Teaching Statics and Strength of Materials Using Digital Technology

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Introduction

Developing innovative approaches to education is not unique to architecture, but as the technical component of a creative degree program, developing innovative approaches to the teaching of structures within the architecture curriculum is not only desirable, but absolutely necessary. The fundamental problem is that although understanding structure lies at the core of the education of the architect, architecture faculty and students struggle with a traditional engineering-based approach to structures instruction, which is increasingly proving to be ineffective in the classroom.

The traditional engineering based approach to teaching structures is largely a product of the historic development of scientific thinking, the evolution of the engineering discipline and the changing role of architecture. The growing role and influence of the engineer within the design and construction of the built environment has lead to the introduction of sophisticated mathematical models into the building construction process. As a result, the scientific method and mathematical rationalism have become the dominant models for teaching structures to both engineering and architecture students.

Architecture students, however, have very different educational needs, technical capabilities and will apply structural design principles differently than engineering students and professional engineers. The unfortunate mismatch between most structures curricula across the country and their students has a fundamental root problem. The instruction based on engineering approaches is highly quantitative, communicating even basic concepts using an advanced mathematics nomenclature. However, architecture students have neither the background, disposition, nor time to master the mathematics skills required to understand or utilize a system based on highly mathematical models. They therefore quickly become uninterested, frustrated, or even intimidated by the structures curriculum.

Facing this dilemma, many architecture faculty have developed new methods, alternative teaching materials, textbooks and other tools for communicating structural principles that respond to the needs, capabilities and perspective of the architecture student. Two recent textbooks and a teaching manual best demonstrate how creative approaches can be used to facilitate the understanding of structural concepts for students. The first book —Shaping *Structures* is written by Waclaw Zalewski and Edward Allen (Waclaw Zalewski and Edward Allen, Shaping Structures). In *Shaping Structures* the authors extensively utilize graphical techniques for introduction of statics principles and finding forces in structural elements such as trusses, arches and cables. Both numerical and graphical techniques are introduced in a highly visual context to appeal and pave the way for teaching statics concepts to students who have very little mathematical background. Christine Theodoropoulos stated her appreciation of Zalewski and Allen's methods:

But the rationale for learning statics through drawing as a means to becoming graphically as well as numerically fluent is compelling. *Shaping Structures* provides educators and students with a tool that effectively merges qualitative with quantitative learning (Christine Theodoropoulos, *Journal of Architectural Education)*.

Taking a step further, the authors also use the graphical method as a tool for generating form, which not only enhances the validity of the subject of "structures" for students in the architectural design context, but it suggests another possible venue for producing creative and expressive architectural design.

Fuller Moore's *Understanding Structures* places an emphasis on the visual description of basic concepts by using descriptive force diagrams and sketches to demonstrate structural behavior under load application (Moore, Understanding Structures). By using a series of case studies he provides a rich visual context for discussing the subject.

In a completely different format, *Demonstrating Structural Behavior with Simple Models* is an instructor's manual and a laboratory guide written by Richard Kellogg (Kellogg, Demonstrating Structural Behavior with Simple). Kellogg details a series of hands-on experiments that are designed to provide first hand experience for observing structural behavior and failures.

Digital Models

Building upon this significantly creative work and the recent developments in digital technology, I have developed a series of digital animation instructional tools. Using computer-generated models, interactive images, and animation, this series of teaching tools integrates quantitative engineering methods with qualitative approaches using a range of digital visualization devices.

One of the greatest advantages of using digital animation technology is that it enables us to fabricate visual environments custom made to demonstrate complex concepts in an easy to understand visual means. These digital environments can also be manipulated to emphasize or de-emphasize certain structural or material properties. Material behavior can be exaggerated to convey certain principles, which are not normally visible to the human eye, such as the stress levels in a beam cross section or deformation of a rigid frame under lateral loads. Members of a structural system can be removed or added to clarify the analysis, or the load travel path diagrams can be animated to demonstrate how the load is collected and distributed in a structural system.

Finally, including a recorded narrative with each animation enhances their teaching effectiveness even more. By explaining working principles with audio, students can focus on the animation and directly connect complex structural concepts with visually demonstrated material or structural system performance, rather than extrapolating these ideas from written text and mathematical symbols. Each animation also has playback controls to slow, stop or repeat the animation at different frames.

Two such digital animation-teaching tools I have used extensively with great success in the classroom are teaching of S*tatics* and S*trength of Materials*.

Strength of Materials

Statics is a branch of mechanics that deals with the analysis of rigid bodies at rest. In order to make the analysis possible all the structural elements are assumed to be completely rigid. However, actual structures are not absolutely rigid and will deform when subjected to loads. These deformations are usually small and do not significantly affect the equilibrium condition and the analytical procedure, but they are very important for understanding

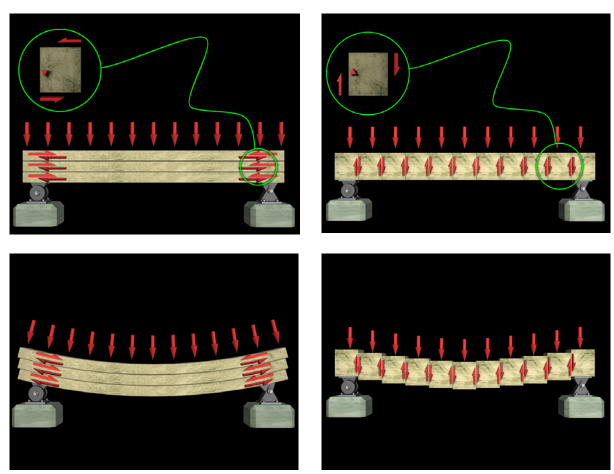

Figure 1 (click for QuickTime animation)

material behavior and its resistance to stresses.

In strength of materials, understanding deformation mechanisms can help students to learn definitions and working principles, the nature of forces (tension, compression, torsion, etc.), and the structural logic for form selection. For example, Figure 1 shows stages of simple animation demonstrating the beam behavior in response to a uniformly distributed load. As the load is applied and the beam begins to deflect and deform, the adjacent parallel components of the beam slip in horizontal and vertical direction, thus visually explaining the mechanics of beam deflection.

Figure 2

Concepts of deflection, horizontal shear and vertical shear are all communicated with animation using exaggerated behavior of the beam, as it is flexes under a load.

Concepts of tension, compression and torsion can all be visually demonstrated using the same type of modeling. Figure 2 shows two frames of an animation of a steel grid undergoing tension. As the member is pulled, the exaggerated deformation shows how the material will change its dimensions and experience strain.

Presenting the stress-strain relationship in a graphical format is a standard exercise for comparing the strengths of various structural materials and introducing Hooke's law and modulus of elasticity. Typically these graphs are plotted for various stress levels and the resulted strain, based on laboratory test results performed on a specimen. The common practice is to use these graphs as a quantitative tool for determination of the modulus of elasticity. With a slightly different approach these graphs can become an important device in understanding material behavior at various stress

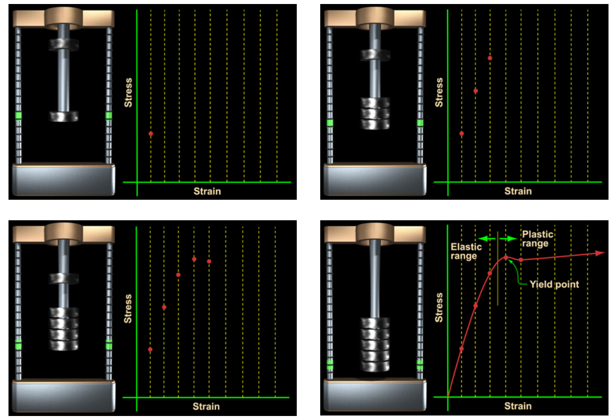

Figure 3

and the stress/strain relationship at a conceptual level.

Figure 3 shows four stages of an animation simulating a laboratory test by subjecting a steel bar to tensile stresses and showing the results plotted in a graphical format simultaneously. In the animated model, increasing stress is achieved by dropping a weight on the steel bar. Each time a weight is dropped, the steel bar elongates slightly and the measured elongation is plotted against the stress. At a certain level of stress after a few weights are dropped, the bar elongates radically, indicating permanent deformation and eventually the failure of the steel bar.

Statics

By using slightly different criteria, almost all statics principles such as definition of force systems, equilibrium conditions, two force members, moments and couples can be explained more clearly and effectively using the digital animation models. For example, simple computer generated models can

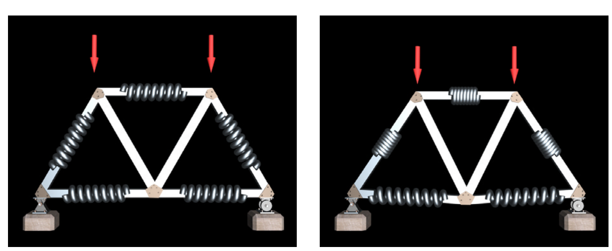

Figure 4 (click for QuickTime animation) be used to show load travel path in trusses and delineate the tension and compression members accordingly. This is achieved by using two sets of digital models. The first set use truss models composed of spring like members. Upon load application, the model is animated and the spring members will be elongated or compressed according to the effect of loading, visually demonstrating the behavior of the tension and compression elements of the truss. Figure 4 shows one of these models.

The second set of truss models demonstrates the behavior of truss members made of different materials. For example, models composed of wood in compression member and steel cables used in tension members are tested under loading. When these models are not loaded the cable members show exaggerated sag. As shown in figures 5 and 6 when the load is applied, the cable members stretch and tighten up demonstrating the effect of tension. The behavior of compression members is demonstrated by a change in the color intensity of the members. When a wood truss member receives its loading share, a change of color is observed in the member. As the member is compressed more, the color intensity of the member increases at the center and the member becomes brighter, emulating the compression of the wood fibers.

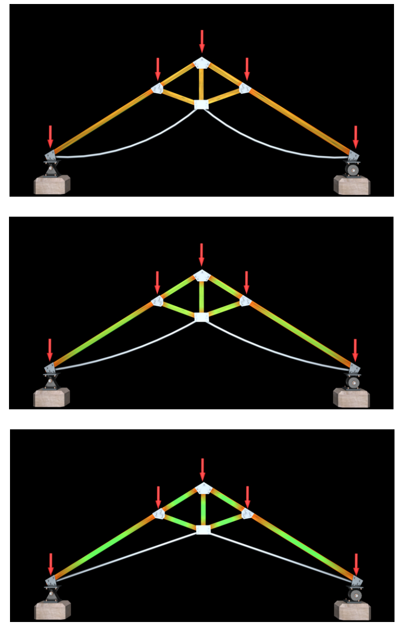

Figure 5 (click for QuickTime animation)

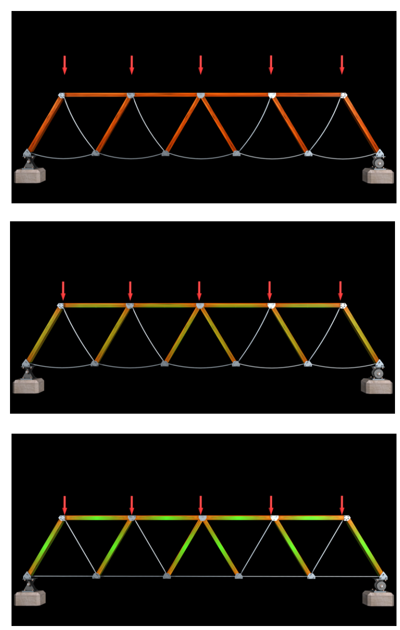

Figure 6

Closing Remarks

The central underlying principle for the development of these teaching tools is to provide a highly visual and direct means of communicating concepts and grounding them in experience. Particularly for Architecture students, who are visually and qualitatively inclined by nature and training, using powerful graphics, animation, and narration, can help build a strong understanding of complex structural concepts and principles. It is also possible the use of digital modeling and high-end graphics can also bring a new level interest and excitement to the subject matter, changing the way structures is treated within the architecture curriculum.

Bibliography

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