"Bridge vs Tower: Introducing Architectural Engineering to Freshmen Students"

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In the first year of study for both Architecture Design and Architectural Engineering majors at Oklahoma State University, students share coursework centered on design fundamentals. The Fall semester includes an 'Introduction to Architecture' course, where basic design principles, drawing conventions, and practical information about the profession of architecture and engineering are introduced. In the Spring semester, students enroll in a six credit hour design studio which meets MWF 1:30-5:20 pm, and is primarily taught by architecture faculty. One three-week project of the semester, however, is focused upon the exploration of architectural structural systems and design, and involves licensed architectural engineers in the presentation of relevant structural concepts and information, and in the critique of student work during the design process.

An important aspect of the structures based project is the inclusion and introduction of the architectural engineering faculty to the beginning students in the programs. The five year curriculums for both the architecture and architectural engineering majors are arranged such that students do not enroll in structural engineering courses and thus do not have direct interaction with the AE faculty until their third year in the program. The only exception is one required engineering science course, Statics, taught by an AE faculty member during the second year of the curriculum. This lack of interaction leaves some students unsure of what it is they have come to this program to accomplish, which can lead to students deciding to switch majors to one in which they better understand the process.

To make sure this is not the case in our program, and to expose students to the concepts of structural integration early in their education, the three AE faculty members agreed to be involved with this Studio I design project, and have been for many years. The interaction with AE faculty in the first year of the curriculum allows students to be introduced to structural concepts that can subsequently be incorporated in studio projects to further build believability into their early design efforts.

Since 2001, we have experimented with two methods of introducing structural design to freshmen students, with both methods allowing the students to explore the use of structures as the dominant design feature. For many years the assignment to design an observation tower was the featured Architectural Engineering focused project, but for the past three years a pedestrian bridge project has served this purpose in the studio curriculum. The projects – tower and bridge - share some similar qualities, but after reviewing student work the past three years, some interesting differences have been revealed.

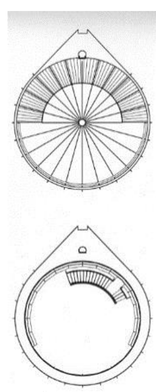
‘The Vertical Construct’, or Tower project program (Bilbeisi 2014)
As written in the problem statement issued to students: “Towers have been built in almost all cultures from time immemorial. What motivates us to build them? Perhaps it is innate within our being that we feel compelled to climb higher to see the world from a different perspective, to escape the limits of the near-at-hand, to broaden our view of life. We want to experience something… but what?” (Heinle, Erwin and Leonhardt 1989) This project encourages students to explore verticality in form and structural logic, while applying and building upon the basic design principles they have learned thus far in Studio I.

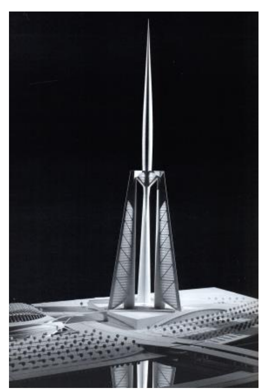
The essence of this design challenge is to create a conceptual and perceptual experience for a human, which must occur ‘at elevation’ (height). In order to address this challenge, each student must conceive of a design concept and an innovative structural solution, and consider how a person will approach, move through and up into the vertical construct while designing the quality of that experience.

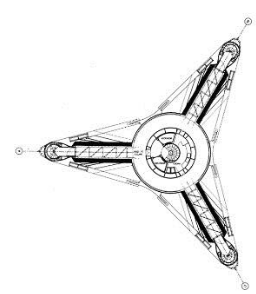
Case studies of towers designed by famed architect/engineer Santiago Calatrava illustrate structural innovation, and the three methods utilized to achieve structural stability within a tower structure: *vertical brace, shear wall, and moment frame*. These include the Communications Tower of Barcelona to illustrate moment connections, the Sondica Airport Control Tower to illustrate shear wall, and the proposed Valencia Tower to introduce the more commonly understood vertical bracing systems of design. That each has a unique configuration in plan helps to convey how both vertical and horizontal systems are necessary to stabilize what is essentially a cantilever from the earth.


Communications Tower


Sondica Airport Tower




Valencia Tower (unbuilt)



Each student is responsible for the design of a vertical construct or ‘tower’ as an individual project effort. The tower is proposed for an imaginary site that is 80’ x 80’ at 1/8”=1’-0” scale. There is a height limitation of 160’, though an additional 20’ below ground level is available for development as well. Any horizontal projections from the main tower structure must not extend beyond the edges of this site.

Student proposals are required to exhibit the following basic design principles:
Structural Soundness: The ability of the vertical construct to…. stand up! (And resist forces.) Utilizing structural logic and innovation in the design of the structural system is very important.
Order: The manner in which form and space are arranged can clarify their relative importance

and functional or symbolic role in a building's organization. Every design solution should demonstrate an understanding of order.
Hierarchy: The articulation of the importance or significance of a form or space relative to the other forms and spaces of the organization should be evident.
Repetition: The use of recurring patterns, and their resultant rhythms, to organize a series of like elements or spaces should be demonstrated.
Focus: In each scheme, attention should be directed to an area of visual interest – focus may be obtained through the use of contrast, color, size, complexity or simplicity of form, etc.
Materiality: Each tower should also exhibit experimentation with basswood as the primary building material. An accent material may be used to enhance the visual experience of the construct. These materials may explore issues of texture, color, visual weight, reflectivity, and sense of enclosure.
Function: The human must interact with the construct; the entry and ascension sequence must be considered carefully. The tower should also be designed from overall form to the detail level; the base plane and base, the shaft and the 'crown' are each design problems that should be well considered individually, but relate as a whole.



Vertical Construct Projects (2)

A student works to complete his finished model

This project is evaluated holistically based on the following criteria - the successful application of the basic design principles of order, hierarchy, focus, repetition, materiality, and function; the creativity, aesthetic quality, and imaginativeness of the design solution; the quality of the experience for the human; evidence of an application of basic structural logic, and further, evidence of an innovative approach to structures; and the quality of craftsmanship, and eloquence of the conceptual interpretation.

'The Utopian Bridge' project program (Bilbeisi 2017)
From the project brief: "A bridge is an idea, a kind of imagining that has an ahistorical, archetypal sensibility and function. People from all walks of life and all ages dream bridges, engage in reverie on and around them, invent them, and find meanings in them. Bridges have the capacity to make a statement from end to end, and from the foundations to the uppermost point. On occasion, bridges have also been seen as examples of 'artistic brilliance', akin to sculpture,

music, and painting." (Bishop 2008) This project encourages you to explore the potentialities within a simple span in form and structural logic, while applying and building upon the basic design principles we have learned thus far in Studio I.

The essence of this design challenge is to create a conceptual and perceptual experience for a human, which must occur along the length of a span over a chasm. In order to address this challenge, each student must conceive of a design concept and an innovative structural solution, and consider how a person will approach, move through and across the construct while designing the quality of that experience.

Case studies of bridges designed by famed architect/engineer Santiago Calatrava illustrate structural innovation, and the four methods utilized to achieve structural stability within a bridge structure: *truss, arch, beam, and suspension*. His Sundial Bridge illustrates both suspension and truss systems working together to produce an extremely long clear span. The Puente de la Mujer bridge is a simple beam bridge with a suspension system integrated with it, but of course when created by Calatrava it also rotates. Finally, the Ponte della Costituzione bridge is composed of a simple steel arch, with truss members further supporting from the underside to allow it to be as thin as possible.


Sundial Bridge


Puente de la Mujer Bridge


Ponte della Costituzione Bridge

Each student is responsible for the design of a pedestrian bridge as an individual project, designed for an imaginary site that has banks 80' wide x 40' deep, with a span of 160' clear. The river surface is 80' below the banks; the bridge must clear 60' of height above water (at the middle third of the span) for any vessel to be able to pass underneath it. There is no height limitation for the bridge elements, except of course within reason. Any projections from the main structure must not extend beyond the 80' width of the site. The faces of the banks, horizontal and vertical, may be used to attach the structural supports for the bridge.

Student proposals must demonstrate the following basic design principles:
Structural Soundness: Structurally, the bridge should look and feel appropriate, though no structural calculations will be necessary for this visionary exercise. Indeed, Robert Maillart, one of the most innovative bridge designers of the 20th century, believed that computations were merely estimates, never the absolute truth. He founded his designs on visual form and physical behavior, on evaluation and conception. (Billington 1997) Students must draw upon what they learn about structural and material behavior in presentations for this project, and what they have learned from simply living in the built environment all of their life!

A "Program" of Conceptual Moments: Each successful proposal shall exhibit the following places for humans to experience - *Thresholds / Transitional Space(s) / A Space of Pause / An Iconic Element...* experienced in any order the designer may choose. Students are encouraged to consider carefully the spaces the span suggests - the points of origins at the ends from which the initiation or entry occurs; the very center or apex of the span with its' suggestive danger; the space below the span, the shadowy underside which is gathered beneath the prime real estate of the span above. All of these areas can and do suggest meaning, and impact how humans perceive space and interact there. (Bishop 2008) It is up to the student to determine how people will *experience* this bridge.

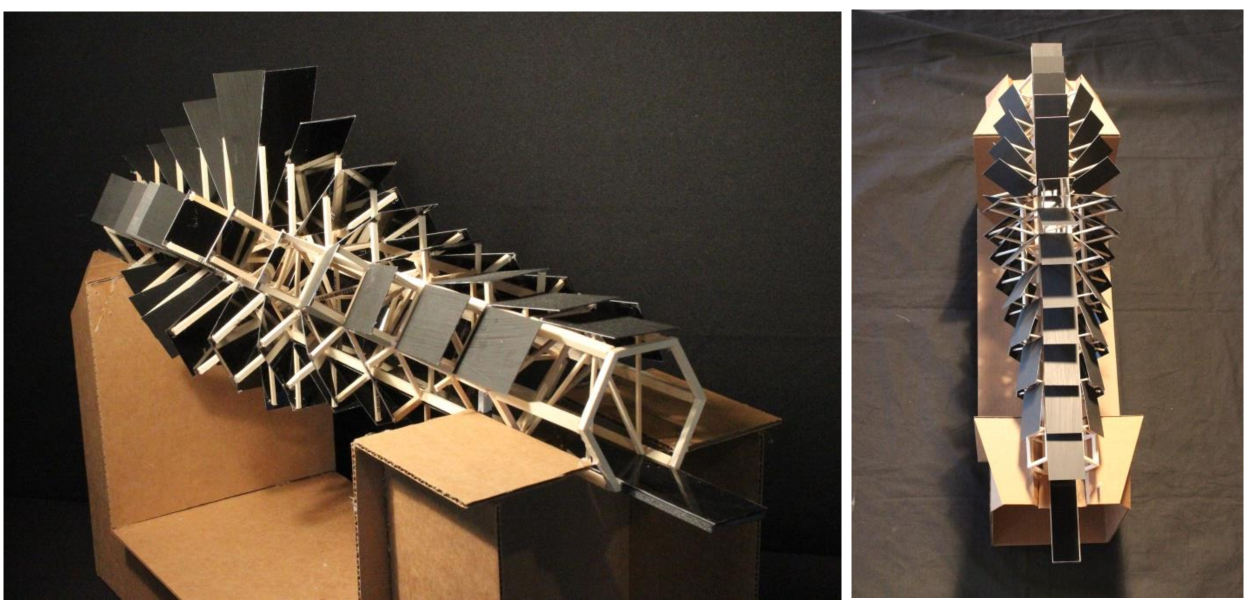
Materiality - Each bridge should also exhibit experimentation with basswood as the primary building material. An accent material may be used to enhance the visual experience of the construct. These materials may explore issues of texture, color, visual weight, reflectivity, and sense of enclosure.

Order - The manner in which form and space are arranged can clarify their relative importance and functional or symbolic role in an architectural organization. Every design solution must demonstrate an understanding of order.

Hierarchy - The articulation of the importance or significance of a form or space relative to the other forms and spaces of the organization should be evident.

Repetition - The use of recurring patterns, and their resultant rhythms, to organize a series of like elements or spaces should be demonstrated.

Focus - In each scheme, attention should be directed to an area of visual interest – focus may be obtained through the use of contrast, color, size, complexity or simplicity of form, etc.

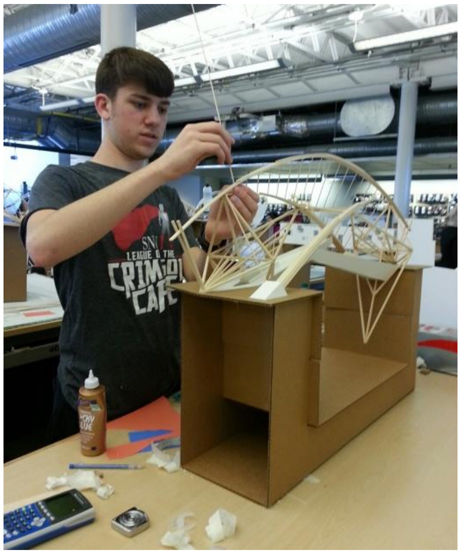


Student Proposal for the Utopian Bridge Project

This project utilizes a similar evaluation criteria as was employed for the tower project; it is evaluated holistically based on the following criteria: the quality of the experience for the human, especially at the conceptual moments; evidence of an application of basic structural logic, and further, evidence of an innovative approach to structures; the successful application of the basic design principles of order, hierarchy, focus, repetition, and materiality; the creativity, aesthetic quality, and imaginativeness of the design solution; and the quality of craftsmanship, and eloquence of the conceptual interpretation.

Teaching Pedagogy

Over the three-week design process, the first week is spent learning about structural elements and potential systems, and experimenting with materials, forms, and systems of connections.



Completing a study for the Utopian Bridge Project

Student and Teaching Assistant confer on the Vertical Construct Project

The process of the AE faculty involvement in the project begins with a seminar on structural concepts presented to the students in an open discussion of the common structural elements used in the construction of these types of projects. This seminar occurs approximately four days into the project which gives time for the students to explore initial designs for their project. The seminars are developed to give students basic structural terminology and to identify structural elements that can be used in the development of their projects. Columns, beams, cantilevers, and load bearing walls are re-introduced to the students, as many of them are familiar with the structural elements in everyday life. In addition, students are introduced to structural rules-of-thumb that can be used to preliminarily size the depth of various structural members based on their spans. Basic concepts and structural requirements for the specific project type (tower or bridge) become the focus of the seminars, and terminology is introduced that will allow the students to be able to express the intent of their designs using the proper vocabulary.

In the second week of the project, the AE faculty members along with guest practicing professional structural engineers provide students with structural consultations. Students present their projects to the consultants and receive feedback that can be incorporated into their design. This interaction with professionals, in a small group setting, allows for a discussion of the importance of the structural systems they have chosen to incorporate into their designs. It also allows for the professionals to give input on what revisions could be made to the projects to make sure they meet the structural needs of the concept. Students are then able to take into consideration the feedback they have received to test and revise their designs before beginning to construct their final proposal. The third and final week of the project is consumed with the act of construction of the final model of their proposal.

A review of preliminary tower proposals with an engineering faculty member; a student works on his bridge proposal.

Analysis of the Results

Both projects share two main points of emphasis: employing structural logic and load paths, and structural hierarchy of members within the system. There are no calculations used, all analysis is tactile and visual. These are the primary criteria used to evaluate structural effectiveness, and the students' understanding of how structural systems work. The hands-on nature of studio learning is a valuable tool, as is the method of group critique with a structural consultant (guest professor or guest professional) midway through the project. The freshmen students learn by observation and by doing, which is the most effective means of testing initial ideas.

The introduction and inclusion of the Architectural Engineering faculty in the beginning year of design is important to the student's education on three fronts:

1) Students begin to understand that they do inherently have a basic knowledge of structures and how the incorporation of structures can affect design decisions.
2) Students can see the importance and significance of structural system design within an architectural design proposal.
3) The students are presented with a knowledge base which can be built upon in subsequent courses within the curriculum, giving the students the tools necessary to be successful in the demanding professions of architecture and structural engineering.

The decision three years ago to change the project from one that involved the design of a tower to one that involved a bridge was made with the intent of finding a better way to reinforce the structural concepts presented to the students in the structural seminars. It was noted that in the tower projects students did not sufficiently understand the ramifications of some of their design decisions as they pertained to structural requirements. Towers essentially cantilever up from the ground and a clear load path is not difficult to create to transfer the loads to the base of the structure. In the tower designs, students could achieve stability without a full understanding of why the load path worked, or how it was achieved. The faculty agreed that this concept takes time and reinforcement of the theories of structural design to be fully understood by students. After discussions the faculty felt that a revision to the project type might help the students better understand structural behavior, so as an alternative to the tower project the design of a bridge was the educational vehicle implemented.

The design parameters for the bridge project are similar to those for the tower project, but with two support points - one on each end of the span - for the bridge project instead of the one support at the base for the tower project, it was anticipated that students would be forced to grasp the structural concepts necessary to sufficiently support the bridge. In addition, bridges can utilize a combination of structural systems (beam, truss, arch, or suspension) in their designs. Combining structural elements gives the students multiple choices to explore when determining how their bridge project can be structured. Also, the introduction of structural rules of thumb based on span to depth ratios of structural members is made more immediately visible in the bridge project than in the tower project, where oftentimes the structural system was hidden. This visual catalog of information more fully adds to the beginning student’s arsenal of design decision making tools.

After assigning the bridge project for the past three years in this freshman studio, we can evaluate the effectiveness of the project with a review of project grades (2015 - 2017) and compare those to the most recent years of tower grades recorded (2012 - 2014). This comparison shows that the overall results for both the structurally focused projects, and for the course itself, showed an increase in effectiveness when the bridge project was employed. Freshmen students appear to embrace the structurally focused project, whether Architecture or Architectural Engineering students, with average grade on the bridge and tower projects for all six years higher than the class final semester average.

Evaluations of Bridge and Tower Projects				
Project	**Year**	**Project Avg.**	**Course Avg.**	**Population**
Bridge	2017	82.7	80.0	77
	2016	85.3	81.2	64
	2015	86.3	81.6	62
Tower	2014	81.1	79.4	66
	2013	82.4	81.2	71
	2012	80.3	77.6	73

Average project and course semester grades for Bridge and Tower projects.

Additionally, these performance metrics for the bridge or tower project are used in the ABET assessment of the course annually. In particular, this assignment serves as a benchmark for the ABET Student Outcomes (g) *an ability to communicate effectively*; and (c) *an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability*. (ABET 2015) The inclusion of these student outcomes early in the programs curriculum allows us to illustrate to ABET the importance our curriculum places on the integration of systems in the design process.

The revision to the beginning design course to include the bridge project has allowed students to look at structural concepts and requirements from a different point of view, one in which they can utilize basic structural systems simultaneously to satisfy structural requirements for the project while utilizing these requirements to help design an aesthetically pleasing bridge. The inclusion of this project allows the beginning architecture student to establish a base upon which their knowledge of structures will be built during their time in the architecture program. For the architectural engineering student, the collaboration with architectural engineering faculty and with practicing professionals gives them a connection with their major in their first year of the curriculum, and allows them to realize the importance of the role of structural systems in the architectural design process.

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Biographical Information

SUZANNE BILBEISI, AIA - Centennial Professor of Architecture and Head
Professor Bilbeisi has been a member of the faculty at the Oklahoma State University School of Architecture since 1993. Her primary role at OSU has been to teach in the Architectural Design Studios, and in her twenty-four year tenure, she has taught students at every level of the curriculum. Professor Bilbeisi initiated in 1995 the "Introduction to Architecture" course, and she has since remained the primary instructor for this required course directed towards all incoming freshmen into the School of Architecture. She has also been the faculty coordinator for Design Studio I at OSU since 2000, which has effectively positioned her as coordinator of the freshman experience in the School of Architecture for almost two decades.

JOHN PHILLIPS, PE - Associate Professor of Architectural Engineering
Professor Phillips is a registered engineer, and practiced as a structural engineer for nine years before returning to his alma mater in 2000 to teach in the School of Architecture at Oklahoma State University. As well as contributing as a faculty consultant to the beginning design studios, Professor Phillips teaches both at the undergraduate and graduate level in Engineering Statics, Analysis I, Foundations, Timbers, Steel I, Concrete I, Steel II, Concrete II, Steel III, and Concrete III. He is also one of five professors teaching in the Comprehensive Design Studio, which takes Architecture and Architectural Engineering students through all phases of the design process on a commercial building of the students own design.