Computer Modeling and Visualization in Design Technology: An Instructional Model

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Computer aided drafting (CAD) has largely supplanted manual drafting in the workplace. As new technologies and practices are adopted in industry, they should also be incorporated in academic curricula (Stephens, 1997). Consequently, CAD has also become the standard in academic environments, and coursework emphasizing manual drafting has been largely eliminated or relegated to introductory classes. However, the increasing use of 3D parametric modeling programs such as Solidworks and Mechanical Desktop is bringing about a fundamental shift to a model-centric paradigm that may ultimately have a similar impact on electronic drafting. The shift from computer drafting to computer modeling is also making it possible to extend the use of CAD beyond its role as a production tool to include analysis and communication with software emphasizing design visualization. While in the past the use of visualization software has been limited and specialized, recent enhancements in interoperability with CAD software have made its application more feasible for a wider range of disciplines. Therefore, students in design fields must be prepared to leave colleges and universities with skills in design visualization technologies as well as with CAD in order to be competitive in the marketplace.

The role of visualization technologies is to provide an efficient mechanism for communication by enabling the nontechnical person to see and understand design (Mealing, Adams, & Woolner, 1995). Disciplines such as mechanical design and architecture have traditionally utilized orthographic drawings such as plans, sections, and elevations as the primary medium for design communication as well as documentation. Orthographic views are discreet 2D images that, when perceived collectively, communicate the design as a whole (Ching, 1996). The images are projected straight or parallel to the viewing plane with only two dimensions, such as length or width, visible at one time (Ethier & Ethier, 2000). Orthographic drawings require the viewer to conceptually assemble the discreet views in order to visualize the proposed design. For the unskilled observer, orthographic views have perceptual limitations since the design elements are represented without forshortening. Mitchell (1992) noted that these parallel views inherently flatten perceptions of space and volume and that "a limitation of this parallel-projection procedure is that it destroys all z-coordinate information; that is, information about depth back from the picture plane. This often results in spatial ambiguity" (p. 125).

Graphic techniques such as shading and variation in line-weights have been used in drafting and technical illustration to communicate depth and distance in orthographic drawings. However, 3D drawings such as para-line drawings and perspectives have significant communication advantages in that they represent form and space in a more realistic manner (Ching, 1996). While more visually "realistic," these drawings cannot document the entire object since a single viewpoint or viewing angle must be selected. Therefore, providing informationally complete representation requires either 3D drawings to be viewed in conjunction with orthographic drawings or the creation of multiple para-line drawings to show multiple 3D views. Additionally, these drawings are also usually time consuming to create in a drafting-centered environment and, since they must be constructed using the measurements and related information provided by the orthographic drawings, must be continually updated as the design evolves. This is why creating realistic 3D representations had been perceived as feasible only after the design was complete.

With the introduction of CAD software, little changed in this process. Modeling of any complexity required the computing power of expensive workstations, and the limited modeling capabilities available on early versions of PC-based CAD applications were often difficult to use and typically too slow on most hardware installations. For most designers and drafting technicians, CAD was used as an electronic version of the manual drafting processes they were already familiar with and the expected productivity increase from computer drafting failed to materialize (Bhavani & John, 1996). The emphasis remained on documenting the end product of the design process rather than facilitating the design process itself. Conceptual development of a design remained a distinct phase in the design process that was perceived to be limited by the precision-driven features of CAD. According to Van Elsas and Vergeest (1998), "it is this ability to allow design of detailed products that makes conventional CAD systems difficult to use during earlier design stages, when not the complexity of the design, but the creativity of the designer, is of dominant importance" (p. 82). CAD applications were seen as most useful at the end of the design process and for representation of complex, finished product models (Van Elsas & Vergeest, 1998).

However, the 3D capabilities now available on PC platforms is closing the gap with high-end workstations (Brown, 1997). Advances in processing power have enabled software vendors to incorporate sophisticated computer modeling tools in software running on desktop computers. This has brought high-end processing power within the reach of the majority of users and is replacing electronic drafting with a model-centric process in which the designer creates a virtual object, assembly, or building as a 3D digital model. These modeling processes are typically parametric. For example, a set of parameters can be established that will control relationships, such as relative size and position, between different components of the model. The designer can modify one component and the other components automatically update in compliance with the specified parameters. The model then functions as the base for all 2D and 3D graphic communication. Increased accuracy, elimination of errors, efficiency in collaborative design processes, and faster design cycles are only a few of the benefits.

The parametric model-centric paradigm provides additional advantages over 2D electronic drafting in that it enhances the potential for computers to be used as both a design tool and a communication medium early in the design process. Since designing is inherently evolutionary in nature, using digital modeling as the primary design tool enables the designer to generate 3D representations from multiple viewpoints throughout the project's development. In contrast to manual drafting, both 2D and 3D images can be generated relatively easily over the course of a model-centric design process. Therefore, the same model can be used for both production drawing and for visualization and communication (Boardman & Hubbell, 1998). Additionally, since digital models can be rotated, moved, changed, and viewed from different vantage points (Goldman, 1997), they afford greater efficiency in producing any number of views for analysis and communication as the design evolves.

The advantages of a model-based process are not limited to increased efficiencies in drawing production. Mitchell (1992) observed that where viewpoint selection with traditional representation mediums can be constrained by technical difficulties in constructing 3D images such as perspective views, this limitation is removed with images generated from computer models. Further, while accurate representations can be produced with "hand-made" perspectives, computer-generated perspectives may be interpreted as more "valid" since automated perspective-synthesis procedures eliminate "the effects of human error, wishful thinking, and dishonest fudging" (Mitchell, 1992, p. 118).

Demand for visualization capabilities has led CAD software vendors to include visualization tools as standard features. However, developing coursework that maximizes the visualization potential of computer modeling requires skills that are more interdisciplinary than those developed in conventional 2D or 3D CAD courses. Computer-based design visualization has been described as a combination of computer graphics, computation, communication, and interaction (Brown, 1997). Design visualization is distinguished from computer modeling by two key objectives: the articulation or rendering of a model with a high degree of realism and the communication of the sequential or temporal characteristics of the design concept. Rendering refers to the process of enhancing an image. However, computer rendering refers to an automated digital process that takes digital models and applies user-defined enhancements to provide a more realistic view (Goldman, 1997), including "taking a 3 dimensional model and applying color, material, and light (or darkness) to its surfaces or faces" (Ethier & Ethier, 2000, p. 8). Sequential or serial visualization involves a series of individual renderings created as an object or viewpoint is moved through or around the computer model over time. These renderings can be physically assembled as a series of still images and displayed as a "storyboard," assembled electronically in a file, or recorded to video to create animations. A significant benefit of design visualization is its potential for increasing awareness of larger issues related to perceptual and psychological aspects of design to which CAD and computer modeling alone may not be conducive. Integrating visualization technologies into design coursework can enhance our students' potential for exploration of these issues.

Core Skills for Design Visualization

The interdisciplinary nature of the skills associated with design visualization requires that content and information be drawn from design disciplines, computer graphics, photography and print media, physics, and geometry. For example, Brown (1997) proposed that "if the visualizations we produce are to be informative and effective, we must understand principles of design, how colors interact, and how we perceive information" (p. 2). Therefore, students must develop a skill set that is more diverse than developed in the scope of conventional CAD coursework utilizing computer modeling.

Knowledge and skills acquired from diverse subject matter outside of technology courses make up the first of three knowledge areas proposed by DeLuca (1991):

1. Related Knowledge: Knowledge gained from classes other than technology classes.
2. Prior Technological Knowledge: Knowledge and skills gained from previous study in technology classes.
3. Knowledge Seeking: Ability to identify missing information and obtain relevant information. (p. 6)

These knowledge areas can be directly associated with the competencies required to effectively utilize digital design visualization technologies. Introducing design visualization within a discipline-specific context requires students to synthesize core coursework, and the interdisciplinary nature of skills necessary for effective design visualization will require students to draw upon learning from other courses outside of technology. By using design visualization technologies as an analysis and assessment tool, students can more effectively evaluate design decisions and therefore support the "knowledge seeking" process. The core skill set for design visualization encompasses three general skill categories: modeling, simulation, and representation. In this context, modeling refers to competency using any software application used to create 3D geometry. This includes nonparametric solid and surface-based CAD as well as the parametric or feature-based 3D applications that are now being widely adopted in industry. However, modeling skills can also include the modeling capabilities that are provided in many design visualization applications.

Simulation refers to the competencies related to the computer rendering process. At a basic level, rendering may be limited to color gradients and shading. These capabilities are available in nearly all CAD software. More advanced rendering processes can attempt to simulate materials and lighting. However, design visualization software is characterized by sophisticated lighting and control of materials that can render the model in a way that is indistinguishable from a photograph. This process, referred to as photo-realism, can "accurately simulate complex textured surfaces under the kinds of lighting conditions that are encountered in real 3 dimensional scenes" (Mitchell, 1992, p. 161). Depicting objects as "real" requires the designer to manipulate 2D images or maps to emulate materials and textures, understand and manipulate color properties and transparencies, and create and control lighting for shade and shadow. Simulation is not simply an automated process. According to Mitchell (1992), "in modeling a scene, a computer artist must decide what to geometrically describe in terms of surfaces and what to treat as texture on those surfaces" (p. 145). However, the primary benefit of increased realism is a reduction in the abstract nature of the design process. The manipulation of materials and lighting produce output that is far more concrete and closely aligned with the physical reality than with the 2D or wire-frame world displayed on the computer screen. The understanding that design decisions have real implications for how objects or spaces are used or experienced in the real world is reinforced by the hyperrealism of the representation.

Simulation also includes animation. Animation skills enable students to analyze and communicate the temporal and sequential issues related to their design proposals. In addition to animations of part assemblies, manufacturing processes, and architectural walk-throughs, these issues can also be used to illustrate conceptual processes such as 3D flow charts. Since animations are a sequential display of still renderings, competency in this area is closely tied to skills in articulation and rendering. Students must also develop a knowledge base of terminology and techniques associated with video and film not only for purposes of composition but also to address technical issues associated with output, storage, and display of animations.

The third skill category, representation, requires students to synthesize rendering and animation output with other graphical mediums into a coherent format for presentation and communication and involves competency with 2D graphics skills. Representation skills with digital media entail high levels of critical thinking. While digital media affords the opportunity to create highly realistic images, students must develop skills for evaluating the level of detail and realism appropriate for the level of development of their proposals. Overly realistic images at an early stage of the design process may detract from the formal issues being presented for consideration. According to Goldman (1997), "the purpose of a rendering should dictate the degree to which there are consistent levels of abstraction and resolution within the image" (p. 232). Similarly, decisions regarding rendering highly detailed objects must be considered in the context in which they will be presented since attention is usually focused on the part of the image with the greatest detail (Goldman, 1997). Composition skills required for visualization must draw on other graphics courses within the curriculum, particularly 2D digital media courses when available. The emphasis on the integration of 3D information as 2D communication can foster development of analytical and critical thinking skills essential for student success in technology and design fields.

Application of the Course Model

An experimental design visualization course recently conducted at a midwestern university was based on this model. The class included students enrolled in the architectural design and interior design programs. Course assignments were structured to culminate in a final project based on a design problem that would provide students with experience applying their modeling, rendering, and animation skills in a context that would parallel the use of design visualization in professional practice.

The use of design visualization is particularly relevant in architectural design courses. Architecture and the product of its practice is inherently public in nature (Scrutin, 1979). This gives rise to a design process that requires an active dialogue between the architect and engineer and individuals and constituencies who will be impacted by the completed project. It is common for those outside of the architecture, engineering, and construction fields to have difficulty interpreting architectural drawings. Campbell (2000) stated that the communication media used by architects "is dominated by highly symbolic, orthographic drawings and text based specifications" (p. 129). Visualization technologies provide a way to bridge this communication gap.

Architecture has historically relied on perspective drawings for nontechnical design communication, a tradition dating back to the development of the science of perspective in the early renaissance (Honour & Fleming, 1982). Mitchell (1992) suggested that the role of the perspective has been to "predict the visual effect that will result from execution of the design" (p. 118). Similarly, Goldman (1997) referenced the importance of the perspective in stating that "there is no image or drawing type used by architects, interior designers, planners, and other members of the building design team that can more accurately or more clearly show what a building or a space will be like in relation to the observer" (p. 150). The ability to efficiently generate these views with computer models enables the designer to evaluate the spatial implications of the design and then use the model as a tool to communicate decisions and receive feedback from those who will use it. Additionally, experiencing architecture is highly temporal and sequential:

> One of the principle concerns of architectural design is space: the internal spaces of a building and its setting. One does not react to space from a static position, as one might view a painting. To obtain a deeper understanding of architectural space it is necessary to move through the space, experiencing new views and discovering the sequence of complex spatial relationships. (Greenburg, 1974, p. 99)

The use of sequential perspectives and animations generated with design visualization technologies provides an opportunity for architectural designers to communicate these characteristics in ways in which no analog exists in traditional mediums.

Course Detail

Enrollment in the class was limited to students in the final year of their academic program. This was intended to ensure that students had completed an appropriate number of "related knowledge" courses (physics and graphic communications) and "prior technological knowledge" courses (architectural design courses, construction courses, and basic CAD) in order to make the necessary conceptual associations between these knowledge areas and the course material presented in the class. AutoCAD 14 was used as the primary modeling application and 3D Studio Viz 2.0 was used for design visualization. This dual-application approach was selected because the combination of conventional CAD applications for modeling and separate visualization applications for rendering and animation is common in professional design fields (Boardman & Hubbell, 1998). 3D Studio Viz provided advanced rendering and animation tools, including an extensive material library. It was anticipated that the combination of the software's extensive library of materials and its advanced lighting-simulation capabilities would enable students to create highly realistic representations. It was also selected for its drawing-linking feature. Rather than importing the CAD geometry into the visualization application, drawing-linking maintains an active connection between the CAD file and 3D Studio Viz. This link is dynamic and can be continuously updated as the project evolves, eliminating the need to re-import the geometry as the CAD model is updated. This increases the integration of CAD and visualization operations and allows design visualization to be introduced earlier in the design process.

The first eight weeks of the semester concentrated on the core skill sets relating to modeling and simulation. Initial course activities were structured to introduce basic modeling, animation, and rendering concepts using 3D Studio Viz. These skills were developed using lecture/lab instruction with a series of five short assignments. Modeling using 3D Studio Viz was limited. Assignment parameters required students to demonstrate competency with lighting, materials, and animation using preconstructed models or with simple 3D scenes created with modeling tools available in the visualization software. Concurrently, other activities were structured to develop competencies with 3D modeling using AutoCAD through lecture/lab exercises focusing on creating increasingly detailed computer models. These activities were used to introduce more advanced modeling techniques and the process associated with linking AutoCAD geometry with 3D Studio Viz.

The second half of the course was focused on an "application project." This design problem required students to synthesize modeling and simulation skills, and provided a context for focusing on the use of design visualization as an analysis, assessment, and communication tool. The students formed groups and were then given the project requirements for three interior renovation projects under consideration on campus. The selection of a potential "real-world" project also provided a "client" the students would need to communicate with as their designs evolved. Limiting the assignment to interior spaces ensured that the scope of the project would be manageable within the class timeframe. The modeling for the final project was developed using AutoCAD. This approach allowed students to utilize the drawing-linking features of 3D Studio Viz while further developing their AutoCAD modeling skills with more detailed modeling.

The students worked in groups of three or four which enabled them to divide modeling tasks among the group members. Each group maintained a single "master-model" CAD file with each of the members' components inserted as an AutoCAD block, which would be updated as they made revisions and then reinserted their file. Throughout the process, the master-model was linked to 3D Studio Viz and viewed for analysis and further development.

The final submission requirements were structured to allow them to demonstrate competencies in all three areas of the core skill areas. Parameters for the solutions included material selection and furnishings. In addition to floor plans and other 2D documentation, the final submission required the students to produce four photo-realistic high resolution still images (defined in this assignment as output of 1024x768 pixels) and a 30-second animation. Both the still image renderings and the animations were to include realistic lighting and shadows. The final drawings, still images, and animations were then made available to the "clients" and others on campus.

Outcomes

The students' success in meeting these objectives was largely consistent across all the groups. While all were able to produce images that could be considered photo-realistic, greater difficulty was encountered by the groups with the highest level of detail in their computer model. The hardware used by the students had sufficient memory and processing power to create relatively complex 3D models with AutoCAD. However, even though the installed memory met the minimum requirements of the visualization software, there was significant performance degradation when students attempted to create renderings and animations using complex and detailed models, particularly at higher resolutions. Calculations associated with rendering processes increase proportionally as the geometry of the computer model becomes more detailed and complex and as the output resolution increases. Additionally, the use of the drawing-linking features in 3D Studio Viz is more memory-intensive than simply importing the CAD file (Boardman & Hubbell, 2000). Therefore, this placed even greater demands on the hardware and resulted in lengthy rendering times. Where added detail in the computer models significantly increased file size it proved to be unfeasible to create animations exceeding more than a few seconds in duration. Incorporating lighting and shadows, which is also computationally intensive, proved to be impractical for animations on the installed hardware since the processing time would increase to several minutes per frame.

This required adjustments to the assignment parameters and resulted in a reduced emphasis on the animation portion of the application project. The length of the animation submission was reduced from 600 to 450 frames. Additionally, the required resolution of the animation submission was also reduced. For the more complex models, the use of lighting and shadows in the animations was also eliminated since these elements also required additional processing power and rendering time. However, the use of lighting and shadows was determined to be essential for the still renderings since longer rendering times of 10 minutes or more were not prohibitive for a single frame.

Despite these limitations, most students expressed satisfaction with course content and final output. The organizations that served as clients found the visualization output to be helpful in understanding proposed solutions, although the still images proved to be more useful to them than the animations. This could be attributed to a range of factors, including the photo-realism of the image, the added detail of the models, and the ease with which still images could be distributed either electronically or in hard copy.

Recommendations and Summary

The experience of teaching this class did lead to several recommendations for faculty or instructors considering teaching courses using CAD and visualization software. Faculty should consider including content covering basic lighting theory and color-composition theory. While students in this course had been exposed to this subject matter in other required courses, including a required physics class and classes using Photoshop, the need to review this content was not anticipated. Given the importance of this subject matter for effective use of lighting and materials in visualization software, it is recommended that time be allocated for its review.

Similarly, retention of skills and material from the prerequisite CAD course was less than anticipated. Many students were not proficient with some of the CAD operations that were integrated into the assignments. For example, several students were not familiar with the use of AutoCAD blocks to redefine updated geometry. This was an essential technique for updating the master-model in the group assignment. Consideration should be given to allocating class time to review key CAD operations necessary for the design visualization class. Instructors should also consider providing specific guidelines regarding managing CAD data, including providing students with written standards for naming files, layers, and blocks as well as project directories. While it may be desirable to have the students develop these conventions themselves, specifying these standards as part of the project assignment may prevent time-consuming errors and allow students to focus on the core course content.

It is also recommended that even though features such as file-linking are intended to make managing design visualization processes more efficient, this benefit may be offset by an unacceptable decrease in software performance in instructional labs with limited hardware. Therefore, instructors may find it necessary to consider alternatives such as limiting file-linking to early stages of the design process when models may be less complex.

Instructors should also carefully consider the necessity of animation assignments in the context not only of hardware resources but also in terms of the intended class outcomes. Options such as "storyboard" rendering (renderings of key frames along a path of movement through the space) can provide an effective alternative to hardware-intensive and time-consuming animations and still serve to develop student abilities in conceptualizing and communicating sequential design issues. In educational settings, assignments involving lengthy animation requirements should likely be avoided in favor of shorter, less realistic animations that still provide a way to include animation-related content in the course. This approach may prove more effective when the less realistic animations are accompanied by more detailed, higher resolution single frame images. Figure 1 provides a comparison between a higher resolution still that included detailed materials, lighting, shadows, and reflections and the identical model rendered at a lower level without materials, lighting, and shadows. The detailed image took over 6 minutes to render on the installed hardware and would have required over 44 hours of processing time to create a 400 frame animation. In contrast, the lower resolution rendering without lighting and shadows was completed in 8 seconds and the full 400 frame animation was completed in less than an hour. The combination of the animation files and the detailed single images used to document key points through the design can prove very effective for communicating design intent.

It should be noted that the limited computing power did provide an unexpected benefit. Students were forced to be more selective in their modeling and rendering strategies. This required them to be more cognizant of what features of their design solution were most significant to communicating their design intent. As a result, students prioritized their design elements earlier in the process in order to selectively add detail to the model in the areas they determined to be most significant. This level of critical analysis was consistent with the intended learning outcomes for the course.

As demand for visualization skills increases, faculty will be challenged to add new learning objectives related to visualization competencies while maintaining pre-existing educational goals. An instructional model based on an integrative approach to mastering the required skills provides a framework for the synthesis of visualization skills and the core skill-set of the discipline (see Figure 2). While hardware limitations that may be commonly encountered in educational facilities must be a consideration, this should not necessarily be the primary determinant in the decision to incorporate design visualization into technology courses and curricula.

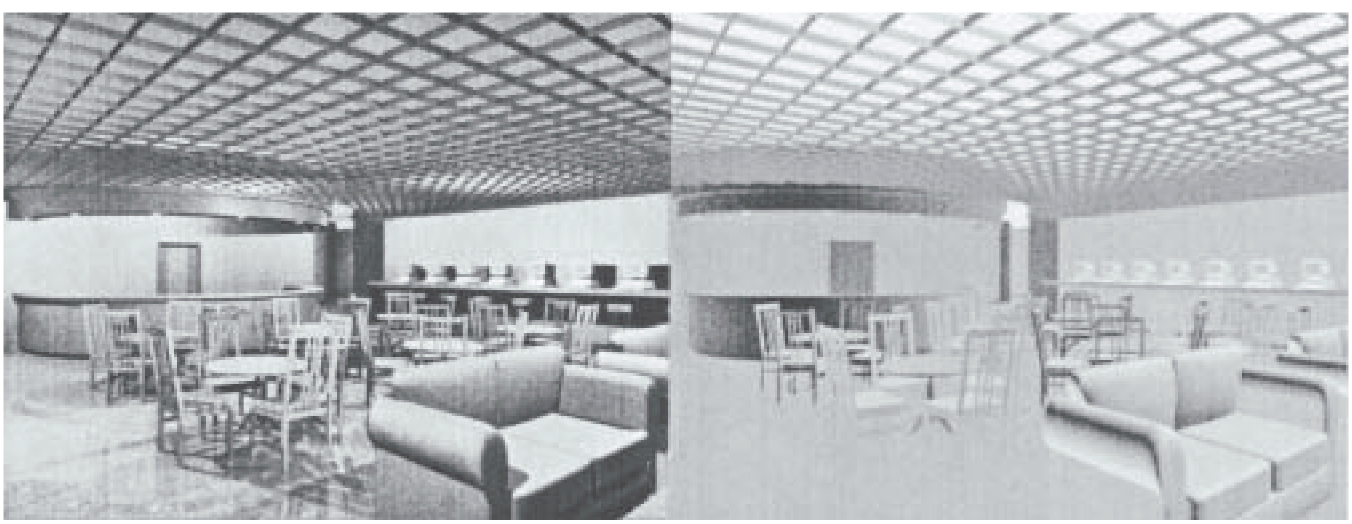

Figure 1. Left image is rendered as a single image at higher resolution with materials, lighting, and shadows. Right image is rendered as one frame in an animation at lower resolution without lighting, shadows, and materials.

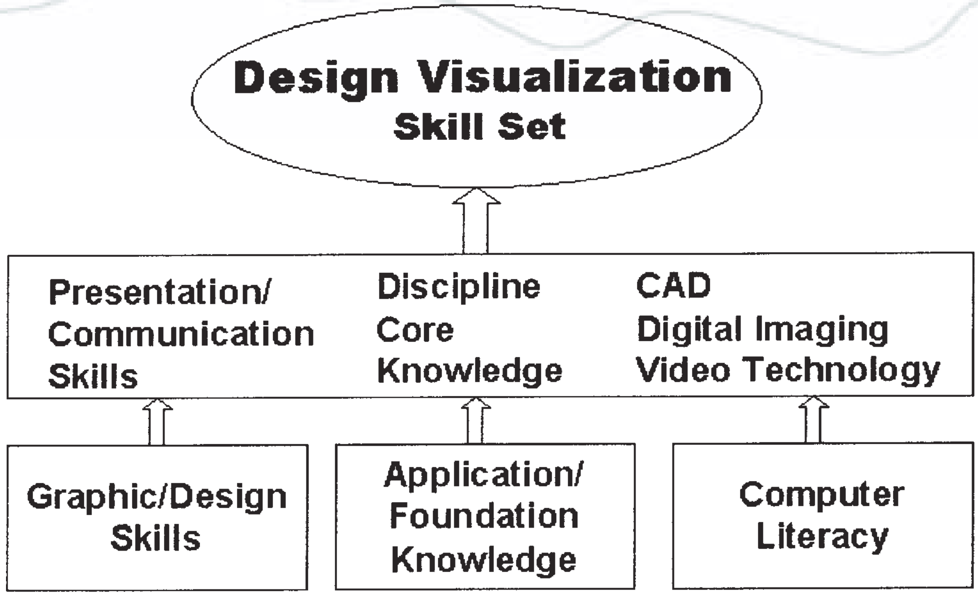

Figure 2. Design visualization skill set framework.

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References

Bhavani, S., & John, B. (1996). Exploring the unrealized potential of computer-aided drafting. *CHI96 Electronic Proceedings.* Retrieved January 12, 2000, from http://www.acm.org/sigchi/chi96/proceedings/papers/Bhavnani/bs_txt.htm

Boardman, T., & Hubbell, J. (1998). *Inside 3D Studio MAX2: Modeling and materials.* Indianapolis, IN: New Riders.

Boardman, T., & Hubbell, J. (2000). *Inside 3D Studio Viz 3.0: Modeling and materials.* Indianapolis, IN: New Riders.

Brown, J. (1997). Visualization and scientific applications. In E. Earnshaw, J. Vince, & H. Jones (Eds.), *Visualization and modeling.* London: Academic Press.

Campbell, D. (2000). Architectural construction drawings on the web: VRML as a case study. *Automation and Construction,* **9**, 129–138.

Ching, F. (1996). *Architectural graphics.* New York: Van Nostrand Reinhold.

DeLuca, V. (1991). Implementing technology education problem solving activities. *Journal of Technology Education,* **2**(2), 5–15.

Ethier, S., & Ethier, C. (2000). *3D Studio Max in motion.* Upper Saddle River, NJ: Prentice Hall.

Goldman, G. (1997). *Architectural graphics: Traditional and digital media.* Upper Saddle River, NJ: Prentice Hall.

Greenburg, D. (1974). Computer graphics in architecture. *Scientific American,* **230**(5), 98–106.

Honour, H., & Fleming, J. (1982). *The history of the visual arts.* Englewood Cliffs, NJ: Prentice Hall.

Mealing, S., Adams, B., & Woolner, M. (1995). *Principles of modeling and rendering using 3D Studio.* Exton, PA: Swets & Zeitlinger.

Mitchell, W. (1992). *The reconfigured eye: Visual truth in the post photographic era.* Cambridge, MA: MIT Press.

Scrutin, R. (1979). *The aesthetics of architecture.* Princeton, NJ: Princeton University Press.

Stephens, M. (1997). Computer simulation in the workplace and technology classes. *Journal of Technology Studies,* **23**(1), 6–13.

Van Elsas, P., & Vergeest, J. (1998). New functionality for computer aided design: The displacement feature. *Design Studies,* **19**, 81–102.