features (.622, p=.041). Additionally, a positive correlation (.612, p=.046) between was found between participant's 3D CAD experience and perceived effectiveness of the computer model for understanding their design. Surprisingly, 3D CAD experience was not found to have a significant correlation with perceptions that computer modeling was easier than physical modeling. The combination of this finding with the strong correlation between 3D CAD experience and CAD proficiency suggested that students with 3D CAD experience may not have found the modeling tools as useable as those they were familiar with.

The responses to the narrative question at the end of the survey did support the somewhat mixed results of the quantitative analysis. While some respondents suggested that the time allocated to learning the software was too limited, responses included comments stating that they liked the software and that it was easy to use, supporting the findings of the qualitative analysis that using and learning the software was not an obstacle. One student stated that "once I got the hang of it, it was fairly simple, easy to learn, and fun to use". Another respondent stated that the software "was very easy to use; I definitely feel it should be used in the class – it shows another way to look at and understand your structure".

Some responses were more tentative. One respondent described the software as "somewhat easy to use" even though "it was the first time I ever used a computer to draw anything". Other statements were more mixed. One of the participants indicated that, although they felt the software was "a good program to use…. it should not replace physical model making." Another respondent indicated that they preferred manual drafting because "the computer software did not always respond or do the things you wanted it to do". They added, however, "for 3D models it may be more useful since making models by hand is so tedious".

Interestingly, responses that referred to either CAD features or experience with CAD operations were more negative. For example, a respondent stated "the software used for 3D models was not very effective" and that "the alignment of items to one another did not create an accurate solution; the program was more a guessing game rather than accurately depicting the design". Similarly, a respondent who had indicated they were "very proficient" with CAD stated that "my experience using (the software) was frustrating due to the close appearance to AutoCad and lack of the amount of control offered". These responses suggest that it cannot be assumed that prior CAD experience may not necessarily translate to increased proficiency with conceptual design applications.

While the data analyzed in this study was collected from a small sample, the combination of the quantitative data and qualitative data suggest that the adoption of digital sketching and modeling software in introductory design and drafting courses would enhance course outcomes. However, the data also suggest several strategies that may influence course structure and improve the learning experience for students. First, while the data analysis and relatively consistent responses regarding ease of use of the software should be encouraging for faculty seeking to experiment with alternatives to traditional design media, it would be necessary to allocate additional class-time to both learning and using the software tools and features. Second, expanding the class-time allocated to training should also be combined with extending the use of the software over the course term. This would allow students more opportunities to become more proficient with basic as well as advanced features. Third, faculty should consider opportunities to provide instruction on the features that emulate traditional practices in parallel with instruction on manual sketching and drafting techniques. Basic concepts such line-weights and traditional media techniques such as the use of tracing paper overlays are two examples. Similarly, both digital and physical models could be used in parallel at least in some assignments. Last, it will be important to consider the courses that will potentially utilize the software in terms of the overall curriculum. While it is likely at least some students enrolled in introductory design courses will have CAD skills, it may be more effective to introduce conceptual design applications earlier in the curriculum prior to students taking more advanced CAD classes.

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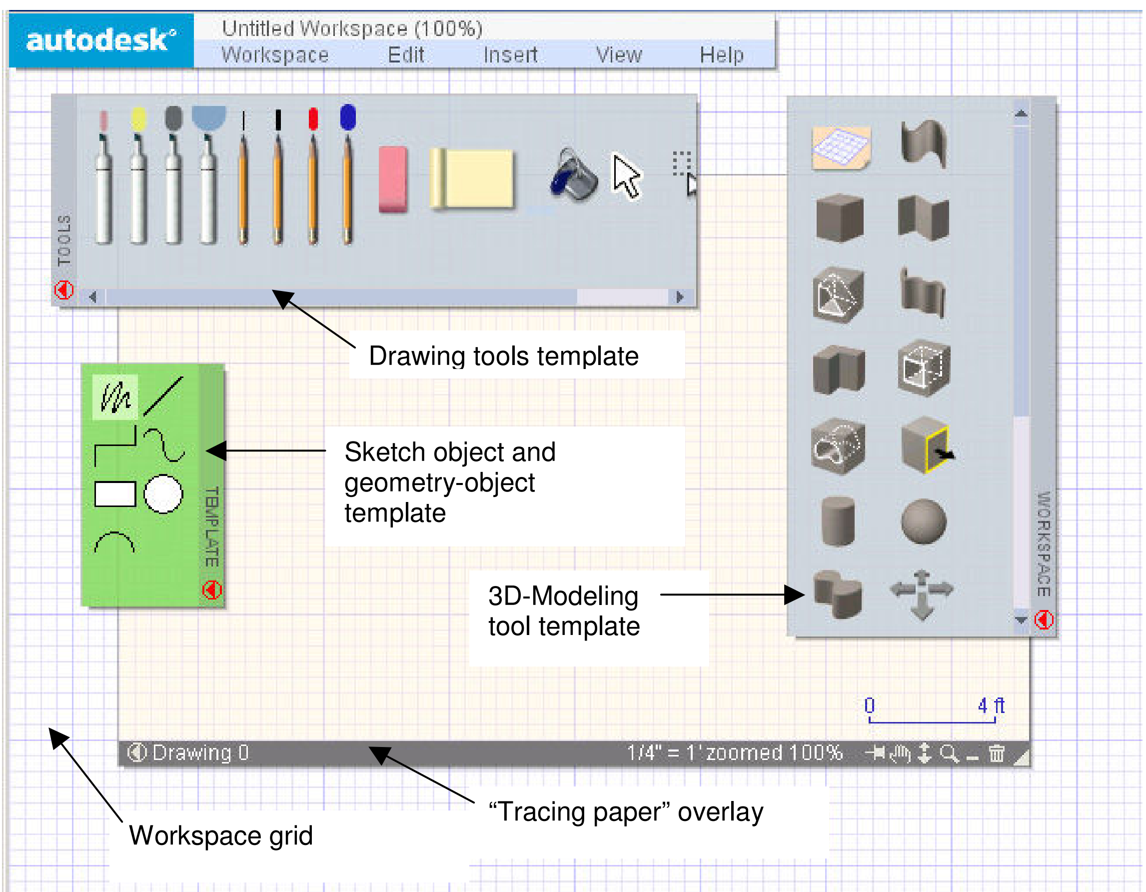

Figure 1. Architectural Studio’s drawing tools and interface.

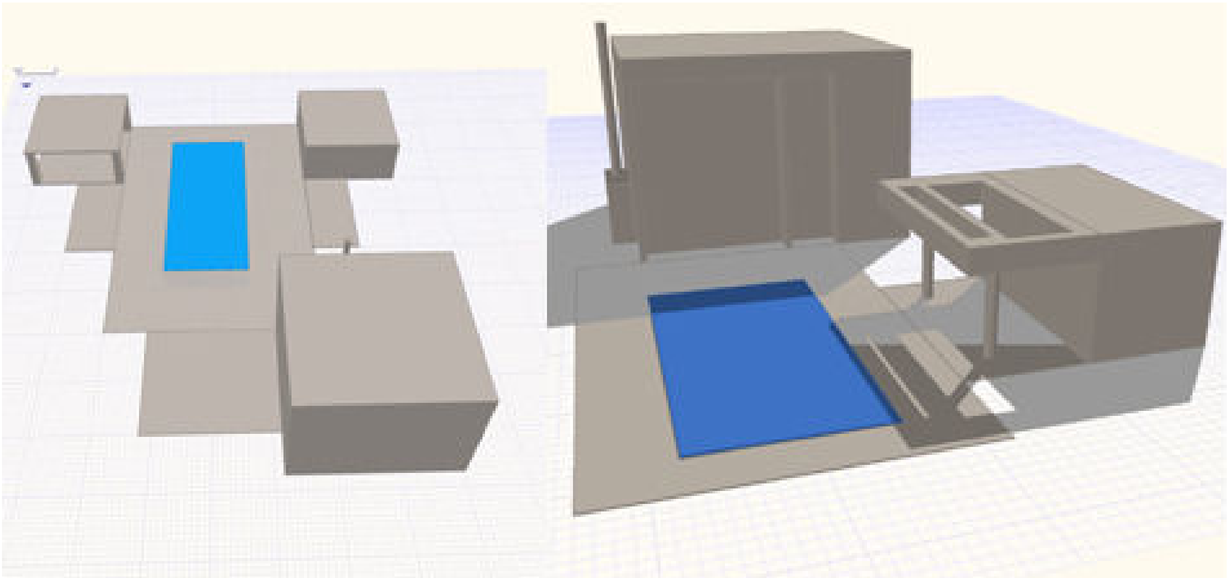

Figure 2: Examples of final computer models.

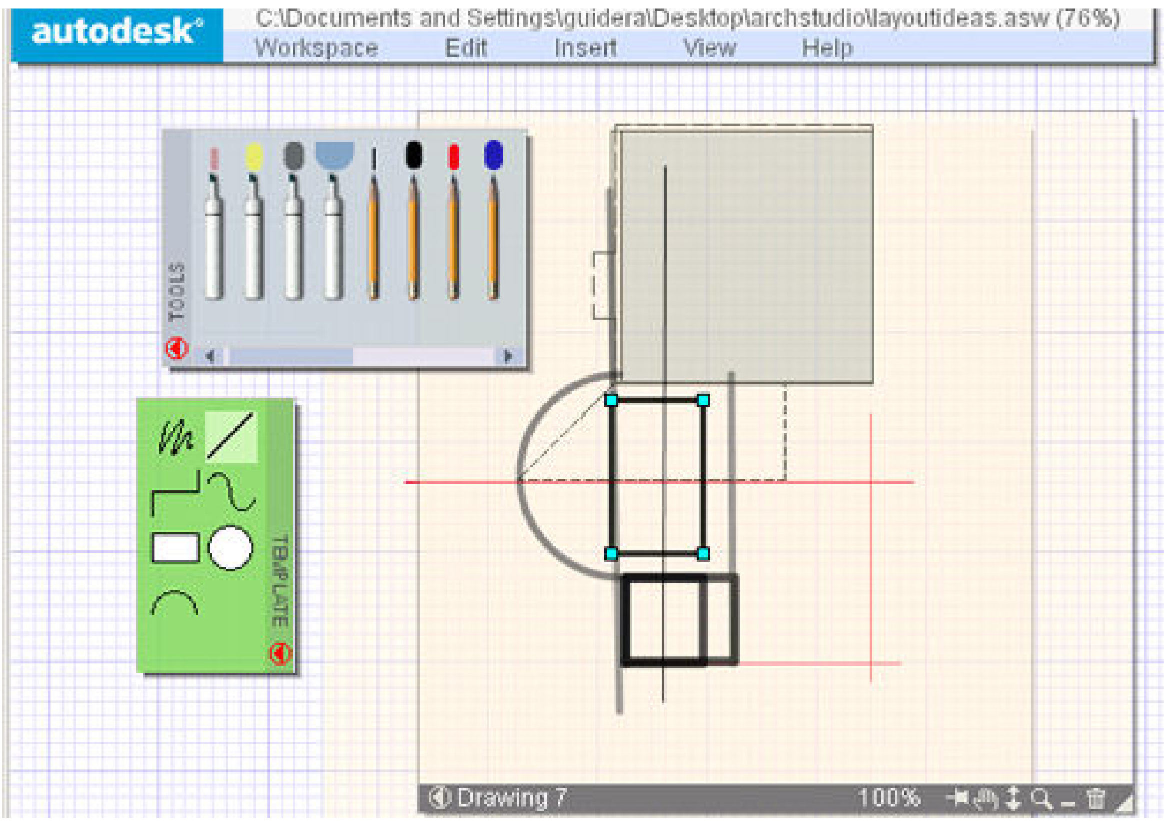

Figure 3: Examples of use of geometry tools for diagramming.