AC 2011-2763: SWEETENING STRUCTURAL PRINCIPLES FOR ARCHITECTURAL STUDENTS

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Sweetening structural principles for architectural students
(An example of visual communication of structural concepts in architectural programs)

Introduction

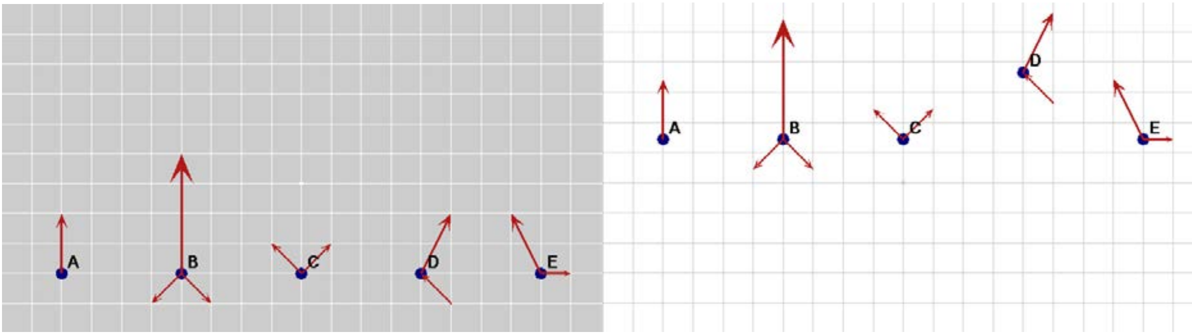
It is interesting to note that the pedagogic approaches of teaching structural principles in architectural programs and in civil engineering disciplines are almost identical and have remained relatively unchanged for the past few decades. Lectures are generally conducted using calculation-intensive platforms and the role of the students in the lecture is relatively limited, and thus they remain in a passive mode of learning throughout the classes. A mathematical approach is unquestionably the most exact, effective and economical way in engineering problem solving as well as in engineering education. However, based on my experiences as a structures professor in architectural programs, this white-board-only teaching methodology associated with platforms of computations has never been very effective or successful for architectural students. Architectural students tend to be readily discouraged by this rigid approach and thus remain inactive during these mathematically intensive lectures. The bitter taste of calculations seems to cause them to feel a lack of confidence in their mathematics background. Thus, structural courses are perceived as engineering subjects, not an integrated ingredient of successful architectural design. This factor has resulted in low levels of motivation of architectural students in structures classes, which in turn has caused poor interaction, inadequate understanding and low retention of structural principles.

Visualizing Structural Engineering Concepts – "*Open the mind*"

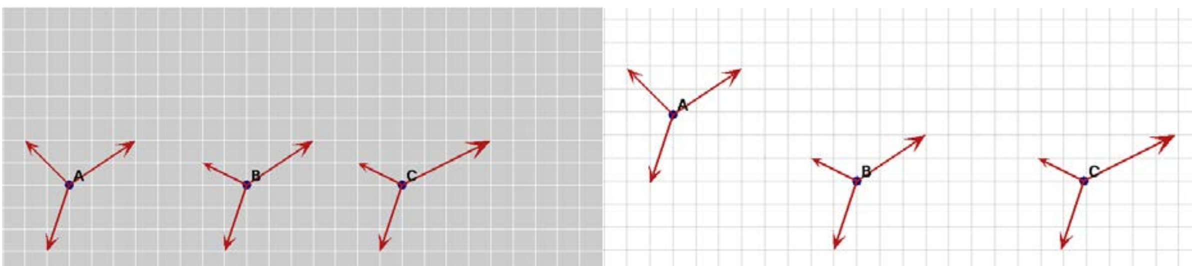
In engineering disciplines, the students' ability to comprehend engineering principles can successfully be obtained by manually solving a series of multiple engineering problems of progressive difficulty as most engineering textbooks are formatted. The results of this mathematical approach in engineering education seem to be straightforward, maybe even obvious.

In architectural programs, however, this most effective teaching methodology of structural engineering principles seems to need some additional pedagogical consideration or "treats" to make the students more attracted, motivated and remain focused. To wake up the architectural students out of the inactive mode in structures courses, the gap between the two professional talents of architects and structural engineers must be correctly addressed and understood. The gap between artistically creative fickleness and rigidly compliant performance must be bridged by carefully devised training. Structural engineers utilize formulae and equations to define and clarify the engineering concepts while architects use drawings and models for communication.

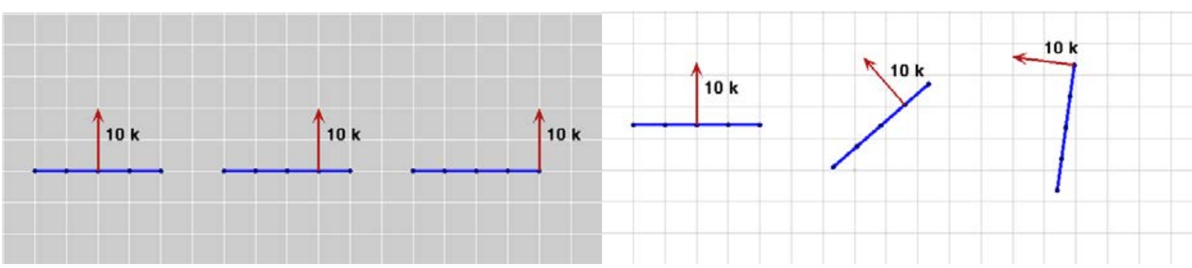
Before Simulation Starts | After Simulation Starts



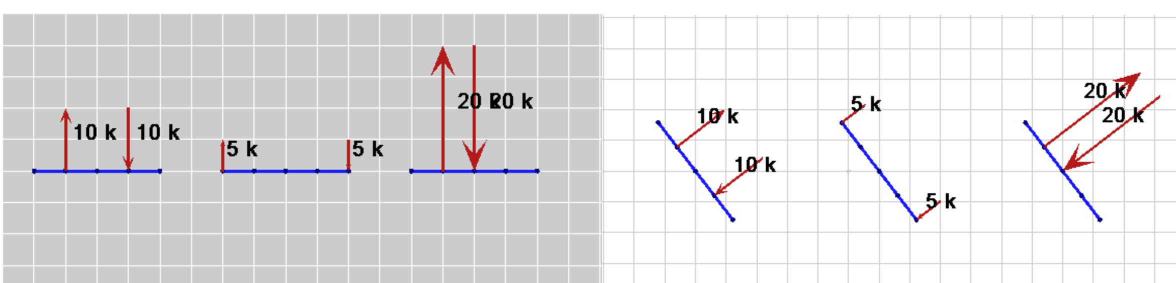
A race of different sets of forces tinged with air of play easily opens the architectural students' mind to engineering concepts.



Effects of horizontal and vertical components and concepts of equilibrium are acquired by simply counting the number of grids in the x- and y- directions instead of using trigonometry.



Moment of force and concept of eccentricity can be effectively visualized and conceived without the mathematical formulae.



Effects of couple moments are understood as the number of unit squares surrounded by the couples.

Thus, promoting visual communication, other than esoteric equations, could be a friendly solution for rigorous engineers to speak to the inactive artists.

When structural concepts are introduced to architectural students for the first time, the conventional mathematical approach is initially placed on hold. Instead, visible, interactive and even tangible (if possible) approaches without "number-manipulating" are opted to be used as the treats. The bitter taste of mathematics is reduced to enhance the level of engagement of architectural students in structures classes. More graphics and less "number manipulation" is the key aspect of this paradigm. In other words, visual thinking is emphasized over mathematical thinking.

An academic real-time simulation program, in addition to physical models and 3-D graphical presentation tools, is used to visualize the fundamental structural engineering concepts, e.g., force, moment, equivalent force systems, resultant, and equilibrium. The interactive non-linear structural analysis and simulation software, Arcade, developed by the University of Virginia is used to 'play' with the fundamental structural concepts, e.g., force, components, resultant, moment, equivalent force systems, equilibrium, and principle of transmissibility. In these sessions, the structural principles are introduced without using the unfamiliar engineering terminologies or trigonometry. Also the Force Polygons for concurrent force systems and Maxwell's diagram for analysis of determinate trusses is adopted to understand the general characteristics of truss behavior and to visualize resulting member forces. Rigorous analysis and solution are not the goals of these sessions. Rather, the sense of the forces and their approximate magnitudes, which are graphically determined with the direction and the length of the arrows, are of main concern. For the same pedagogic reason, the semi-graphical method for the shear force and bending moment diagrams are introduced followed by the equilibrium method in the later step.

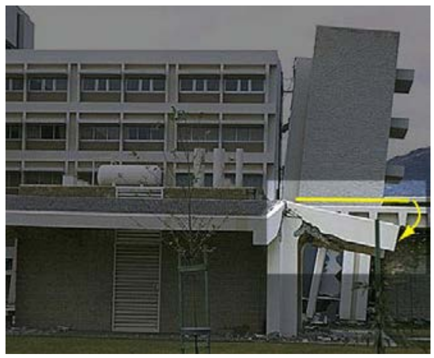
Changing Viewpoint – "*Second Intuition"*

The role of the underlying structural principles in an architectural form-finding process is played in an implicit fashion, instead of an explicit way. Structural principles are swallowed, digested and lose their original shapes to be absorbed and become an invisible but stable guideline toward a balanced architectural outlook. Moreover, in reality, it is not an architect's duty to reach one exact numerical answer, but to conceive multiple attractive aesthetic forms which are structurally and thus economically feasible. To develop and nurture this intuitive talent, it is critical to train architectural students to be able to view physical phenomena from different perspective.

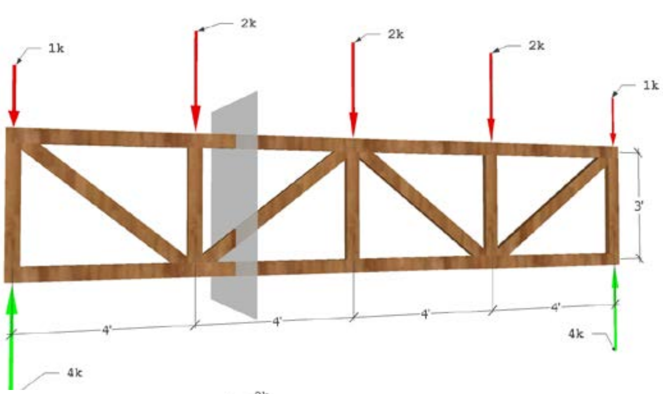
Change of Viewpoints - "Second Intuition"

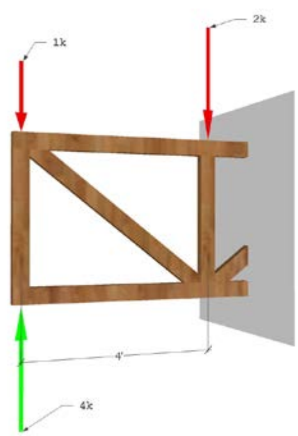


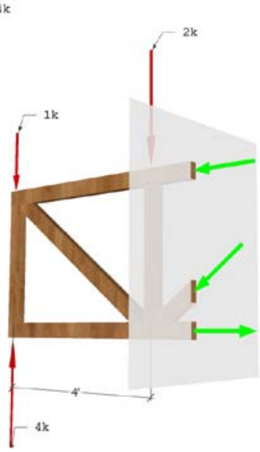
The students are instructed to view the limb as being "rotated" about the junction instead of falling "vertically" down. As a result, structural eyes to "read" the rotational equilibrium in architectural forms are properly developed.

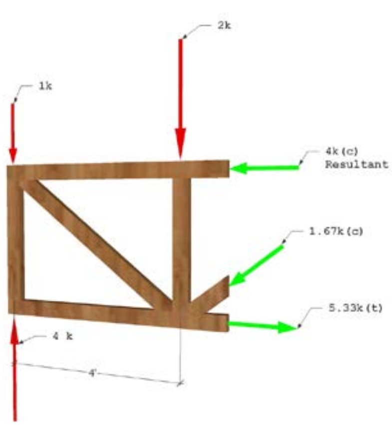




The bending failure of the canopy due to seismic tremor can better be understood by changing viewpoints.









Teaching architectural students the concept of the free-body could be very challenging but this task can be easily accomplished by viewing the structural system and its free-body hanging in the air under the action of the external and the resulting internal forces that are in equilibrium.

Visual Thinking vs. Mathematical Thinking

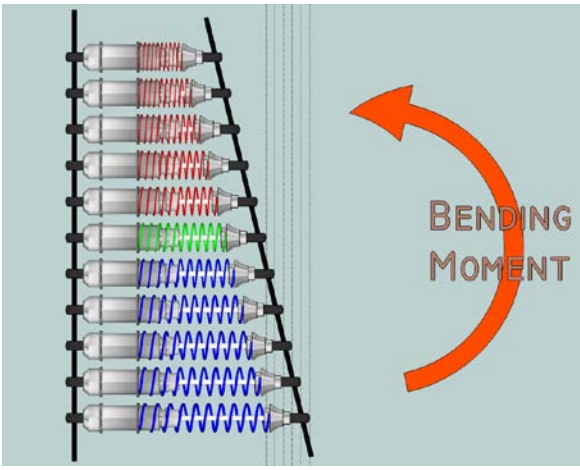
Familiar examples that can be found often around us or that one can recall easily are selected for this stage of teaching, and the students are encouraged to view the physical phenomena through new engineering eyes. This procedure allows the students to obtain their own viewpoint to 'read' physical phenomena and thus make appropriate engineering judgments on various real situations. In this approach, the students' ability to visualize the engineering concepts is formed and matured gradually as they repeatedly solve exercise problems pertaining to the engineering concept. If this training is successful, the students are prepared to start to think in "structurally logical" ways.

Developing Comprehension Models – *"Visual to Mathematical Thinking"*

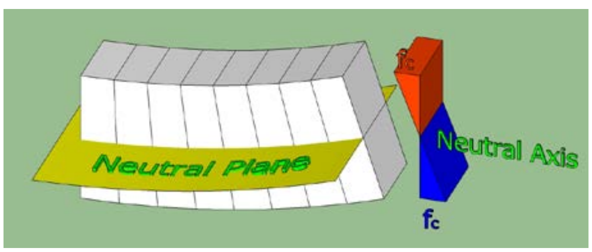
Now comes the turning point toward the engineer's language – formulae and equations, after some level of acquaintance is formed through multiple forms of visualization e.g., graphics, drawings, diagrams and demonstrations. In this stage, the mathematical approach is eventually introduced and is expected to be swallowed with a minimum level of reluctance. If this approach is successful, the structural engineering design formulae and related equations are not dull, life-less collections of variables and numbers. They become simple but precise textual translations of the physical phenomena as the students have viewed through their changed viewpoints. The students shift from visual thinking to mathematical thinking for mastery of knowledge. Their ability to visualize structural principles is further clarified and sharpened by using the engineering formulae.

In this stage, it is essential not to make such a sudden turn towards mathematical thinking, since the architectural students may easily lose their appetite if the approach looks calculation intensive. Instead of using structural engineering terminologies that may sound esoteric to architectural students, the use of everyday language may be a good guideline for this stage. The link between the two may be made in the next stage more easily as the students will have become much more familiar with the abstract engineering concepts.

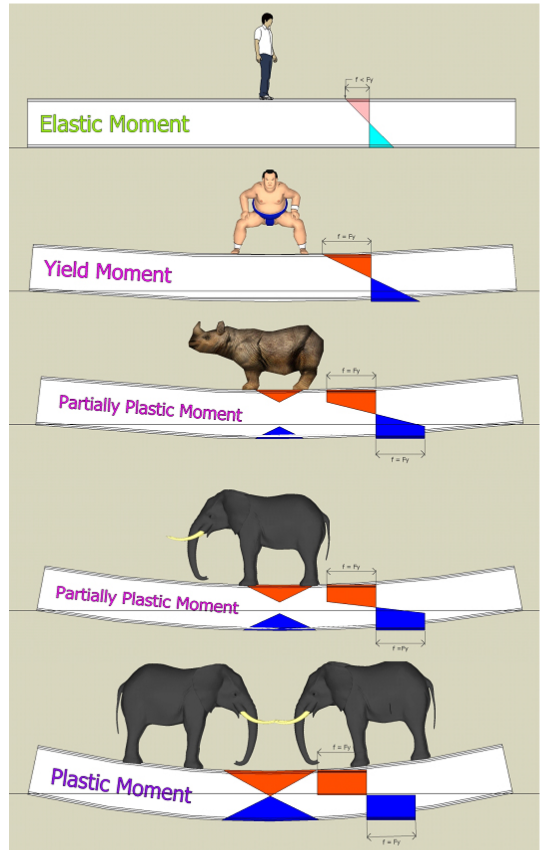
Some engineering formulae look complicated, scaring off architectural students. Thus, it is essential not to lose the students' focus in this stage, as students tend to be distracted easily by sudden changes. One way of keeping the students focused during the introduction of engineering formula is a sensitivity test of variables in the formula. This is to monitor the change in the independent variable while the dependent variables are changed to meaningful quantities. This monitoring is made through a parallel viewing of 3-dimensional interactive demonstration of the physical phenomenon and graphical presentations of the engineering formula with different font sizes of the variables under consideration. In this way, the students get to know what each variable represents in reality, and find meaningful links between those engineering variables and their architectural forms. During their form-finding process, the variables are no longer inactive ingredients but become dynamic and imperative elements. 3-dimensional interactive graphics demonstrators created by Google Sketchup are actively utilized for better visualization of the engineering concepts that the design formulae carry.



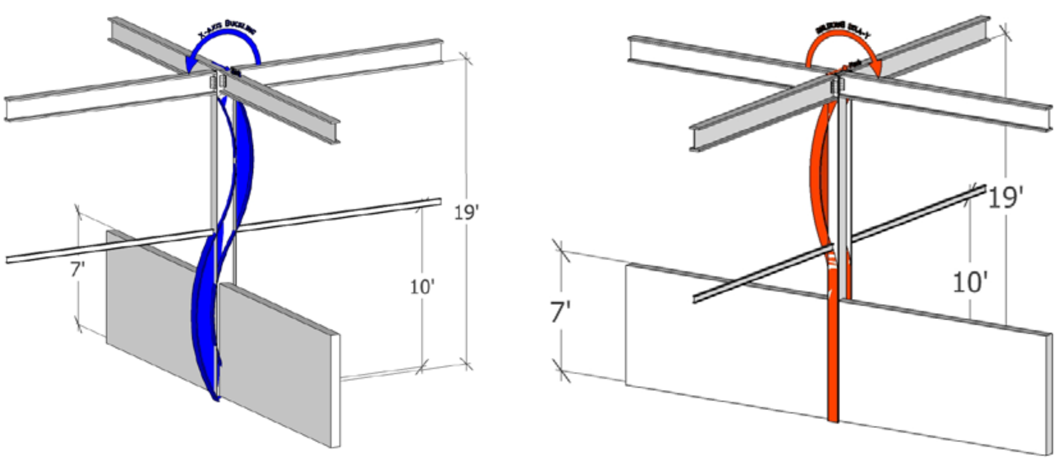
Concepts and formulae of flexural stress and strain can be easily visualized by a set of elastic springs.



The neutral axis can better be understood by the neutral plane and the stress block in a 3-D space.



Familiar examples can be used to minimize the inactive mode due to esoteric subjects.



Column buckling behavior may become a very complicated physical phenomenon to conceive without a proper 3-D interactive demonstrator because of its out-of-plane deformations.

Testing/Completing Comprehension Model – *"Simply Mathematics"*

A series of case studies of the historic and modern architectures where the structural principle under consideration is built into a reality are presented as the first element of this stage. In these presentations, students get to connect the seemingly abstract and unfriendly structural principles to familiar and aspiring built realities.

The intensive mathematical approaches are eventually introduced much more actively in Stage 4 because mathematically testing an understanding model is not only the most effective and economical but also the easiest way (in this stage only). In addition, by this stage, the architectural students will have become more comfortable with the structural concepts and thus confident in their capabilities. So, the seemingly esoteric engineering terminologies are introduced and linked to the structural principles for which everyday language were temporarily used as intermediate steps. A select set of structural engineering problems with progressive difficulties are utilized as lab exercises. These are almost the same as ordinary civil engineering classes except that the architectural and structural portions of real construction drawings are used for better motivation. In this stage, quantity of practice is critical for a fuller understanding and mastery of structural principles. While several variations of a structural formula are utilized for deeper confidence in the previous stage, multiple different exercises using the same formula are provided for wider adaptability and longer retention in this stage.

Implementation of Comprehension Model – *"Hello, Reality"*

This teaching methodology culminates in linking architectural forms to underlying structural principles in reality. To verify and fortify the structural knowledge acquired through graphics and calculations, students are to work with 3-dimensional real objects in a small group environment. Small-scale models, commercial construction toys, and structural term projects are utilized in this stage. The real 3-dimensional structural behaviors understood and appreciated during their designing, building and testing of their models are to provide the students with strong tools to verify and fortify their idea on architectural shapes.

Moreover, the 3-dimensional structural behaviors often reveal the limited scope of the class and allow the students to realize the gap between the textbook solutions, which are generally in 2-dimensional planes, and the real-world physical phenomenon. Brief qualitative solutions are given by the instructor about the deviation to quench possible curiosity.

Implementation of Comprehension Model – Hello, Reality

Small-scale modeling, balsa wood truss contests and plate girder contests were found to be the most effective and yet enjoyable. These components have received the strongest supports from the students in the evaluations and surveys. The experimental performance data and team presentation material have been documented every semester for future references.

Student Evaluation and Surveys

Course evaluations and mid-term surveys over the last 3 years reveal that student strongly support this teaching methodology. The term project and small-scale models have received the most favorable feedback. Construction toys and physical demonstrators rank the second, the 3-D interactive demonstration tool the third, the real-time simulation sessions the fourth and the conventional mathematical approach sessions the last. Another sign of the students' support is that the enrollment for this class, among 4 sections of the same course, becomes full on the very first day of registration while the numbers of enrollment of other sections still remain low. Most importantly, an increasing number of students bring their architectural ideas for their studio projects to my attention for structural consulting during schematic design stage even though a structural feasibility check is not a requirement of the studio course or a part of final grade. This is a very promising sign that the architectural students become more capable of speaking some structural language to communicate with structural engineers.

Conclusions.

1. The use of architects' language in a structure class, visualization and models, encourages architectural students to open their mind to the seemingly esoteric subjects of structural principles and to get ready for fuller engagement.

2. 'Playing' with engineering concepts without the bitter taste of mathematics more easily engages the students in the subject concepts for a deeper understanding.

3. Small-scale modeling provides students with opportunities to find that learning structures could be an enjoyable experience that leaves a stronger impression for longer retention.

4. Materialized abstract concepts in reality greatly help students to complete a comprehension model of those concepts. Studying historic and modern buildings which have distinctive structural elements as architectural expressions strongly connects them to the technological side of architecture.

5. Visualizing and experiencing 3-D structural behaviors help students realize the deviation between the textbook solutions and the real-world physical phenomena.