Digital Imaging and the Web in Teaching Structures: A Rigorous Visual Approach

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ABSTRACT

The paper outlines a project to incorporate digital images and the world wide web in teaching introductory structural design in architecture. The objective of the project is to move beyond technology substitution, toward innovation by using digital imaging and the web to do things that are otherwise not possible. The discussion of digital imaging gives examples of image enhancement, annotation, and manipulation in illustrating structural concepts. The discussion of the web addresses web-based image archives for structural engineering, image-based modelling assignments, collective inductive learning, and collective review. An extended presentation of examples from the course can be found on a companion web site at http://urban.arch.virginia.EDU/~km6e/ti/ti-summary/.

INTRODUCTION

The normal first step in the introduction of a new technology is substitution, or early concrete first substituted for stone and early word processors substituted for typewriters. This pattern has marked the introduction of two of the most prominent information technologies of the 1990s: the world wide web and digital imaging. The web is dominated by technology substitution, in the form of catalogs, pamphlets, and advertising. In teaching, the web is widely used as a substitute for course handouts, with advantages of richer content with high-quality photographs and broad access. Although there are benefits to this substitution, it is also clear that there are new opportunities for meaningful technology innovation, moving beyond doing old things in new ways to doing things that are inconceivable without the technology.

These opportunities are particularly clear in education, where teachers in many fields have recognized the potential of the web to enhance content and communication in teaching, particularly in graphic-intensive fields such as architecture (Webster 1996; Mahler 1996). This paper describes a project at the University of Virginia to integrate digital imaging and the web into a larger pedagogic framework of an architectural structures course. Digital imaging offers unique possibilities for image enhancement and manipulation to visually explain structural concepts. Combining digital images with the web provides opportunities for presentation and access that allow visual materials to become central rather than supplementary. These technologies enable a strongly visual approach that teaches students not only to think the way a structural designer thinks, but also to see what a designer sees. The discussion begins by identifying pedagogic objectives, then illustrates digital image techniques to illustrate structural concepts, and then outlines methods for using such images with the web.

PEDAGOGIC OBJECTIVES

The course is based on the premise that design centers on making and manipulating formal models, where a successful model employs two concepts: rigor and metaphor. Rigor refers to the internal logic of the model, while metaphor refers to the correspondence of the model to the real world. Closely related to the duality of rigor and metaphor are two other dualities: principle vs. precedent and deductive vs. inductive inquiry. In the principle vs. precedent duality, principle refers to the deductive application of clear assumptions and well-defined methods to reach logical conclusions; precedent refers to an inductive process of drawing conclusions based on a large set of observations. Traditionally, architectural courses in structures have chosen either a quantitative approach based on deduction from principle, or a qualitative approach based on induction from precedent. The project seeks to combine
these two so that the application of rigorous principle is seasoned with an understanding of real systems and aspects of their behavior not captured in the modelling metaphor.

In addition, the course takes a broad spectrum approach, involving students with visual, verbal, mathematical, and tactile techniques to illustrate and explore structural concepts. This approach seeks to acknowledge the variety of learning styles among students by offering alternative starting points to grasp a new concept.

DIGITAL IMAGING

Irrespective of the web, digital images offer a powerful medium for extending the utility of photographs. The potential of image processing in visual design and historic reconstruction has been widely recognized (Mitchell 1992); there are also important opportunities in enhancing technical photographs and teaching physical concepts of structures and construction. The discussion below identifies three fundamental operation types: enhancement, annotation, and manipulation. The examples included in this paper are a limited selection that illustrate the concepts reasonably well as small-format, monochrome images suitable for low-cost print reproduction. Full color versions of these and several other examples are included in a companion web site (Martini 1996).

Image Enhancement

Digital imaging allows for the adjustment of contrast, color balance, image sharpness, and perspective distortion. These operations can reveal unclear or indistinguishable features and highlight features of interest. Figures 1a and 1b show a before-and-after example of image enhancement. Figure 1a shows the original image, where the cracking in the earthquake-damaged bridge pier is hidden in deep shadow, while irrelevant background material is sharp and clear. The enhancement shown in figure 1b brings out the detail in the pier while washing out the background, severely distorting fidelity, but conveying the content of the photo much more effectively than the original.

![Figure 1a](image_url)  
*A shadowy photograph of a bridge pier damaged in the 1994 Northridge earthquake (Image from the EqIFS collection, EqIFS 1995; photograph by Graham C. Archer)*
Figure 1b. An enhanced version of the photo from figure 1a. The enhancement severely distorts fidelity but conveys the content of the photo much more effectively than the original.

Image Annotation

Digital images enable convenient annotation of images with text, symbols, guidelines, and transparent overlays. Such annotation is useful for highlighting the important features of an image and in clarifying the relationship between the real phenomena in the photo and the more abstract symbolic representation in theory. Figure 2 shows an image of a structural connection overlaid with the notation of a free body diagram. The transparent gray mask isolates the free body that the forces act on; the image shows that the connection was designed to make the force lines converge at a point.

Figure 2. An image with annotation illustrating a free body diagram of a structural connection, and the convergence of force lines of action (Library of the Phillips Academy; Exeter, New Hampshire; photograph by the author)
Image Manipulation

In addition to adjusting the contrast, color, sharpness, and perspective of an image, it is also possible to make more aggressive changes to an image by manipulating the image content, using operations such as adding, distorting, or rearranging elements of an image. These methods can be used to illustrate structural concepts in several ways, such as exaggerating the deformation due to loads, removing portions of a structure to reveal its organization and load carrying mechanism, or simulating a failure mode. Figures 3a, 3b and 3c show a series of images which study the organization and action of the Forth Rail Bridge in Scotland. The second image in the figure removes the approach structure and center suspended truss, revealing the cantilever action of the primary spanning structure. The third image removes a portion of the approach support tower, revealing that this portion of the tower is included primarily a visual transition element rather than a structural support.

Figure 3a. The Forth Rail Bridge (Original photograph courtesy of W.G. Godden)

Figure 3b. A manipulated image where the approach structure and center spanning truss are removed to reveal the cantilever action of the primary spanning structure
(Original photograph courtesy of W.G. Godden)

Figure 3c. A manipulated image where the top of the approach support tower is removed to reveal that it is primarily a visual rather than structural element
(Original photograph courtesy of W.G. Godden)
In addition to removing elements from an image, it is also possible to distort and rearrange an image to illustrate structural concepts. Figures 4a, 4b, and 4c illustrate the concept of shear in a reinforced concrete beam: Figure 4a shows a beam end with a diagonal crack; in figure 4b, the image is manipulated to widen the crack, illustrating the mode of failure that the crack implies; figure 4c overlays the manipulated image with the common diagrammatic representation of shear, with the characteristic racking deformation and cracking perpendicular to diagonal elongation.

Figure 4a. A diagonal crack near the support of a reinforced concrete beam (photograph by the author).

Figure 4b. A manipulated version of figure 4a where the crack is widened to illustrate the mode of failure that the crack implies.

Figure 4c. An annotated version of figure 4b where the image is overlaid with the common diagrammatic representation for shear.

Figures 5a and 5b illustrate the use of image distortion to explain shear at a larger scale. Figure 5a is a photograph of a San Francisco building damaged in the Loma Prieta earthquake. The characteristic pattern of X-cracking in the spandrel beams is the result of alternate shearing forces on the building during ground shaking. Figure 5b illustrates this effect by extracting the perspective view of the facade from the image from figure 5a and distorting it to an elevation view, and then applying a shearing distortion to that view to create the views to either side. The diagonal cracking phenomenon is very similar to the beam shear shown in figure 4, although the loading and scale are very different.
Figure 5a. A San Francisco building damaged in the 1989 Loma Prieta earthquake; note the X-cracking in the spandrel beams (photograph by the author).

Figure 5b. A manipulated image using elements extracted from figure 5a, illustrating alternating the shearing action induced by ground motion.

Summary

These image series shown in figures 3, 4, and 5 illustrate the use of annotation and manipulation as tools for visual analysis to extract the lessons contained in a photograph. Each of the three series is based on a single photograph, the annotation and manipulation convey information that would be conveyed by gestures with hands or a pointer in a conventional slide presentation, and so the annotation and manipulation can be considered as digital gestures that can accompany conventional physical gestures. Digital gesturing in an image series offers important pedagogic benefits. The gestures are very clear and can be impressed on the strong visual memory of most architecture students. The gestures are also recorded and available for study outside of class. Diagrammatic gestures such as the overlay shown in figure 4c provide an important link between real world phenomena and abstract diagrams encountered in texts and on the chalkboard.
THE WEB

In addition to new opportunities for enhancing, annotating, and manipulating images, digital imaging also enables unprecedented avenues for image distribution and combination with text via the world wide web. The following discussion outlines possibilities for using the web in teaching, both for digital images and as a more general communication medium. These examples are far from a comprehensive list, but are rather the beginnings of exploration.

Image Archives

The power of the web as a medium for distributing photographs has been widely recognized, and high quality, well organized image archives are emerging. For structural engineering, the most important archive is the EqIIS collection at the Earthquake Engineering Research Center Library of U.C. Berkeley (EqIIS 1995). This archive currently includes nearly 8,000 earthquake related images that can be freely duplicated and distributed; the image resolution is 768x512 pixels. Most of the images concern seismic damage, however they have much broader teaching applications, since the damage photos are extremely useful in explaining general structural phenomena. Figures 6a and 6b, for example, graphically illustrate the difference between buckling and crushing failure in columns. Traditionally, these modes of failure are illustrated in lecture demonstrations with props such as rulers for buckling and chalk for crushing. The images do not replace such demonstrations, but rather enrich them by providing a visual means to extrapolate the small scale demonstration to the behavior of real buildings.

Figure 6a. An example of compression failure due to buckling. (Anchorage Westward Hotel damaged in the March 1964 Alaska earthquake; image from the EqIIS collection (EqIIS 1995); photograph by Karl V. Steinbrugge. The image has been cropped and enhanced).
Figure 6b. An example of compression failure due to crushing. (County Services Building, damaged in the October 1979 Imperial Valley earthquake; image from the EqUS collection (EqUS 1995); photograph by Karl V. Steimbriego. The image has been cropped and enhanced).

Other web-based sources of structural images include the following:

- The Visual Engineering Database at Virginia Tech University (SUCCEED 1995). This archive distributes approximately 900 images on a broad range of engineering subjects, with a limited selection of structural engineering images. Image resolution is limited to 640x480.
- The Digital Image Access project at Columbia University, which includes a large collection of construction photographs of the Empire State Building. (DIAP 1995). The resolution is limited to fit within a 640x480 screen.
- The Architectural Courseware collection assembled by Roger Clark at North Carolina State University (Clark 1995). This collection includes several important 20th century buildings. Image resolution is generally 1024x700.

Modelling and Image Analysis

In contrast to conventional slides, digital images can be made accessible outside of lecture via the web. This accessibility allows images to play a very different pedagogic role in a course since they can provide a basis for assignments and study rather than serve only as an in-lecture supplement. The following is a simple example where students sketch a computer model of a structure (modelling supports, connections, and loads) based on photographs of the structure. The problem statement is as follows, with the images shown in figures 7a through 7c:

For the timber footbridge shown below sketch an analytic model of one of the supporting trusses, judging as best you can based on the information available in the photos. Clearly indicate nodes, elements, applied loads, boundary conditions, and end releases using notation outlined in lecture. Briefly explain your interpretation of boundary conditions and end releases.

This problem directly addresses the issue of modelling and the concept of a model as a metaphor for a real-world object. It is one of the most important concepts in design and in structures, but receives little attention in structural texts and conventional teaching methods. The ability of students to access and study photographs is key to this teaching technique, and the web and digital imaging support it very well.
Collective Inductive Learning

One of the web's most common uses in teaching is distributing information to students: a technology substitute for handouts. It is also widely used as a resource for gathering information, supplementing the library. One of the greatest potentials for innovation in teaching with the web is collecting information from students, processing it, and reporting it back. This process creates a new kind of feedback mechanism that enables a class to participate in a collective effort, producing something larger than the sum of individual assignments.

One course assignment uses this technique by having students find an example of a truss, and report various aspects of its construction, scale, and proportions via a web-based form, the data is processed and graphed on a

Figure 7a. An elevation view of a timber truss (all photographs by the author).

Figure 7b. A close-up view of the truss

Figure 7c. A detail of a truss joint

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scatter chart as shown in figure 8. Plotting a regression line through the points establishes a rule of thumb based on
the data, the wide variation around that line illustrates the nature and limitations of rules of thumb.

![Figure 8. A scatter plot and regression analysis for truss cases collected by students.]

This assignment illustrates the use of the web in inductive learning. Conclusions are drawn not from gener-
al principles but from specific cases, by induction rather than deduction. Induction is rarely used as a formal method
in technical education, but is extremely important, since the specific cases provide a context for the theory and its
exceptions. The expertise of seasoned designers arises not only from their command of theory but also—perhaps
more so—from the depth of their experience; they have many points on their mental scatter plots.

Collective Review

Architectural education has long recognized the benefits of collective review of student work; it is one of
the fundamental principles of the jury review process. The public display and discussion of work is an important
opportunity for students to learn both from critics and from each other in analyzing different approaches to a prob-
lem. The jury allows the instructor to categorize the various approaches and point out lessons that students can learn
from one another.

The web offers opportunities for collective review of student work in a non-studio setting by taking sam-

tles of student work and compiling it into a web site that identifies and interprets overriding themes in the collective
body of work. This technique was used in conjunction with a structural model project where students built small
structural models that were loaded to failure. There were 38 projects that were tested in small groups during four sep-
arate section meetings and one general meeting. Using a digital camera to document testing in each section and com-
piling the images with interpretation and commentary in a web document, it was possible to document the overall
project and allow the entire class to benefit from its own collective effort. The complete web site documenting the
model testing is linked to the companion web site of this paper (Martin 1996).
CONCLUSIONS

Digital imaging and the web offer a variety of new opportunities for teaching in general, and for teaching architectural structures in particular. Photographs have a long tradition as a tool in architectural education for linking theory to reality, digital imaging creates new opportunities for strengthening that role through enhancement, annotation, and manipulation. Annotation and manipulation can be used to create images that incorporate digital gestures, graphic commentary and analysis normally done with physical movements and pointers. Including the gestures gives them more impact on visual memory and provides a link between real world structures and abstract diagrams used in theoretical analysis.

By making images available outside of lecture, the web further enhances the opportunities to integrate effective visual materials into a technical course. The web also offers important opportunities for establishing new kinds of feedback loops that engage students in a collective effort; this is especially useful for inductive learning, an important mode of learning that typically receives little attention in technical education.

The development of this course has taught many lessons and provides a model for developing a whole structures curriculum, which is the next step in the process. Many of the techniques are also applicable to broader areas of design.

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REFERENCES


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