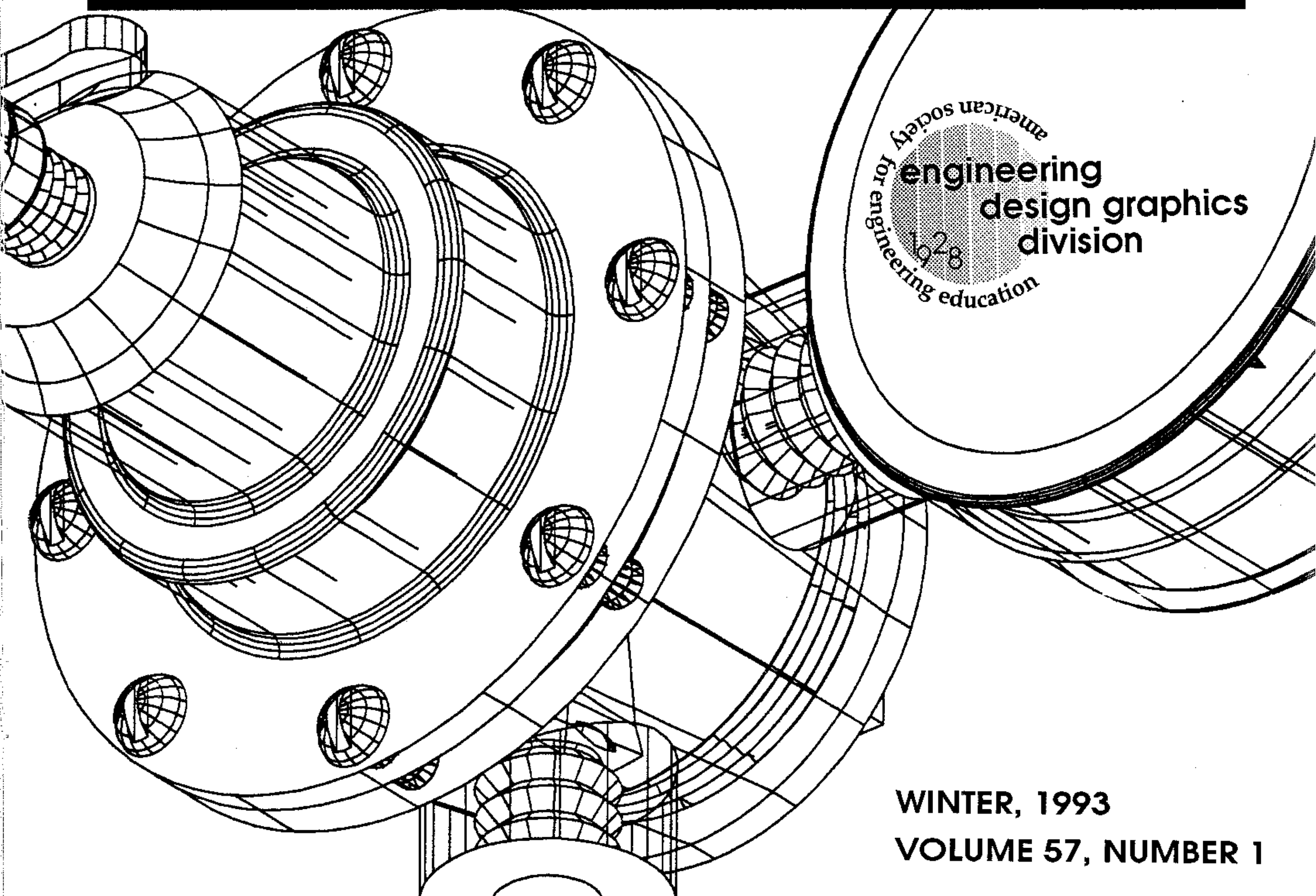
# THE ENGINEERING DESIGN GRAPHICS JOURNAL




WINTER, 1993
VOLUME 57, NUMBER 1

ENGINEERING DESIGN GRAPHICS DIVISION
AMERICAN SOCIETY FOR ENGINEERING EDUCATION

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# THE ENGINEERING DESIGN GRAPHICS JOURNAL

Volumn 57 Number 1 Winter1993





The *Engineering Design Graphics Journal* is the official publication of the Engineering Design Graphics Division of ASEE. The scope of the Journal is devoted to the advancement of engineering design graphics, computer graphics, and subjects related to engineering design graphics in an effort to (1) encourage research, development, and refinement of theory and applications of engineering design graphics for understanding and practice, (2) encourage teachers of engineering design graphics to experiment with and test appropriate teaching techniques and topics to further improve the quality and modernization of instruction and courses, and (3) stimulate the preparation of articles and papers on topics of interest to the membership. Acceptance of submitted papers will depend upon the results of a review process and upon the judgement of the editors as to the importance of the papers to the membership. Papers must be written in a style appropriate for archival purposes.

**ISSN 0046 - 2012**



## . . . from the EDGE • Engineering • Design • Graphics • Editor

It seems that the rest of the university world is beginning to catch up to what graphics educators have known for years. In January, President Beering at Purdue University appointed three task forces to help lay the foundation for strategic planning for Purdue in the 1990s and into the 21st century. It so happens that I have been appointed to participate on the committee which will examine the different aspects of the undergraduate experience at Purdue. In doing so I have found myself reading several reports and books on 'the undergraduate experience'. One in particular was *A Campaign for Excellence: The report of the Task Force on Undergraduate Education*, which was issued at Penn State in 1991.

The Task Force at Penn State suggested that in order to affect excellence in undergraduate education three goals must be achieved.

- elevation of the art and science of instruction;
- elevation of the academic atmosphere; and
- elevation of student-involved learning.

As I read through this report it appeared many of the recommendations by the Penn State Task Force were things that most graphics instructors have been doing for years. They recommended that senior faculty staff more of the freshman and sophomore course offerings. (This is something that we do as a matter of course.) They recommended an increase of opportunities for students to enroll in small classes. (Due to the type of classes that we teach, including the need for hands-on lab time, our courses are usually restricted by the number of stations we have in our labs.)

Another recommendation was that the curriculum should be strengthened to relate better to the world outside the academy. It seems to me that this is something we have been doing in graphics for years with our application and design problems. Oppenheimer Award winner Steve Howell showed us how he had applied real-world situations to problem solving for his freshmen students.

Another report is, *Campus Life: In Search of Community,* by the Carnegie Foundation for the Advancement of Teaching. One of its conclusions was that the quality of a university must be measured first by the commitment of its members to the educational mission of the institution. The Carnegie Foundation recommends that the university must be more than a place for learning, it must be a community. Students should have the opportunity to know their professors from a viewpoint other than at the podium. Professors must have the time to interact with students in ways other than giving lectures and exams.

These task forces could use many of the EDGD graphics instructors and their classrooms as examples for what is good about the university. Senior faculty have and continue to teach freshman and sophomore level graphics courses. We tend to work with small groups, get to know many of our students by name, and get (as Jon Duff would say) cheek to jowl with the student as we attempt to explain the mysteries of graphics. In many ways some of our labs become mini-communities as faculty and students interact while trying to solve the problem at hand. I don't know about you, but I often find a student in my lab who knows considerably more about a specific topic, software, or piece of hardware than I do. I know that I can learn from, as well as, teach my students.

My point here is that while we have been doing many of the things these task forces are recommending for the future of university life, our departments have been disappearing at a rapid rate. Maybe we can use reports like these to reinforce our own importance within the university community. If task forces are going to recommend smaller classes, senior faculty in the classroom, and a feeling of community, let's inform them that, indeed we're already there, and we want to remain.

Mary Sadowski

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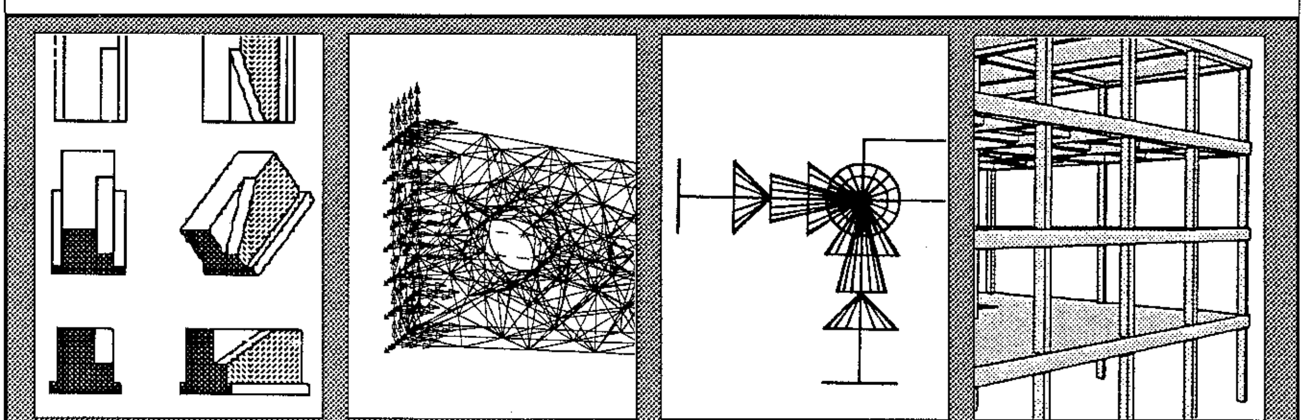


# SOLID MODELING FOR ARCHITECTS?

James E. Bolluyt
Iowa State University
Ames, Iowa

## Abstract

*This paper will discuss the potential of solid modelers in architectural design and the introduction of solid modeling techniques to architecture students at Iowa State University. During the spring semester of 1990, students were introduced to the use of solid modeling for architectural design in the Architecture/Freshman Engineering 234, "Introduction to Computer Applications in Architecture" course. This course is the first in a series of three elective courses on computers in architecture.*

*Most applications of solid modeling seem to suggest that it is applicable only in mechanical engineering and related areas. But many of the characteristics of solid modelers make them excellent tools for architectural design, from preliminary design to final presentation and documentation.*

## Introduction

"In design and drafting, the engineer's activities will soon be more like sculpting than drafting, enabling designers to rapidly create highly complex models by using combinations of simple solid shapes" (Mortenson, 1985).

This look into the future by Michael Mortenson in Geometric Modeling (1985) is already upon us. Though Mortenson's prediction referred only to engineers, the advantages and versatility of computer modeling are making it attractive (perhaps even irresistible) to a broad range of design fields, including architecture, architectural engineering, and interior design. Creating things immediately in 3 dimensions involves definite changes in thinking and working compared to 2-D drafting (and the presumed 3-D thinking that accompanies it). But the advantages of having an immediate and unambiguous 3-D model far outweigh the initial frustrations of making these necessary adjustments.

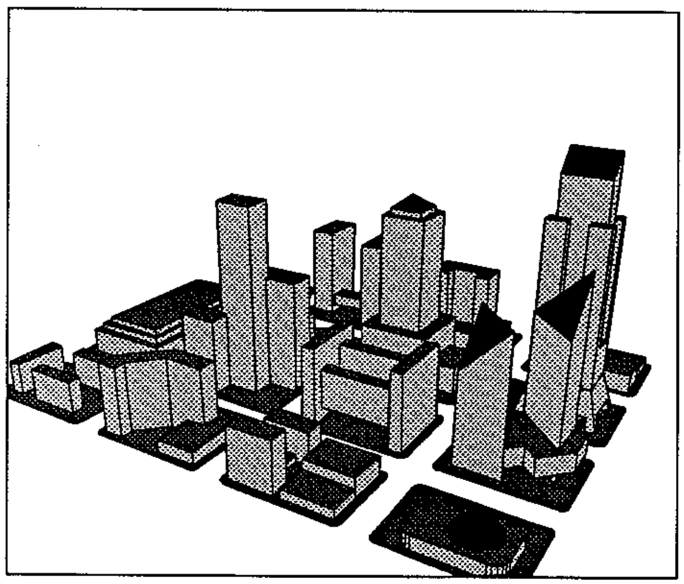


Figure 1. Overall building forms created using solid modeling techniques

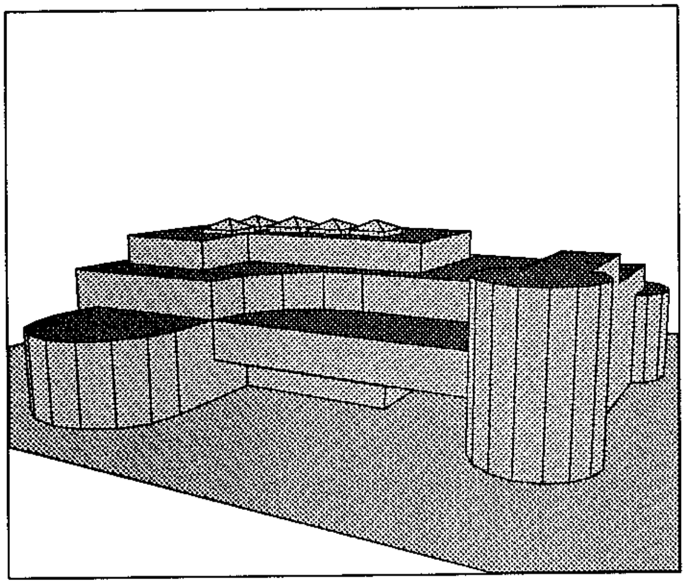


Figure 2. Solid modeling techniques make it easy to create initial massing concepts for a building design.

## Solid Modeling for Preliminary Design

### *Massing Studies*

In architectural design, solid modeling has the potential to be an invaluable tool for most of the design process, from preliminary design and planning through the production of final construction documents. In the initial design stages, the architect needs to be concerned about the mass (volume and shape) of the building and its relationships to the proposed site, including nearby buildings. Solid modelers provide an efficient means of quickly creating representative masses of nearby buildings. All of the "buildings" in Figure 1 were created using simple 3-D primitives and Boolean operations and though building details are not important for typical massing studies, solid modelers provide the means of creating as much detail as is desired. (Solid modelers that run on higher end PCs include SilverScreen™, Auto Modeling Extension™, and CADKEY SOLIDS™. All the models for this paper were created using SilverScreen™ running on a 80386 PC.)

Solid modelers also provide an easy way to create initial massing concepts of the building to be designed. Both technical and aesthetic considerations affect these initial concepts. Technical considerations include setback and step back requirements, required accesses, easements, and other zoning restrictions. Aesthetic considerations include proportions, scale, and the "effect" on the skyline. Most overall building shapes can be described using various combinations of simple 3-D shapes (blocks, cones, cylinders, pyramids, spheres, etc.). Such building shapes are easily created using 3-D primitives and Boolean operations provided by typical solid modelers. The design concept shown in Figure 2 was created using such

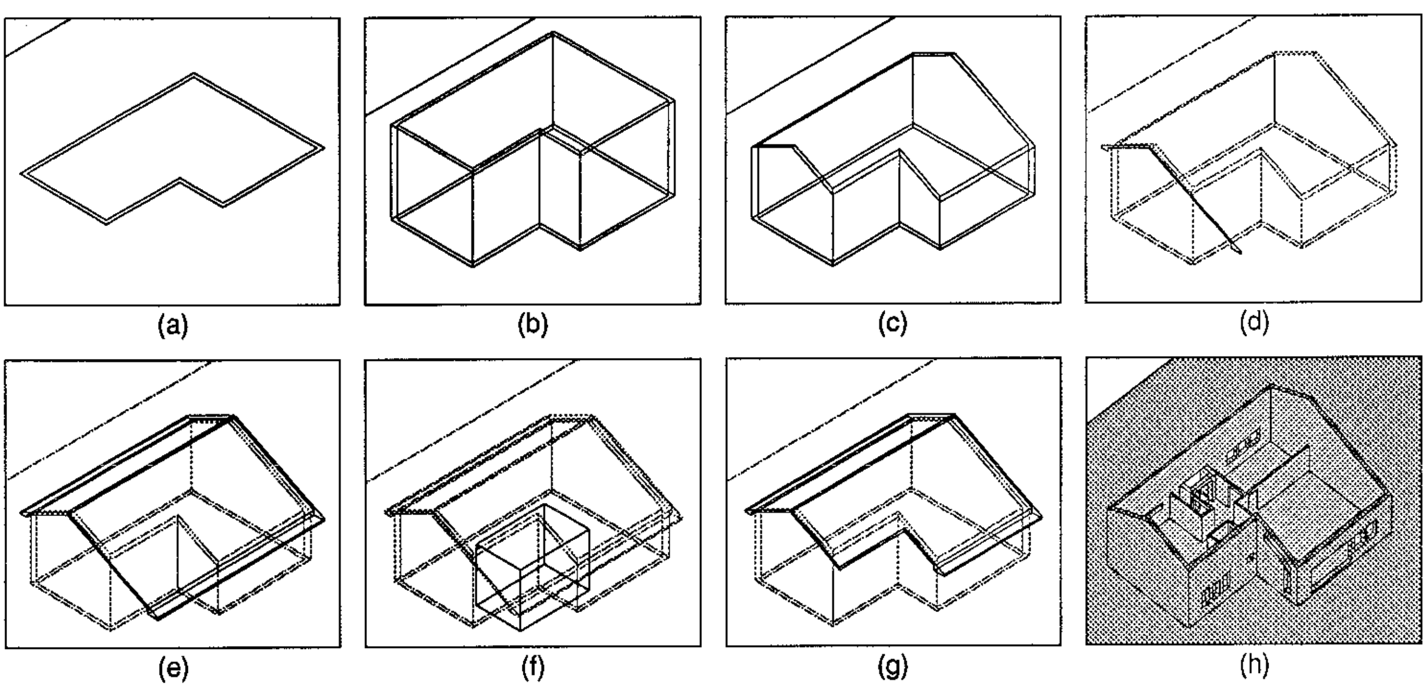



Figure 3. Primitives, sweeps, and Boolean operations can be used to easily and quickly define interior spaces as summarized in (a) - (h)

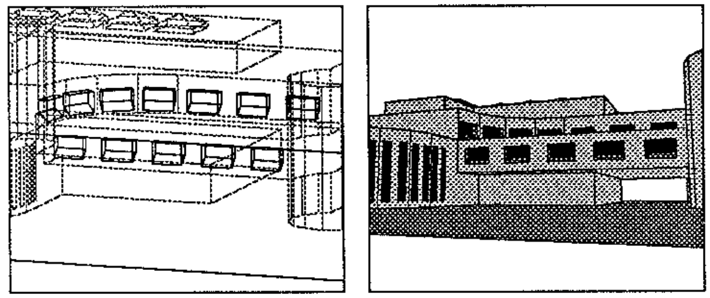
techniques. Once building mass is defined, the various technical and aesthetic considerations can be checked. Most modelers make it relatively easy to modify the building mass as required. Solid modelers also provide an easy means of doing preliminary concept studies of additions to existing buildings.

### *Creation of Interior Architectural Volumes*

Though massing studies are often the first "drawings" to be created in architectural design, attention must soon turn to consideration of interior spaces and the relationships between them. Architects often talk of "positive" space vs. "negative" space where positive space is the volume accessible to occupants and negative space is the volume taken up by walls, ceilings, utility spaces, etc. Whereas most engineers are initially more concerned with filled volumes, architects are initially more concerned with the empty volumes; i.e., what they call the "positive" space. But positive space is delimited by negative space; i.e., by "solid" elements. So here again, solid modelers, if considered appropriately, are a natural way to define interior spaces, even though the volumes being created are "empty", not solid. Sweeping, Boolean operations, and 3-D primitives provide excellent tools for creating such interior spaces (see Figure 3).

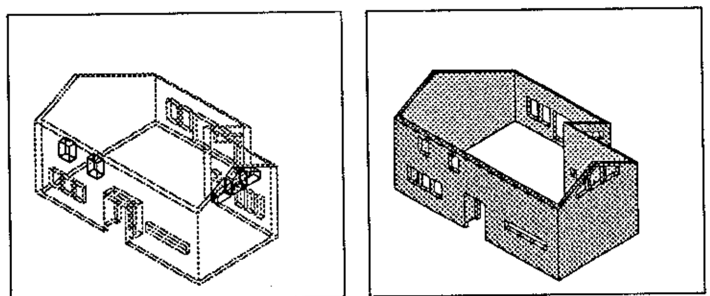
### *Fenestration Studies*

3-D primitives and the Boolean difference operator also provide an easy method for designing the initial fenestration for a building, especially if the modeler provides convenient ways of moving, resizing, and/or reshaping the openings. In Figure 4, modified 3-D primitives and Boolean differencing are used to suggest the fenestration patterns to help evaluate an initial massing concept - the interior spaces are not yet part of the computer model. In Figure 5, openings in the exterior walls are created after the major interior spaces have been defined. This allows a quick evaluation of the sizes, positions, and patterns of the openings from both outside and inside.



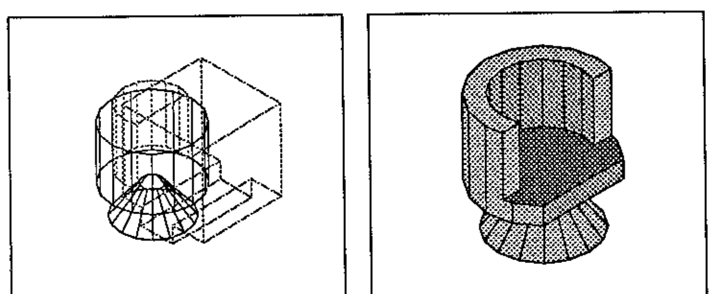
(a) primitives sized and positioned (b) fenestration after Booleans

Figure 4. Solid modeling for preliminary fenestration concept



(a) primitives sized and positioned (b) fenestration after Booleans

Figure 5. Solid modeling for openings in exterior walls



(a) primitives sized and arranged (b) bucket chair after Booleans

Figure 6. Solid modeling to create furniture shapes for interior context

### Creation of Interior Context

Once the interior spaces are defined, context, especially furniture, can be added to make the space more realistic. Modelers such as SilverScreen allow furniture models to be created and stored in model libraries and then inserted into the design wherever and as often as desired. Or furniture can be created on the fly, again using solid modeling techniques (see Figure 6). Once the model is created in sufficient detail, the model can be rendered, either within the modeler or after exporting the model geometry to a software package specifically designed for such tasks. The capabilities of some of these rendering packages (e.g., RenderMan™ and Model Vision™) are fast approaching photo realism. Combining solid modeling, rendering, and animation makes it possible for the client to "walk around and through" the building before it is even built. Even a relatively inexpensive modeling package such as SilverScreen can create a series of scenes from a walkaround/walkthrough such as is shown in Figure 7.

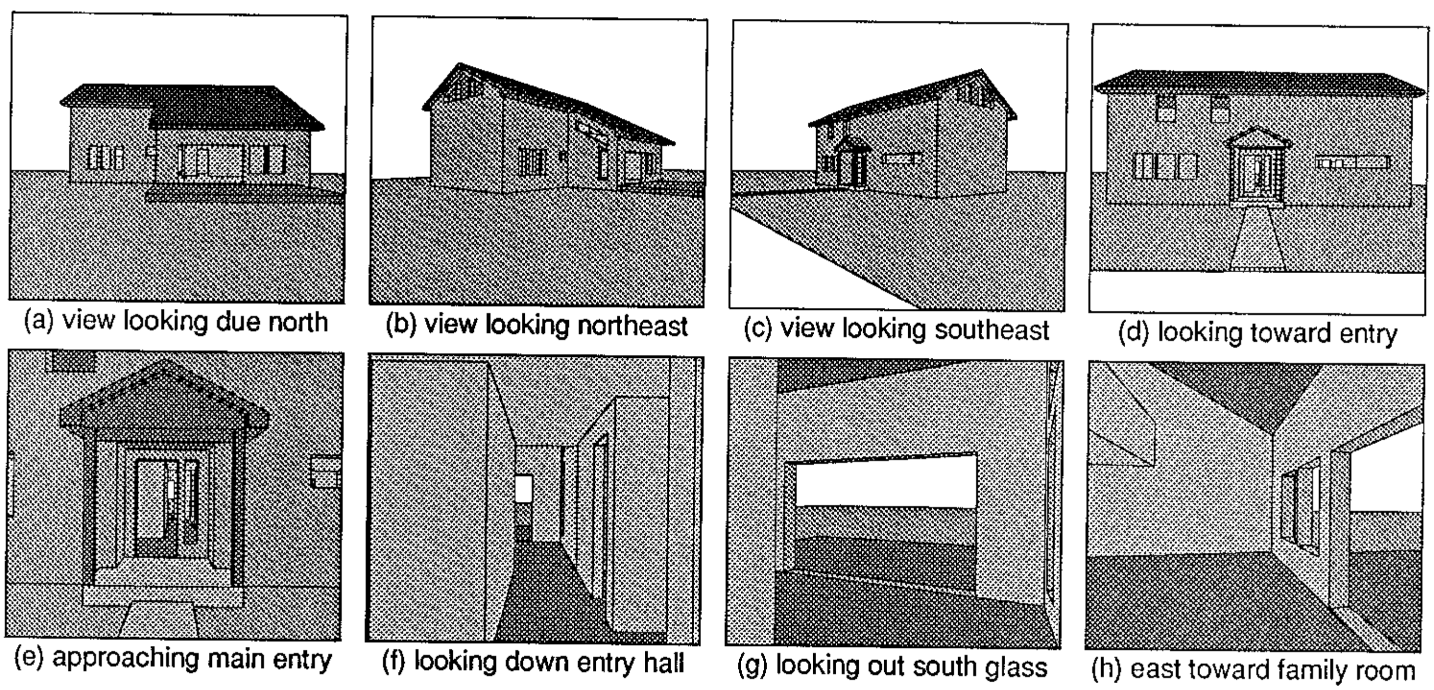
## Solid Modeling for Technical Analysis and Documentation

### *Structural, HVAC, and Lighting Analyses*

Solid modelers can also be used for the more technical aspects of architectural design. By careful organization of the solid components used to initially create, refine, and modify the design, most, if not all, of the information necessary for such things as structural, HVAC, and lighting analyses are readily available. For example, all the principle structural elements can be kept in a separate layer or block and then exported to a frame or finite element analysis package (see Figure 8). Because the structure is modeled as a solid, such things as areas, volumes, masses, and centroids are readily available for use in the structural analysis. Many modelers allow non-geometric data to be associated with the geometrical elements, in which case such properties as densities, strengths, and moduli of elasticity can also be made readily available directly from the model data base. Similarly, such things as volumes, masses, areas of glass, exterior wall, and roof along with associated thermal properties can be made available from the solid model data base for use in heating, ventilating, and air-conditioning analyses.

### *Construction and Cost Analyses*

Much of the geometrical information inherently available from the solid model is also useful in construction analysis (refer again to Figure 8). Volumes and areas are often essential for cost analysis. Interference checks are usually easy to make because of the nature of solid modeling software. If identifying tags and other non-geometric data can also be associated with model components, determining component counts, material quantities, and costs are made that much easier.



(a) view looking due north
(b) view looking northeast
(c) view looking southeast
(d) looking toward entry
(e) approaching main entry
(f) looking down entry hall
(g) looking out south glass
(h) east toward family room

Figure 7. Scenes from a walkaround/walkthrough done on a solid modeler running on a PC

### Documentation

Lastly, the existence of an unambigous solid model of all the major components that make up the building make the generation of the required construction drawings relatively easy. Modelers often provide for the semi-automatic generation of associative dimensions. True sections can also usually be generated very easily by solid modeling software. Based on this author's experience, work still needs to be done to enable solid modeling software to create construction drawings that follow standard drawing conventions, don't contain redundant lines in the output drawing data, and show hidden lines and centerlines and such details when and where appropriate. But the potential is most certainly there. It seems within the realm of possibility that the creation of "correct" construction drawings could become almost totally automated within the not-too-distant future.

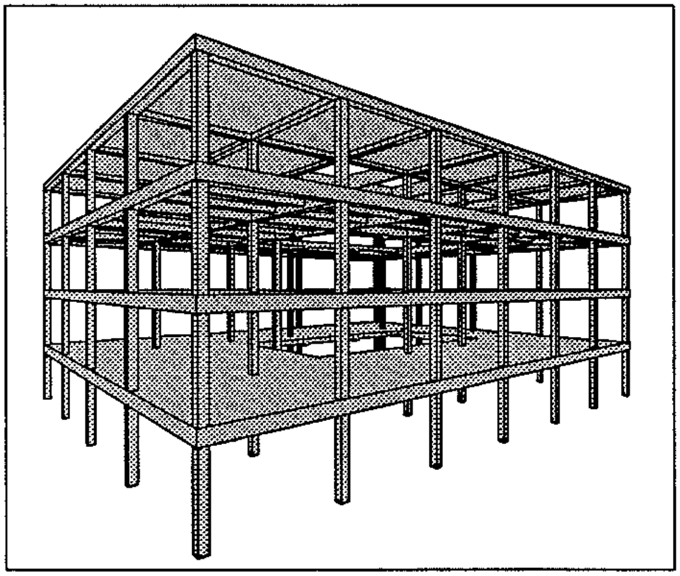


Figure 8. Solid model of the structural framework is stored in a separate block where it can be used for various analyses

## Conclusion

Fortunately for educational institutions such as Iowa State, several such modeling software packages (e.g., SilverScreen, Auto Modeling Extension, CADKEY SOLIDS) have recently become available for use on hardware that is affordable in large quantities for use at the undergraduate level. Because of this and all the advantages of solid modeling in architectural design described above, we have begun introducing architectural students to solid modeling concepts in a "Computer Applications for Architects" course. We used the solid modeling package SilverScreen for about one-third of the spring 1990 semester and plan to increase that to about one-half the semester this coming spring semester (1991). Experience so far seems to support the contention that solid modeling is one of the best computer-aided design tools available for architectural design.

## Note

*This paper was initiated at the NSF Seminar in May, 1990.*

## Trademarks

- SilverScreen is a trademark of Schroff Development Corporation, Mission, Kansas.
- Auto Modeling Extension is a trademark of AutoDesk, Sausalito, California.
- CADKEY SOLIDS is a trademark of CADKEY, Inc., Manchester, Connecticut.
- RenderMan is a trademark of Pixar, Point Richmond, California.
- Model Vision is a trademark of ASG, Sausalito, California.

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# An Assessment of Research Activities in Engineering Design Graphics

Professor Robert A. Chin
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East Carolina University

## Abstract

*An assessment of research activities in engineering design graphics was undertaken. A panel of experts was identified and asked to provide input on the research activities currently underway and the nature of research efforts that must be undertaken in the next five years. The findings suggest that some disparity exists between research underway and research that must be conducted in the next five years.*

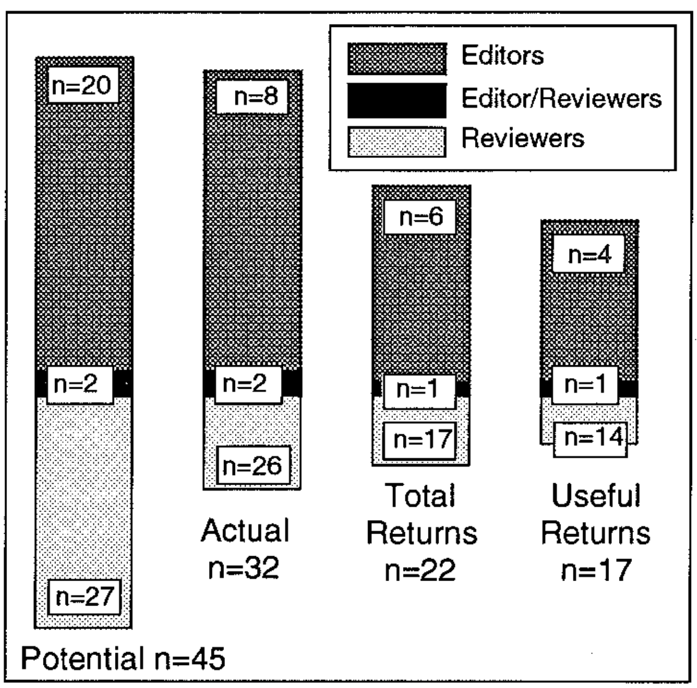


Figure 1. Research Topics Currently Under Investigation by Engineering Design Graphics Faculty

## Introduction

The Engineering Design Graphics Division is the component within the American Society for Engineering Education responsible for:

1. Providing leadership and guidance for those engaged in the teaching of conceptual design and graphical analysis and their use in industry.
2. Investigating matters relating to engineering graphics and to inform the membership of current developments.
3. Encouraging early participation of engineering students in the areas of graphics and design.
4. Promoting, stimulating, and providing opportunities for the professional interchange of ideas among the membership.

The *Engineering Design Graphics Journal* (the *EDGJ*) is the official publication of the Division and has been the principal medium of formal communication in English for engineering design graphics professionals since 1936. Its scope is devoted to the advancement of engineering design graphics, computer graphics, and subjects related to engineering design graphics in order to:

1. Encourage research, development, and refinement of theory and applications of engineering design graphics for understanding and practice.

2. Encourage teachers of engineering design graphics to experiment with and test appropriate teaching techniques and topics to further improve the quality and modernization of instruction and courses.

3. Stimulate the preparation of articles and papers on topics of interest to the membership.

A major tenet of most leading United States universities is the concept that scholarship and advanced research training be conducted jointly in institutions of higher learning (*Science and Technology in the Academic Enterprise: Status, Trends, and Issues*, 1989). That is, a dual emphasis on new knowledge and pedagogy has established an interdependence between education, including advanced research training, and research. As a result, universities produce new generations of teachers, researchers, and other professionals, as well as fundamental knowledge.

This tenet has evolved over a period of about four decades. While funding has sustained this concept, it has not kept up with the pace of increased demand being placed on the system. As a result, program administrators are being forced, more and more, to find the perfect balance between numerous demands for competing resources. The Government - University - Industry Research Roundtable (*Science and Technology in the Academic Enterprise: Status, Trends, and Issues*, 1989) has noted that to continue worldwide eminence and to continue experiencing the same success it has always experienced, policy makers must address three major challenges:

1. To maintain the overall quality of the nation's universities and their academic research, in an increasingly diversified enterprise with financial constraints.

2. To ensure sufficient scientific and technical human resources.

| | |
|---|---|
| **TECHNICAL** | |
| 1 | Micro chip design |
| 1 | Computational fluid dynamics |
| 1 | Finite element analysis |
| 1 | Modeling |
| 3 | Solid |
| 1 | Comparison of approaches |
| 1 | Feature based |
| 1 | Application of |
| 1 | Surface |
| 1 | Rational splines |
| 1 | Algebraic surfaces |
| 1 | Techniques versus visualization/ understanding of models |
| 1 | Computer geometric |
| 1 | Boolean geometry |
| 1 | Production of engineering drawings from models |
| **INSTRUCTIONAL METHODOLOGY** | |
| 1 | Presentation of graphics principles |
| 2 | Use of computers |
| 1 | Linkage between instruction and computer graphics |
| 1 | Teaching effectiveness |
| 1 | Techniques |
| 1 | Effectiveness of CAD |
| 1 | Grading techniques |
| 1 | Test validity and reliability |
| 1 | Use of classical spatial CAD analysis |
| **VISUALIZATION (1)** | |
| 1 | Use of CAD techniques |
| 1 | Perception--spatial and projection |
| 1 | Static and animated diagnostic test development |
| 1 | Techniques |
| 1 | Spatial |
| 1 | Real world models versus computer models |
| 1 | Use of interactive software |
| 1 | Impact of computers on |
| 1 | Testing |
| **CURRICULUM PROGRAMS (2)** | |
| 1 | Nature of computer graphics curriculum |
| 1 | Requirements |
| 1 | Faculty in aerospace and computer engineering |
| 1 | Use of facilities |
| **ENGINEERING DESIGN GRAPHICS** | |
| 1 | Role of |
| 1 | Relevance of |
| 1 | Significance of |
| 1 | Standards |
| 1 | Defining |
| 1 | Archiving |
| **INSTRUCTIONAL MATERIALS** | |
| 1 | Revision of texts and workbooks |
| 1 | Hypercard courseware |
| 1 | CD ROM |
| 1 | Educational software development |
| **COMPUTER** | |
| 1 | CAD |
| 1 | Standardization of CAD terms, operations, and procedures |
| **DESCRIPTIVE GEOMETRY** | |
| 1 | Relevance of |
| **HISTORY and PHILOSOPHY** | |
| 1 | History |

Table 1. Research Topics Currently Under Investigation by Engineering Design Graphics Faculty

| | |
|---|---|
| **TECHNICAL** | |
| 1 | NC documentation |
| 1 | Micro chip design |
| 1 | Computational fluid dynamics |
| 1 | Finite element analysis |
| 1 | Modeling |
| 1 | Comparison of packages |
| 1 | Manufacturing simulation |
| 1 | Technical aspects of programming, software, and hardware |
| 2 | Solid |
| 1 | Surface |
| 1 | Spatial |
| 1 | Rational splines |
| 1 | Algebraic surfaces |
| 1 | Dynamic systems |
| **CURRICULUM PROGRAMS** | |
| 1 | Industrial technology students |
| 1 | Link between design and manufacturing |
| 1 | Development of curriculum |
| 1 | Faculty in aerospace and computer engineering |
| **COMPUTER** | |
| 2 | CAD |
| 2 | CAD applications |
| 1 | Simulation |
| **VISUALIZATION (2)** | |
| 1 | Static and animated diagnostic test development |
| 1 | Techniques |
| **ENGINEERING DESIGN GRAPHICS** | |
| 1 | Standards |
| 1 | Defining |
| **ARTICULATION/OUTREACH** | |
| 1 | CAD needs analysis of small businesses |
| **INSTRUCTIONAL MATERIALS** | |
| 1 | Educational software development |

Table 2. Research Topics Currently Under Investigation by Graduate Students in Engineering Design Graphics

3. To enhance the nation's ability to address new scientific and technological opportunities and concomitant societal demands.

Seemingly, the objectives of the Division and the scope of the *EDGJ* are quite consistent with those of the research component of our nation's universities. The challenges facing the Division and the *EDGJ* with respect to research, no doubt, are the same or are very similar to those facing policy makers. That is, how and to what end should the discipline direct its resources and efforts?

One approach in responding to the aforementioned challenges is to conduct a needs assessment (Nickens, Purga, & Noriega, 1980). While there is a variety of reasons for conducting a needs assessment, its role in responding to noted challenges is to serve as a feedback mechanism toward doings a better job of serving a community.

## Purpose

The purpose of this study was to provide some direction for the allocation of efforts and scarce resources that support research in engineering design graphics. Thus, within the context of this framework, the following questions were posed:

1. In what areas are faculty and graduate students expending efforts and resources?
2. In what areas should faculty and graduate students be expending efforts and resources over the next five years?
3. Do gaps exist in the involvement of faculty and graduate students in the research being conducted and the research which needs to be conducted in the next five years?

## Background

A review of literature failed to produce any recent information on an assessment of or recommendations for the direction of research efforts in engineering design graphics. The last time results were published in the *EDGJ* related to an examination of research efforts in engineering design graphics occurred when Earle

(1965) reviewed the research activities in engineering graphics at Texas A & M. The work, however, was limited to research (1) produced in a given year and (2) used or in use at that time in doctoral dissertations. Even prior to Earle's publication, very little was written on the nature of research in engineering design graphics.

## Need

A need for this study was quite apparent given the challenges posed by today's ever shifting economic climate, in particular as it relates to financial constraints imposed on today's universities, and the lack of a research agenda in engineering design graphics. Minimally, such findings can provide researchers and administrators of resources with guidance for expending efforts and resources. The findings can also serve as a springboard for an ongoing program designed to assess research efforts in the discipline.

## Method

While a needs assessment can be approached from a number of different directions (Warheit, Bell, & Schwab, 1975), this study made use of two by melding their strengths: the key informant approach (that is, input was solicited from experts), and the survey approach.

## Subjects

For the purpose of this study, a panel of experts composed of past and current *EDGJ* Editors, Technical Editors, and Reviewers was identified. This group of individuals was chosen because they are usually elected to or selected for their respective positions because of the expertise they possess and because of their interest in serving the Division and profession.

Since the inception of the Journal in 1936 to the publication of issue number 2, volume 55, 18 different individuals have served as the Journal's Editor, and two other individuals have served as its Technical Editor. The introduction of the review process to the Journal in 1983 added a Review Board to

| | |
|---|---|
| **ENGINEERING DESIGN GRAPHICS** | |
| 3 | Role of |
| 1 | Relevance of |
| 1 | Significance of |
| 2 | Standards |
| 1 | Defining |
| 2 | Prerequisite learned capabilities necessary for success in |
| 1 | Engineering design thought processes |
| **TECHNICAL** | |
| 2 | Global design--automated design/manufacture |
| 2 | Modeling |
|   1 |   Production of engineering drawings from |
|   2 |   Solid |
|   1 |   Surface |
|   1 |   Rational splines |
|   1 |   Algebraic surfaces |
|   1 |   Modeling for analysis |
| **CURRICULUM/PROGRAMS (1)** | |
| 1 | Concurrent engineering as curriculum model |
| 1 | Computer graphics |
| 1 | Course content |
| 1 | Computer graphics curriculum |
| 2 | Curriculum development |
| 1 | International faculty exchange |
| 1 | Incorporating change |
| **VISUALIZATION (3)** | |
| 1 | Use of solid modeling |
| 2 | Effects of color, value, texture, animation |
| 2 | Techniques |
| 1 | Impact of computer on |
| **COMPUTER** | |
| 1 | Standardization of CAD systems, software, terminology, methods, procedures |
| 1 | Net cost of computer use |
| 1 | Impact of engineering database on design and manufacture control |
| 1 | CAD to the design process |
| 2 | Development of new and refinement of existing algorithms |
| 1 | Application of fractals |
| **INSTRUCTIONAL METHODOLOGY** | |
| 1 | Presentation methods |
| 1 | Linkage between instruction and computer graphics |
| 1 | Use of industrial problems in CAD instruction setting |
| **ARTICULATION/OUTREACH** | |
| 1 | Needs of industry and interfaces with industry |
| 1 | Needs assessment of industry |
| **INSTRUCTIONAL MATERIALS** | |
| 1 | Application graphics technology |
| 1 | Technologies and reaction/effectiveness in engineering graphics education |
| **DESCRIPTIVE GEOMETRY** | |
| 1 | Relevance of |
| **HISTORY AND PHILOSOPHY** | |
| 1 | Development of a philosophical foundation |

Table 3. Research Topics that Need to be Investigated by Engineering Design Graphics Faculty in the Next Five Years

| | |
|---|---|
| **TECHNICAL** | |
| 3 | Current CAD, modeling, rendering and animation, CAD/CAM, and CIM technologies |
| 1 | Animation |
| 1 | Design Analysis |
| 1 | Global design--automated design/manufacture |
| 1 | Vocabulary |
| **VISUALIZATION (3)** | |
| 1 | Use of solid modeling |
| 1 | Effects of color, value, texture, animation |
| 1 | Techniques |
| 1 | Skills--U. S. students versus those from other developed countries |
| **COMPUTER** | |
| 1 | CAD applications |
| 1 | Development of systems to improve use of design database in manufacture |
| 1 | Attitude of students on use of computers versus the need for traditional skills |
| 1 | Graphics |
| 1 | Refinement of graphics projection algorithms |
| 1 | Application of fractals |
| **CURRICULUM/PROGRAMS (1)** | |
| 1 | Concurrent engineering as a curriculum model |
| 1 | Educational research |
| 1 | Graduate programs |
| 1 | Undergraduate programs |
| **ENGINEERING DESIGN GRAPHICS** | |
| 1 | Standards |
| **HISTORY and PHILOSOPHY** | |
| 1 | History and evolution of engineering graphics |
| **INSTRUCTIONAL METHODOLOGY** | |
| 1 | Ability of students to communicate graphically without the aid of a computer |

Table 4. Research Topics that Need to be Investigated by Graduate Students in Engineering Design Graphics in the Next Five Years

the Journal's Editorial Board. In its short history, 27 individuals have served or are currently serving on that Board. Of the 20 editors (Journal and Technical), two have served as both an editor and as a reviewer, though not concurrently.

The total number of potential panelists then was 45: 20 editors and 27 reviewers (see Figure 1). All individuals identified, however, could not serve because some were deceased and others were simply no longer active in the Division.

## Instrumentation

A questionnaire was developed to gather data from the panelists. Through the questionnaire, each panelist was asked to respond to the following statements with respect to their perception of engineering design graphics research in academic settings:

1. Identify the research topics currently under investigation by faculty.
2. Identify the research topics currently under investigation by graduate students.
3. Identify the research topics that need to be investigated by faculty in the next five years.
4. Identify the topics that need to be investigated by graduate students in the next five years.

In addition, the panelists were provided an opportunity to make additional comments and were encouraged to staple an additional sheet to the questionnaire if more space was needed.

## Procedure

Two sources were used to generate addresses for the panelists: the *EDGJ* itself and the engineering design graphics directory (Boyer, 1990). While there were 45 potential panelists, only 32 individuals were considered active in the Division or available to participate--8 editors and 26 reviewers (see Figure 1).

Three mailings were conducted: an initial and two follow-ups. Twenty-two panelists responded for a return rate of 69%

(see Figure 1). Among the 22 respondents, five indicated that they did not feel qualified to provide input.

## Results

Following an examination of the responses provided by the panelists, categorical classifications were developed, the frequency of the responses was tabulated, and the nature of the responses was categorized.

Table 1 summarizes the nature and extent of nine categories of research currently under investigation by engineering design graphics faculty as perceived by the panel of experts. The data tend to suggest that faculty have been focusing their efforts first and foremost on Modeling, one of the topics in the Technical category. This was followed by efforts in the areas of Instructional Methodology and Visualization.

Table 2 summarizes the nature and extent of seven categories of research currently under investigation by graduate students. Again, the Technical topic of Modeling was cited as the one in which graduate students were most active. Graduate students were also involved in research related to Curriculum/Programs, Computers in general, and Visualization.

Table 3 summarizes the nature and extent of ten categories of research in need of attention by engineering design graphics faculty during the next five years. Two categories--Engineering Design Graphics and Technical--were perceived as requiring the greatest attention. A focus on Modeling, however, tended to drive the Technical category. These two categories were followed closely by the need to direct resources at research in Curriculum/Programs and Visualization.

Table 4 summarizes the nature and extent of seven categories of research in which graduate students should be involved during the next five years. The data tend to suggest that graduate students need to involve themselves in research associated with Technical topics, Visualization, Computers in general, and Curriculum/Programs.

Nine panelists took advantage of the opportunity to provide additional comments. Seven of the panelists' comments are

- "EDG is a Design course"
- "Research (funded) in graphics is difficult to obtain outside the areas mentioned above."
- "Much work remains in graphics curriculum development. I don't see a solution to the current scism [sic] where CAD tool users have little or no input to CADD tool creators. Possibly, through research, we might provide the bridge between programmer and user."
- "I felt unqualified to comment on activities at univ. other than [name of institution cited by panelist omitted for confidentiality]."
- "We need to develop a philosophical foundation for the discipline then begin work on a research agenda. If this is not done, engineering graphics will continue to flounder and may even cease to exist."
- "I'm afraid there is very little research among us that is adding to the 'body of knowledge"
- "We must drop our elitist atitude [sic] that we are only interested in engineering students. Technologists require & use as much or more graphic [sic] as engineers. We need to encourage & incorporate their interests & needs into EDG."

Table 5. Additional Comments

| Category | *Currently Underway* | *Five Years Hence* |
|---|---|---|
| Technical | 17 | 11 |
| Engineering Design Graphics | 6 | 11 |
| Visualization | 10 | 9 |
| Curriculum/Programs | 6 | 9 |
| Computer | 2 | 7 |
| Instructional Methodology | 10 | 3 |
| Instructional Materials | 4 | 2 |
| Articulation/Outreach | 0 | 2 |
| Descriptive Geometry | 1 | 1 |
| History and Philosophy | 1 | 1 |

Table 6. Comparison of Research Currently Underway by Faculty at Present and That Which Must be Undertaken in the Next Five Years

# Visualization of Three-Dimensional Form: A Discussion of theoretical models of Internal Representation

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## Abstract

*Current research in perception, cognition, and human-computer interaction is explored as a source of theories explaining the process by which three-dimensional forms are visualized. A number of theoretical models are summarized and compared in an attempt to uncover variables important to future research conducted by the EDG profession. The appropriateness of dynamic versus static imaging techniques to develop a student's visualization abilities becomes a vehicle for applying some of these theoretical models and proposing specific display techniques.*

## Introduction

Animation of computer graphics has been a topic of considerable interest among computer users. With the ever-improving price/performance ratio of computer equipment, the dynamic display of graphic information using traditional animation techniques has become affordable to a broad range of computer users. Educators involved in teaching engineering and technical graphics realize the potential of these powerful display tools for assisting students in developing their visualization skills (McCuistion, 1991; Wiley, 1990a).

An important skill taught to engineering students is the interpretation of multiview drawings. The mental synthesis of orthographic views into a three-dimensional form can be a difficult technique to learn. One approach to teaching students how to perform this synthesis would be to start with a 3-D object, choose a stationary viewpoint, and rotate the object in small increments between the standard orthographic views. This demonstration cannot only be done with a real object, but also with a dynamic sequence of images on a computer. If we generalize this process, we can see how using computer animation techniques can be used to help develop visualization techniques to describe how objects undergo all types of changes over time: in location and orientation and also in shape and size (Zsombor-Murray, 1990).

In addition to generating dynamic displays, computers are just as capable of producing static images much like the ones that have historically been used in teaching engineering and technical graphics. The question arises: are dynamic or static image presentation techniques more appropriate for teaching various visualization skills? A question such as this certainly does not have an obvious and straightforward answer. The visualization of three-dimensional form does, though, strike directly at issues of considerable current interest to the Engineering Design Graphics (EDG) profession. Authors such as Wiley, Miller, and Bertoline have advocated developing curriculum and a methodology of future research based partly on existing visualization research in psychology and education (Miller & Bertoline, 1991; Wiley, 1990b).

Experimental psychology in the areas of cognition and perception have a rich tradition in exploring issues related to the visualization of three-dimensional form. In addition, more recent research in this area has been directed specifically at the design of computer displays. Perceptual and cognitive principles are critical for understanding Human-Computer Interaction (HCI) and, of most interest here, the use of the computer to assist in the visualization of three-dimensional form (Allen, 1982; Haber & Wilkenson, 1982). For these reasons, this paper explores research in perception and cognition for potentially useful insights into understanding what techniques of visual display on the computer might show the most promise in teaching visualization skills to students. The central interest is a better understanding of the mechanisms involved with the mental representation of three-dimensional form as it is understood by researchers today.

Research work across disciplines is an inherently difficult task to achieve. Differing end goals, research methods and semantics all interfere with the melding of useful information. The EDG profession is not only attempting to make use of psychological research, but many distinct areas within this discipline. Eliot (1987) uses the concept of models as a way of transcending some of these boundaries. In his definition, theoretical models are descriptions or analogies that help us to visualize something that cannot be observed. Models may be substructures of theories, or they may stand on their own. Most importantly, they draw attention to variables of importance for future research. There is a synergy in working with theoretical models in our minds to help understand the representation of physical forms in the minds of students.

## Theories of Internal Representations

### *Imagery*

One does not have to look very far to find professionals in science and technical fields who use mental imagery of three-dimensional form to assist them in solving problems. It might be a medical researcher exploring the structure of a protein molecule or a mechanical engineer working on a mechanism design for a car. Though psychologists, philosophers and others have attempted to answer questions pertaining to mental imagery over the years, a major resurgence of interest took place among cognitive psychologists in the early seventies. Instead of looking at the nature of abstract, logical thought, Shepard & Metzler (1971) looked at a more analogical issue: how do we mentally image and manipulate a set of connected cubes.

As the result of a series of experiments that he and his colleagues performed, Shepard (1978) came to a number of broad conclusions. First, though it may be unwise to think of the brain process underlying a mental image as some sort of picture, there is a close, analogous relationship between the mental image and a perceived object. Secondly, subjects are able to formulate a mental image of an object even if it is not physically perceived. Furthermore, subjects use very similar mental processes on the image in both the perceptual and imaginal conditions.

These results confirm what graphics educators have always known; that perceived objects and mental images of objects influence the way we understand 3-D form. If, indeed, there is a close analogous relationship between the perceived object and the mental image formed of it, consideration must be given to the way the object is presented to students if a sound mental image is going to be formed. This becomes particularly critical if it is not the object itself, but a computer generated image of one that is being presented.

> "The question arises: are dynamic or static image presentation techniques more appropriate for teaching various visualization skills?"

### *Retinal Patterns*

For those mental images formed by perceiving an object directly or as a graphic representation, the visual information must be received through the eyes and form a pattern on the retina. Not only is a single, static pattern useful in discerning form, but changing patterns (such as those produced by a computer animation) can create its own unique information. These changing patterns of retinal stimulation — even when the cues are viewed monocularly and showing no perspective convergence — can produce the perception of three-dimensional form (Wallach & O'Connel, 1953).

Gibson (1966) also concluded that these patterns, or optic array, contain enough information to fully comprehend three-dimensional form in the environment around us. An important point he makes is that visual sampling which forms a retinal image should not be thought of as discrete, but as an overlapping mosaic. The resulting perceived three-dimensional form is not so much a product of what is in each discrete image, but comparisons made between them.

Researchers such as Julesz (1975) agree that considerable processing can be done on these patterns with purely automatic perceptual mechanisms. At the same time there is a distinct limit to how much pure perception can contribute to form recognition. Julesz contends that the purely perceptual pattern detection can only extract the simplest features of a form from an image and that for full comprehension of a form, higher level processing involving conscious thought is necessary.

"One does not have to look very far to find professionals in science and technical fields who use mental imagery of three-dimensional form to assist them in solving problems."

Marr (1982) is one of many contemporary researchers who have worked on a computational model of perception. He considers that, from a historical perspective, Gibson came the closest to the level of computational theory. Gibson asked the critically important question of how does one perceive constancy in the world around us on the basis of continually changing sensations. We internally work with a representation of an object that constitutes its "real shape", not one based on a single retinal pattern.

It is at this point that Marr diverges from Gibson. Marr agreed that we are actively searching for physical invariants in patterns that add to our understanding of a three-dimensional form. Where he disagrees is in the belief that this problem is exactly and precisely an information processing problem and that the detection of these invariants is vastly more complicated than Gibson stated. Rather, these mental processes can be viewed as a symbol-manipulating system. The computation it supports is the construction of useful descriptions of the visible environment.

Approaching the interpretation of retinal images with many different models, researchers have developed a much clearer understanding of how visual information is processed. Disagreements do, however, exist on a number of fundamental issues. For example, how are sequences of images on the retina combined and how is this information processed?

## The Mind as an Information Processor

The analogy of the human mind as an information processor affords some unique approaches to understanding the generation of internal images or representations. Whereas Shepard emphasized the functional aspects of imagery, Kosslyn (1980) developed a model of imagery more structural in nature. The structural mechanisms involved in internal imagery are similar to those used in perception and involve information being stored in specialized locations. Furthermore, the information stores are acted upon by different processes that manipulate and modify the information. Kosslyn took this model to its logical extreme by developing computer programs that simulated this model.

Another approach to this information processing model is to look at the "bandwidth" of the mind to receive and process information (Baecker, 1987). Perception, as an active process, needs resources to process visual information. When these critical resources are limited, our ability to make use of visual information degrades. Though there is a point of diminishing return, if more resources are made available, performance will be enhanced. If no more resources are available, another way to increase performance would be to improve the quality of information being received so not as much processing has to be done. Yet another way to improve performance is to be able to rely on "previous experience" to assist in the processing of the information. The efficiency in which this information can be retrieved from long-term memory will influence how much use it is in processing information currently being received.

Paivio (1983) looked specifically at the role that long-term memory played in imagery. He maintained that long-term memory contained two different but interconnected symbolic systems for coding and representing information. One, imagery, is a memory code for processing spatially synchronous information, whereas a verbal coding system processes in a sequential fashion. This dual-coding model helps to remind us of the uniqueness of generating and manipulating internal representations of spatial forms over working with verbal or written information.

Looking again at the computational model, Marr (1982) postulates that the retinal patterns generated through vision go through a number of stages of processing in order to build up a final internal representation of an object. At the early stages, a primal sketch is formed through algorithms that make explicit important information within a retinal image. This information is made up of such primitives as edge segments, boundaries, curvilinear organization and the like. Later stages of processing are 2 1/2-D sketch and finally 3-D model representation. As in most of the previous models mentioned, this model takes into account both static and dynamic imagery. Dynamic imagery, in particular, has led to interesting models of how the final three-dimensional form is perceived from a stream of visual stimulation.

## Transformation of Stimulation into Form

The models outlined so far hold that patterns resulting from retinal stimulation are transformed into internal representations of the object being viewed. It is a big jump to now try to outline more specifically how the transformation actually takes place. A seemingly profitable approach of a number of researchers has been to try to understand this transformation not for a static object, but one in motion. The question can then be asked, what type of geometric or mathematical model best describes the changes in the retinal image resulting from the object in motion?

Much of our thinking about the description of objects and space continues to be influenced by Newton's and Kant's view of three-dimensional Euclidian space (Eliot, 1987). It is a conception that gives rise to the notion that we can use an extrinsic measurement system (usually linear and two-dimensional) to directly measure the retinal image. A number of researchers have pointed out that when applied to the real-world case of geometry in motion, this Newtonian approach leads to many artificial complications (Johansson, 1975; Lappin, 1986). If we are to believe that our internal representation of a three-dimensional form is independent of any particular orientation, a geometric model that preserves the perceptual invariance of an object as it undergoes motion will be the most profitable approach. Given the temporal nature of an object undergoing motion, Eliot urges us to consider non-Euclidian models that capture the spirit of Einstein's contention that timeless space does not exist.

"... perceived objects and mental images of objects influence the way we understand 3-D form."

Johansson (1975) advocates a complete break from the Euclidian model by proposing a nonmetric geometry based exclusively on relations rather than particular measurements. This geometry, *projective geometry*, is based on the concept that certain relations remain invariant under perspective transformation. Like Gibson, he believes that the perceptual system abstracts these invariances in the changing retinal image and constructs percepts of rigid objects moving in three-dimensional space. Using a model titled *perceptual vector analysis*, Johansson has performed a number of experiments exploring phenomenon surrounding this concept. Though the model proposes a non-Euclidian method for processing the visual information, the resulting perception (from the internal representation) is as we would expect: constant Euclidian shapes in rigid motion in a three-dimensional world.

The computational model of Ullman (1979) also directly addresses the issue of objects in motion but from the standpoint of symbol processing rather than the spontaneous abstraction of three-dimensional form from changing retinal patterns. The first step (not elaborated on here) is the matching of different images representing the same physical object by the correspondence process. Once this is done, one of two distinct interpretation processes is used to transform the images into the representation of three-dimensional form.

"... computer-assisted instructional material containing dynamic imaging improved performance on mental rotation tests relative to similar instructional material containing only static images."

The first interpretation process, *Structure from Motion* (SfM), states that we have the capability to infer 3-D structure from a changing image when each static projection by itself contains no useful 3-D information. The fundamental problem underlying this interpretation process is the ambiguity that arises from the lack of a one-to-one correspondence between a given 3-D structure in motion and a given 2-D (retinal) image transformation. The application of *reflective constraints* — uniform use of knowledge that reflects general properties of objects — to 2-D image transformations reduces the range of possible interpretations. The primary constraint proposed is the *rigidity assumption:* that the image transformations should be interpreted with a bias towards understanding it as a rigid object.

Building on the rigidity assumption, Ullman derives his *structure from motion theorem*: "Given three distinct orthographic views of four non-coplanar points in a rigid configuration, the structure and motion compatible with the three views are uniquely determined." (Ullman, 1979, p. 148) Again, we can see how the thinking of researchers such as Ullman so closely parallels the experiences and work of members of the EDG profession. He goes on to highlight some readily identifiable points. Namely that 3-D structure can be derived from as few as three distinct orthographic views and of the importance that the four identifiable points are non-coplanar. This theorem forms the minimal nucleus on which the interpretation scheme can operate.

Ullman resolves the fact that the projection of the environment to the eye is perspective and not parallel by proposing that perception of objects is based on a polar-parallel system. Under this system, local features are resolved through rigid interpretations applied to a nuclei of elements using an approximation of orthographic projection. The polar component of the projection system is then applied globally to the object to fully resolve the 3-D form of the object.

The second interpretation scheme proposed by Ullman, *Motion from Structure* (MfS), recognizes that often 3-D structure is perceived from single static frames. Under this scheme, known structure can be used to derive motion in space from a series of static frames. It follows that when static 3-D perception is present, both SfM and MfS operate simultaneously. It is not perfectly clear, however, to what extent the static and dynamic interpretations interact.

This last section demonstrates that when attempting to explain the internal processes that transform 2-D retinal images into an internal representation of a 3-D form, researchers in perceptual and cognitive psychology are relying on tools very familiar to those in the EDG profession. The computational model proposed by Ullman was a good example of this connection. There are a number of elements the models of Lappin, Gibson, Johansson, Ullman and others have in common. For example, they all find the exploration of geometry in motion and the resulting dynamic retinal patterns a valuable approach to trying to understand how we perceive three-dimensional form. Also, just as important, is all of the proposed geometric systems attempt to achieve a resulting internal representation independent of any particular viewpoint of the object. This internal representation is not a collection of individual snapshots of an object in motion but, rather, a singular, canonical form.

## Dynamic Versus Static Imaging

Arguments for the use of dynamic imaging for enhancing visualization abilities can be formulated from a number of models outlined in the previous sections. Very directly, Gibson argues that we normally perceive the world dynamically and that this dynamism removes ambiguity in our perception of three dimensional objects (Kaiser & Proffitt, 1989). McCuistion (1991) argues that enhanced spatial schema skills should be measurable through mental rotation tests. His studies show that computer-assisted instructional material containing dynamic imaging improved performance on mental rotation tests relative to similar instructional material containing only static images.

Empirical studies by Barfield, Lim, & Rosenberg (1990) have shown that dynamic image sequences created by the rotation of the subject's viewpoint about a perspective display improved the accuracy of some aspects of the spatial relationship between two bodies. Braunstein (1986) would contend the most important component of Barfield's enhanced display was the ability to rotate the scene rather than the perspective projection. Braunstein found that convergence, the cue that separates perspective from parallel projection was not as important as dynamic rotation in understanding 3-D form. The earlier stated model of Ullman (1979) would also support this contention. His theorem of structure from motion states both that a parallel projection is perfectly adequate for resolving 3-D form but that at least three distinct orthographic views are needed (easily generated by dynamic rotation).

Many of the previously outlined models make use of comparisons of multiple retinal images to extract information used in the construction of an internal representation of the 3-D object. Where is the raw retinal information stored as these comparisons are made? One explanation of the information processing model holds that as a subject views a sequence of dynamic images, the unstructured visual information is received in a visual buffer (Norman, 1982). This is called a buffer in part because what has been seen is retained for some length of time. This memory trace allows us to compare the current frame of the animation to the ones seen in the near past, giving context to the animation. Though the visual buffer allows for context to some past visual information received, the time span is very short. The information in this buffer decays exponentially: by 1/3 every 100-150 msec.

Some of the information in the animation may be retained by being passed on to short-term or long-term memory. There is, however, a severe limit to how many "chunks" of unrelated material can be held in short term memory (Haber & Wilkenson, 1982). These chunks in turn have a short life-span and will only be passed on to long-term memory if the information can be organized. Because of the nature of long term memory, the information stored there is filtered and incomplete and can be hard to recall relative to short-term memory and the visual buffer.

This model of how human memory functions argues against flexibility in making mental comparisons between what is currently being displayed in an animation and what was displayed at some time beyond the near-past. In our normal everyday lives we have the capability of extracting the necessary information from a constant real-time stream of images to navigate the environment successfully. When teaching our students, however, we are working with an impoverished visual information source — the computer display — and asking them to interpret novel forms at a level of detail with which they are not accustomed. It is in this environment that the bandwidth of visual information processing may be surpassed.

"In our normal everyday lives we have the capability of extracting the necessary information from a constant real-time stream of images to navigate the environment successfully."

## Techniques for Organizing Information

On one hand dynamic imaging techniques seem to support those models that use comparisons of multiple retinal images to develop an internal representation of 3-D form. Yet, information processing models seem to suggest that there may be a bandwidth limitation as to how many frames of a dynamic image sequence we are able to effectively process. Employing techniques of organizing and enhancing the information presented on the computer display may overcome some of these barriers (Haber & Wilkenson, 1982; Morse, 1979).

One potential solution would be to present all or some of the frames of a dynamic sequence on the computer display at the same time. Using selective attention, the viewer could make comparisons between

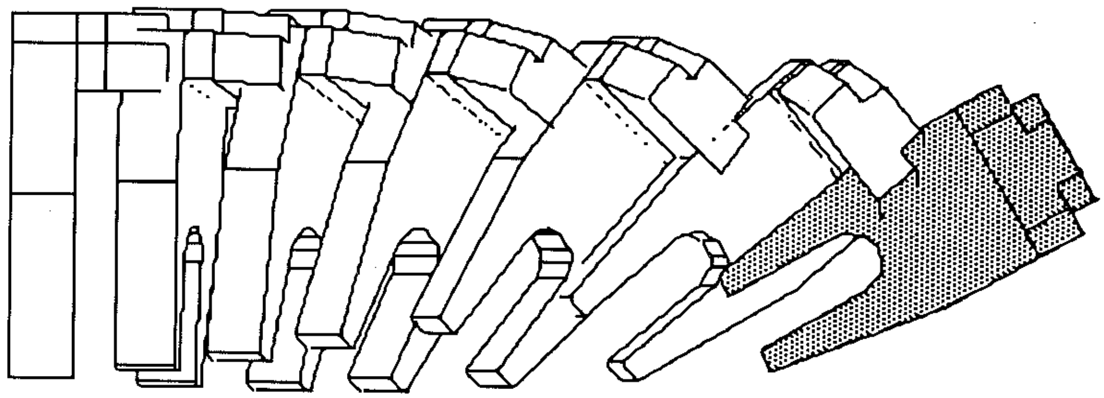

Figure 1. Trail of images

different portions of a single computer display rather than multiple unique displays. Here the challenge is to generate retinal patterns that allow comparisons to be made on discrete portions of the image without the temporal pressure of the display changing on the viewer as it would in a dynamic sequence. Paivio's (1983) model indicates that visual information is encoded in a parallel — or synchronous — manner versus serial encoding of verbal information. This would indicate that performance in processing visual information, such as that depicting a 3-D object, would be less sensitive to an increase in information in a single display than would verbal information. This gives support to the potential of simultaneously presenting a larger temporal slice than a single frame of an animation at one time.

Displaying multiple frames of a dynamic sequence simultaneously increases the complexity of the display considerably. If a large number of frames are displayed simultaneously, there is a need to organize the information in ways that the maximum amount of spatial information is derived from it as efficiently as possible. When looking at the interpretation of a 3-D object, Sanford, Barfield, & Foley (1987) and Yuille & Steiger (1982) both found that when figure complexity increased, the object was evaluated on a feature-by-feature basis. This feature-based analysis is akin to symbol manipulation in the computational model of perception (Marr, 1982; Ullman, 1979) or Paivio's (1983) contention that an image is a visual nested hierarchy based, in part, on levels of complexity. These features can be seen as components of the overall retinal pattern. If comparison of these components contributes significantly to the generation of the internal canonical representation, then techniques that enhance the viewer's ability to locate and organize these components of the overall retinal pattern should increase visualization performance.

Numerous researchers have proposed employing spatial organization techniques in order to relieve the perceptual and cognitive load on the viewer. In some cases the suggested spatial organization is based on an understanding of cognitive structure (Haber & Wilkenson, 1982), whereas in other cases historic principles of aesthetics and graphic design are employed (Morse, 1979; Tufte, 1990).

One recommended approach — referred to as *Small Multiples* by Tufte — is to organize graphic information based on a Cartesian grid or matrix, much as in a spreadsheet. This differs from a spreadsheet because instead of holding only a single numerical value, each node of the grid contains a unique graphic image. Though the graphic information contained within a node of this grid may not be highly structured, the organization of the overall image on the screen is. This arrangement allows for scanning large quantities of information with little effort. Since all of the nodes are displayed as a static image, the viewer can scan at will, conjecturing and testing visual relationships at a pace suitable for learning.

One of the real powers of a static display of a 2-D matrix is in the holistic nature of the information displayed. Not only does each node of the matrix represent a self-contained image, but the combination of all of the nodes creates a whole new image. If each node is thought of as an element in a pattern, then the subtle shifts between each node can set up a larger, overall perceivable pattern. This technique has been used in the encoding of multivariate information derived from satellite images (Pickett & Grinstein, 1988). The same techniques can be applied here with multiple views of a 3-D object.

One of the distinct disadvantages of the Small Multiples technique is the loss of spatial context of the individual frames. Each frame has been placed in a uniform spatial order based on the defined axes of the Cartesian grid rather than the actual location of the object in the original reference frame. It may be that preservation of spatial context is an important factor in making visual comparisons between frames. An alternate technique would be to allow the frames of the dynamic sequence to remain on the screen rather than overdraw them. This can be particularly effective if the object underwent a spatial displacement, leaving a trail of previous locations and orientations on the screen (Pollack, 1974).

For both of the above mentioned organizational schemes, various rendering techniques could be used to assist in the coding of the visual information. Color has been found to be a very powerful tool for coding information on the computer screen (Salomon, 1990; Truckenbrod, 1981). One way that color can be used is to highlight critical information. Since the goal is to identify the changes between a sequence of patterns, those elements of the pattern that do change can be highlighted using color coding. Another rendering tool to use is transparency. Though transparency does not have the same degrees of freedom that color does, it can be used in conjunction with other rendering techniques to depict a single variable such as time. Transparency used in conjunction with the trail technique can give the effect of fading over time.

The use of photorealism in rendering 3-D objects has been explored extensively as a method of increasing visual understanding of the object. Among the most common techniques explored are shading surfaces of the object to simulate a light source and hidden line removal. Research has not, however, come to a definitive conclusion as to whether these techniques improve the viewer's judgement of spatial relationships or performance on fundamental cognitive tasks such as mental rotation (Barfield, et al., 1990; McWhorter, et al., 1990; Sanford, et al., 1987).

## Specific Examples

There are a number of ways that static and dynamic display techniques can work together. One way of remedying the problem of bandwidth limitations in viewing an animated sequence of images is to record each of the images in a computer file. This history file provides a quick reference to past images seen on the screen. Used like a video recorder, the animated sequence could be played backwards or forwards at any speed and stopped for inspection at any point. Unlike the information stored in short or long-term memory, this historical record on the computer would consist of an unfiltered, complete record of past images seen. Though only one image would be seen at a time, the viewer would have a high degree of control over the speed and sequence of images. This should allow for flexibility in making visual comparisons with holistic information. One of the disadvantages to this technique is the tremendous amount of computer disk space that can be taken up with these history files.

"Research in perceptual and cognitive psychology provides a rich source of information for reshaping the EDG curriculum."

This problem is exacerbated when the resolution and number of supported colors is increased to make more realistic images.

A modification to the history file technique is leaving all or some of the frames of an animation on the screen. The trail of images on the screen provides for a tracing of the transformation through which the object has gone (Fig. 1). Each of the individual images in the trail has a specific time associated with it. That is, the image is part of a sequence with some images being drawn before and/or after it. This time dimension, in turn, can be represented by a degree of opacity. The most current image could be completely opaque with the older images being progressively more transparent, giving the effect of the images fading over time. An alternative would be to use hidden line removal and to overlap the images in the

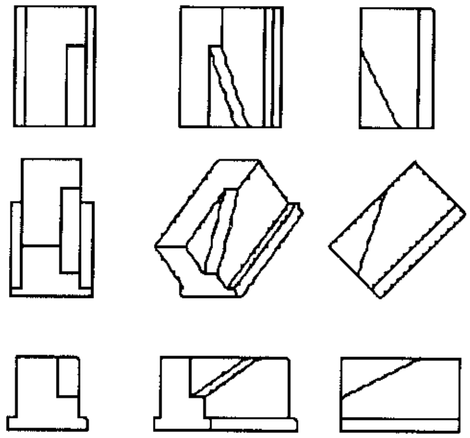

Figure 2.

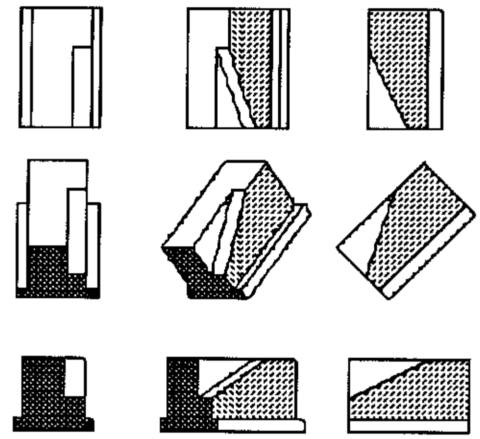

Figure 3.

sequence they are displayed. The most current image could be further highlighted by using a color contrasting with the rest of the images. This technique could be used while a dynamic image sequence is being played or to create static images seen by themselves. In many ways this technique mimics the way the visual buffer is thought to work. The difference is that the temporal control of the visual information on the computer screen can be returned to the viewer. For instance, the viewer can control the number of frames to remain on the screen, the speed of the decay, and time spacing between frames.

Though the tracer technique by and large avoids the computer storage problems of the history file, it still has weaknesses. By its very nature, the images in each frame reside on the screen unchanged in their location from where they would be in the animation. This is needed because the change in relative locations and orientations between frames is the primary information being conveyed by the overall image. The visual structure of the overall image is dependent exclusively on the dynamics of the object being observed. If the object undergoes very little displacement across the computer screen, the images may become bunched to a degree that features of individual frames become illegible.

One solution to the cluttering is to impose an overt ordering to the individual frames of the image sequence. This can be done by organizing the frames into a one or two-dimensional grid or matrix using the Small Multiples concept. Though the absolute location of the object to some global or screen coordinate system is lost, the absolute coordinate system can be used to represent specific variables and to order the visual information in a way that is easily scanned. Students have had many years of training in reading information on a Cartesian grid. This skill can now be put to work at interpreting spatial information and improving visualization skills.

For example, with a 1-D matrix, the axis can represent the time dimension creating a history timeline. Each node of the grid can represent the change in the spatial relationship between two objects. With a 2-D matrix, each axis could represent rotation of the object about orthogonally opposed axes (Fig. 2). A matrix such as this could incorporate a traditional multiview drawing by highlighting the nodes in the matrix that represent standard orthographic views in a different color.

Another possibility for the use of color coding in the matrices is in highlighting particular edges or faces of the object and tracing their foreshortening as they undergo rotations relative to the viewer (Fig. 3). Length and angle coding, like color coding, are powerful perceptual cues (Morse, 1979). Though length and angle are poor ways of representing an absolute value, they are quite useful at showing relative change. A student can scan a matrix of an object undergoing rotation and perceive the change in length and angle of the same edge highlighted in all of the nodes.

## Conclusion

Research in perceptual and cognitive psychology provides a rich source of information for reshaping the EDG curriculum. The models outlined show considerable overlap in interest with the EDG profession and provide mechanisms for furthering our understanding of how 3-D visualization skills develop in students. In addition, these models can be of assistance in evaluating how computer technology could most effectively be integrated into the classroom.

Central to the models presented is the examination of the retinal images created by the viewing of real or virtual 3-D forms. The perception and subsequent processing of these images form an important component of our understanding of the world around us. This internal processing is facilitated by mental representations we form of the 3-D object being viewed. These representations, in turn, are intimately linked to larger mental structures that organize the visual information.

As mentioned earlier, perceptions of images are not only processed in an existing mental structure, the process of perception also influences the structure itself. Our goal as educators is to influence the formation of these structures so that the student can most effectively understand and mentally manipulate 3-D form. Hochberg (1964) believes that forms are perceived via their prototypical elements such as edges and corners. These prototypical elements — whether they are edges and corners or other features — may also be the building blocks of the internal representations. For us to perceive an object in motion, photorealistic images are not as important as images that contain the characteristic elements that make up its canonical form. That is, the canonical form becomes the internal structure into which we gather the information from successive images and ultimately understand the nature of an object's three-dimensional form.

A number of specific display prototypes were presented that attempted to embody some of the paradigms outlined in the models. In addition, research on information display techniques was used to propose ways in which visual information might be organized, highlighting those elements that may be critical to the formation of internal representations of 3-D objects. Only further experimentation with these and other prototypical displays, both dynamic and static, will reveal which ones support the best learning environment.

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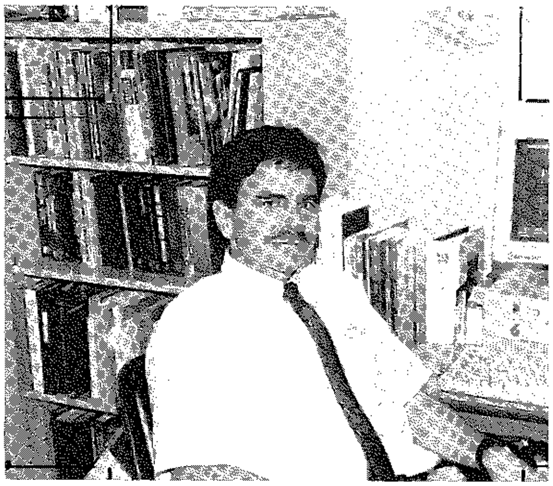
# Finite Element Analysis in a Freshman Graphics Course?

## 1992 Oppenheimer Award Recipient



Presented at the
47th Annual Engineering Design Graphics
Mid-Year Meeting
January 12, 1993

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### Abstract

*A new course, "Engineering Design Graphics", is being offered at Northern Arizona University. This course was instituted in 1991 to help reduce the high dropout rate during the freshman year by exposing students to the "creative" aspects of engineering through the design process. This is accomplished by introducing freshmen engineering students to the use of the computer as both a problem solving and communication tool in engineering. The basic philosophy of this course is to integrate traditional design principles and visual thinking with the new trends in computer graphics simulation and visualization techniques. The finite element method (FEM) is introduced in this course as a tool to be used in the refinement stage of the design process. A new program, COSMOS/Designer allows a seamless integration between AutoCAD and a finite element analysis program, COSMOS/M. This program works within AutoCAD, using AutoCAD pulldown menus and dialog boxes to create, analyze, and view the results of the FEM analysis. Unlike most FEM modeling tools, this package is easy to use for a person already versed in the basics of AutoCAD. A student can create a model of a part within minutes after completing a CAD drawing of the part. The part is then subjected to various loads, both mechanical and thermal (all within the AutoCAD environment), and the response to those loads then viewed graphically within AutoCAD. Student feedback at the end of the first year has been encouraging, indicating a high level of enthusiasm and interest in engineering.*

### Background

Northern Arizona University is a public institution located in Flagstaff, with instructional sites throughout the state serving rural Arizona. NAU maintains a primary emphasis on undergraduate education through a commitment to quality teaching and small classes taught by full time faculty. The College of Engineering and Technology offers baccalaureate degrees in Computer Science and Engineering, Electrical Engineering, Civil Engineering, Mechanical Engineering, Electrical Engineering Technology, and Mechanical Engineering Technology. Approximately 900 students are enrolled in the College of Engineering and Technology.

Recently, the National Action Council for Minorities in Engineering (NACME) took statistics from reports done by the

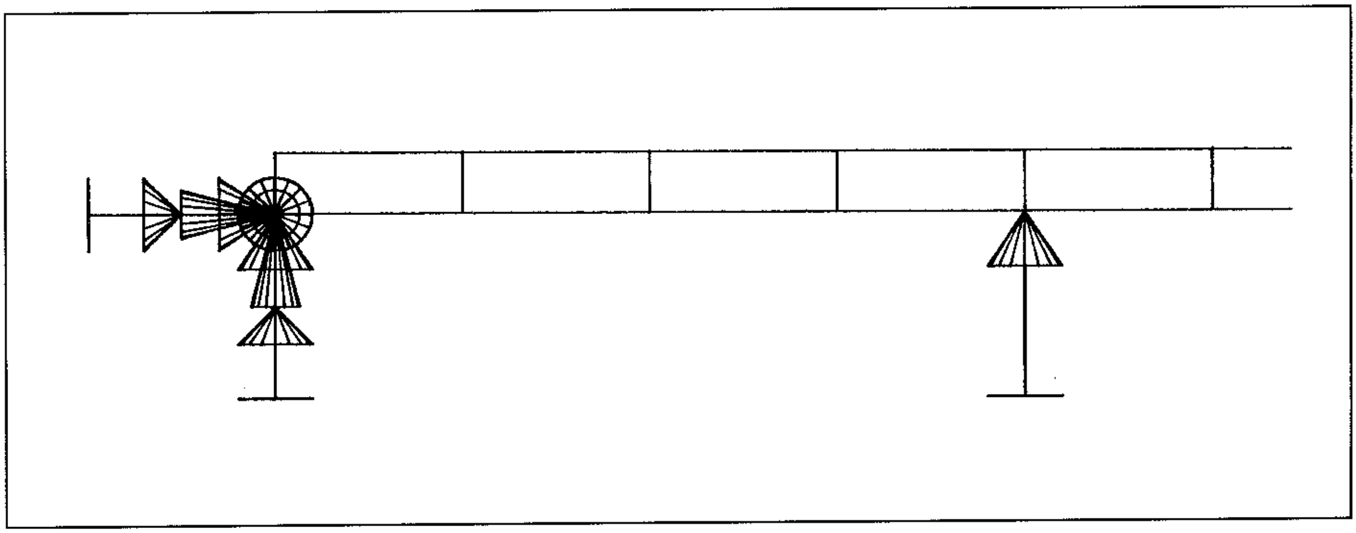

Figure 1. Zoomed portion of model showing applied constraints

Engineering Manpower Commission (EMC) to determine graduation rates for minorities at different levels in their engineering programs (Jones, 1992). The results indicate that only 36 percent of the minority students who enter engineering as freshman go on to complete an engineering degree! Yet white male students do nearly twice as well, with 68 percent completing their engineering degree. The rates improve, however, if students make it to the sophomore year, with 57 percent of the minority students earning engineering degrees. Clearly, an effective freshman engineering program is critical to improving the number of successful under-represented groups in engineering.

This fact was recognized by the NAU College of Engineering and Technology (CET) adminis-tration in 1989. The CET began planning a new freshman engineering program with a major goal to help freshman students succeed as engineering students, with a particular emphasis on assisting those students with a low success rate in engineering. A full time faculty member was hired in 1991 with the primary responsibility of implementing this freshman program. A new freshman level course was instituted at that time, *Engineering Design Graphics*, or EGR 180. This course was designed with two major objectives; (a) to introduce the tools needed to succeed as an engineer, and (b) to help reduce the high dropout rate during the freshman year by exposing students to the "creative" aspects of engineering through the design process.

## Implementation

EGR 180 attempts to go beyond a traditional graphics course by exposing the students to several of the tools they will need to succeed as engineers (in addition to classical engineering graphics). The computer is used as both a problem solving and communication tool in engineering. Topics covered include; engineering graphics, word processing, spreadsheets, equation solving software, the use of CAD software, and finite element analysis of engineering models, all within the context of the engineering design process.

The basic philosophy of this course is to integrate traditional design principles and visual thinking with the new trends in computer graphics simulation and visualization techniques. The course culminates in a "capstone" design project where the students work in teams to produce a solution to an engineering design problem. They apply the computer as a tool to both model and communicate the results of their design. The class is scheduled to provide flexibility for activities by meeting in two hour blocks, twice per week.

The unifying theme throughout this course is "design." All computer tools and concepts are introduced within the context of the design process. The finite element method (FEM) is introduced in this course as a tool to be used in the refinement stage of the design process. The FEM is employed in EGR 180 as a mathematical tool that allows engineers to subject a computer model of a component or structure to various loads (such as thermal, force, vibration, and pressure) and determine how it will react.

A new program, COSMOS/Designer, allows a seamless integration between AutoCAD and a finite element analysis program, COSMOS/M. This program works within AutoCAD, using AutoCAD pulldown menus and dialog boxes to create, analyze, and view the results of the FEM analysis. Unlike most FEM modeling tools, this package is easy to use for a person already versed in the basics of AutoCAD. A freshman student can create a model of a part or mechanical device within minutes after completing a CAD drawing of the part. The model is then subjected to various loads, both mechanical and thermal (all within the AutoCAD environment), and the response to those loads then viewed graphically within AutoCAD.

The FEM is typically introduced in the upper level engineering courses. With the "integrated design software" available for the PC, it is now possible to expose freshman level students to the finite element method without overwhelming them in the detailed math required to set up a model. Once the students learn the basic AutoCAD editing and drawing commands, it is possible to generate a finite element model within the CAD program using familiar AutoCAD menu's, commands, and dialog boxes.

During the first year this class was offered at NAU, the students were given the assignment to design a simple "diving board" and use the software to observe the stresses, deflections, and loads in their diving board design. Due to budgetary constraints a limited "demonstration" version of the software was used during the first year. This version is limited to 125 nodes, 60 elements, and only a two-dimensional analysis.

The design was "optimized" according to the constraints provided with the assignment through the use of FEM software. The students used AutoCAD to draw the board, and then used COSMOS/Designer software to simulate the board's response to varying the important parameters. The design parameters for the "diving board" were that it must be 10 feet long, have a fulcrum point 2 feet from the end and support a "250 pound fat man" standing on the end. A two dimensional model of the board was drawn in AutoCAD according to the given constraints. The Designer software was then used (within the AutoCAD environment) to generate the finite element mesh, boundary conditions, loads, etc. AutoCAD dialog boxes were used to select material properties, mesh type, etc. Figure 1 shows a zoomed view of the constraints applied to the end of the board. The icons used in this figure were automatically produced by the Designer software. The graphical user interface for this software simplifies the creation of a finite-element model. This is illustrated in Figure 2, which shows the AutoCAD screen used to select the element types.

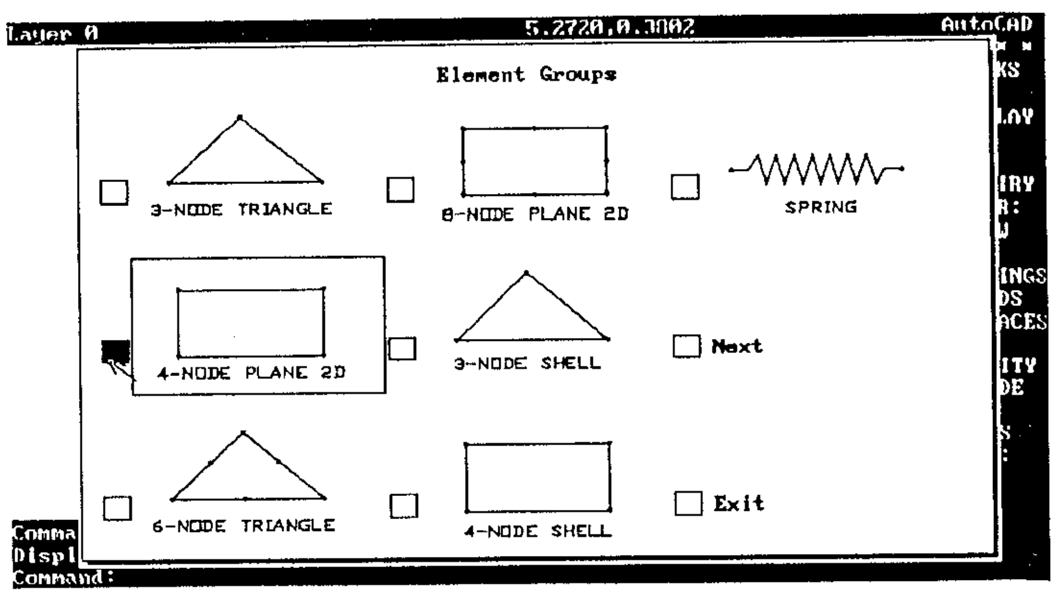


Figure 2. Element group screen.

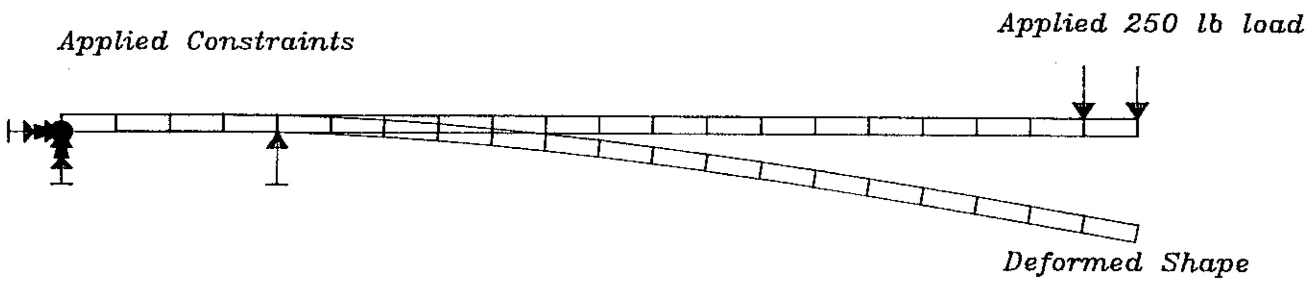


Figure 3. Diving Board Finite Element Model showing loads, constraints, mesh, and deflect shape

After the model was created, Designer exited AutoCAD for the analysis. An AutoCAD drawing file (.dwg) was generated by the finite element software as a result of the analysis. At the completion of the analysis, AutoCAD was re-loaded and used as a post-processor for the finite element analysis. Using familiar AutoCAD commands, the student could view the stresses, strains, deflections, and even see an animation of the deformed shape. The Designer software placed the results of the analysis in different layers of the output drawing file, which could be selected for viewing or plotting using the layer control features of AutoCAD. AutoCAD drawing and editing commands could be used to annotate the post processing results. A paper copy of the deformed board was produced with the AutoCAD "PLOT" command which is shown in Figure 3.

## Results and Conclusions

Enrollment in EGR 180 for the first year was 240 students (120 per semester), with a waiting list. During the Fall 1992 semester, another section was added, for a total of 4 sections. The enrollment in the second year of this program (Fall 1992) increased to over 140 students per semester. Of those students approximately 20% are minority status, with over 30% female. It is too early yet to measure the effect on retention rates from this program, but student feedback during the first year (1991-1992) was encouraging, showing much enthusiasm and interest in engineering. Comments written on the course evaluation forms at the end of the semester were overwhelmingly positive.

While some students complained about the amount of work required for the "capstone" design project, the majority felt that it was interesting and worthwhile. Several comments were made that the design experience brought together everything covered in the course. When asked what was the most interesting about the course, the finite element analysis solicited the most responses. They were particularly impressed when their "diving board" could deflect and bounce in response to the applied loads. Many people expressed the opinion that they would like to see and do a more complex FEM model.

The FEM portion of the course is being expanded at this time, based upon the positive feedback received during the pilot phase. NAU is in the process of purchasing a regular "unlimited" version of the software. This will allow students to create larger models will include a link to AutoCAD AME, thereby allowing a fully three-dimensional finite element model to be created.

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# Introducing Graphical Finite-Element Structural Analysis to an Undergraduate Curriculum

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## Abstract

*The University of California, Berkeley, currently trains all of its undergraduate mechanical engineering students (~150/year) in graphical finite-element analysis as part of a regular course in the mechanical behavior of materials. This paper presents the hardware, software, and curriculum decisions made during the implementation of this new material. IBM RS/6000 workstations and customized commercial finite-element software are used. The emphasis of this part of the course is in the proper usage and interpretation of finite-element methods, rather than a theoretical development of the technique. Graphical presentation enhances the conceptual understanding of structural loading and their effects on the stresses of irregularly shaped objects. It becomes possible to introduce some elements of design into the traditional course material. A student can synthesize geometrically complex parts without an overriding concern or the burden of analytical complexity. Student surveys indicate that this aspect of the course is perceived to be fun, challenging, and extremely worthwhile.*

## Introduction

Finite-element analysis (FEA) has become a powerful design and analysis tool for many industries. The advent of powerful computer graphics workstations has made the presentation and interpretation of the analysis results much simpler for design engineers. By eliminating the burden of analytical complexity from their designs, engineers are freed to concentrate on the function and/or packaging of the design. In engineering education, however, FEA has usually been limited to high level graduate courses for small numbers of advanced students.

In a traditional undergraduate course on the mechanical behavior of materials, a student learns material processing, stress and deflection analysis, and material failure theories. A semester long course typically includes 45 hours of total lecture and several hours of laboratory. The stress and deflection analysis emphasized in the course, however, is limited to very simple geometries due to analytical complexity. A typical problem is shown in Figure 1, where the basic components are beams of simple cross section. The solution to the stress analysis problem requires locating the point of maximum stress, and then calculating the magnitude of that stress. Although such problems are necessary for a student's basic understanding of the fundamental material, it may leave the student under-prepared for the type of design usually required in the field, where geometries are usually complex. At worst, it may leave the student believing that any structure can be treated as simple beams. A student's capacity to synthesize a design is often limited by his or her perceived ability to analyze the design.

Recent improvements in the price and performance of workstations have made possible the introduction of FEA at the undergraduate level. At the University of California, Berkeley, an introduction to graphical finite-element stress analysis was implemented as part of the regular, required curriculum for all undergraduate mechanical engineering majors. The material is presented as part of the mechanical behavior of materials course, usually taken in the third year of the program. The change to the curriculum was made in the Fall semester of 1991, and the experience is documented below.

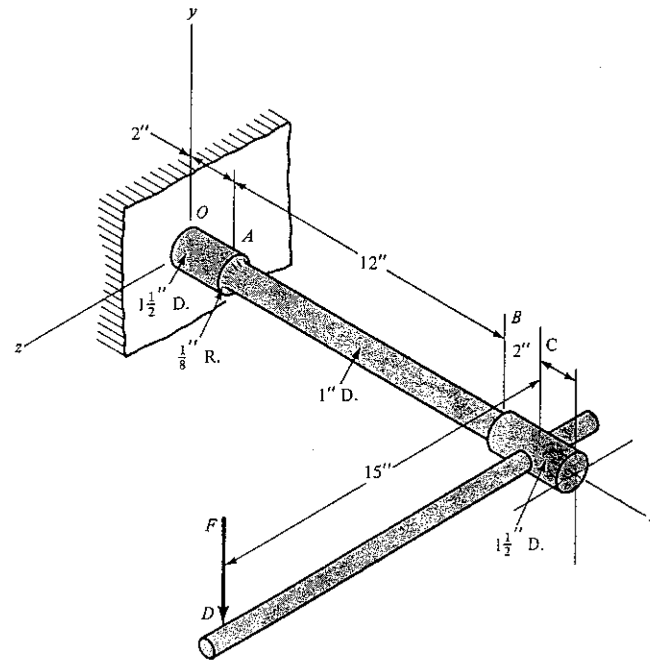



Figure 1. A traditional mechanics of materials problem, mandating simple geometries.

## Laboratory Facilities

The laboratory consists of 24 IBM RS/6000 model 320 (RISC based) computer workstations, which was used as student stations. Each student station has a 19" color monitor, a mouse, 16 Mbytes of RAM, and 320 Mbytes of disk memory. Additionally, an IBM RS/6000 model 530, with 1.2 Gbytes of disk memory, is used as the fileserver for the facility. Networking is accomplished through Ungermann-Bass communications boards and ether-net lines. Hardcopy output is routed through the fileserver and obtained through 2 IBM 4019 laser printers and an IBM 6182 color plotter. A schematic of the laboratory layout is shown in Figure 2.

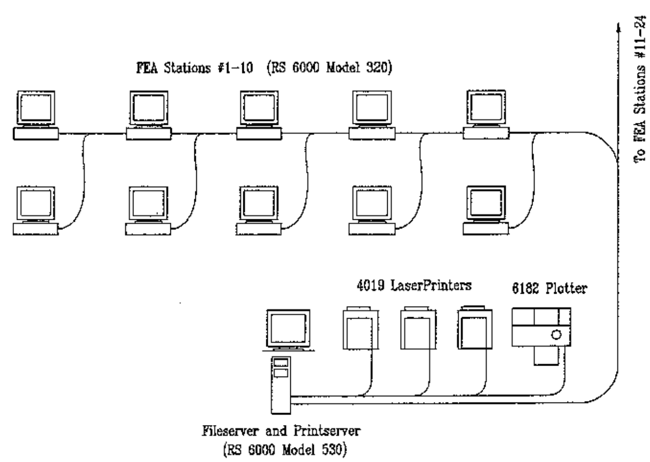



Figure 2. Schematic of the computer workstation laboratory layout for FEA.

AIX 3.1 is used as the software operating system, and CAEDS as the FEA software, running in an X-windows environment. Trautner (1992) stated that " ... a critical feature of the chosen structural software for use in computer aided structural engineering is that it has a preprocessor that

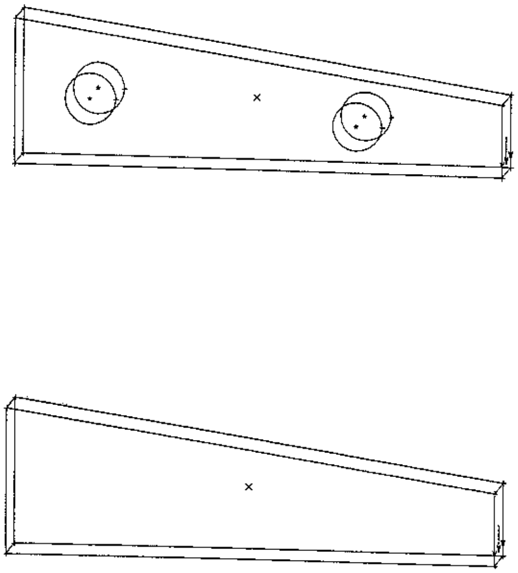


Figure 3. A simple stress analysis problem used for demonstrating FEA usefulness

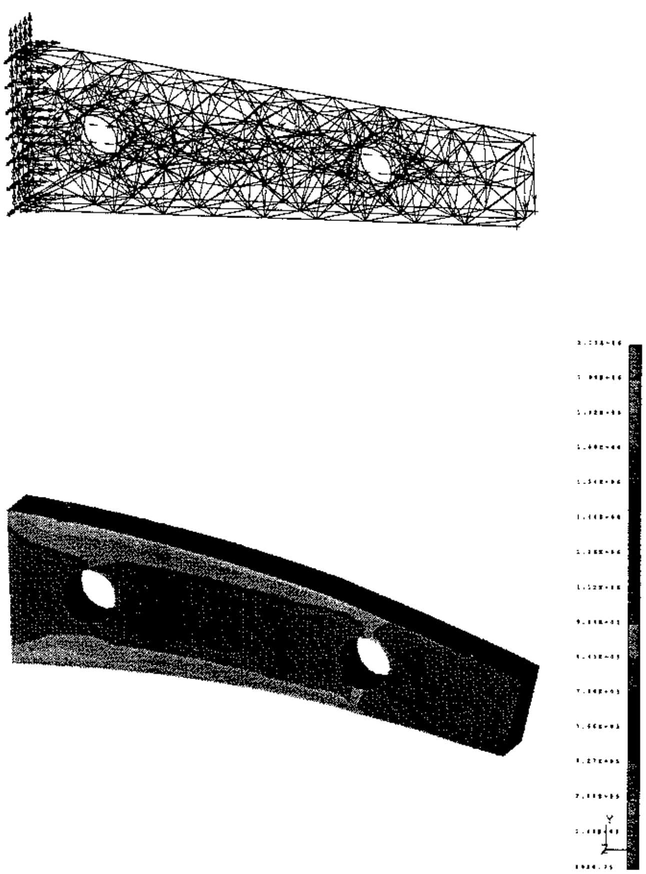


Figure 4. The demonstration problem meshed, with boundary conditions, and fully solved.

allows the user to input his/her finite element models graphically." CAEDS and X-windows were chosen because of their commercial acceptance and highly graphical interface. The workstation processor speed and its 16 Mbyte of RAM permitted dynamic viewing of both the input and output graphics. Since the FEA software is roughly 150 Mbytes in size, the software is resident on the fileserver only. Upon login at a student station, only the necessary software operating packets are sent from the fileserver to the student station. This procedure marginally increases the login time, but saves much disk storage space on the student stations. The actual solution computation takes place within each student station.

## Administration

The commercial software was customized to make it suitable for a multi-user, student operating environment. A special shell script automatically sets up the student working environment for CAEDS in X-Windows, eliminating direct student contact with the operating system. Special windows icons were created which allowed the students to format diskettes, plot, and save and recall files directly to removable diskettes. To most efficiently use the existing hard disk memory on the student stations for the large number of student users, permanent storage of student files is not permitted on the workstations. The shell also keeps the hard disk clear of permanent data files. By erasing the working area of the hard disk memory upon logout, a single login signature and password can be used for the entire class without fear of students having their work plagiarized unwillingly. Students maintain soft copies of their work on their own removable diskettes (and on a backup diskette).

The experience of Lorimer and Lieu (1992) in CAD instruction concluded that lecture type instruction of computer usage was most effective with 2 students per computer. Thus the laboratory accommodates 50 students during formal instruction periods, which were 1.5 hour sessions held twice a week. Formal instruction is rather conventional, consisting of the instructor giving instructions and using the blackboard, while students follow using the workstations. In addition, during formal instruction, a graduate student instructor walks through the laboratory to offer assistance. Students are provided a short set of printed notes detailing the steps for the class exercise, but are required to acquire their own diskettes for file storage. Students are permitted free access to the facility for practice and to work on assignments except when the facility is being used for formal instruction. The laboratory is accessible 24 hours per day, 7 days per week. A graduate student instructor is available for 10 hours per week in the laboratory for assistance. The laboratory is otherwise unattended. Laboratory security is provided through lock-down of all computer hardware and a combination lock on the room door.

## Course Topics and Content

The emphasis of this part of the course is placed on use of FEA as a practical design tool, rather than the FEA theory usually presented in graduate courses. Both stress and deflection analyses are performed. The students receive approximately 6 hours of formal instruction on FEA usage over a two week period. The first 1.5 hours are spent in introducing the concepts of FEA. Proper use of the tool, especially its limitations, is emphasized. The second 1.5 hours are spent in the construction of geometric models. This is necessary because a majority of the class have experience in computer-aided drawing from a class equivalent to that detailed by Lorimer and Lieu (1992). This type of drawing, however, is mainly two-dimensional. FEA requires a 3-dimensional model, and thus the course includes the building of 3-dimensional wire frame structures of mediocre complexity. Without a prior knowledge of solids modelling, the distinction between concept based 3-dimensional modelling and tool based 2-dimensional drawing would be unclear for some students. The problems with this distinction were summarized by Leach and Matthews (1992), who stated that the " ... ability to understand the spatial description of a solid model ... is not the same as the ability to create or read a conventional engineering

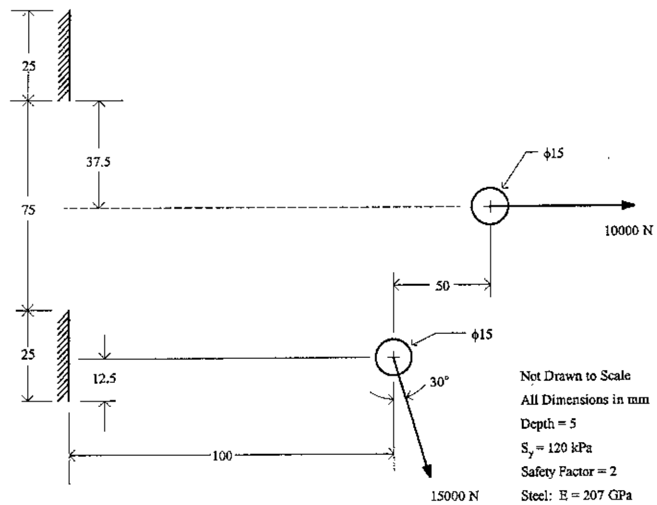



Figure 5. The minimal mass bracket design problem assigned for student solution

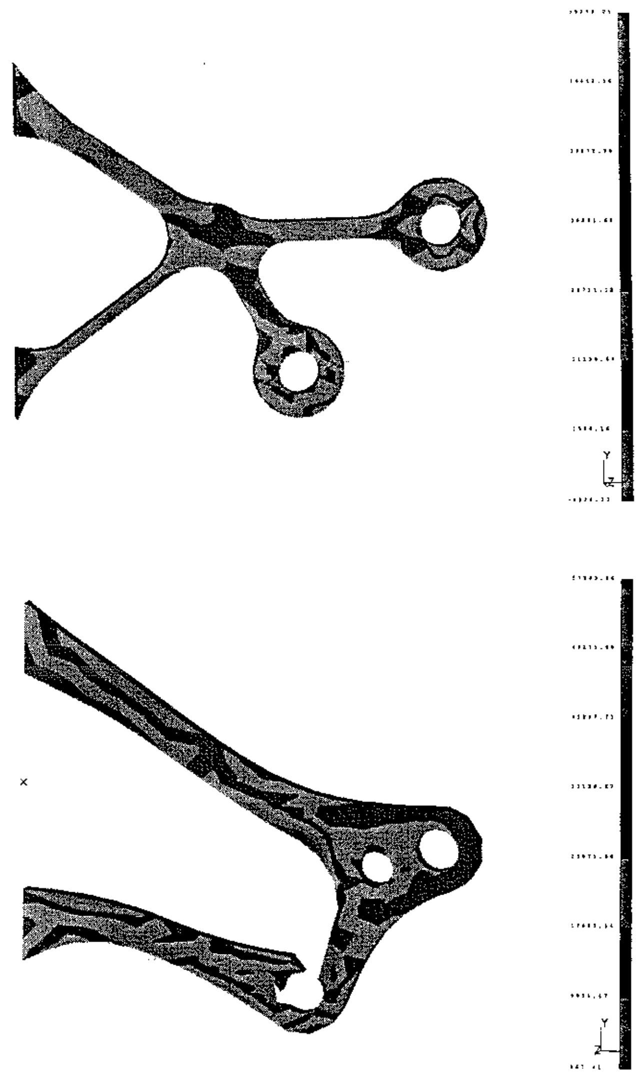
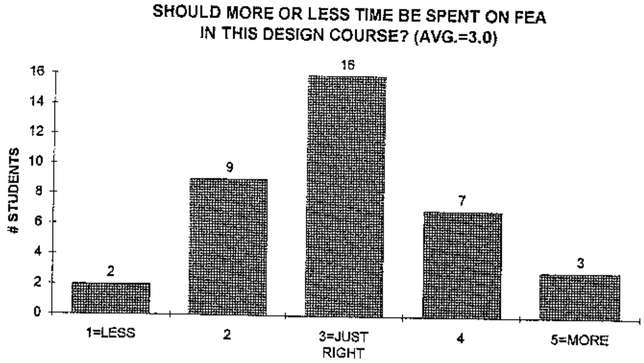


Figure 6. Two student solutions to the minimal mass bracket design problem.



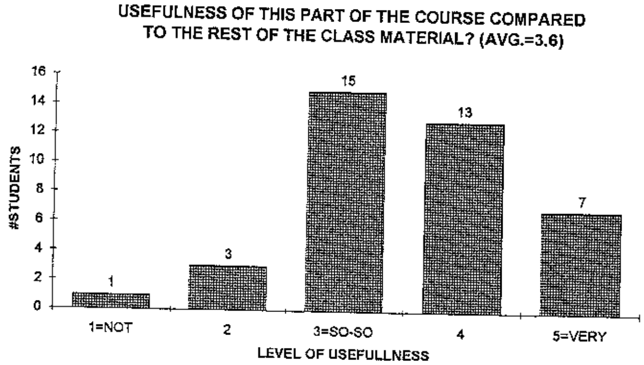




Figure 7. Student perception of FEA usefulness in a mechanics of materials class.

drawing." The creation of some 3-dimensional wire frame models is assigned to the students after this part of the class.

During the remainder of the 6-hours of formal instruction, a model of a tapered cantilever beam, with two holes through it, is built and analyzed. The basic problem is shown in Figure 3. The solid beam is a straightforward problem in beam mechanics, which can be easily analyzed by a student. The addition of any hole, however, makes the analysis extremely difficult. This problem is used to demonstrate that even objects with extremely simple geometries can become nearly impossible to analyze with traditional analytical methods. The model serves as the example for creation of surfaces from the wire-frames, creation of a solid from surfaces, meshing of the solid, and finally graphical display of the solution. The example is shown meshed, with boundary conditions applied, and fully solved for stress and deflection in Figure 4.

The graphical display of the results was critical to the success of this project. The graphical output immediately provides an incredible wealth of analog information to the student. Color contour plots of the stress, for example, immediately indicate both the magnitude and the location of the high stress regions. The 3-dimensional object could be rotated in space in real time permitting inspection from any viewing angle. Thus, interpretation of the analysis results and subsequent modification of the structure to reduce the stresses could be easily accomplished.

A working knowledge of the software and FEA required substantial student efforts outside of class. Formal instruction was intended only as a means of guiding students through the various FEA steps and to explain the theory and significance of each step, in order to eliminate student apprehension about using the workstation. CAEDS is very comprehensive, and in the short time allotted for formal instruction, only a small fraction of the capabilities of the program can be explored. Student surveys showed that individual and group practice on the computers was as effective, or even more effective, than formal guided instruction.

## Project Assignment

After two weeks of formal instruction, a two-week mini-project is initiated. Peterson (1991) summarized that for a basic mechanics of solids course " ... the integration of design experiences into this subject has proven extremely valuable, perhaps even essential to the task of improving engineering education." For the mini-project, students are required to design a bracket of "minimal mass" required to support 2 specified loads without failure. The basic problem boundary conditions are shown in Figure 5. Beginning with an intuitive guess at a first design, students would perform a FEA analysis of the design. Material would then be added to the high stress regions, and removed from the low stress regions, until an acceptable design was produced. Ideally, the stress contours of the part would show a single color, indicating a constant stress part. This simple project requires the students to create, analyze, and modify (according to the results of the analysis), many possible designs. The assignment permits the students to be innovative in the design, being guided by intuition, aided by the computer, and almost unrestricted by analytical complexity. Every student produces a different design that would work. Two student produced designs are shown in Figure 6. This type of assignment would have been extremely difficult or perhaps even impossible under the traditional methods of instruction for this course.

## Evaluation by Students

FEA was very well received by the students. Student evaluations were solicited at the end of each semester and compiled at the end of one year. Figure 7 shows that the majority of students believed that FEA was as important as the traditional course material, with a significant percentage believing that it was among the most important topics in the course. Figure 7 also shows that the students believed that the time spent on FEA in the course was about right. The design exercise proved to be fun for most students. Many became almost obsessed with running the program and desired much more time devoted to the topic. Though extremely worthwhile, Figure 8 shows that the students believed the design exercise to be quite challenging. Figure 9 shows that the short time spent in formal computer and FEA instruction was adequate to give most students a fair degree of confidence in using FEA as a design tool. Although more instruction would have been desirable, additional time could not be sacrificed from the traditional course material.

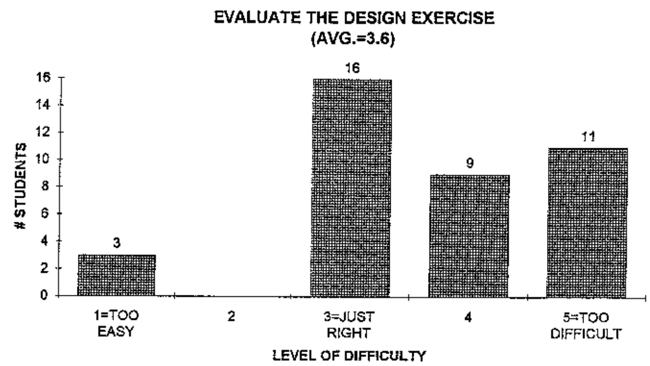



Figure 8. Student evaluation of the difficulty of the design exercise.

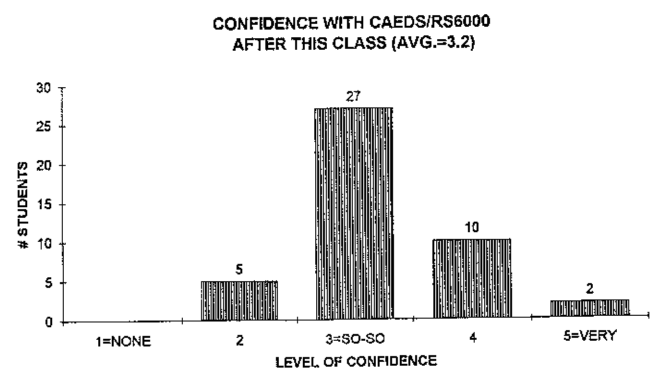



Figure 9. Student confidence with the computers and FEA at the end of the class.

## Concluding Remarks

Some initial student confusion was present due to the lack of 3-dimensional modelling experience. It seems that, with the limited time allotted to FEA in the mechanics of solids course, an initial introduction to 3-dimensional computer geometric models, as described by Bertoline (1991), would have been useful. An introduction to solids modeling, perhaps during the freshman year as executed by Barr, et al. (1991), probably would have been ideal. In fact, an existing solids model could have been used directly as the input for the FEA solver, thus saving a great deal of time and effort in FEA instruction.

Most student frustration centered about program errors due to non-convergence of solutions, excessive element distortion, excessive computation time, and exhaustion

**Hall, C. E.** (1978).
In conclusion. (pp. 142-144).
**Harrison, W. P.** (1978).
The descriptive, analytical, and differential geometreies of ruled-surface transition ducts. (pp. 56-60).
**Hohenberg, F.** (1978).
Several methods of drawing axonomteric pictures without auxiliary lines. (pp. 155-159).
**Lang, R. S.** (1978).
A case study relating to the design and development of a remote meter reading system. (pp. 174-175).
**Loeb, A. L.** (1978).
A studio for spatial order. (pp. 13-20).
**Marasco, J.** (1978).
Shadow moire and three dimensional geometry. (pp. 102-107).
**March, L., & Steadman, J. P.** (1978).
From descriptive geometry to configurational engineering. (pp. 21-24).
**Mitchell, P. D.** (1978).
A graphical technique to represent knowledge for modular instruction. (pp. 188-192).
**Nagata, T.** (1978).
Bridging the gap between freehand drawing and formal perspective construction. (pp. 98-101).
**Nannichi, A.** (1978).
'Graphic Science' in engineering education at Tohoku University. (pp. 29-30).
**Niayesh, H.** (1978).
Graphical Composition and resolution of vectors in space. (pp. 77-79).
**Odaka, S.** (1978a).
Fundamental equation of perspective projection and its application. (pp. 95-97).
**Odaka, S.** (1978b).
Study on the approximate development of ruled surfaces from the viewpoint of differential geometry. (pp. 92-94).
**Osers, H.** (1978a).
Descriptive geometry as taught at the Univeridad Central De Venezuela. (pp. 26-28).
**Osers, H.** (1978b).
Excavation for the foundation of a building. (pp. 85-87).
**Parker, J. E.** (1978).
Photogrammetric application of descriptive geometry. (pp. 109-113).
**Pearce, G. F.** (1978).
The use of analglyph methods for teaching descriptive geometry. (pp. 80-84).
**Roark, I. W.** (1978).
Descriptive geometry in modern industry. (pp. 117-119).
**Rotenberg, A.** (1978).
The descriptive geometry of refections and reflections on descriptive geometry. (pp. 135-139).
**Sauvageau, M.** (1978).
A new system for exact axonometric projection, directly from multi-view projection. (pp. 121-125).
**Seybold, H.** (1978).
Computer construction and development of the transition torse of two curves. (pp. 114-116).
**Slaby, S. M.** (1978).
Geometry in applied science and engineering. (pp. 129-131).

The following is a bibliography of the papers found in:
*Proceedings of the (1st) International Conference on Descriptive Geometry* sponsored by the Engineering Design Graphics Division of ASEE on its 50 Anniversary. This was compiled by Dennis R. Short.

Editor: Garland K. Hilliard
Associate Editor: William J. Vanderwall

University of British Columbia
Vancouver, British Columbia
June 14-18, 1978

Library of Congress Catalog Card Number: 78-68611

APA format for each listing would look like this:

Abramowitz, J. S. (1978). The advantages of the modular approach to instruction. In G. K. Hilliard & W. J. Vanderwall (Eds.), *Proceedings of the (1st) International Conference on Descriptive Geometry,* (pp. 171-173). Vancouver, British Columbia, Canada: WM . C. Brown Co., Inc. for ASEE EDGD.


**Abramowitz, J. S.** (1978).
The advantage of the modular approach to instruction. (pp. 171-173).

**Almgren, F. J., & Taylor, J. E.** (1978).
Descriptive geometry in the calculus of variations. (pp. 133-134).

**Alting, L.** (1978).
Manufacturing process - Geometrical possibilities and limitations. (pp. 40-43).

**Beil, R. J., & Keedy, H. F.** (1978).
Curriculum flexibility through a modular approach. (pp. 182-187).

**Berg, F. W.** (1978).
Descriptive geometry and graphics solve product and machine design problems. (pp. 50-54).

**Blade, M. P.** (1978a).
A new method for pictorial drawing. (pp. 149-154).

**Blade, M. P.** (1978b).
Recent developments in the application of the theories of the geometry of description. (pp. 44-49).

**Brisson, D. W.** (1978).
Curved hypersurfaces. (pp. 67-75).

**Charit, Y.** (1978).
Computer-aided tracing of an equilibrium line of intersecting surfaces of revolution. (pp. 126-128).

**Chlebo, S.** (1978).
A graphic solution for the differential equation of the form Ady/dx=f(y). (pp. 88-90).

**De Guise, C.** (1978).
Mongean descriptive geometry. (pp. 31-38).

**Elwood, W. F.** (1978).
Modularization - the key to flexibility. (pp. 167-170).

**Garcia, S. R.** (1978).
Application of descriptive geometry to maritime systems engineering. (pp. 61-66).

**Gorczyca, F. E.** (1978).
Graphics I: Personalized system of instruction description and evaluation. (pp. 176-181).

of memory paging space. Although students were repeatedly instructed about methods to avoid these errors, they nevertheless occurred quite frequently as the students built their initial models. As their experience with FEA grew, however, they quickly learned to recognize errors and to reduce their incidence by observing simple rules such as avoiding meshes that were either too coarse or too fine, and avoiding sharp corners in their designs. Having the students gain this experience was one of the goals of this part of the course.

Workstation computation speed is absolutely critical for FEA in an education environment, especially when large numbers of students are involved, or when classes are held back-to-back. Even though only simple models were examined, students are generally impatient and demand almost immediate feedback from the analysis. It is difficult to explain that the problem that they just solved in 5 minutes required an entire day of computing only a few years ago.

## Acknowledgments

This work was supported by the University of California, Berkeley, Committee on Teaching and IBM Corporation.

## References

Barr, R. E., & Juricic, D. (1991). Engineering Design Graphics Curriculum Modernization Project: An NSF Curriculum Initiative. *1990 ASEE Annual Conference Proceedings,* Toronto, Canada.

Bertoline, G. R. (1991). Using 3D Geometric Models to Teach Spatial Geometry Concepts. *ASEE Engineering Design Graphics Journal,* 55, (1), 7-47.

Leach, J. A., & Matthews R.A. (1992). Utilization of Solids Modeling in Engineering Graphics Courses. *ASEE Engineering Design Graphics Journal,* 56, (2), 5-10.

Lorimer, W. L., & Lieu, D. K. (1992). Hardware, Software, and Curriculum Decisions for Engineering Graphics Instruction Using CAD. *ASEE Engineering Design Graphics Journal* 56, (1), 14-21.

Peterson, C. R. (1991). Experience in the Integration of Design into Basic "Mechanics of Solids" Course at MIT. *1991 ASEE Annual Conference Proceedings*, Session 1625, New Orleans, LA, 360-364.

Trautner., J. J. (1992). Intergrating Geometric Modelling into Computer Aided Structural Engineering Courses. *ASEE Engineering Design Graphics Journal,* 56, (1), 9-13.

# Division News and Notes

## Chairman's Message by Vera Anand

The Mid-year meeting in San Francisco turned out to be a great success, with excellent conference arrangements and a technical program that mingled industrial and educational speakers. Many thanks to Ron Pare, Jimm Meloy, Rodger Payne, Bobbi Gelleri, and all others involved in the organizational aspects of the conference. The open discussions were the best we have had in a long time, and left us with the realization that much thought should be placed in the task of identifying future goals and objectives for the engineering design graphics curriculum.

Where should we go with our graphics programs, where is the "subject matter" that we should be teaching? These are the questions that were raised at the conference and that will have to be answered in the near future. A suggestion has been made that a block of time be set aside at the next midyear meeting, in October, to conduct unrestricted discussions related to the development of a vision statement and a set of goals for engineering graphics instruction. A promising start into a difficult task! The executive committee is also in the process of putting together a five-year plan that will hopefully address many of the areas that need work.

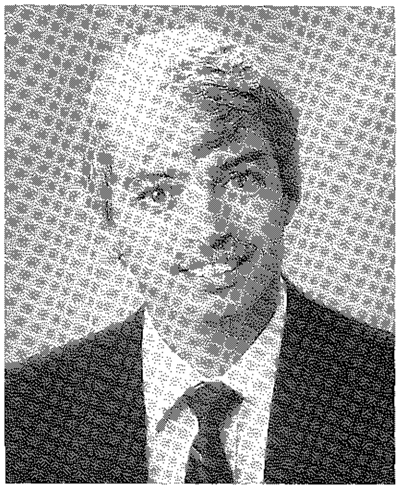
It is of utmost importance that all members of the Engineering Design Graphics Division participate in this process of self-evaluation so that many – most certainly opposing! – points of view can be expressed. After all, our survival as a group and our role as graphics educators are at stake.

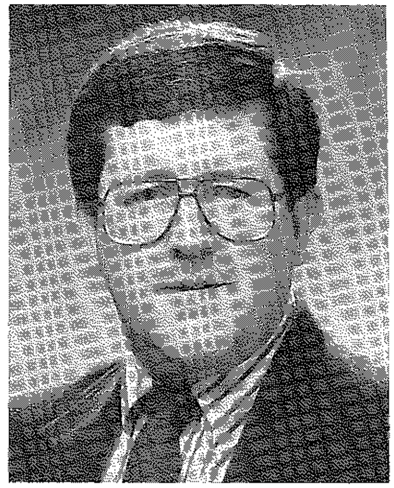
## Nominees of Division Officers

The following persons have been nominated for the positions indicated. Ballots will be mailed in the spring.

*EDGD Nominating Committee*

## Vice-Chair 1993 - 1994





### Gary R. Bertoline

Gary, an associate professor in the Department of Technical Graphics at Purdue University, received the Ph.D. degree from The Ohio State University in 1987. Prior to joining the faculty at Purdue, he served as a faculty member at The Ohio State University and Wright State University.

He has been a member of ASEE and EDGD for nine years, having served as treasurer and vice chair for the North Central Section. He served as chair of the Industrial Advisory Committee, is chair of the Technical and Professional Committee of the EDGD, and was program chair for the 1990 EDGD Mid-Year Meeting. Gary has been awarded the Frank Oppenheimer Award for the best paper at the EDGD Mid-Year Meeting three times. In 1990, Gary was named to the Steering Committee for the International Society for Geometry and Graphics.

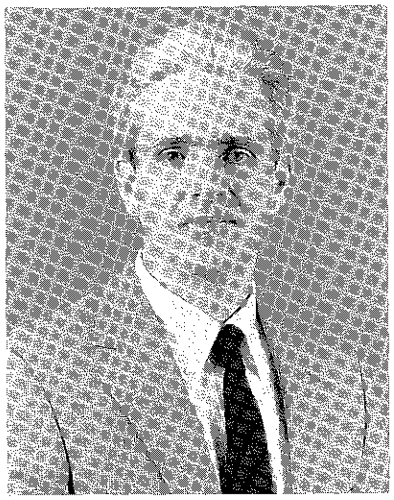
Gary has presented over 30 papers at professional conferences, and has authored numerous papers in journals and trade publications on engineering and technical graphics, CADD, and visualization research, and currently is the administrator for the Autodesk University Partners Program at Purdue and the engineering and technical graphics series advisor for Irwin Publishing Company. Gary serves on the Board of Review for the *EDG Journal*, and *Journal of Technical Graphic s & Computing.*

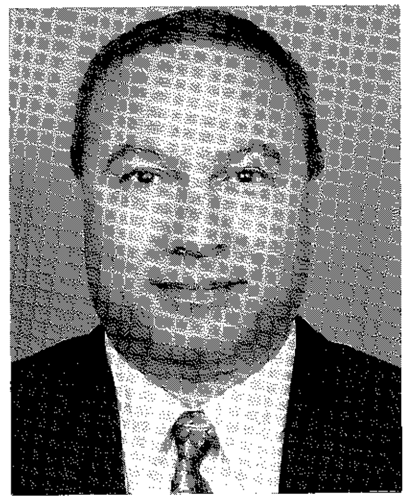
### William A. Ross

Bill is an associate professor in the Department of Technical Graphics at Purdue University. He has been a member of the EDGD/ASEE since 1981 and has served as Director of Programs (1889-1992), EDGD Program Chairman for the 1991 Annual Conference in New Orleans, and as a member of the Review Board for the *Engineering Design Graphics Journal* from 1987-1992. He has co-authored two texts, *Integrated Engineering Drawing & Modeling with VersaCAD* and *Freehand Concepts in Technical Graphics* with Jon M. Duff. During the past twelve years, he has presented more than thirty technical papers and seminars to a variety of audiences and has published numerous serial journal articles on the topics of engineering graphics and CAD. Currently he is engaged in developing a text and curriculum package on Solid Modeling with Gary R. Bertoline, and is developing the groundwork and background for research in Virtual Reality.

Prior to moving to Purdue in 1988, he taught engineering graphics and CAD for seven years at North Carolina State University where he also received BS (1973) and MEd (1976) degrees. His industrial experience includes experience in commercial and industrial construction as well as consulting and industrial training with IBM, the RCA Corporation, and Hewlett-Packard.

# Director: Zone Activities
## 1993 - 1996





**Timothy J. Sexton**

Tim is an associate professor of Industrial Technology in the College of Engineering and Technology at Ohio University, Athens, Ohio. He received his B.S. in Architecture from the University of Illinois, M.S. in Industrial Technology from Western Illinois University and a Ph.D. in Education from Ohio University.

His responsibilities at Ohio University include teaching engineering graphics, architectural drawing, computer applications in industry, quality control, and managing the college's computer graphics lab.

Tim's research interests include measuring and fastening spatial visualization, design and development of presentation graphics, ergonomics of computer hardware.

Tim is the facilities chair for the 1993-94 EDGD 48th Mid-Year Conference which will be held at Ohio University in November 1993.

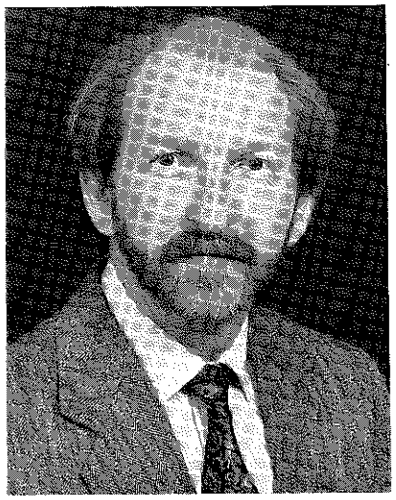
**Moustafa R. Moustafa**

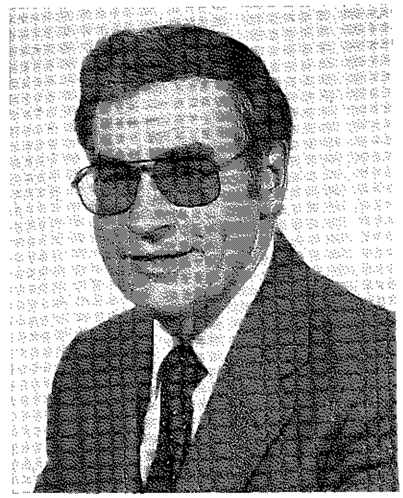
Moustafa is an associate professor of Mechanical Engineering Technology. He received an M.S. in Structures and Stress Analysis in 1979, and an M.S. in Machine Design in 1976, both from the University of Illinois.

His teaching experience includes Design of Machine Elements, Mechanical System Design, Computer-Aided Graphics, Computer-Aided Design Engineering Graphics, Technical Drawing, Statistics, Dynamics, Thermodynamics, Lubrication, Vibration. He is also a certified manufacturing engineer and a member of the Educational Committee of the Division of Design Graphics of the Society of Engineering Education.

Moustafa is the program chairman for the EDG Division of ASEE for the 1993 annual conference in Lincoln, Nebraska. He has been elected to the organizing committee of the International Conference on Descriptive Geometry in Sidney, Australia, 1992. In November 1991, he was the facilities chair for the EDGD Mid-Year Conference in Norfolk, Virginia.

## Director: Professional and Technical 1993 - 1996





### Robert A. Matthews

Robert is an associate professor and director of the Engineering Graphics Program at the University of Louisville Speed Scientific School. He earned his undergraduate degree from Western Kentucky University and his graduate degree from the University of Louisville. Robert is actively involved with the EDGD and other divisions of ASEE. He has served as chairman of the Educational Relations Committee (EDGD), Program Coordinator of the 1988 ASEE Zone II Conference, and Conference Host for the 1987 EDGD Mid-Year in Louisville.

He is credited with the development of the CADD labs and instructional program and the nationally recognized AutoCAD Training Center at the University of Louisville. Ongoing research and creative activity include Technology Transfer and curriculum development.

### Michael J. Miller

Mike is an associate professor of Engineering Graphics at The Ohio State University. Prior to joining the University, he was employed in the manufacturing arm of the telephone industry and in the aerospace defense industry.

Mike is co-author of two graphics and one computer graphics textbooks and is author of two educational CADD software packages and numerous papers and presentations relating to engineering graphics. Mike currently serves as treasurer of the North Central Section of ASEE.

# Engineering Design Graphics Division

American Society for Engineering Education

## *Call for Papers*

**1993-94 48th Mid-Year Conference**
Ohio University, Athens, Ohio
October 31 - November 2, 1993

The Engineering Design Graphics Division is developing its program for the 1993 Mid-Year Conference. Abstracts related, but not limited, to the suggested topics listed below are being sought. Specify if your abstract should be considered for a paper presentation or poster session.

### Suggested Topics

Problem Solving Using
- Incorporation into basic courses
- Role of descriptive geometry
- Using advanced graphical analysis and modeling

Presentation/Communication Graphics
- Using graphics to explain engineering concepts

Teaching Strategies
- Instructional innovations
- Effective teaching aids

Visualizations
- Experimental research methods, results, evaluation

Curriculum/Program Development
- Promoting the use of graphics throughout the curriculum
- Integrating design throughout the curriculum

**Abstract Length:** 250 Words

**Submit Abstract by:** July 1, 1993

**Send Abstracts to:**

J.D. Frampton, Technical Chair
Engineering & Technology Division
The University of Akron
120 Schrank Hall South
Akron, OH 44325-6104

(216) 972-5139
Fax: (216) 972-5300
e-mail: jdframpton@vax1.cc.uakron.edu

Completed papers of accepted abstracts
must be submitted for publication in proceedings by:
**September 1, 1993**

## ASEE & EDGD Programs

*Prepared by Del Bowers*
*EDGD Director of Programs*

**1993 Annual ASEE Conference**
June 20-24, 1993
Champaign, Illinois
Host: University of Illinois
Program Chair: Michael H. Pleck,
University of Illinois
(217) 333-3160
Theme: ASEE 100th Anniversary

SHAPING OUR WORLD – CENTURY II

**1993-94 EDGD**
**48th Mid-Year Conference**
Athens, Ohio
October 31-Nov 2, 1993
Host: Ohio University
General Chair: Timothy J. Sexton
Department of Industrial Technology
122 Stocker Center
Ohio University
Athens, Ohio 45701-2979
(614) 593-1459
Program Chair: Doug Frampton
University of Akron
(216) 972-5139
FAX: (216) 972-5300

**1994 Annual ASEE Conference**
June, 1994
Edmonton, Alberta, Canada
Program Chair: to be named

**1994-95 EDGD**
**49th Mid-Year Conference**
Location: to be named
Host: to be named

### FACULTY POSITION IN ENGINEERING GRAPHICS
### CLEMSON UNIVERSITY

The Engineering Graphics Program in Clemson University College of Engineering invites applications for a tenure-track faculty position in Engineering Graphics available August, 1993. The Engineering Graphics Program is non-degree granting and offers courses at the undergraduate and graduate levels in the areas of Engineering/Computer Graphics and Geometric Modeling. Responsibilities include teaching, course development and research. Qualifications are an earned doctorate in an engineering field with training in computer graphics/geometric modeling or an MS degree with related teaching or industrial experience. Rank and salary commensurate with qualifications. Screening of candidates will begin March 1, 1993, but applications will be considered until the position is filled. Send resume and name, address and phone number of three references to:

Dr. William Beckwith, Director
Freshman Engineering and
Engineering Graphics Programs
223 Earle Hall
Clemson University
Clemson, SC 29634-0902
FAX: (803) 656-1327

*Clemson University is an affirmative action / equal opportunity employer*

# Calendar of Events

*Prepared by Dennis R. Short*

**Association for Experiential Education 20th Annual Conference**
Banff, Canada
October 8-1, 1992
*For further information:*
Karen Hirl
3407 - 54 Ave. SW
Calgary, Alberta, CANADA
T2E5H3
(403) 242-5702 (home)
(402) 240-8969 (fax)

**CHISIG Annual Conference**
**Interface Technology: Advancing Human - Computer Communication**
November 26-27, 1992
Gold Coast, Queensland Australia
*For further information:*
OZCHI 92 Secretariat,
School of Information & Computing Sciences,
Bond University, Gold Coast, Qld 4229
AUSTRALIA
+61 (0)75 953324
+61 (0)75 953320 (fax)
E-mail: ozchi92@bu . oz . au

**ICCG93**
**International Conference on Computer Graphics: Interaction, Design, Modeling, and Visualization**
February 22-26, 1993
Bombay, India
*For further information:*
ICCG93 Secretariat
National Centre for Software Technology
Gulmohar Cross Road No. 9
Juhu, Bombay, 400 049, INDIA

**Society for Information Display (SID) International Symposium, Seminar and Exhibition**
May 16-21, 1993
Washington State Convention Center
Seattle, Washington, USA
*For details contact:*
Todd Reed
EE Dept. - UC Davis
Davis, CA 95616
(916) 752-4720
(916) 752-8428 (fax)
E-mail: reedt@eecs . ucdavis . com

**Ninth Annual ACM Symposium on COMPUTATIONAL GEOMETRY**
May 18-21, 1993
San Diego, California
*For further information:*
Program Committee Chair:
Mark Overmars
Department of Computer Science
Utrecht University
P.O. Box 80.089
3508 TB Utrecht, the Netherlands

**CALL FOR VIDEOS**
**2nd Annual Video Review of Computational Geometry**
Authors are requested to send one copy of a videotape to the organizers by February 2, 1993. The videotape should be at most five to eight minutes long.
*For further information:*
John Hershberger
E-mail: johnh@src . dec . com,
(415) 853-2242
DEC Systems Research Center
130 Lytton Ave.
Palo Alto, CA 94301
(415) 324-4873 (fax)

**SOLID MODELING '93**
**Second ACM/IEEE Symposium on Solid Modeling and Applications**
Montreal, Canada
May 19-21, 1993
This symposium provides an international forum for the exchange of recent research and practical results in all areas and applications of solid modeling. Emphasis is on the impact of solid modeling in design and manufacturing.
*For further information:*
Mary Johnson
Design Research Center, CLL 7015
Rensselaer Polytechnic Institute
Troy, NY 12180-3590
(518) 276-6751
(518) 276-2702 (fax)
E-mail: mjohnson@rdrc . rpi . edu

**PACIFIC GRAPHICS '93**
**The First Pacific Conference on Computer Graphics and Applications**
Seoul, Korea
August 30 - September 2, 1993
Pacific Graphics is an international conference on computer graphics and applications. The conference brings all computer graphics people to discuss and exchange their researches for promoting computer graphics in the East in cooperation with international professional societies.
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Sung Yong Shin
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Korea Advanced Institute of Science and Technology
373-1 Kusung-dong, Yusung-ku
Daejon 305-701, Korea
+82-42-869-3528
+82-42-869-3510 (fax)
E-mail: syshin@cs.kaist.ac.kr

**The EUROGRAPHICS '93**
**International Conference**
Barcelona, Spain
September 6-10, 1993
EG '93 will highlight three major threads of R&D and four application areas in Computer Graphics, Advanced Interaction Cooperative Working Visualization in Computer-Aided Design, Animation, Electronic Publishing, Geographical Information Systems.
*For further information:*
Palau de Congressos
Dept. de Convencions
Fira de Barcelona
Avda Reina Maria Cristina s/n
08004 BARCELONA
+34-3-423-3101
+34-3-426-2845 (fax)
Telex 53117 FOIMB-E
E-mail: eg93@lsi.upc.es

# Book Review

## *The Macmillan Visual Dictionary*

Macmillan Publishing Company, New York, 1992.
ISBN 0-02-528160-7

Reviewer: William A. Ross
Purdue University

Every once in a long while, a truly innovative and useful reference book comes along. *The Macmillan Visual Dictionary* is such a book. What should be of interest to designers, illustrators, and graphic specialists is the fact that the images represent a clean and professional graphic standard for computer generated illustrations. The Macmillan Visual Dictionary is to computer illustration what Machinery's Handbook is to the mechanical designer or Ramsey and Sleeper's Architectural Graphic Standards is to the architect. Is a 'Visual Dictionary' a dictionary for the reading impaired? In a manner of speaking, yes! The Macmillan Visual Dictionary may be used to find the correct term for something you can picture but not name (such as a widget or a whatchamacalit), or to find out what something looks like when you know its name but can't visualize it. As an example of the profusion of illustrations and terms contained in the book, consider the following questions. What is the baize on a billiard table? Can you describe the machicolation and crenel on a castle? What is the flow bean on a pipeline christmas tree? Where is the nacelle on a horizontal-axis wind turbine? What is the difference in shape between a gonfalon and a burgee flag? Where is the pantograph on a high speed train located? Confused? Look it up and see what it looks like.

How is a 'Visual Dictionary' organized? The book's nearly 900 pages are divided into 28 chapters each giving detailed graphical coverage of topics such as the human body, geography, architecture, measuring devices, optical instruments heavy machinery, astronomy, and many more subjects. Over 600 subjects are included, described with over 3,500 computer-generated illustrations which are clearly and beautifully printed as high resolution (2500 dots per inch) four-color images. To make the book a true reference manual, the illustrations are labeled with over 25,000 terms. A complete index of all terms is included at the end of the book in case you know the term but can't visualize it.

What are some of the obvious strengths and weaknesses of the book? One weakness of this book, as with most reference books, is the limited number of topics that can be covered in a single 900 page book. It is difficult to create a book that can be everything to everyone. In addition, some of the illustrations could be improved aesthetically and technically. On the other hand, the book contains a wide range of technical topics illustrated with colorful, cross sectional and graphically detailed images. Professionally, it furnishes a computer generated graphic standard which should be equalled or improved on by those creating computer-generated illustrations. Perhaps the most pleasant surprize about the book is its amazingly reasonable price of $45.00.

In an age of increasing use of electronic media and digitial images, Macmillan would be wise to consider releasing the images as high quality electronic digitial Post Script clip art using compact disk technology. This would allow the publishers to continue to expand the topics and illustrations in a logical and affordable manner. The images are vivid, high quality, useful artwork and should attract a wide following regardless of the media used.

Who might benefit from owning or using a visual dictionary? This book is highly recommended for students, engineers, illustrators, designers, artists, or anyone who might require a visual reference for technical subjects. Also, browsing through this unusual and beautiful reference book is just plain enjoyable.

# Book Review

## Geometric Dimensioning and Tolerancing: For Engineering and Manufacturing Technology

Cecil Jensen, Delmar Publishers, Inc.
ISBN: 0-8273-5033-3

Reviewer: Patrick J. McCuistion
Ohio University

Cecil Jensen has been active with the subject of geometric dimensioning and tolerancing (GDT) for many years in Canada. In the past he has been a liaison between the United States and Canada on the American national Standard Institute (ANSI) Y14.5 Dimensioning and Tolerancing Standard.

With these facts in mind, I was surprised to see two geometric dimensioning mistakes on the drawing displayed on the front cover of his GDT book. The drawing is copied from the Y14.5 standard (Fig. 85), but with some incorrect additions. Copying figures from the Y14.5 standard is common, but making incorrect additions to those figures is not common. This is the part that surprised me.

I have reviewed many books on geometric dimensioning (see partial listing below for comparison texts). They all have mistakes. Some of the mistakes are unintentional, while others show a lack of understanding – sometimes a complete misunderstanding.

Most of the mistakes in Jensen's text are forgivable with a few exceptions. The biggest mistake is his treatment of the projected tolerance zone. He illustrates the cylindrical tolerance zone encompassing the thickness of the part as well as the projected area above the part. In the ANSI standards and ISO standards the tolerance zone does not include the thickness of the part.

Figure 7-17 shows a zero tolerance for straightness followed by a maximum allowable tolerance. The stated geometric is always a maximum value. Therefore, the first tolerance is unnecessary.

His comparison between coordinate and positional tolerancing is not accurate. It is not correct to assume that the cylindrical tolerance for position may be the same as the diagonal distance of a square coordinate zone. This is a common, but potentially disastrous, mistake made by many authors.

Figure 19-7 shows a Position control for plane features. This is an ISO concept that has not yet been adopted by the ANSI Y14.5 committee (and probably won't be). In the United States this requirement would be dealt with by using a Profile control.

The ultimate question is, "Would I use this book?". The answer is, "No. Not as a textbook that I would have my students purchase." There are too many major mistakes. This serves to impart wrong ideas to the uninitiated and confuse those with some knowledge. With Mr. Jensen's background there should be no mistakes.

But I will not discount it totally. Many of the figures representing inspection techniques are very practical. Also, some of the test question concepts are usable. However, there is little in this book that is new either in text or graphical presentation. Also, most of the books listed below have better printed figures.

On the following page is a partial listing of other GDT textbooks including Author, Publisher, ISBN, and comments by the reviewer.

*EDITOR'S NOTE:*

*If you would like to review a book, or product pertinent to the graphics field and interesting to our readers, please contact me. You will find my address on page 60.*

Title: *Design Dimensioning and Tolerancing*
Author: Bruce Wilson
Publisher: Goodheart-Willcox
ISBN: 0-87006-908-X
Comments: Very good. New on the market.
Includes general dimensioning.

Title: *Geo-Metrics II*
Author: Lowell Foster
Publisher: Addison-Wesley
ISBN: 0-201-11527-1
Comments: The undisputed king.
Most thorough treatment of the subject.

Title: *Modern Geometric Dimensioning and Tolerancing*
Author: Lowell Foster
Publisher: National Tooling and Machining Ass.
Catalog #: 5021
Comments: Simple, easy-to-understand.
Uses many Geo-Metrics II examples.
Good beginner textbook.

Title: *Geometric Tolerancing*
Author: Richard Marrelli
Publisher: Glencoe Publishing
ISBN: 0-02-829810-1
Comments: Very good graphics (could use some color).
Good test questions.

Title: *Fundamentals of Geometric Dimensioning and Tolerancing*
Author: Alex Krulikowski
Publisher: Delmar
ISBN: 0-8273-4694-8
Comments: Good teaching text for beginner.
Nice decision diagrams. Odd crossword puzzles.

Title: *Geometric Dimensioning and Tolerancing Simplified*
Author: Gary Whitmire
Publisher: TAD Products
ISBN: 84-051506
Comments: An inspection point of view.
Good treatment of zero position tolerancing.

Title: *Geometric Dimensioning and Tolerancing*
Author: David Madsen
Publisher: Goodheart-Willcox
ISBN: 0-87006-673-0
Comments: Avoid the 1984 and earlier editions.
1988 edition is much improved.

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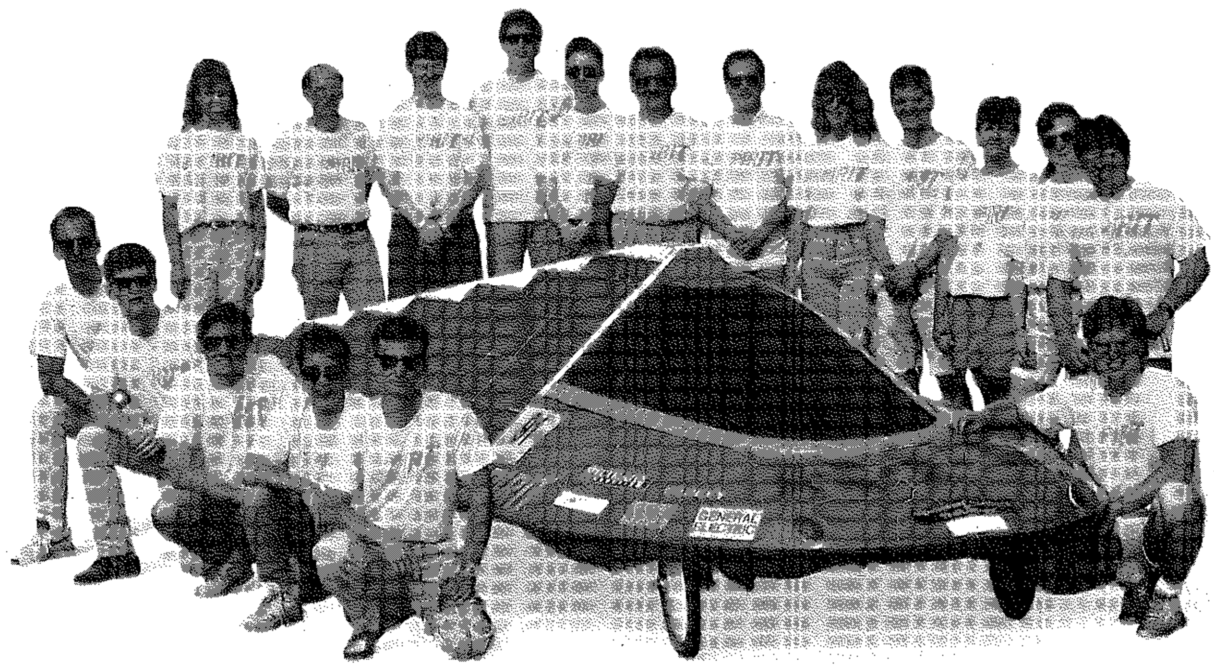


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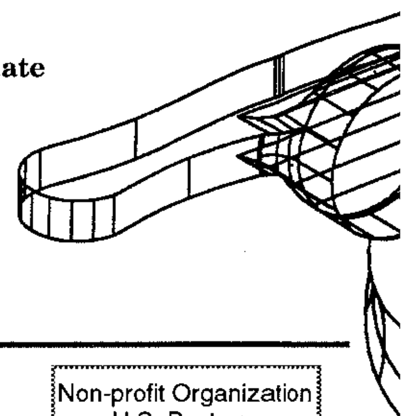


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