A Comprehensive Approach to Teaching Structures Using Multimedia

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Introduction

The project *A Comprehensive Approach to Teaching Structures Using Multimedia* was the outcome of a collaboration of an inter-institutional, multi-disciplinary team from the University at Buffalo, State University of New York; University of Oregon and University of Utah. The project aim was to create an environment for teaching and learning structures that facilitates the comprehension of fundamental principles, practical aspects of structural design, and the creative possibilities of applied structure within the built environment. The project began by a seed grant from the University at Buffalo in 1999 and was funded by the U.S. Department of Education, Fund for the Improvement of Postsecondary Education (FIPSE) from 2001 to 2004. The faculty team project included: Shahin Vassigh and Dr. Scott Danford from University at Buffalo, the State University of New York; Patrick Tripeny from University of Utah; Ronald Shaeffer from Florida A&M; Christine Theodoropoulos from University of Oregon; and Edward Allen.

Motivation

The teaching of structures (the analysis, behavior, and design of structural systems) within academic architecture programs faces a fundamental problem - understanding structures is central to the education of the architect, but the content "content" (theory and pedagogy) and "delivery systems" (teaching methods) currently in use are distinctly inappropriate for the vast majority of architecture students. Architecture faculty and students struggle with a traditional engineering-based approach to structures instruction, which is increasingly proving to be ineffective in the classroom.

Architectural educational preparedness has been examined extensively over the last decade, with most almost universal agreement that the nation's universities are producing graduates who are technically unprepared for the professional practice of architecture. Numerous analysts and writers have documented this problem as a national educational weakness, and identified it as a threat to the architecture profession.

The practice of architecture requires an applied understanding of structures, construction, and technology. Yet as early as 1989 P/A Magazine surveyed its readers on the quality of architectural education. Eighty-one percent of those who responded agreed that architecture schools do not adequately prepare students for practice. "Seventy-five percent of those respondents who identified themselves as faculty and students agreed that education for the world of practice was inadequate."[1] A 1994 national study by the National Institute for Architectural Education recognized a clear and "widening gap between theoretical and practical knowledge and the conflicting objectives of academic preparation and professional practice."[2] The study also concluded that recent graduates lack of skills pose a serious problem which damages the practice of architecture and its professional influence. A 1995 study by the National Academy of Sciences National Research Council reached similar conclusions, noting that "recent [architecture] graduates possess a good understanding of broad design concepts and the design process, but lack knowledge of the practical aspects of construction and building technology."[3]

Poor technical preparation and the failure to adequately educate architecture students in structures is the result of three basic problems. First, the structures curriculum, teaching methods, and instructional tools are borrowed wholesale from engineering programs with little modification. Instruction is therefore highly quantitative, communicating even basic concepts using a high-level mathematics nomenclature. Architecture students do not have neither the background, disposition, nor time to master the mathematics skills required to understand or utilize a system based on highly abstract mathematical models and therefore, quickly become uninterested, frustrated or intimidated by the structures curriculum. The consequence is that many architecture students fail to master the basics of structural theory, much less the more demanding aspects of applied structural design and innovation.

Second, the applied-engineering approaches to teaching structures and building technology uses a methodology which consecutively subdivides and dismalness a structure into extremely small subcomponents, focusing on a particular element, detaching it from all other connected structural members, and then reducing it to a notation system of structural symbols, mathematical formulae and annotations. The engineering approach places an emphasis on the quantitative analysis and performance of structural sub-assemblies. Structures are therefore studied in the abstract using an arcane system of symbolic notation. Structures instruction delivered in this way almost never attempts to connect detailed analysis back to broader building design and construction principles.

Lastly, in most architecture programs the structures curriculum is taught separately from the remainder of the architecture program. Structures instruction is rarely, if ever, fully integrated into the broader architecture curriculum. In particular, creative structural design and application is left out of most architecture design studio courses. Architecture design studios are where architecture students interact one-on-one with faculty to solve design problems and are the central means by which students learn to apply concepts learned elsewhere in the program. Design studios provide the means for highly directed, interactive instruction and the opportunity for students to integrate, demonstrate, and apply the cumulative concepts and issues they study throughout their learning tenure. By excluding or limiting issues of structure within the design studio, students miss primary opportunities to reinforce structures concepts, the importance of structure as a design element (and opportunity) is also overlooked; meaning new opportunities for students to develop innovative and expressive design using innovative structural design is also lost.

Structures in many architecture programs is therefore treated as the unwanted stepchild of the curriculum—viewed as difficult to teach by faculty and a complicated and uninteresting requirement for graduation by students. Unfortunately, these conditions have critical consequences for the professional practice of architecture. First, failing to adequately prepare architecture graduates in structural design and application creates unnecessary economic costs. Professional architecture firms are forced to invest in the technical training required to properly educate practicing architects in the basics of structural design. P/A magazine, writing in 1995 on the failure of architecture programs to adequately prepare new graduates for practice, noted that "many architects now take it for granted that they will have to train them [new graduates] to be valuable employees or they refuse to hire new grads altogether."[4]

Complex construction and advanced building design require an understanding of structures and construction technology, so that under-preparing architecture graduates may pose a significant risk to the quality of the built environment and a clear and present danger to the professional practice of architecture. Modern building design and construction is highly interdisciplinary, requiring a clear understanding of applied structures in order to effectively manage the teams of technical personnel required to complete complex building and design projects. Architecture students, for the most part, leave the academy poorly prepared to communicate and work with engineers. Mario Salvadori[5], Heino Engel[6], the Building Art Forum,[7] and Gary Black[8] have written extensively on the growing gap between architecture and engineering.

With shrinking technical capability important decisions regarding the design of the built environment are increasingly *not* made by architects, meaning that architects have increasingly less control and influence over the design of the built environment. By effectively limiting the role of the architect within the design and construction process, the profession risks being marginalized, increasingly reduced to addressing only aesthetic issues of building design and urban form.

Elizabeth Padjen, commenting on the architect's loss of professional "turf," has said that "the practice of design was a...process in which the architect was in charge of the whole ball of wax, peeling off pieces to give to consultants and contractors. Now...the architect's role is only one of many small bits assembled along the way by any number of construction coordinators."[9]

Improving Structures Education Using Advanced Media

Improving the technical preparedness of architecture graduates has important ramifications for the practice of architecture and society as a whole. Large scale reform of architecture curricula nationally is and will be a complex, ongoing, and difficult debate and effort. However, improving structures teaching tools could have immediate impacts on improving architectural educational quality.

The project described is an alternative structures teaching/learning tool that seeks to better meet the architecture student's needs and capabilities and improve the understanding and application of basic and intermediate structural engineering and technology principles. The project harnesses the capabilities of advanced multi-media graphics and Internet based communications technologies to provide a powerful set of tools to improve the delivery of structures instruction.

The three broad objectives of this project were to first, demonstrate that new multi-media digital technologies could be utilized to develop instructional tools to study structures in ways that not only better meets the needs of architecture students, but demonstrably improves their understanding and mastery of the subject. Based on an alternative pedagogy, this project aimed to show that quantitative scientific methods can be effectively integrated with qualitative and conceptual methods, grounded both in the practical aspects of building design. The second objective is to develop and implement an evaluation procedure and performance indicators that measures changes in student performance and the application of learned structures concepts in their design process. The third objective aimed at showing that the project's outcome can be easily distributed and used, and that the same positive results can be attained across many programs—that the results were not unique to a single instructor and can therefore be used in any architecture program.

Proposed Strategy: Interactive Structures Software

The starting point for improving the technical education of the architect begins with the recognition that if architecture students are to effectively learn and apply structural analysis and design, teaching methods and tools must respond to their needs, capabilities, and perspective. Therefore, the design of the project is based on a pedagogy based on the following principles:

- Teaching structures should facilitate comprehension of fundamental principles of the practical aspects of structural design as well as the creative possibilities of applied structure within the built environment. The communication of basic theory and principles should focus on reinforcing and demonstrating principles of application.

- Particularly for architecture students, the instruction of structures should be visually and spatially grounded, so that it is understood as an integral part of the conceptual and theoretical aspects of design.

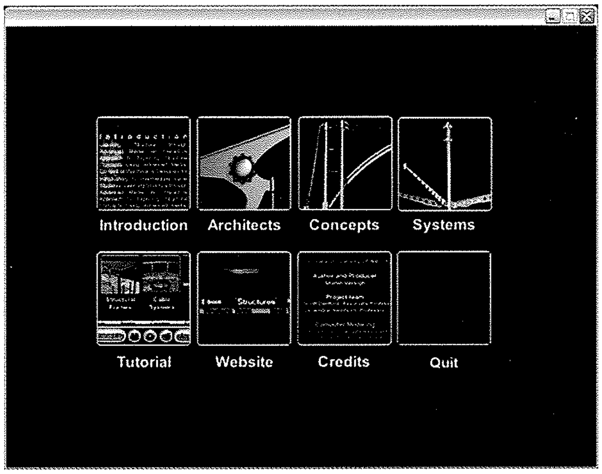


Image 1 Menu options for the ISS

- Teaching tools should make the instructor more effective in the classroom, make the student a more efficient learner, and make student-faculty interaction as effective and efficient as possible.

- Instruction should aim at increasing student interest in structural design, particularly as a life long learning skill. Since architecture is a continuous learning process, creating an interest in structures can positively affect a student's predisposition to further explore structures as a practicing professional. Effective education should not be uniquely dependent upon a single instructor or a single discipline. The educational materials should be developed as interdisciplinary ventures among architects, engineers, and others.

The project is composed of three components: the Interactive Structures Software "ISS"; the instructional support center "Structures Learning Center", and student performance evaluation tools.

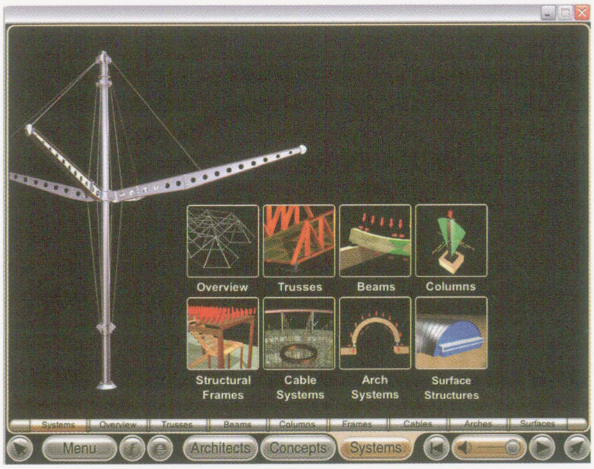
1. Interactive Structures Software ("ISS")

The ISS is a multimedia program that uses a wide range of digital and graphic technology including computer generated 3D models, interactive images, full motion video, audio narration, and hypertext functionality to improve the teaching and learning of structural concepts. The ISS divides the study of structures into three concept areas. These include Basic Concepts, Structural Systems and Architects modules.

Each module is divided into eight sections. There is an average of 20-30 animations in conjunction with fully graphical illustrations and images in each module that explain general structural analysis, concepts, definitions, working principles and architectural design issues. The Basic Concepts module includes statics, loads, structural materials, mechanics of materials, connections, lateral supports, foundations and structure & form.

The Structural Systems module includes an overview section, trusses, columns, beams, cables, arches, frames, and surface spanning elements. The organization of Basic Concepts and Structural Systems are similar in that all the presented principles are demonstrated with the use of highly detailed and realistic 3-D computer generated models and animations. Each module is designed to overcome the limitations of two-dimensional abstract representations of structural behavior in the traditional textbooks by providing a relatively realistic context.

Image 2 Basic Concepts menu



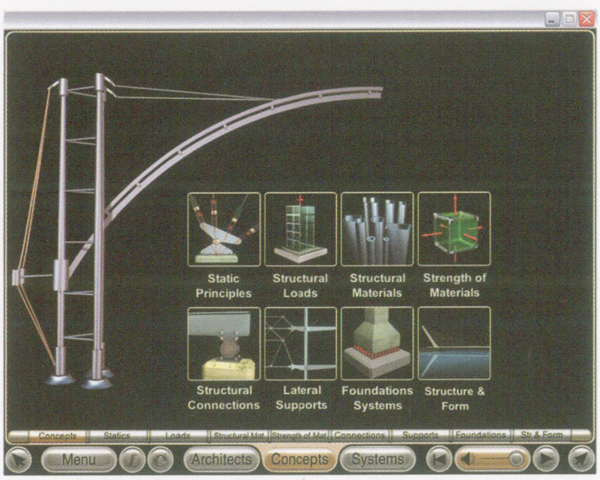


Image 3 a Sample screen from the Basic Concepts menu introducing typical structural connections

Both of these modules include numerical interactive example problems and quizzes. The interactive examples are also highly visual and allow the user to interact with the graphics to alter variables in order to create new problems and solutions. Each quiz is presented in a graphical interface with a 30 second timer and a series of five questions that are randomly selected from a large data bank. Each question that is answered correctly is rewarded with a score and the unveiling of a structure to the right of the screen.

Image 4 Structural Systems menu

The Architects module features eight prominent architects with three building structures selected from each architect's work for purposes of analysis. This module has a different organization than the Basic Concepts and Structural Systems modules. Once the user selects an architect and a building, the general information regarding the location, function and major structural systems of the structure are displayed. The user is then presented with five windows that interact with each other. The four windows located on the right side of the screen contain lessons on the structural function and construction details of the building. The fifth window on the left side of the screen functions as a guide and provides the exact location on the structure for the details being explored. Every time the cursor enters one of the four windows on the right side of the screen, the fifth window on the left side of the screen automatically adjusts to the proper scene. This provides an immediate context grounding the structural principles in a virtual building environment.

Written using multimedia-authoring software, the ISS is available on a 3 volume CD-ROM or a single DVD in both PC and MAC formats. Each CD or DVD includes a printable version of the entire text. ISS is published and distributed by John Wiley and Sons, Inc.

Image 5 Architects menu

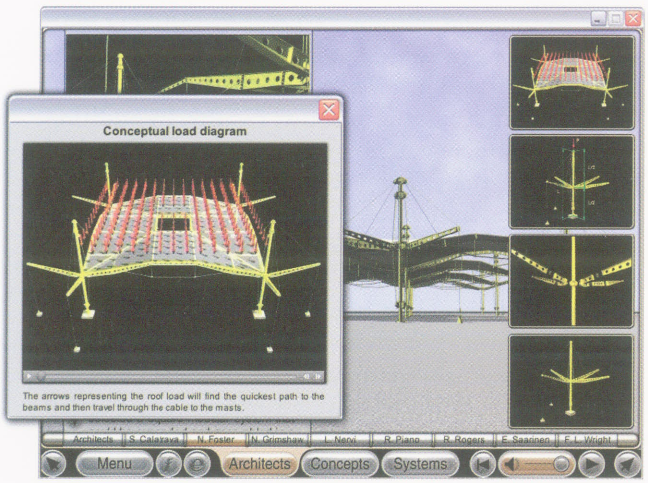


Image 6 Sample screen from the Architects menu showing the analysis of a cable supported structure

2. Instructional Support Center Website: "Structures Learning Center"

The second component of the project is the instructional support website or the *Structures Learning Center*. The objective of the website is to provide additional resources to students using the ISS. The website is relatively comprehensive and is composed of terms, concepts, resources, student performance evaluation tools, instructional support relevant to structural analysis and design, and demonstrations, purchase options, and technical support related to the ISS.

The website is organized into three main components that include: *Structures, Resources, and ISS*. The *Structures* component is organized into sections similar to the ISS and contains a glossary of terms, information on basic structural concepts and systems, and an interactive quiz and a puzzle section for students' self performance evaluation. In addition, this section contains a complete series of tables providing general guidelines for span lengths, load capacities, size, spacing and depth ratios, and various interactive animations that visually demonstrate the structural behavior of the system. The purpose of the tables is to provide architecture students a general range of rules that can be applied in the design-studio setting. There is also a section of quizzes, games, and puzzles related to structures.

The *Resources* section contains an extensive list of books, videos, CD-ROMs, and websites relevant to structures. Currently, the list contains roughly 200 books, 100 web sites, and close to 20 video/CD-ROM sources—making it one of the most comprehensive list of structures resources on the web.

The ISS section contains demonstrations and purchase options. The software can be ordered, and eventually upgraded from the website. On the main page, there is also a list of contacts that are available to augment, support, improve, and answer questions on the use of the ISS, the web page, or the structural content itself. Questions can be posted on a message board and will be added to a searchable database of Frequently Asked Questions (FAQ's). Comments from users will be solicited and used to continuously improve and refine the educational program and instructional materials.

To expand use of the website it is also for visually impaired users. This feature allows the users to customize the screen based on their vision. By pressing the "customize" icon the user can change the font size and color, and adjust the screen background color. In addition, the website is equipped with Breadcrumbs. Breadcrumbs provide a trail of text above each page explaining system operation and the navigation.

3. Student Performance and Evaluation

The objectives of the project evaluation was to measure whether the use of ISS improved student test scores, application of structures principles to architectural design work, and whether it changed student attitudes toward structures. The primary target population for the project evaluation was the undergraduate sophomores and juniors taking two required structures course and two design studios at University of Buffalo.

In order to establish that the project results were not unique to a single instructor or institution, another group of students participating in a similar program were identified at The University of Oregon and took part in the project. The evaluation of the gathered data from University of Buffalo is completed and presented here. However, the result of the evaluation at the University of Oregon is in progress and has not been concluded at this time.

Evaluation Procedure

Prior to implementation and testing, student SAT scores and were obtained. This data was used to insure consistent student groups and compensate for individual variations in test results. In addition to design and development of the tests, projects and survey questions, evaluative standards and performance indicators were established to provide accurate, consistent, quantitative measures of student performance.

Students taking two structures courses, introductory structures 1 and intermediate structures 2, were divided into two groups—a *control group* which received traditional structures instruction *not* using the (ISS), and an *experimental group* which received instruction using the ISS. The Structures 1 experimental course used the ISS heavily as its content covered the entire introductory course requirement. The Structures 2 experimental course used the ISS less intensely as the latter part of the course was design oriented.

Throughout the evaluation cycle, each group was monitored closely.[10] All the course work such as exams, assignments, and class projects was graded and recorded according to the evaluation program grading criteria. Once the implementation of evaluation program was completed, the data was analyzed with various statistical programs. The project team selected T-test results to interpret the student score data and grades. The evaluation program also measured attitudes toward the structures by delivering an Attitude Survey which questioned basic attitudes towards structures, how knowledge of the subject is utilized within the design process, and gauged basic interest level in the subject at the beginning and end of each structures course. The survey data was analyzed by using the Mann-Whitney test.

The complete project evaluation, individual survey questions, and statistical analysis of student of student performance and responses are posted at the project's website www.learningstructures.org. The following is a summary of findings.

Structures 1 Course: T-Test Results

The results of t-test comparing the performance of students in the control and experimental group in the Structures 1 course showed significantly positive results for all the tests. Both experimental and control group were given three identical tests. Comparing three test grades from each course showed an increased improvement in the student performance as their exposure to the ISS increased. This was evidenced by an increase of 10 points in the class mean grade for the first two exams with a significance level of 0.049 and an increase of 18.5 in the class mean grade for the final test with significance level of 0.005.

In order to further analyze the students test scores, and examine the project's team hypothesis that the ISS would help the students with lower SAT scores and weaker mathematics skills at a greater extent, a second t-test was performed. This test compared the test scores of the students in control and experimental group in two separate categories of high SAT mathematics performers, and low SAT mathematic performers.

The t-test results showed that although both groups benefited from using the ISS in the experimental course, the low SAT math performers were impacted the most. The mean grade for the final exam of the students with lower SAT mathematics score increased by 15.5 points with significance level of 000. This finding approved the initial hypothesis of the project team.

Structures 1 Course: Mann-Whitney Test Results

The evaluation program measured attitudes toward the structures subject by conducting *Attitude Surveys* that questioned the level of student interest, effectiveness of the course, impact of digital media in learning, and the students' ability or desire to apply their knowledge of the subject in the design process. Each group was given two sets of survey questions, a pre-survey set at the beginning of the course and a post-survey at the completion of the course.

The Mann-Whitney test was used to compare the pre-survey and post-survey data from the control and experimental group. The analysis of this data showed a significant improvement in the students' attitude towards structures in the experimental course, with 15 out of 27 post-survey questions showing a statically significant improvement. For example, when students were asked if they agreed that multimedia digital technology can enhance learning concepts related to structures, the post-survey course results in the experimental course showed a strong improvement in the students' perception of digital media, with a 34 percent increase in students who strongly agreed with the statement at significance level of 0.000. When students were asked if they felt that architectural education can benefit through gaining a better understanding of structural concepts, in the post-survey of the experimental course, the students' response changed by a third from ambivalence to positive at a confidence level of 0.023

When asked if they felt competent in applying basic structural principles to their design work, 22 percent more of the students in the experimental group agreed strongly while the ambivalent and disagreed answers dropped by 18.5 percent. This is was at a significance level of 0.038. When asked if the use of visual graphics makes understanding structural concepts less complicated, the post-survey of the experimental course showed considerable improvement. Most dramatic was the 26 percent increase in students' response who strongly agreed with this statement. The number of ambivalent answers dropped to half in favor of utilizing visual graphics to teach. And finally in response to if architectural education can benefit through gaining a better understanding of structural concepts, the post-surveys of experimental course showed 13 percent increase in strongly agreed answers, and a drop of 25 percent in the ambivalent and negative responses. This was at a significance level of 0.023.

Structures 2 Course: T-Test Results

In structures 2, the students were given two tests. The results of t-test comparing the performance of students in the control and experimental group in the structures 2 course showed an overall improvement in both tests. The class mean grade for the first test in the experimental group improved by 10.4 points with a significance of 0.000. The result of the second test did not show a statistically significant improvement in the experimental group performance. This could be explained by the content of second part of the course, which concentrated on sizing structural members and did not involve using the ISS.

Structures 2 course: Mann-Whitney Test Results

In general the change in student response to the survey questions were less drastic than Structure 1 course. Although the attitudes toward the structures course still improved with exposure to ISS in the experimental group, the results were only statistically significant in a few questions. For example, when students were asked whether they find the methods of teaching material related to structures in the architecture curriculum educational and appropriate, the post-survey in control group showed a 31 percent increase in the positive answers with a significance level of 0.003, indicating that the ISS offers a more appropriate teaching method. When asked if an understanding of structural concepts makes them more employable, there was an increase of 22.5 percent of strongly agreed and a 25 percent increase in agreed responses in post-survey of the experimental group.

The less keen responses in the structures 2 courses could be related to the fact that by the time the students took the post-survey in Structures 2 experimental course, they were answering the same survey questions for the fourth time, and have been using the ISS for two consecutive semesters, thus being less enthusiastic in their answers.

Studio Evaluations

The evaluation of the students' application of structures principles to their design work was done in each studio immediately following each of the two structures courses. This was based on a self evaluation by the students and an objective assessment of students design work by an independent reviewer from the University of Utah.

The results of the self evaluation and expert reviewer did not show any significant improvement in design work in the studio immediately following Structures 1 course. This results are not discouraging since the content of Structures 1 is introductory, and is not application oriented.

This trend changed in the studio immediately following the Structures 2 course, indicating an improvement in both categories of assessment. For example, when students were asked to what extent the consideration of structural issues was a part of their personal initiative, the number of students responding "to a great extent" increased at a significance level of 0.01 from pre to post self evaluation. In answering to what extend they thought about selecting a particular structural system, again the number of "to a great extent" increased at a significance level of 0.049 from pre- to post self evaluations.

The expert reviewer looked at ranking five different categories in students' design work.[11] The results of this assessment followed the same pattern. There was an improvement in all categories however, the students consideration of "lateral supports" in their design work showed a statically significant improvement in studio following Structures 2.

Closing Remarks

The problems with the current approach to teaching structures are rooted in the use of an engineering based model, which is founded on abstraction and reduction. Architects think, learn, and approach the design of the built environment differently than engineers. Unfortunately, the standard engineering-based approach employed to teach structures does not address the thinking, strengths, and weaknesses of architecture students. Clearly, most architecture students do not have a strong mathematical background, but they do possess a strong facility for and training in three-dimensional visualization and can quickly absorb information through this medium.

Therefore, any approach, which is used to teach architecture students effectively and to promote an intuitive understanding of the subject, needs to be sensitive to these issues.

The project described above was built on addressing these issues. The evaluation results of the project's first round of implementation are extremely encouraging, and confirm the central underlying principle for the development of the project, which was utilizing visual techniques to improve student performance. The project findings also point to the great potential of digital technology in other areas of architecture education such as lighting/electrical, plumbing, heating/cooling/ventilation, and construction. Since architects are well trained in digital modeling and providing visualization tools, it is a natural step for architecture education to benefit from this advantage.

Notes

1. Thomas Fisher, "Reader Poll: Education," *Progressive Architecture* (1989): 15.
2. See National Institute for Architectural Education, "Architectural Education and the Built Future" (1994).
3. Commission on Engineering and Technical Systems, "Education of Architects and Engineers for Careers in facility Design & Construction," in *The National Academies Press* (1995), 30–31, 51.
4. Thomas Fisher, "Can This Profession be Saved?"*Progressive Architecture* (Septembe, 1995): 46.
5. See Mario Salvadori, *Structures in Architecture: The Building of Buildings* (Englewood Cliffs, N.J.: Prentice Hall Inc., 1986).
6. See Heino Engel, *Structures Systems*, Deutsche Verlags-Anstalt GmbH Stuttgart, 1967.
7. See Building Art Forum Publications, *Bridging the Gap: Rethinking the Relationship of Architect and Engineer* (New York, N.Y.: Van Nostrand Reinhold, 1998).
8. See Gary Black & Steffen Duff, "A Model for Teaching Structures," in *Journal of Architectural Education* (September 1995).
9. Fisher, "Can this profession be saved?"47.
10. The average number of students (or sample size) in each course was 75.
11. These categories looked at ranking the students' projects in the selection of overall structural systems; systems resisting gravity forces; systems resisting lateral forces; materials; and the compatibility of the structure with the architectural design scheme.