AC 2010-1319: GET THE FORM RIGHT!

Robert Dermody, Roger Williams University

Get the Form Right! Teaching Structures in a Design Studio

Abstract

Teaching structural design concepts to architecture students in a studio setting is a powerful way to educate future architects about designing efficient, exciting forms for building structures. The key to good structural design is to get the form right. The brilliant Uruguayan engineer, Eladio Dieste phrased it best: "There is nothing more noble and elegant from an intellectual viewpoint than this: to resist through form." This paper describes an advanced undergraduate architectural design studio focused on the design of efficient, elegant, expressive long-span structures. Examples of student design solutions for various projects are shown and explained. An assessment of the benefits of teaching structures in a studio is presented. The studio projects demonstrate that structure is an important determinant of architectural form. Form should follow force, and not merely function.

Introduction

Technology is design. Technical concepts, especially in architecture curricula, should be taught as design. However, structures courses in most architecture programs have long relied on calculation based problem sets as their primary pedagogy. This approach is unrealistic and does a disservice to students. It does not accurately represent the limited role that calculations play in developing forms for building structures. Numerical problem sets reinforce the notion that structural design is all about number crunching. In their studio courses, students are challenged to create beautiful spaces in response to practical programs on real sites. In their structures courses, they are often force-fed calculation methods for individual structural elements. There is no commonality between the two courses, as a result of which they seldom relate in a meaningful way.

An informal review of architecture programs across the U.S. reveals that most schools require between two and four "structures" courses. These are most often given in a lecture/problem solving format. The most common topics covered include statics, strength of materials, wood, steel and concrete. When a curriculum is organized in this fashion, it is quite common to rely on traditional textbooks which are often written for engineering students, and "problem set" style homework assignments. This approach concentrates almost exclusively on a minor part of the structural design process that is usually performed by structural engineers and almost never by architects. It largely ignores those parts of the process in which architects are usually active. This suggests that the teaching of structural design to architects should be re-oriented away from calculations toward selecting and configuring structural systems.

It is never too early to teach structural concepts within the context of architectural design. In a curriculum that teaches structures as design, even beginning architecture students can gain a better appreciation of the implications of spatial design on the corresponding structural system requirements. In the design studio, students should be challenged to design structures by determining ideal forms that satisfy both programmatic and loading requirements. Technical design problems allow students opportunities to use structure as a determinant of architectural form. Simple first order calculations to determine member sizes can confirm proposed structural forms. Students readily see the influence of their proposed structural configuration on sizing of constituent members. This approach can be especially liberating for students who are used to more traditional numeric problem solving structures classes. Configuring the structural system to enhance the architectural space can lead to mutually beneficial results.

Context of Teaching Technology in a Design Studio

The studio setting is an ideal learning environment of technical subjects[1]. The primary benefit of teaching technical subjects in a design studio is that it allows students both to acquire and to practice the skills of designing building structures. It is traditionally a more active learning environment where students have much more direct interaction with the instructor and with their peers. Studios are smaller than lecture courses and there is typically more contact time per week. Studio design problems also foster a more open-ended solution seeking process than problem sets. Structural design problems, like any design problems require critical thinking skills, representation of ideas, and careful iteration and evaluation. All these facts contribute to a more flexible, yet realistic learning environment.

Students in the BS/MArch degree program at the University of __________ take 11 design studios. Three of these are classified as Advanced Architectural Design taken and are taken in their 3rd and 4th years. These bridge from the core undergraduate studios to the graduate and thesis studios. Advanced studios cover a range of issues including urban design, housing, sustainable practices, and contemporary technologies. Advanced studio therefore is an ideal setting in which to teach basic structural design concepts to architecture students. The author recently taught an advanced studio with an emphasis on structural design. All the students had already taken traditional lecture courses in statics and strength of materials, which helped, but was by no means a prerequisite for this studio. The studio intentionally focused on the design of efficient, elegant, and expressive forms for long span structures.

Content and Goals of the Form and Force Studio

In the spring 2009 semester, the author taught an advanced studio titled "Form and Force: Designing Long Spans for Architecture". The learning objectives as outlined in the course syllabus were to:

- Explore structure as a determinant of architectural form.
- Explore the relationship of architectural form to the flow of forces through its structure.
- Develop the ability to analyze and design structures using graphic statics.
- Develop the ability to design and craft structural details.
- Research the great designers of structure and analyze some of their seminal works.
- Develop good verbal and graphical presentation skills.

The first two goals made up the dominant theme for the entire course. Starting with the premise that structure is a potentially expressive determinant of form; students explored the relationship between architectural form and the flow of forces through its corresponding structure.

Graphical methods of structural analysis and design were used in this studio for several reasons:

1. Graphical methods clearly demonstrate the relationship between form and force in statically determinate structures.
2. Different structural schemes can be compared visually in terms of efficiency and form based on their respective force polygons.
3. The graphical methods focus on the relationship between form and force rather than on calculations.
4. Potential revisions to schematic designs can be derived from evaluation of force polygons.
5. Relatively compact force polygons indicate relatively efficient structural forms.

Students used mathematical calculations to determine loads on the structures, but not to determine the form. The graphical method facilitated quick evaluation of the overall structural form. This was a key design tool for the students, and one they adapted to quickly. They now had the ability to critically evaluate structural form based on efficiency rather than pure formal approaches. Critical member sizes could then be determined using basic allowable stress design principles.

Students also designed and modeled significant connections in their structures. These connections were studied both digitally and in physical form. Detailing connections reinforces the idea that good structural design occurs at several scales, from overall building structural system to connection details. Details can even influence the proper selection and orientation of larger members. When they are exposed, structural connections can also enhance the beauty of the overall form and space. It is also another chance to explore and understand the flow of forces through structural elements.

Assignments

The semester began with short "warm-up" exercises to learn the graphical methods of analysis and design for four basic categories of structures; trusses, arches, cables and fan-like structures. These served as springboards for specific design problems; a pedestrian bridge, a waterfront concert pavilion, and finally a municipal ice rink facility for a local town. Students were encouraged to explore funicular forms for each project that had been studied in the warm-up exercises. Precedent studies/analyses of great designers and their projects including Gaudí, Maillart, Nervi, and Candela, were also used to inspire students' responses to these problems. The complexity of the architectural programs was purposely limited so that students could focus on structural form finding and development. The site and scale of each project was also carefully selected to force students to focus on structural solutions.

A refreshing occurrence during the semester was the students' tendency to work primarily in section or elevation of their project. This is what the author calls the "structural parti" of the structure. Too often architecture students develop their projects by working in plan only. Students quickly learned via the graphical method whether their initial design ideas were feasible. They could also compare their design proposals with their peers by evaluating the force polygons of similar systems drawn to the same scale. Another benefit of the graphical method is its usefulness in revising proposed forms for structures. The students can use the force polygons generated to increase the efficiency of their designs by manipulating the form diagrams and corresponding force polygon. Arches and/or trusses that were too shallow had extremely high forces in their members as was evident in their corresponding force polygons. Students quickly realized that finding good structural forms could/should be based on efficiency instead of purely pleasing or desired forms.

The first project, a pedestrian bridge, is an excellent design exercise for architecture (or engineering) students. Its explicit program and functional nature lends elicits designs based on structural requirements. The students were asked to design a footbridge to span 90 ft. over a river on an imaginary site. The small scale of this project allowed student to compose design solutions that included graphical analysis and some detailing of connections, all composed into a project drawing set. This was a good introduction to preliminary design at a range of scales from a site plan to detail drawings.

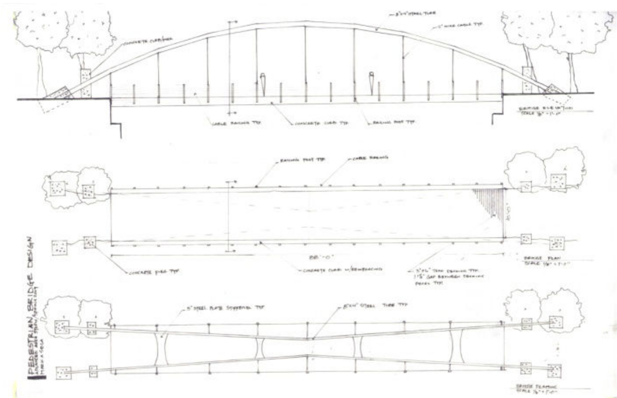


Figure 1a. Pedestrian Bridge Design by Mark Sidla, Plan (view from above) and Elevation (side view).

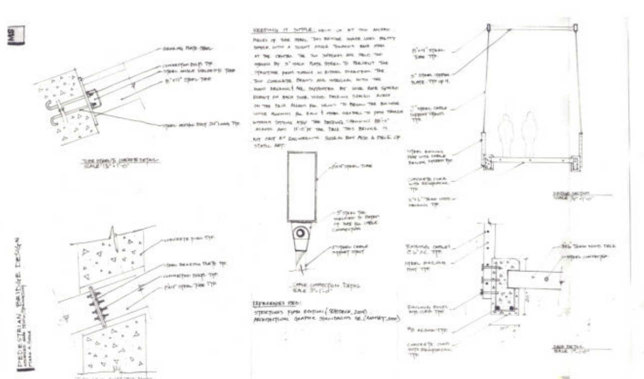


Figure 1b. Pedestrian Bridge Design by Mark Sidla, Details of Connections.

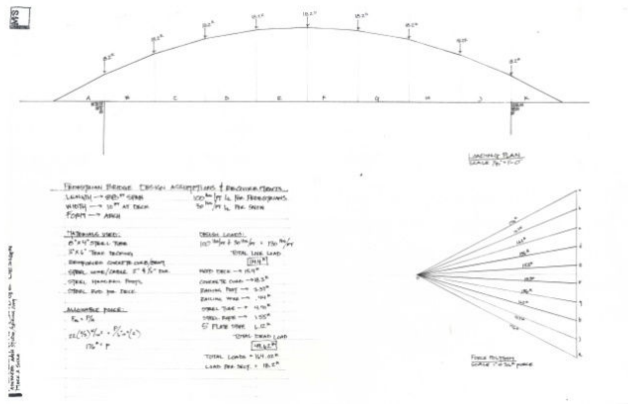


Figure 1c. Pedestrian Bridge Design by Mark Sidla, “Form Diagram” and “Force Polygon”, these are graphic representations of the structure’s shape and the corresponding forces in its elements.

The second project involved a slightly larger program for an open-air concert pavilion covering about 8,000 SF in a harbor-side park. This assignment required more three dimensional analysis than the footbridge. A local site was selected to allow student response to real conditions. Materials selection was left up to the students, providing an opportunity to teach them about the process of and timing of materials selection for a structure. Most of the student chose steel or wood framing systems, which worked well for the linear articulated forms they were developing.

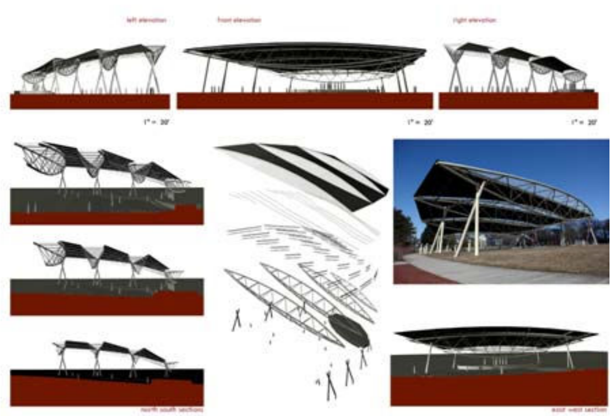
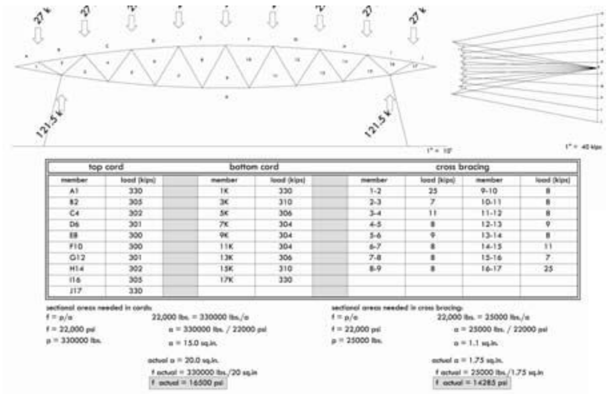


Figure 2a. Pavilion Design by Ryan Decker, Elevations (side views) and Sections (cut-away views).



top cord			bottom cord			cross bracing			
member	load (kips)		member	load (kips)		member	load (kips)	member	load (kips)
A1	330		1K	330		1-2	25	9-10	8
B2	305		3K	310		2-3	7	10-11	8
C4	302		5K	306		3-4	11	11-12	8
D6	301		7K	304		4-5	8	12-13	9
E8	300		9K	304		5-6	9	13-14	8
F10	300		11K	304		6-7	8	14-15	11
G12	301		13K	306		7-8	8	15-16	7
H14	302		15K	310		8-9	8	16-17	25
I16	305		17K	330					
J17	330								

Figure 2b. Pavilion Design by Ryan Decker, “Form Diagram” and “Force Polygon”, these are graphic representations of the structure’s shape and the corresponding forces in its elements.

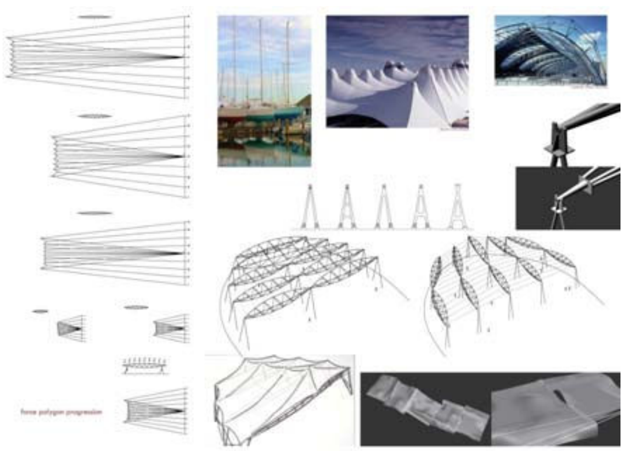


Figure 2c. Pavilion Design by Ryan Decker, Details of Connections, “Form Diagram” and “Force Polygon”, these are graphic representations of the structure’s shape and the corresponding forces in its elements.

The final and major project (taking approximately half of the semester) was a design for a municipal ice rink for the local town. This involved a somewhat more complex program with a long span requirement. A site next to the local high school was selected. This project required organization of the program for a large ice surface, locker rooms and associated spaces; site development strategy, plus the careful study of the structure to provide the required long span over the ice surface. The students were encouraged to explore further the spanning potentials of the systems they investigated in either the footbridge or the pavilion. Issues of climate control were also present. As a research exercise, all the students were required to visit a local ice rink and go skating to gain firsthand experience using such a facility.

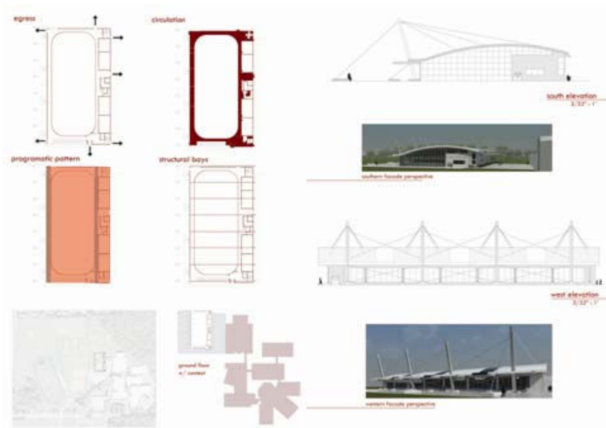


Figure 3a. Ice Rink Design by Kristen O'Gorman, Plans (views form above) and Elevations (side views).

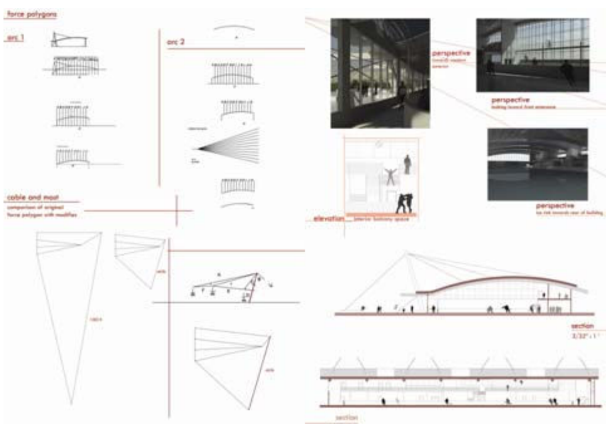


Figure 3b. Ice Rink Design by Kristen O'Gorman, Sections (cut-away views), "Form Diagram" and "Force Polygon", these are graphic representations of the structure's shape and the corresponding forces in its elements.

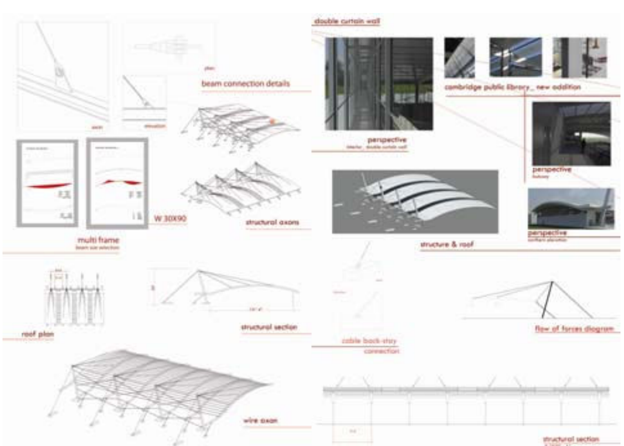


Figure 3c. Ice Rink Design by Kristen O'Gorman, Structural System and Details of connections.

Outcomes

The power of expressive, efficient structure to enliven architectural spaces and the thoughtful detailing of those structures were the key themes of this studio. Teaching basic structural design in a studio setting proved to be very rewarding. When students are challenged to design structural forms for buildings, the positive role structure can play in determining good architectural form is more evident. When structure is used as a determinant of form as opposed to something designed after the architecture is "done", students realize the benefits of a more integrated design process. Students learned that the graphical method is a powerful way to both analyze and design simple structures. Basic structural concepts regarding depth to span rations come alive in the generation of force polygons. Students quickly see the influence of form on the flow of forces through a structure.

Overall, the architectural forms created by the students were more rationally based and more responsive to physical forces than to formal or theoretical concepts. Their designs integrated structure and architecture to a greater degree than they had typically achieved in their previous studios. The students also realized the power of designing in section instead of relying on the plan. Their design process evolved from a tendency to create designs based on aggregations of programmatic areas to working mostly in the "structural parti" or section. There were also several "Aha!" moments in the studio wherein students suddenly understood some structural concept they had studied in another lecture based structures course. For example, the concept of depth of a structural system vs. its ability to span is extremely evident in the force polygons produced in the graphical method. The students were quite comfortable creating form diagrams and force polygons after only a few quick exercises demonstrating these techniques.

The Form and Force studio took advantage of the studio format to explore structural problems from a design solving perspective. Students were encouraged to experiment with different forms to study various programs. Alternative schemes were evaluated on the basis of their efficiency and their aesthetic quality. Unlike a lecture problem-solving course, open-ended design problems have multiple possible solutions. Structures is design. It can and should be taught in a studio setting.

Bibliography

1. Allen, E. 1997. "Second Studio: A Model for Technical Teaching." JAE Vol. 51 No.2, pp. 92-95.
2. Allen, E. 2005. "Some Comments Concerning Technical Teaching in Schools of Architecture", ACSA News, May 2005.
3. Allen, E. and Zalewski, W. 2009. Form and Forces: Designing Efficient, Expressive Structures. John Wiley & Sons, Inc., New Jersey. 1997.
4. Billington, D. 1985. The Tower and the Bridge, The New Art of Structural Engineering. Princeton University Press, Princeton, NJ.

5. Brock, T. 2006. “Updating the Miesian Curriculum” in proceedings of the Building Technology Educators’ Symposium, University of Maryland, August 3-5, edited by Oakley, D.J. and Smith, R.E.
6. Charles, P. and Dermody, R. 2009 “Linkage: The Undergraduate Materials and Methods Lecture Course and Its Companion Studio” in proceedings of the Building Technology Educators’ Symposium, University of New Mexico, August 3-5, edited by Guling, D. and Armpriest, D.
7. Dong, K and Leslie, T. 2006. “Cross-Discipline, Cross-Country: A Collaborative Design Studio Integrating Architecture and Engineering” Proceedings of the 2006 Meeting of the American Society for Engineering Education.
8. Gelernter, M. 1988. “Reconciling Lectures and Studios” JAE Vol. 41 No. 2 pp.46-52
9. Oakley, D., Smith, R. E., 2007. “Bridging the Gap: Reviving Pedagogical Discourse in Architectural Technology Education”, Proceedings of the 2007 ACSA Annual Meeting.
10. Smith, D.L. 1987, “Integrating Technology into the Architectural Curriculum.” JAE Vol. 40 No.4 pp-4-9.