Integrating Surface Modeling into the Engineering Design Graphics Curriculum

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Abstract

It has been suggested there is a knowledge base that surrounds the use of 3D modeling within the engineering design process and correspondingly within engineering design graphics education. While solid modeling receives a great deal of attention and discussion relative to curriculum efforts, and rightly so, surface modeling is an equally viable 3D modeling option in many circumstances within industry as well as academic settings. However, is often not given its due consideration within engineering design graphics (EDG) curricula for a variety of reasons, some being more practically oriented than others. This paper is an effort to provide a rationale for the inclusion of 3D surface modeling into the EDG body of knowledge, an example of the inclusion of such a course in an EDG curriculum, and potential topics to be covered and assessment strategies to be used during the instruction.

Introduction

Engineering design graphics educators are a diverse group of people who do not always serve the same interests within their respective academic institutions (Branoff, Hartman, & Wiebe, 2002). Some teach graphics within engineering programs where all topics are covered within a single course, while others teach in technology programs that have many courses devoted to the examination of graphics. Still others teach somewhere in between the previous scenarios. Given the range of interests to be served, there is often disagreement about what should be considered part of the EDG curriculum.

Despite these differences, there has been some basic agreement that solid modeling should be included in contemporary engineering graphics curricula. Indeed the EDG literature includes many course and curriculum revisions centered on the use of the 3D solid model as a means to capture and communicate the design intent of a product (Barr, 1999; Ault, 1999; Miller, 1999; Connolly, Ross, & Bannatyne, 1999). Suggestions have also been made regarding instructional methodologies and assessment strategies for developing proficiency in the creation of solid, constraint-based geometric models (Branoff, Wiebe, & Hartman, 2003; Wiebe, Branoff, & Hartman, 2003), as well as the relationship of the instructional process to larger issues concerning learning theories and cognitive and educational psychology surrounding the strategic use of modeling tools by students and industry professionals (Hartman, 2003 & 2004; Hartman & Branoff, 2004; Wiebe, 2003). However, if engineering graphics is to be taught as a body of knowledge (Duff, 1990), there must be complete coverage of the topic. By only teaching solid modeling concepts, students are not exposed to the entire gamut of appropriate geometry creation techniques for product design. They are not presented with the fundamental differences in how surface and solid geometry are created and represented within modern CAD tools. These differences account for not only a level of expertise on the part of the student, but also a level sophistication in the 3D geometric database that is not well understood at this time by most students in engineering design graphics curricula.

Rationale for Including Surface Modeling in the EDG Curriculum

One suggested EDG curriculum model (Branoff & Hartman, 2002) includes the examination of surface modeling in addition to solid modeling and other topics. It advocates the development of a surface modeling course that combines the use of conceptual modeling tools and constraint-based surfacing techniques to create geometry. In addition, it also deals with translating surface geometry between different computer-aided design (CAD) systems using standard file formats. This is due in part to the increasing geometric complexity of today's highly stylized consumer and industrial products and the communication

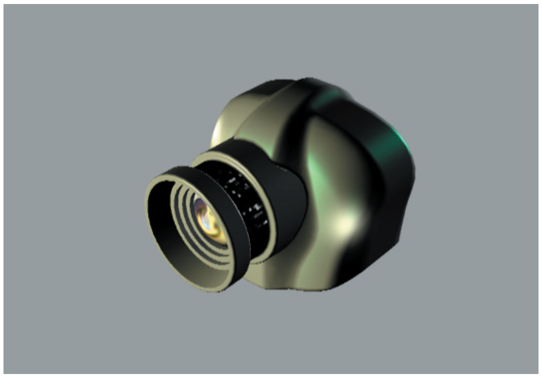

Figure 1. Body of a Camera Containing Lofed Contours.

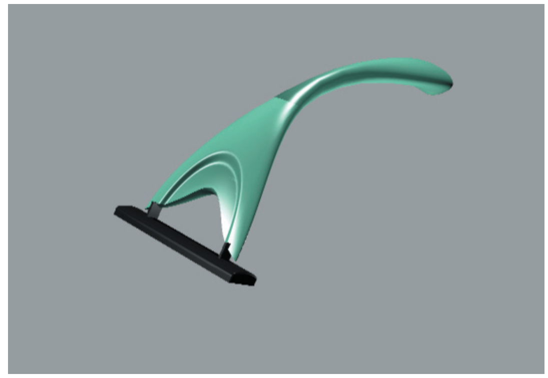

Figure 2. Razor with Ergonomic Handle.

of design information across the enterprise. Some products more readily lend themselves to the use of surface modeling (Cohn, 2000 & 2002; Rowell, 1997; Rowe, 1996; Potter 1998), such as bicycles, toys, aerospace, automobiles and sports equipment. However, not all consumer products today are manufactured in the same manner. In addition to casting, forging, and traditional material removal operations, sheet metal fabrication (punch and die) and plastic molding and forming technologies create finished products whose geometry readily lends itself to creation with surface modeling tools and techniques. Figures 1 and 2 are examples of these types of objects. Note the smooth and stylized surfaces and the virtual absence of sharp corners and edges on the body of the object.

In scenarios where maintaining the integrity and continuity of large surfaces is necessary, surface modeling tools have been employed (Orr, 1996; Rowe, 1997b). However, the creation of such objects was traditionally done with a company's standard, solids-based CAD system, which typically did not offer the flexibility of modeling complex curves and surfaces accurately (Weisberg, 1995). As technologies have advanced, the tie between surface and solid modeling within applications software has become stronger (Wilson, 2002; Rowell, 1997) to a point that many CAD systems work simultaneously between surfaces and solids.

The interactivity between solid and surface geometry in contemporary CAD tools has driven the need for engineers and designers to be versed in both types of geometry (Wilson, 2001; Rowe, 1997a). While contemporary surface and solid modeling systems can create similar types of geometry, there are important differences, particularly in the way geometry is validated by the modeling system (Orr, 1996). Solid models and surface models are not required to follow the same mathematical rules during the creation process. Surface modeling tools often are used to create free-form, stylized geometry whereas solid modeling tolls are typically used to create more traditional machined-style objects. In addition, due to solid modeling software limitations, data exchange between disparate CAD systems still often takes the form of an IGES-based surface model that must be edited and repaired after the translation process (Wilson, 2001; Weihe & Willhalm, 2000). Using surface models also requires a change in corporate culture, as it is often the industrial designer and not the engineer who is using these tools to define the overall shape and contours of the object (Potter, 2000).

The remainder of this paper focuses on the development of a course that addresses these concepts within the context of an EDG curriculum.

Development of a Surface Modeling Course

Begun in the fall semester of 2002 at North Carolina State University, and continued regularly in the fall semesters at Purdue University, the author developed a course centered on four concepts inherent to contemporary surface modeling tools: conceptual sketching, detailed object modeling, visualization, and information transfer (Potter, 2000; Weisberg, 1995). Conceptual sketching is done by exploring geometric forms in a free-hand fashion followed by the layout of critical contours using the CAD tool. Detailed geometric modeling involves the

List of General Topics in CGT323: Introduction to Surface Modeling	
Curve types	Editing strategies
- Bezier	- Edit Points
- B-splines	- Control Points
- NURBS	- Knots
NURBS surfaces	- Weighting factors
Boundary conditions	Alternate geometry input
Curvature conditions	- Digitizing
Conceptual design	- Photo tracing
Constraint-based design	Rendering techniques
Combination of solid and surface geometry	Data translation

Table 1.

use of the contours in the CAD system to generate surface patches that are merged together to form the finished shape of the object. Realistic lighting conditions and materials applications allow for the visualization of the finished object using techniques not commonly found in basic solid modeling systems. Finally, standard file formats are used to transfer information between conceptual modeling tools and constraint-based modeling tools.

The format of the course includes two one-hour lectures each week and one two-hour lab each week. The lectures are used to present conceptual information and to demonstrate software techniques. The lab sessions are used to guide students through various geometric creation techniques in the form of tutorials, with the techniques learned being used in the completion of three major projects over the course of the semester. Table 1 includes a listing of the major topics covered within CGT 323: Introduction to Surface Modeling.

Assessment of Student Work

Student assessment in the course consists of short-answer midterm and final examinations used to assess knowledge in the primary content areas of the course. The questions aim to address a synthesis of information or the solution to a problem scenario. Additional items include grading of lab-based exercises and three major projects. Each major project focuses on design and modeling criteria in a design scenario meant to exemplify a real design setting as much as possible. Students are asked to model objects of their own choosing, which helps provide an authentic learning experience for the student (Hartman, 2003 & 2004; Polanyi, 1962).

The following paragraphs detail the various stages of a typical major project in CGT 323 (the design of an infant's toy) with excerpts from a typical project description. This project was intended to be conceptual in nature, and as such, only the outer "skin" of the object was defined. Students used Rhinoceros modeling software for this project, although they use Pro/ENGINEER and CATIA, in conjunction with Rhinoceros, in later projects that deal with data exchange between CAD systems and constraint-based surface geometry (Potter, 1998). Below is an excerpt from the project description for modeling the infant toy. It was intended to give the students a context or design scenario from which to operate.

> "A major toy manufacturing company has asked you serve as a contract designer in the development of their new infant toy design. The company is considering a theme that will center on either animals or vehicles, so a toy representing a car or a giraffe would not be out of the question. An age group of less than two (2) years will be the target range for this new product. In order to successfully market their product and ensure its safety for infants, several criteria have been developed by the corporate marketing and consumer affairs staff."

Further criteria are defined to control geometry conditions, material specifications (for rendering purposes and potential mass properties calculations), and the ability and ease by which it can be modified. Students are asked to develop modeling procedures as an aid to conceptual modeling of objects in an effort to promote good modeling strategies and techniques (Hartman & Branoff, 2004). Boundary conditions between surface segments are also assessed, because one of the primary goals of some projects is the ability to convert the surface model to solid geometry to be used for downstream applications. Students are required to submit a model which is examined in light of surface boundary conditions, blending techniques used, degree of curves and surfaces used, model organization techniques, and spatially unique nature of the object.

Once an object is selected, ideation sketching begins as described in the project descriptions, such as "…make engineering/technical sketches of at least five (5) possible design families that meet the design parameters…" After the sketches are finished, students engage in a refinement and a decision making process concerning their potential modeling techniques. This allows them to arrive at a final iteration of their object to begin modeling.

After modeling the final iteration of the object, the students assemble all sketches, rendered images, decision matrices, and project rationales in to a bound packet that is graded. A list of grading criteria might include:

- Rationale for final selection
- Unique design
- Quality of sketches
- Final size of the object
- Number/nature of the different parts in the design
- Continuity conditions
- Curvature changes across the body of the object
- Material/color/transparency

Indeed several of the aforementioned criteria are typically assigned a point value and are used as the rubric to assess the project. On most projects, the rubric includes an assessment of all stages of the project and general criteria.

"All steps will be checked against the items identified in the various stages of this design document. The sketches will be evaluated on neatness, proportions, and how well you apply the conventions technical sketches. Your project will be judged on the quality of the models, your ability to quickly communicate your design, and how well you followed the specification. A great deal of emphasis will be placed on the uniqueness of the design and the ability of the student to stay within the given project requirements."

The following is a list of typical grading criteria with point values assigned to them. Projects are generally valued at one hundred points.

- Rationale for final selection - 5 pts.
- Quality of sketches - 30 pts.
- Final size of finished object - 15 pts.
- Inclusion of safety concerns (moving parts) - 10 pts.
- Geometry consistent with target audience - 10 pts.
- Surface continuity issues - 20 pts.
- Color and materials are specified and included in model - 5 pts.
- Ability to be used by an infant or small child - 5 pts.

Figures 3 and 4 depict two examples of final models created for the previously described infant toy example. Notice that sharp corners, edges, and planar surfaces have been kept to a minimum. These are good examples of projects that fit most of the criteria and the format that a finished model would take.

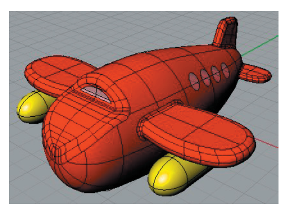

Figure 3. Example of Infant Toy Airplane.

Figure 4. Example of Infant Toy Animal..

SUMMARY

As our profession continues to define the knowledge base that makes up our discipline, it is imperative to be as inclusive as possible in the content that we present to our students. Doing so will enhance their technological and geometric literacy. As educators, we do not always have the luxury of introducing new topics in favor of the more established curriculum, but surface modeling is more than just a "new topic". As CAD tools have become increasingly sophisticated in their ability to create geometry, and as software vendors have developed seamless transitions between various modules of the software (Cohn, 2000 & 2002), students need to be versed in the various geometric forms they will encounter. Using context-based modeling and design assignments allows students to have meaningful exploration of the required geometry while still operating within defined parameters, which is inherent to the engineering design process (Vincenti, 1990).

While this paper lays out the content for a course dedicated to the creation and manipulation of surface modeling, most of these topics are modular in nature. They could be incorporated into any course where students had access to appropriate software and enough modeling experience to facilitate completion of the projects. While it has been suggested in this article that surface modeling should stand alone as a separate topic, the content in such a course could easily be incorporated into existing introductory and advanced solid modeling courses. Basic conceptual modeling could be incorporated into an introductory geometry courses, and more advanced hybrid modeling techniques could be place in an advanced solid modeling course. Generally, the techniques and operations for creating surface geometry are similar to those used in the creation of solids. It is simply the resulting geometry that is different. However, those differences are what merit the study of surface modeling as a distinct topic under the larger umbrella of geometric modeling.

The ability to create both solid and surface geometry within the same model interchangeably using contemporary CAD tools has driven the need for engineers and designers to be versed in both types of geometry. While contemporary surface and solid modeling systems can create similar types of geometry, the topics have been separated in this paper purely for pedagogical reasons. While the instructional techniques are similar, it is crucial for students to understand their options for creating geometry and the ramifications for choosing certain techniques. Of relevance to those choices made in modeling are discussions of manifold versus non-manifold geometry, the creation of NURBS curves and how to edit those curves, and the process of joining and merging of surfaces to create enclosed volumes. The eventual goal in most of the modeling and project assignments is the transition of the surface model to solid geometry to support downstream applications.

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