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# Effective Graphics in Structures Class: Integrating Structures into Architecture

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## Abstract

*This paper focuses on alternative teaching methods of illustrating structural behavior and concepts for integration into architectural design thinking. To reach this state, the pedagogic gap between architectural and structural classes needs to be bridged. The teaching methods are based on two viewpoints: 1) To comprehend structures in a graphical manner, and 2) To understand structures as a potent sculptor of form.*

*Keys to effectively teaching structures to an architectural class are to communicate with graphics, drawings, demonstration models, and familiar language. These keys are employed for topics such as stress-strain, shear-moment diagrams, beam-column shapes, Maxwell truss diagrams, Polygonal Force diagrams for profiles of arches and cables. Use of well-known examples from daily life further clarify and demystify structures, integrating it into architectural language and experience. Subsequent computations follow to appreciate comparative solutions, and material and construction issues. The formulae variables are recognized as tools for shaping structural-architectural elements. Furthermore, architectural cases are analyzed in a series of slide lectures, revealing the variety of dynamic forms generated from structural issues. Finally, bridge or tower models are built and tested to realize the three-dimensional aspect of structural behavior. To help validate these methods and ideas to the reader, the paper shall be more graphical than textual.*

*The effectivity of these alternative methods are manifested in projects of later design studios, and are also noted in student evaluations of the structural class.*

## Keywords

structures, graphics, teaching methods, architecture education

## 1. Introduction

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<sup>1</sup> While an assistant professor at the College of Architecture at the University of the Philippines, Arch't. Bronne Dytoc became a recipient of the University of the Philippines Gawad Chanselor para sa Natatanging Guro (Chancellor's Award for Outstanding Teacher) in 2006 and a recipient of the First University of the Philippines President's Award for Innovation in Teaching. He graduated with a Master of Building Science from the University of Southern California (USC) School of Architecture at Los Angeles where he was a recipient of Outstanding Teaching Assistant Award; he finished the Bachelor of Science in Architecture from the University of the Philippines as a University Scholar. He already presented several papers both in national and international conferences. He specializes in structures-forms, technology & theories design.

It has been often said that the state of the built environment can influence the quality of daily life. Well-known engineers such as Fritz Leonhardt<sup>2</sup>, and architects such as Renzo Piano<sup>3</sup> echo such a view. Recognizing how architecture and infrastructure are quite unavoidable, it becomes the responsibility and opportunity of designers to take this issue into consideration, thus giving direction to their design philosophy and their works. Such built designs would exhibit a symbiosis between aesthetic form and optimized performance. Defining and nurturing such a design outlook for architects and engineers would mean symbiotic training as well, specifically in the understanding of structural behavior, form, and concepts. This understanding forms the basis for further architectural and engineering details. Focusing on only one half at the expense of the other has often resulted in less than desirable results. As an educator of architecture, I have observed that opening the minds of architecture students poses both a challenge in terms of classroom-culture and communication.

## 2. Bridging the Gap between Architecture and Engineering

The gap that separates architects and engineers as designers is as much perceived as it is enforced, both in training and in practice. Basic words such as design, efficiency, beauty, and strength mean different things to both parties. The disunity feeds a self-cycling belief of separation that directs the subsequent outlook and training of future professionals. And yet in construction, both inevitably meet up, sometimes as unnecessary adversaries. After noting the low effectivity of the "traditional" approach of a structures class<sup>4</sup> for

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<sup>2</sup> "We have also become aware of the fact that human well-being and happiness, joy in living, and psychic health depend to a large extent on the esthetic quality of the environment in which we live." Leonhardt, Fritz. (1990) Preamble to **Esthetics in Concrete Bridge Design**. American Concrete Institute, Detroit, Michigan. Several other papers submitted by other engineers in this symposium are also worth reading.

<sup>3</sup> "What is architecture?...it is an imposed art. You can put down a bad book; you can avoid listening to bad music; but you cannot miss the ugly tower block opposite your house. Architecture imposes total immersion in ugliness; it does not give the user a chance." Piano, Renzo. (1998) Acceptance speech, **Pritzker Prize in Architecture**.

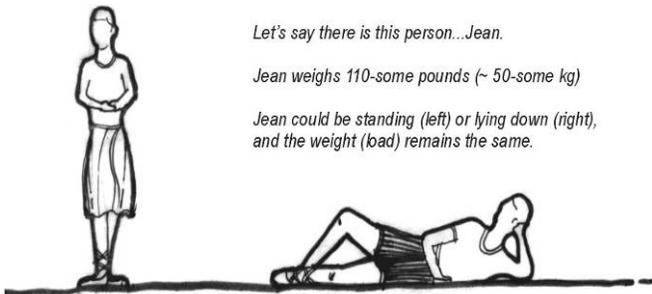
<sup>4</sup> The focus on technical procedures and calculations has become the norm in most engineering classes worldwide since the 1970s, influenced by the improvement and complexity of the tools used for calculation and simulation. For most part, the graphical aspect of designing and its big-picture context issue has been given less emphasis in practice. This commentary has been

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architects, it becomes evident that a decision to bridge the gap must be made before developing more unified, “whole-brain” designers can be reached.

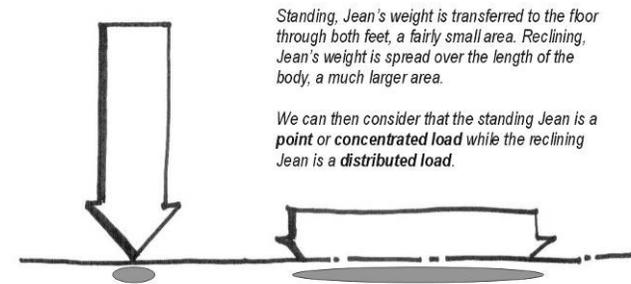
Architects use graphics and models for communication, not the symbol-laden vocabulary of mathematical formulae. Moreover, design in architecture promotes making several valid solutions, instead of developing only one “right” answer. Employing these basic tools of graphics and multiple solutions makes the learning of structures in an architecture class more effective and enjoyable. Furthermore, cultivating this open and mindful environment can encourage creativity, interaction, understanding, and retention – these are signs of effective mastery of knowledge<sup>5</sup>.



Let's say there is this person...Jean.

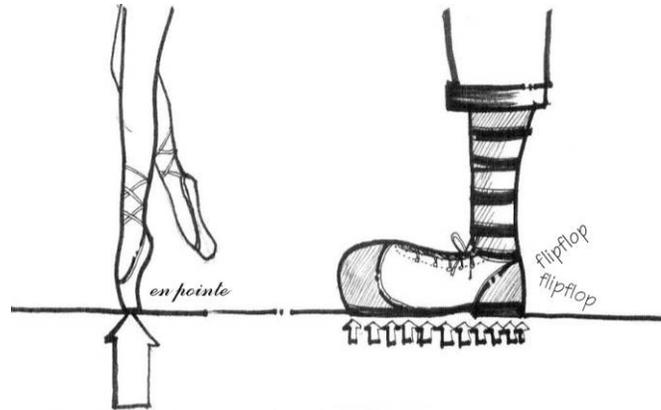
Jean weighs 110-some pounds (~ 50-some kg)

Jean could be standing (left) or lying down (right), and the weight (load) remains the same.



Standing, Jean's weight is transferred to the floor through both feet, a fairly small area. Reclining, Jean's weight is spread over the length of the body, a much larger area.

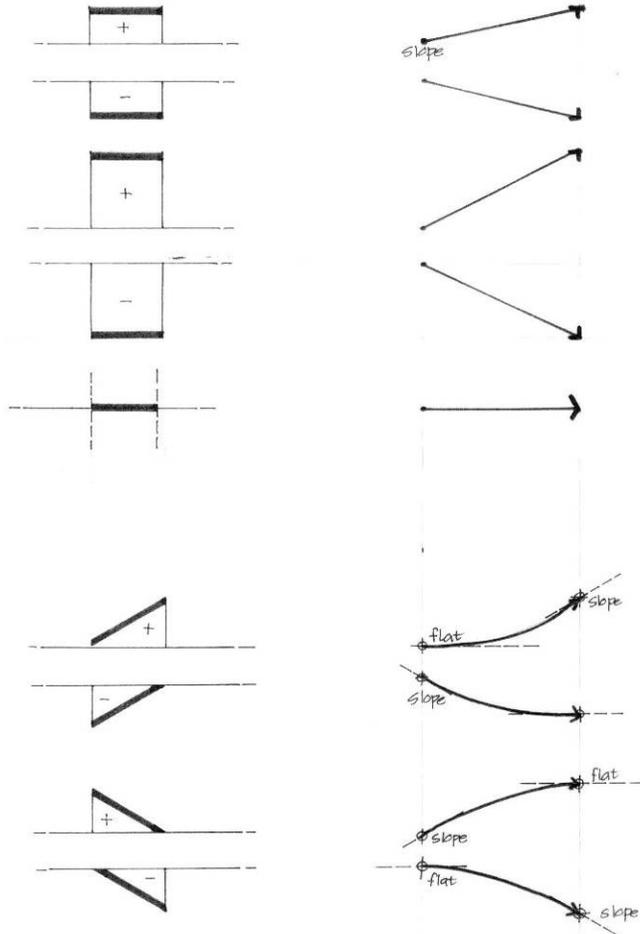
We can then consider that the standing Jean is a point or concentrated load while the reclining Jean is a distributed load.



To make things clear, we can also look at it this way :

The ballerina, with her pointe shoes, balances on her toes, while Bozo, with his huge size 20-EEE wingtips, flipflops his way to infamy.

Jean's contact with the ground through her shoe toe-tip is an obvious example of a point load, while Bozo's weight is spread all over the sole surface of his shoe, is a distributed load.



expressed via interview with engineering professors in local and international universities.

<sup>5</sup> Ellen Langer, a professor of psychology at Harvard, enumerates several mindsets that undermine learning. Some of these are : The basics must become second nature; paying attention is focusing on one thing at a time; delaying gratification is important; rote memorization is necessary; and there are right and wrong answers. She writes that a mindful approach to any activity has the characteristics of creating new categories, openness to new information, and awareness of multiple perspectives. Langer, Ellen J. (1997) **The Power of Mindful Learning**. Addison-Wesley, Massachusetts.

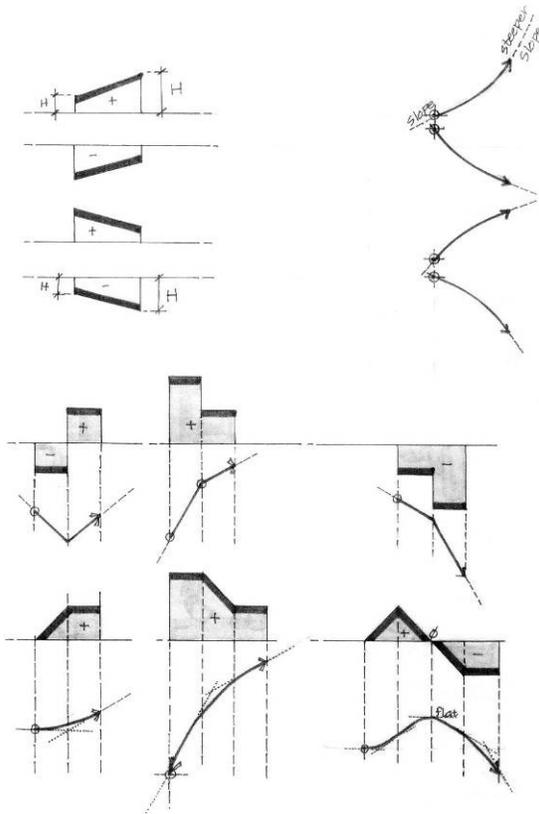


Figure 2: Developing a shear diagram is easy. It's the drawing of the moment diagram that is always difficult for students to comprehend. Shear sub-shapes are equated to appropriate moment curve segments; each segment is joined to the next segment, resulting in the final Shear-Moment diagram.

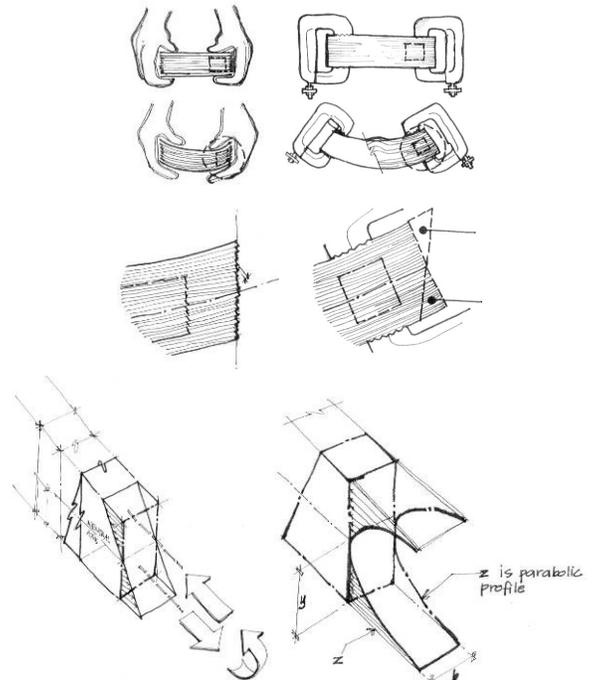
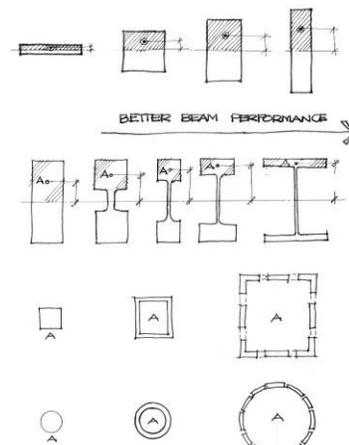


Figure 3. Understanding beam behavior by using the example of the pages of a thick book (upper), and isometric diagrams illustrating stress blocks and moment of inertia shapes (lower).

### 3. Graphics for Techniques and Examples for Experience

Graphics go a long way in clarifying structural topics. The key is to start with an example that most people can recall or imagine. This point is critical as it establishes a basic connection or experience from which all participants can progress. As the example is explored, further graphics start to intermingle with colors, stress blocks, lines, and symbols. It is also important to remember to use familiar "everyday" language, and to gradually ease the technical terms into the lectures' conversation as synonyms, implicitly defining them without their esoteric intimidation.



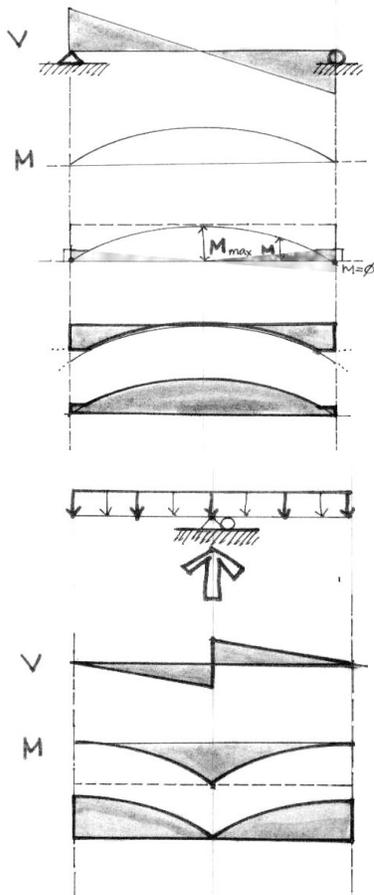


Figure 4. Beam shapes evolving into new sections with increasing moments of inertia (left), and optimized profiles for simply supported beams (end supported and center-cantilevered).

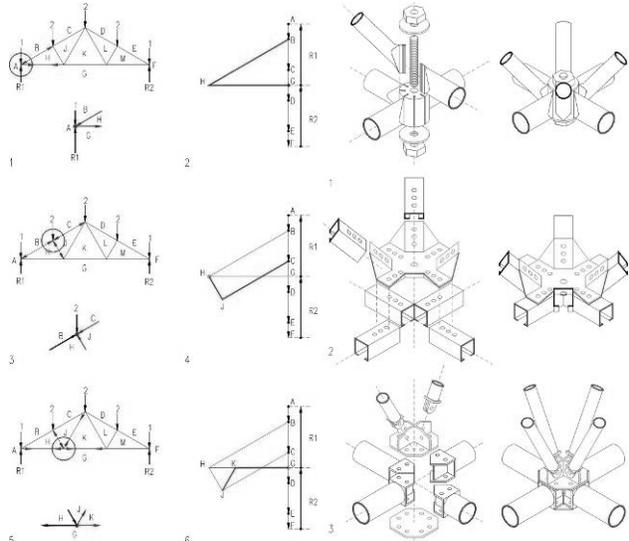


Figure 5. Graphically scaled force diagrams aid in precisely resolving forces in equilibrium. Using its basic graphic principles, the graphic method is adapted into the Polygonal Diagrams to generate arch and cable profiles, forces, and reactions. The same graphic principles also are used in the Maxwell truss diagram methods. Various space truss joints give the exercises a sense of constructability and reality.

Upon understanding the nature of the structural issues, computations are introduced as tools of precision. As with most calculations, the equations' complexity can be simplified by studying and manipulating its variables in a graphical-proportional mode, such as below :

$$f_b = 6M / bd^2 \quad f_b = 6M / bd^2 \quad f_b = 6M / bd^2 \quad f_b = 6M / bd^2 \quad (1)$$

These few examples are ways of "graphicizing" formulas by exhibiting that any variable has manipulability and that anything in the formula that is not fixed in value can be fiddled with. In doing so, the conventional practice of solving linearly for one final "right" answer is expanded into generating various possible solution-combinations. And where there are variations, there are variations in shapes. And where there are variations in shapes, there lies the connection to form-finding in architecture. Through this manner of learning, the understanding and mastery of the structures topics becomes an act of discovery tinged with an air of play. As written by Charles Holden - "A formula may be a good servant, but it is a bad master at any time".

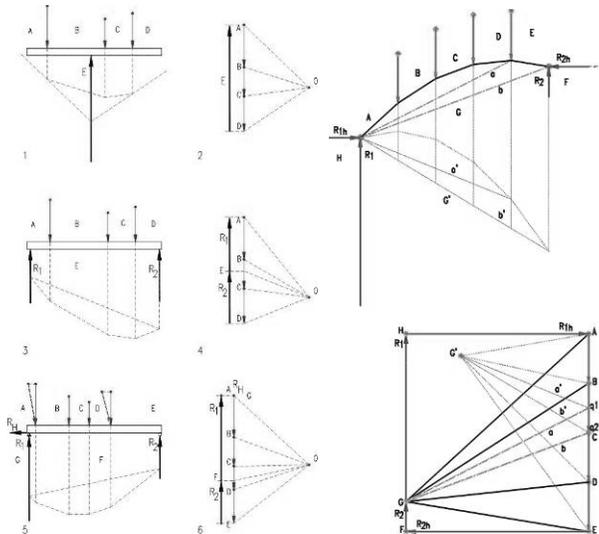
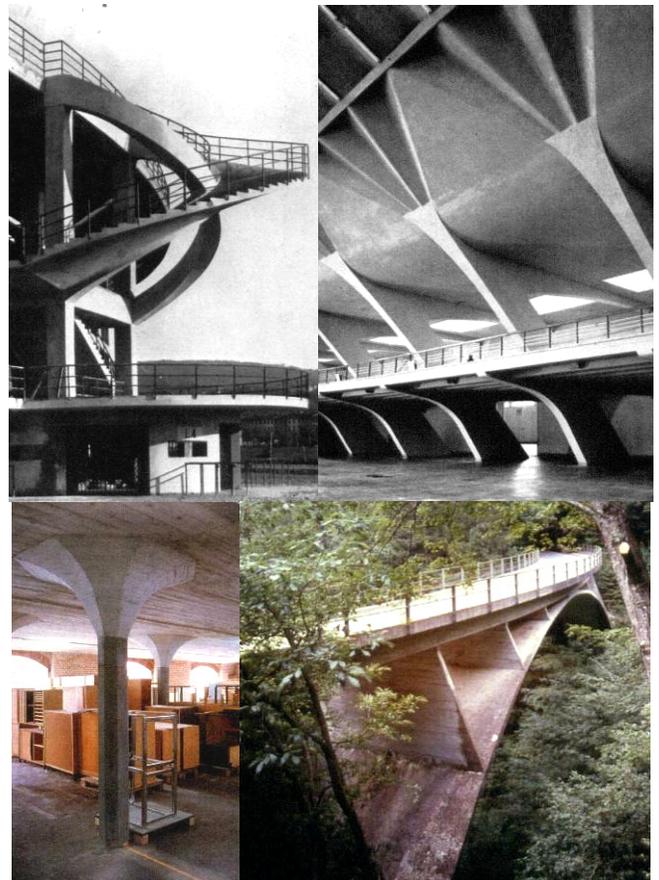
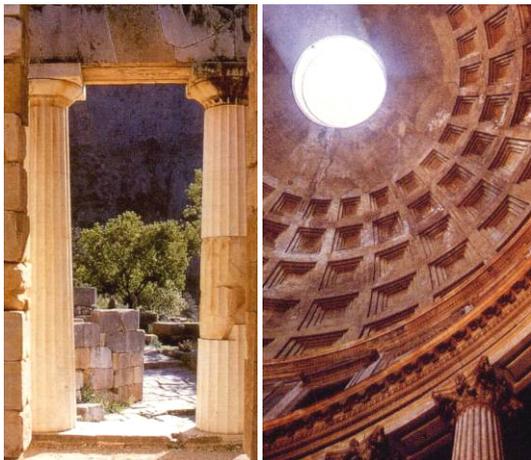


Figure 6. More structures-related examples from everyday life. Pregnant woman and eccentrically loaded columns (left), Moto GP bikes with destabilizing counter-steering to respond to gyroscopic stability (middle), and athletic manipulation of the body's center of gravity and moment of inertia in figure skating's fast spins (right).



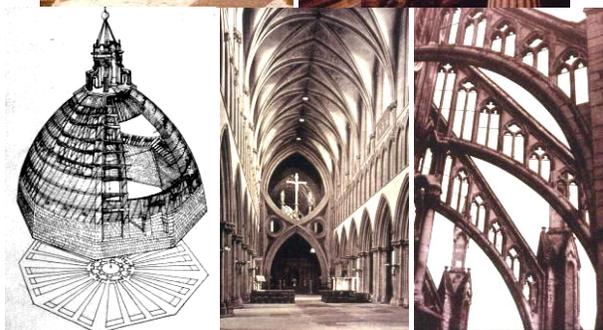
**Figure 7. Modern golf equipment. Companies show off their products which exhibit extreme mass distribution in the putters by Ping and Odyssey (left), gradual changes from cavity-back long irons to muscle-back shorts in the Nike Pro set (right), and the inverted cone face for expanding the sweetspot and forgiveness in the TaylorMade 500 series drivers (right).**

Perhaps the strongest connection to be made lies in the several cases in architecture which are arranged in a series of slide lectures, examining various historical examples and their use of ballasts, arches, vaults, and flying buttresses. This is followed by an extensive series of modern cases which are arranged according to lightness of structure and material, with consequent changes in structural shapes; understanding structures paves the way for a larger vocabulary of forms. In fact, it is a way to develop a feel for shapes and materials in conjunction with structural behavior. The lecture-shows come with music, as retention of the image is stronger with the emotional element present in music. And with the retention of image, concepts of structure and shape and architecture are enforced. The lectures help to unify structures with architecture, history, construction, technology, music, and artistry.

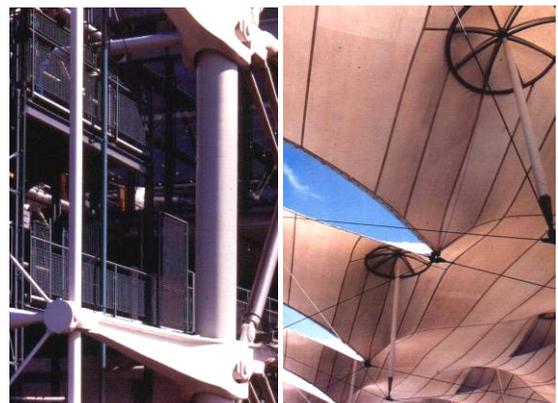


**(L-R) Structures in recent history: Helix-braced stairs for a sports arena, inclined columns with fan-ribs by Pier Luigi Nervi; flared-capital column (eliminating beams), and Schwandbach arch bridge by Robert Maillart.**

Figure 8. These are some of the cases used in the slide lecture series (more in Fig. 9). By arranging the cases according to history and material lightness, participants are given an entertaining show of documented proof where variety of forms has always been dynamic when architecture and engineering unite. The lecture series applies an education-entertainment approach by applying different media simultaneously: information about the case study, color images of the projects and its details, and background music to tie it all together.

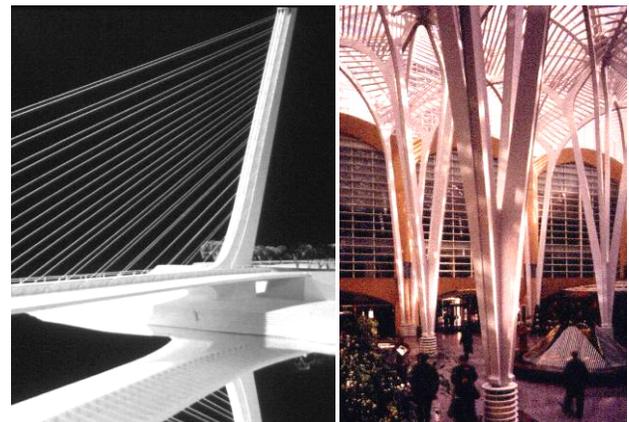
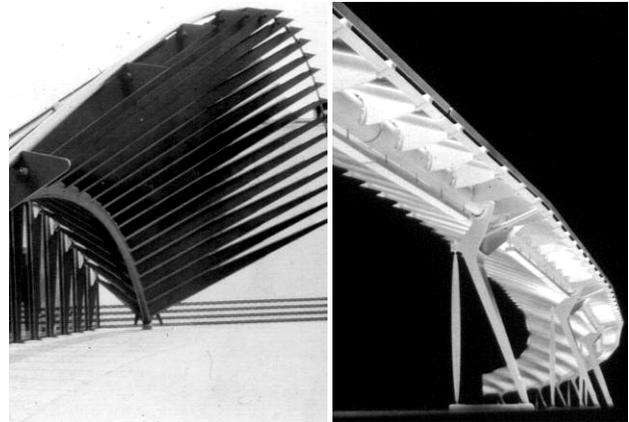


**(L-R) Structures in history: Cracked lintel of a Greek temple; the Pantheon's dome, with its coffers and ribs; an isometric cut-away detail of the Duomo of Santa Maria del Fiore; Gothic vaults at Exeter Cathedral, and stone flying buttresses typical of Gothic cathedrals.**





Selected works by Renzo Piano : Gerberette detail at Centre Beaubourg, tension nets at Schlumberger Renovation, “hives” of Tjibaou Cultural Centre, arch-rib structure assembly for Padre Pio Pilgrimage Church.



Selected works by Santiago Calatrava : Portico of Wohlen High School, Stadelhofen Station concourse, Amarillo bridge in Seville, End Atrium of BCE Place in Toronto.

Figure 9. Modern examples that express a unity of architecture and structures in dynamic forms and details. As mentioned in Figure 8, the lectures are multimedia in nature. The use of music to accompany the slide sequence recognizes how the mind receives information through different senses. Using the power of information, image, and music aids in higher retention and understanding of structures.



Selected works: Hong Kong Shanghai bank, and Renault Distribution Centre by Norman Foster; Waterloo International Station by Nicolas Grimshaw; and the New Parliament Building by Michael Hopkins.

#### 4. Practicing what you Preach

Actions speak louder than words, as it is often told. The making of exercises and examinations for effective learning is based on consistency between what is taught and what is done. For this reason, the exercises given to evaluate performance of architecture students are delivered with a behavior-shaping-concepts phase, as well as the computed sizing of the defined elements. By developing the assignment or test along the lines of an architectural-structural shaping exercise, the actions further promote this unity.

Students themselves partake in this unified culture by building bridges or towers and having them put to the loading test. Taking a cue from the masters, learning from experience has proven to leave a very strong impression and remains a reliable method for verification of knowledge;

Leonardo da Vinci refers to this as *dimostrazione*<sup>6</sup>. While this loading session becomes a solid proving ground for their ideas, they also learn about behavior of structures in three dimensions. The session also draws the attention of other students from other classes and courses. The models and their basic performance data are documented every semester, gradually raising the spirit of competition for future students.



## 5. Students Give their Opinions

Course evaluations over the last two years reveal that students (average age of 21) give strong support for these graphic methods. Slide lectures and model tests rank highest, classroom sessions rank second, and computational examples rank third. There is a wider variety of opinion regarding the pace of the classes, the personality of the teacher, and the requirements and grading system. In comparison to conventional methods of teaching, all the respondents express that these alternative methods make the structures learning more encouraging, effective, and enjoyable.

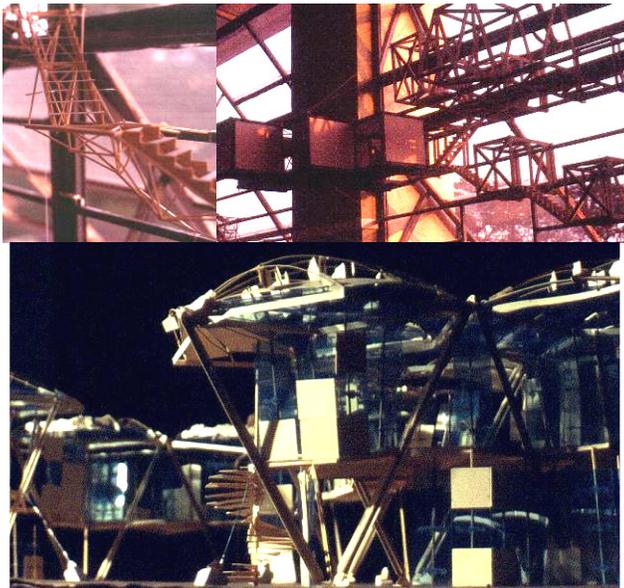
<sup>6</sup> "...but to me it appears that those sciences are vain and full of error that have not been born of experience, mother of every certainty, and which do not likewise end in experience; that is to say those that have neither at their beginning, middle, nor end passed through any of the five senses" Kemp, Martin. (1989) from "Disciple of Experience", Leonardo da Vinci. Yale University Press for South Bank Centre, and Gelb, Michael J. (1998) How to Think like Leonardo da Vinci. Dell Publishing. New York.





**Figure 11:** Selected bridge designs tested to failure. The bamboo-stick bridges have a clear span of six feet. To date, the standing record is 300 kilograms load on a 2.30 kilogram bridge. Bridges come in various shapes. The ones that show better load-bridge weight-sag performance have arch shapes or bowed/propped cable shapes. Bridges are designed by the following groups : (top) Dag-Macaraig-Sobretodo; and Jimenez-Reyes-Tejada; (bottom) – Javier-Peraz; Arlanza-De Villa-Tagle; Arevalo-Rebucas-Relivo; and Tangangco-Tobias-Quevedo.

The two-fold objective of the teaching methods are: 1) to understand structures and sharpen the structural-shaping instinct, and 2) to apply that sharpened understanding in the designing of dynamic and responsive architecture. Possibly the most encouraging proof that the teaching methods have been effective is seen in the students' designs in studio where their ideas of stability and strength have evolved into various shapes beyond the familiar box.



**Figure 12.** Selected architectural designs by students. These topic design projects have the objective of being structurally light and expressive. With no design precedent, the student designers created models that work. Designs above are by (clockwise from top left) Apacible, Regala, and Mooney et al.



**Figure 13:** Selected designs for MRT stations. Aside from considering issues of structure, construction, and economy, the forms are also refined for visual elegance and identity from both the exterior and interior. These designs and details are by (top) Reyes et al, and (bottom) Tambis et al.

## 6. Conclusions

- The use of graphics engages the mind visually and intellectually in topic discussions. Graphics have been proven as an effective tool in increasing retention of subject matter.
- The use of familiar language, examples, and situations can discourage intimidation of esoteric subjects and encourage a more open mind to engage in the topics being discussed.
- Manipulation of formula variables graphically connects equations with shaping and sizing potential. This is significant in giving the participants a sense of understanding and control.
- Series of case studies are the most effective means of providing proof of structures in architecture. Seeing an idea done in reality and understanding its characteristics open the mind to architecture's strong connection to structures, construction, and artistry.
- Building and testing models engraves the learning experience deeply. Experience is learned and earned. Once earned, it will be difficult to forget the learning significance.