

Structural Gizmos

Samir Abdelmawla, Illinois Institute of Technology, USA

Mahjoub Elnimeiri, Illinois Institute of Technology, USA

Robert Krawczyk, Illinois Institute of Technology, USA

Abstract

Architects are visual learners. The Internet has enabled interactive learning tools that can be used to assist in visual thinking of structural concepts, especially at the introductory levels. Here, we propose a visual approach for understanding structures through a series of interactive learning modules, or 'gizmos'. These gizmos, are the tools that the student may use to examine one structural concept at a time. Being interactive, they offer many more possibilities beyond what one static problem can show. The approach aims to enhance students' visual intuition, and hence understanding of structural concepts and the parameters affecting design. This paper will present selected structural gizmos, how they work, and how they can enhance structural education for architects.

Precise computation is no more certain than a belief or a dream, but we must try by means of more exact analyses to prevent the harmful effects of human error.

Louis I. Khan

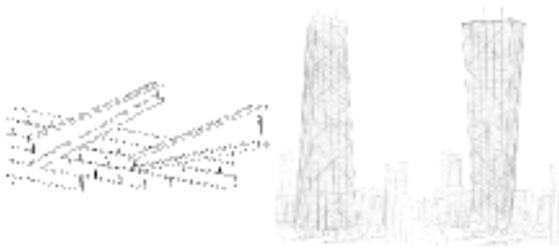
1 Introduction: Structure for Architects

A major portion of an architect's education is structures. The study of structures includes engineering concepts presented in mathematical terms and architectural design presented in non-mathematical terms. The simulation and physical testing of structural concepts are considered the best approach to understand engineering and design. With the evolution of multimedia and animation, as computer-aided instruction techniques, an interactive learning environment can be developed to meet most of the needs of architectural students, who are best suited for such a visual approach.

1.1 *Visual Intuition of Structures*

A visual approach should enhance *visual intuition*. We need to enhance such intuition so students can *feel* when a system is not quite correct or when a structure member is not efficient. Through visual intuition, principles of structures become an unconscious part of student's way of thinking. We all possess a purely visual intuition of structural behavior through our daily experience. We understand why columns at the bottom of a building must be larger than those at its top, since they must support the accumulated weights of all the floors of the building. Without any theoretical knowledge, we are ready to say that a cantilever beam is right if shaped with a decreasing depth towards its tip, Figure 1a. The same concept applies to light poles or high rise buildings, Figure 1b. We may even have aesthetic feelings about this matter and say that the form is in the first case *>lovely=* and *>ugly=* in the second. We are trying to enable the student to understand the underlying reasoning for judging.

A *quantitative* interpretation of these examples should explain *why*. At the same time, a visual approach may introduce a *qualitative* presentation of structural concepts as the basis for *quantitative* analysis and selection of parameters that affect the ultimate design.



1.2 The Beginning of Visual Approach

Although it is not necessary to make every architect an engineer, architects still need to understand the structural system and the structural performance of the design. Structural education has been addressed by some masters in the field, such as *Mario Salvadori*, *P. Corkill* and *Jafar Vossoughi*, who have written valuable books in the 1960s and early 1970s (Abdelmawla 2000). Salvadori had the talent of explaining. He wrote many books that simplify not only structures but math as well. He wrote *Math Games for Middle Schools*,

Figure 1. Intuitive judgment of correct and incorrect (a) cantilever beams, (b) high rise buildings.

The Art of Construction, Why Buildings Stand Up, Structural Design in Architecture and *Structure in Architecture*. Yet, the manual he put together for 70 lessons of *Architecture and Engineering* in 1963 is the first to use the concept of a visual approach, Figure 2a.

In 1998, W. Zalewski and E. Allen published *Shaping Structures: Statics* revives late nineteenth- and early twentieth-century graphical methods in which the relationship between structural forms and forces is explored geometrically through the manipulation of scaled vectors. This book, with a supplementary CD-ROM, invites students to analyze structures through the generation of simple structural forms of their own design.

Understanding Structures, published in 1999, by Fuller Moore is a survey style compilation of several classic non-quantitative approaches to structures education presented through analogies drawn from everyday life, diagrams of analytical concepts, and images of physical demonstration models. This book and the previous present a departure from the use of mathematical expressions and calculations as the primary vehicle for introducing structural concepts. Neither addresses the potential for using computer-based analytical methods to introduce students of architecture to struc-

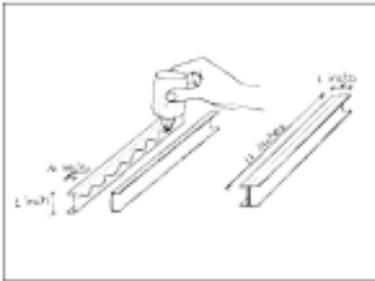


Figure 2. (a) Visual Approach through Building Models – M. Salvadori, 1963.

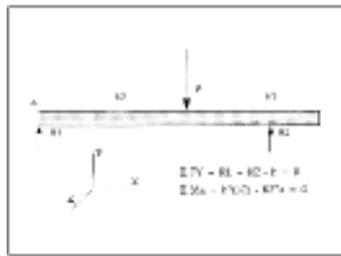


Figure 2. (b) Structure Programs in BASIC – Kern International 1983.

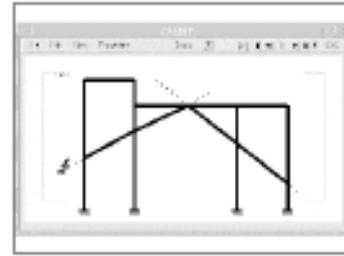


Figure 2. (c) CASDET – Piccolotto & Rio 1995.

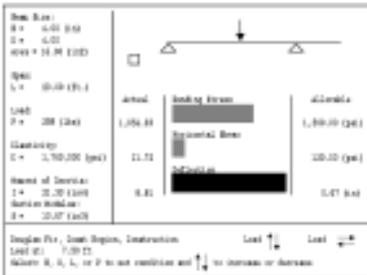


Figure 2. (d) Interactive Beam / Structural Workbench – Elnimeiri & Krawczyk 1996.



Figure 2. (e) Architectonics on the Web – C. Luebke, 1997.

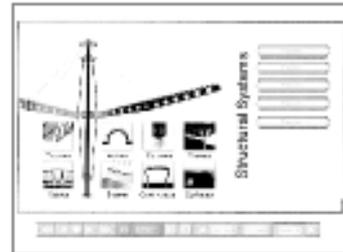


Figure 2. (f) Structures E-Book -- S. Vassigh, 1999.

tures (Theodoropoulos 2000).

1.3 Computer-Aided Instruction and Visual Approach

At the same time as the introduction of personal computers in 1983, Justin Cole published a review for the role of computers in structural education at the School of the Built Environment, South Australian Institute of Technology. He also described the development of SSADS; a computer based Structural Selection Analysis and Design System.

In 1985 Kern International produced a set of simple structural programs. These programs were to be used as educational tools at the college level or engineers who may find them useful as a self-study course. They were also intended to be used as a supplement to a standard course in mechanics, Figure 2b.

In 1993 a team at the Illinois Institute of Technology built the first prototype of an interactive simple beam program. The Interactive Beam allowed the user to move or increase the load or move support location; at each change shear, moment and deflection diagrams are refreshed. The work was further developed in the “Structural Workbench” research project. The project was completed in 1996 and constructed a hierarchy of structural concepts as a prototype for a learning multimedia package (Elnimeiri 1996) , Figure 2c.

In the annual conference of ACADIA in 1995 Piccolotto and Rio presented a paper entitled “Structural Design Education with Computers.” The paper presented a program for the simulation of structures called CASDET (Piccolotto 1995). The program was quite advanced in the methods used for the composition and analysis of planer structures. The program as well displayed the results of user interaction and kept the analysis process behind the scenes, Figure 2d.

In 1996 Chris Luebkehan put to the Web a series of lectures for a structural course to be accessed online at University of Oregon. In 1997, he presented a paper about web-based interactive visualization tools to enhance the effectiveness of teaching/learning of Architectonics, at the ACSA National Conference. He also developed at University of Hong Kong interactive programs for simple beam behavior and pencil tower loading, Figure 2e.

At State University of New York at Buffalo, Shabin Vassigh developed another prototype for a multimedia instructional software package that utilizes a wide range of graphics, animation and sound to demonstrate the principles and application of structural analysis and building technology (Vassigh 1999), Figure 2f.

2 What is the Visual Approach?

Visual analysis relies on the ability to develop abstracted model and to get the sense of structure and how it works. Consider the simple truss shown in Figure 3, the questions below are to arouse student interest and create attention.

The student is asked to answer this group of questions before hand, i.e. (a) which member carries more load? (b) The lower chord of the truss is in tension or compression. (c) If we decrease the depth of the truss, the forces in members are going to (increase – decrease – stay the same)?

Through visual analysis we could answer these questions if the diagrams could ‘talk’ back to us. For the question in Figure 3a, as an example, as we move the load left, over the support, the vertical member would carry 100% of the load (as shown in Figure 3c). By the movement of the load moves towards the right, we can anticipate an increase of the force in the right member. This means the members will carry more load as they become vertical.

2.1 The Use of Visual Approach in a Structural Class

The learning model proposed in Figure 4 shows the relationships between the on-line supporting material and the direct instruction class at three level of: (a) offer information through lecturing, handouts, and web pages, (b) reinforce the concept through examples and the interactive gizmos, and (c) test students’ knowledge through quizzes and exams.

Figure 5 delineates the hierarchy of basic knowledge of structures for architects. The flow starts with an introduction to structure; i.e. to define what is structure, structure development and its boundaries. The comprehension of “Basic Concepts” is considered as a prerequisite before getting into the analysis modules. Of course, these analysis modules could expand to cover other compo-

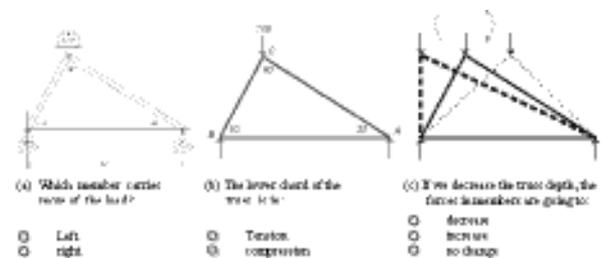


Figure 3. Visual Analysis as Problem Solving Method.

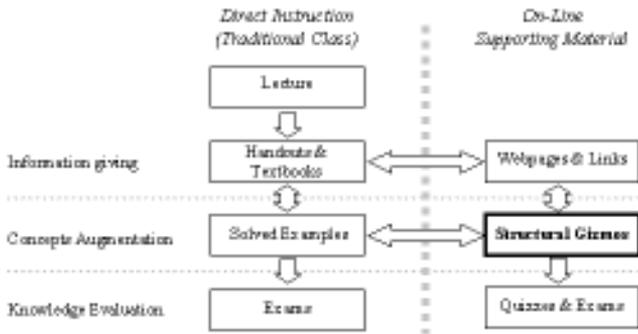


Figure 4. Structural Gizmos as Concept Support within a Class.

“a usually small and often novel mechanical or electronic device or contrivance”
(Merriam-Webster Dictionary)

The gizmos as constructed here are interactive Java programs designed to simulate the behavior of structural components. They are mechanisms that are able to simulate a seemingly mechanical property by having moving parts. As these parts move, forces can be applied and responses can be shown. In all aspects we consider these to be digital machines with the same qualities of real gizmos.

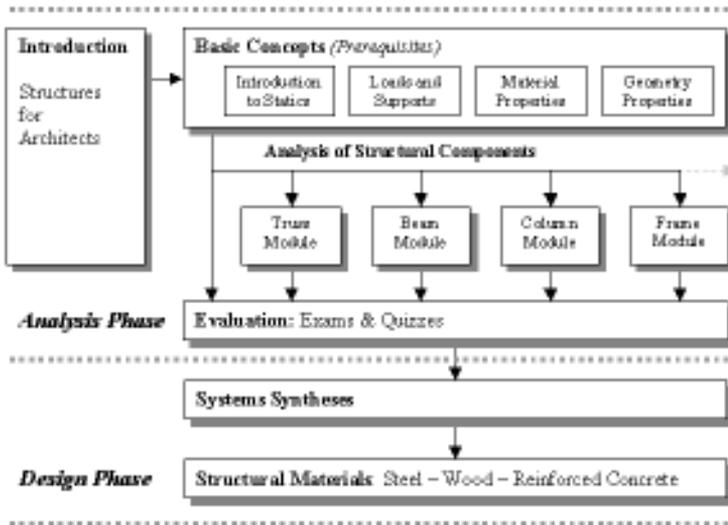


Figure 5. Hierarchy of Basic Knowledge for Structures for Architects.

The response of the structural components and the magnitude of the forces induced in members or reactions is represented visually based on changes made by the student, Figure 8. These visual cues designate members subjected to higher strength and flow of forces within the structure. Reactions at supports are represented visually, as well as, by percentage values. These responses give the visual feedback of the behavior of the component under certain loading condition. Through the changes the student makes for different load and geometry conditions, he/she can begin to understand the parameters that affect the component performance and/or efficiency.

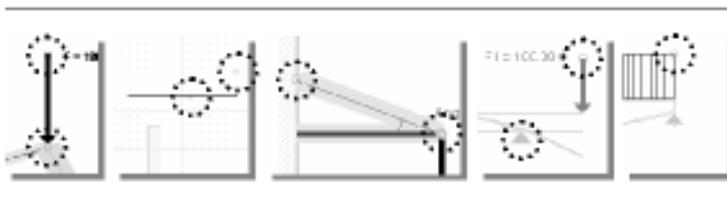


Figure 6. Visual Controls of Values and/or Geometry.

Critical values as well are shown in some modules, i.e. maximum bending moment and its location. At the same time, some values have been omitted from display for more clarity of the display area. Information, such as, forces in truss members are not shown but could be sent through email or displayed in another window.

Colors add another dimension to visual information representation. Colors are used to differentiate

elements, e.g. frames and arches, cable structures, shells, etc. Evaluation can help students to identify points that need revision and test misconceptions. Series of quizzes and exams can take place after the completion of the prerequisites, as well after the completion of each module. Upon the understanding of the structural analysis process the student can proceed to the design phase.

3 What is a gizmo?

giz·mo also *gis·mo* (gzm). n., pl. *giz·mos*. [20th c.; origin unknown.]

“any small and usu. ingenious mechanical device or tool. sl. a gadget” (Oxford Dictionary)

3.1 Visual Qualities of Gizmos

Visual analysis is supported with the gizmos through certain visual cues. These cues manage the visual representation of the concepts we are trying to convey which are based on calculated values. Some typical visual controls are shown in Figure 6. Testing of different values and/or geometric configurations is handled visually by dragging object grips, hot spots, or moving the object itself.

The student as well has the ability to plug in specific numerical values for testing components. Through the use of multiple text-fields, he/she can change force magnitude, application point, member angle, span, or locations for supports. Check-boxes are used as well to control the visibility of certain visual cues. By turning these check-boxes on or off, they are able to change the number of forces applied, control the visibility of reactions, or visual representation of force magnitudes, Figure 7.

between different types of forces, e.g. tension, compression, or zero-force members, as shown in Figure 10.

The gizmos, through interactivity, help in the comparison of different geometrical configurations and loading conditions. Figure 11 shows some of visual comparison possibilities. Through the changes of the cable angle shown in Figure 11a, we can see how cable angle affects the amount of tension induced in the cable as well as the compression in the horizontal rod. In the Section Properties gizmo, Figure 11b, the student can modify the selected section and compare its efficiency to other sections. Section efficiency is obtained in this case as a ratio of “Moment of Inertia” to “Cross Section Area.”

In the Truss gizmo, as to be discussed later in the following section, we would be able to see the forces flow and the pattern of tension/compression members in different trusses, Figure 11c. We also can compare the effect of changing the number of bays for the same truss and same span. High stressed members as well are represented wider than low stressed one. Through this designation we can see the effect of changing truss depth for the same truss and same span.

3.2 Gizmos within Learning Modules

The following series of figures, Figures 12 through 18, outlines the complete set of modules that will be part of the course material. An attempt was made to have at least one gizmo in each module. In each module, the gizmo is accessed through accompanying web pages. A close examination of these gizmos demonstrates the variety of visual cues that can be implemented for each single structural concept.

Module A: Introduction to Statics - Resolution of Forces

Module B: Loads and Loading - Loads, Supports and Reactions

Module C: Members in Bending Beams Shear force & Bending Moment Diagrams

Module D: Material properties - Stress, Strain and Modulus of Elasticity

Module E: Section properties - Centroid, Moment of Inertia

Module F: Members in Bending - Beam stresses

Module G: Axial Loading Members - Trusses

4 Conclusions

Better understanding of structures leads to better architecture. Efforts have been made to make learning and teaching structures as easy as possible. But, there is no such thing as easy learning, or teaching; only methods or devices can make them distinguishable. The paper introduces visual representation of structural concepts as a natural approach for students of architecture to promote structural intuition. Meanwhile, intuition by itself cannot be expected to lead to quantitative knowledge in a field as complex as structures. For this, the visual approach considers both visual examination and numerical analysis of the structural component. The critical issues addressed in this part of this study are the visual cues that can be developed to enable greater understanding of structural concepts and what material can be applied which enhances, not replaces, classroom instruction.

The advantage of web-based learning aids is obvious. Anytime, anywhere learning reinforces the instruction in the classroom. The ability to introduce additional material and examples allows the instructor to concentrate on core concepts and detailed explanations knowing that the student will have the ability to examine them at great length on their own. The gizmos also allow the instructor to



Figure 7. Numerical Input of Values and Visibility Options.

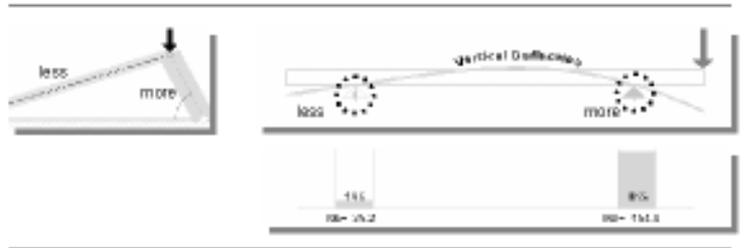


Figure 8. Visual Representation of Values and Structure Response.



Figure 9. Display of Numerical Values.

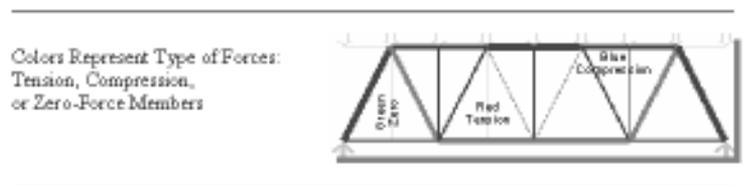


Figure 10. Usage of Colors.

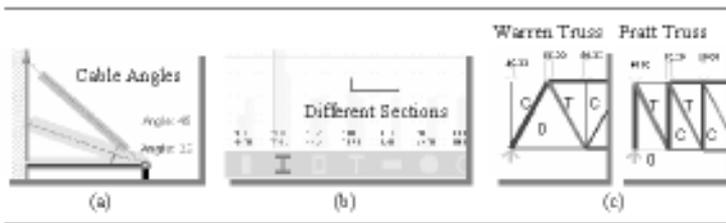


Figure 11. Visual Comparison.

show in class structural concepts that may be difficult with traditional means. Future research will attempt to quantify the actual benefits of this approach. Using testing of structural knowledge before and after the use of the gizmos may begin to tell us better how this method can increase learning. The gizmo concept can also be applied to other areas of architectural education. Most engineering related areas that rely on computations that can be visually demonstrated are good candidates. The greater challenge is to develop visual methods that could be used in teaching architectural form and spatial organization.

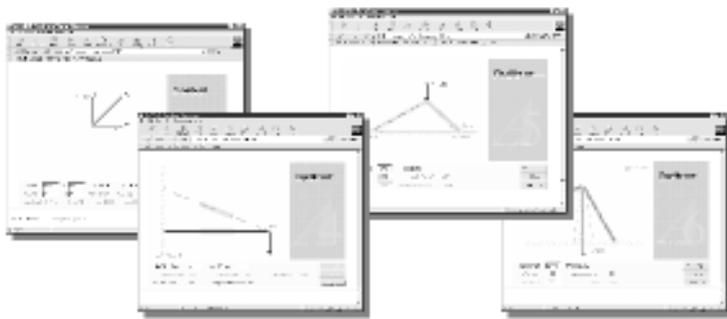


Figure 12. Group of Gizmos Designed for the Resolution of Forces Concept.

ings: 285-298. Association for Computer Aided Design in Architecture.

Theodoropoulos, C. (2000). Book Reviews, *Journal of Architectural Education*: Volume 53, Number 3, February 2000: 186-187. Washington, D.C.: Association of Collegiate Schools of Architecture.

Vassigh, S. (1999). *Structures E-Book*. ACADIA Quarterly. Volume 18, Number 3, 1999: 14-15. Association for Computer Aided Design in Architecture.

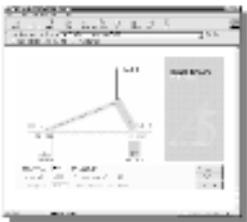


Figure 13. A Gizmo Showing Distribution of Reactions from a Simple Truss.

References

Abdelmawla, S. (2000). A Visual Approach of Structural Analysis for Architects. Unpublished Ph.D. Arch. Thesis, Chicago: Illinois Institute of Technology.

Elnimeiri, M. and R. Krawczyk. (1996). *Structural Workbench*, Unpublished, Final Report. Educational and Research Initiative Funds (ERIF), Illinois Institute of Technology.

Piccolotto M., and R. Olga. (1995). *Structural Design Education with Computers*. ACADIA' 95 Proceedings: 285-298. Association for Computer Aided Design in Architecture.



Figure 14. A Series of Beam Gizmos with Pointed and Distributed Loads.



Figure 15. Modulus of Elasticity for Different Materials.

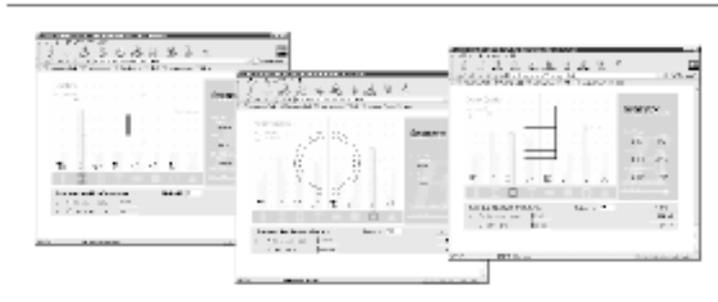


Figure 16. Comparison of Moment of Inertia for Different Sections.



Figure 17. Beam Shear / Moment Stresses and Critical Range.

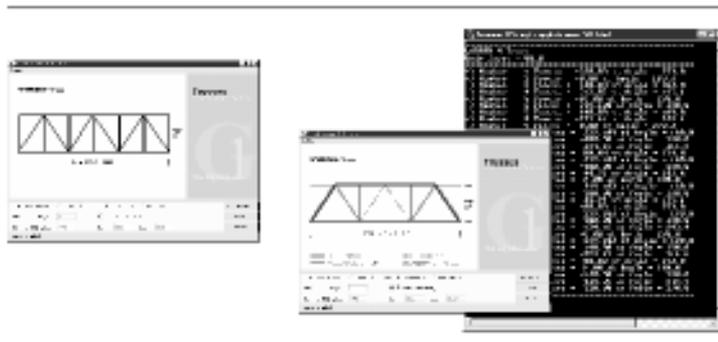


Figure 18 (a). The Truss Gizmo - Warren Truss Analysis with and without Forces Display and the Forces. Magnitude in Members as to be Emailed.

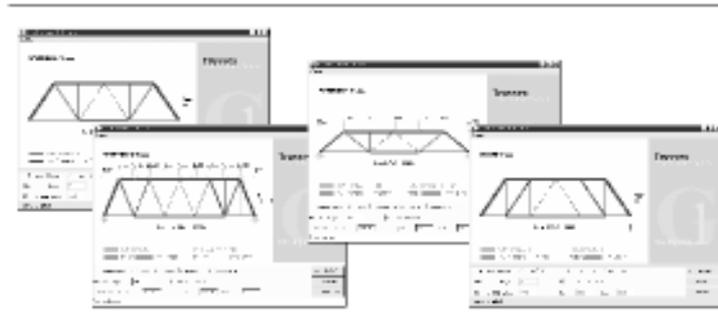


Figure 18 (b). The Truss Gizmo - Comparison for Different Truss Solutions by Different: Number of Bays, Truss Depth, and/or geometry.

