

The Structural Origins of Form: A Digital Approach to Investigate form

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Abstract:

The origins of modern form in architecture engages many significant issues such as philosophical and ideological discourse, social/cultural issues, symbolic intents, construction tectonics, and structural logic. Although all these issues can be equally significant in many situations the following paper will focus on the “structural logic of form” and will introduce a method to investigate and analyze form in relation to structures using advanced media. Specifically this paper will focus on introducing an alternative teaching tool, which aims to increase students’ understanding of the structures and enhancing their interest in the expression of form through creative and innovative use of structures.

The paper will present a small aspect of a much broader project, which is supported by the Fund for the Improvement of Postsecondary Education, a program of the U.S. Department of Education involving faculty at various Institutions. The funding is used to develop a teaching tool that utilizes a wide range of digital and graphic technology including detailed and realistic three-dimensional computer generated models and animations to communicate the basic structural principles in relation to form development. The strong visual approach used in the development of this tool, also provides an intuitive understanding supported by experiencing the structural behavior and engaging the students with the consequences of architectural form selection.

Typically, studying the variation of forces and moments in a structural member is a critical component of teaching structures. In most traditional teaching methods, this is achieved through numerical exercises, which involve longhand calculations of the internal forces and moments, followed by plotting shear and moment diagrams that indicate the critical stress areas and values. The final stage of this exercise is the design of the structural member. Although this is a very important exercise in analyzing structural behavior, most often it does not go beyond a quantitative exercise, does not foster an intuitive understanding of structures and remains detached from any exploration of form. However, this exercise could be significantly improved if the relationship of the structural forces, moment diagram, and deflection mechanism of a structure or structural member were to be explored simultaneously in relationship to form generation.

This teaching tool provides an option to view the loading, deflection mechanism and dynamic behavior of structures under the application of loads. Visualizing the structural deformation at key locations such as mid-spans, connections to other members, and anchorage to the foundation can demonstrate how the form can be a direct derivation of the structural logic.

The paper will present progress in development of this teaching tool through analysis of several structural principles used in the work of Santiago Calatrava and Norman Foster.

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Introduction

The design of architectural form is the product of the investigation of a number of issues, including philosophical and ideological approaches to architecture, social and cultural issues, symbolic intent, construction tectonics, and structural logic. Although all of these issue areas are significant in the design process, structural behavior, or “structural logic of form,” has been used by modern architects to produce entirely new and aesthetically appealing architecture.

This paper introduces a new method to investigate and analyze form in relation to structures using digital media, and more importantly, show that digital media technology can be used to produce an alternative teaching tool that increases students’ understanding of, and interest in, structures. These new tools provide opportunities for students to apply structural principals to their design work, ultimately fostering innovative structural design and more creative expressions of architectural form.

Under a project supported by the U.S. Department of Education *Fund for the Improvement of Postsecondary Education* (FIPSE), State University of New York at Buffalo faculty are developing the *Structures E-Book* — a teaching tool that utilizes a wide range of digital and graphic technologies including detailed and realistic three-dimensional computer generated models and animation to teach basic structural principles. The visual approach used in the development of this tool also provides an intuitive understanding supported by experiencing structural behavior and engaging the students with the consequences of architectural form selection.

Typically, studying the variation of forces and moments in a structural member is a critical component of teaching structures. In most traditional teaching methods, this is achieved through numerical exercises that involve longhand calculations of the internal forces and moments, followed by plotting shear and moment diagrams that indicate the critical stress areas and values. The final stage of this exercise is the design of the structural member. Although this is a very important exercise in analyzing structural behavior, most often it does not go beyond quantitative exercises or foster an intuitive understanding of structures, consequently remaining detached from any exploration of form. However, this exercise could be significantly improved if the relationship of the structural forces, moment diagrams, and deflection mechanisms of a structure or structural member were to be explored simultaneously in relationship to form design.

In addition to providing extensive structures instruction, the Structures E-Book provides functions to view the loading, deflection mechanism and dynamic behavior of a limited number of building structures under the application of loads. Visualizing structural deformation at key locations such as mid-spans, connections to other members, and anchorage to the foundation can demonstrate how form can be a direct derivation from structural logic.

The following examples from the Structures E-Book shows how digital tools facilitate an understanding of how common structural members such as beams, columns, frames and arches can be turned into expressive structural forms through knowledge of their behavior. Using the work of Santiago Calatrava and Norman Foster, the E-Book explores and demonstrates the relationship of structural analysis to the development of innovative architectural form.

Arch profile: Orient Station, Lisbon, Portugal, 1998, Santiago Calatrava

The construction of the Orient Transportation Hub is as a great demonstration of a successful approach to integration of structure and form. Calatrava's use of innovative structural elements coupled with expressive architectural gestures shows how structural principles could be interpreted and used to arrive at form.

The Orient Station includes standard rail services, a tram and metro network and several bus terminals. Calatrava was successful in obtaining the project through his winning entry in an international competition called by the Expo' 98 World organizing body in 1993¹.

Calatrava proposed to place the station platforms on a bridge structure composed of 10 rows of reinforced concrete arches creating a two-level park and ride facility. The design scheme also called for large-scale steel and glass canopies that covered the bus platform located on the ground level. The roof canopies of the bus station were to rise five meters above ground level to cover the elevated entrance gallery of the station. Calatrava's proposal was accepted and construction of the station was completed in 1998.

Figure 1 shows images of a computer-generated model that was prepared to highlight the structural features of the building. All images in figure 1-a are selected frames of an animation that provide a general view of the structure supporting the station platforms. Figure 1-b is a front view of the arch structure. The deep section of the arch on two sides of its central axis suggests that higher stresses are present at those locations and the structure must have more mass and stiffness to resist them. The arch profile tapers off toward the center and the base suggesting lower bending stresses. Figure 1-b also shows the moment diagram for a three-hinged arch transposed on the model. The moment diagram profile and the arch form are closely matched. The location of maximum moment and the deepest concrete section are the same. In addition, the zero moment location at the center of the arch and at the supports corresponds to the smallest cross sectional area of the arch.

The images in Figure 2 relate to the canopy structure covering the bus terminal. They demonstrate how the form of the canopy's support structure is interpreted as a direct reflection of the moment diagram. Figure 2-b shows a simply supported beam with overhangs at both ends. The lower image of the figure illustrates the moment diagram for the beam subjected to uniform loading. The moment diagram is also placed directly on the canopy's steel support. The series of images demonstrate how the tapering form of the steel structure follows the intensity of bending moment as drawn on the moment diagram.

¹ Anthony Tischhauser and Stanislaus Von Moos, *Calatrava-Public Buildings*, Birkhauser, Basel, Switzerland 1998, p.99

Rigid Frame: Lyons Airport Railway Station, France 1994, Santiago Calatrava

The Lyon Railway Station is a landmark building for the City of Lyon. The building structure is composed of two parts; a station hall placed over the train tracks supported by tapering steel beams and roof platforms supported by a concrete structure that covers over 500 meters of railways.²

Figure 3-a and 3-b are images of a computer-generated model showing interior space of the structure supporting the roof platform. Image 3-a has a moment diagram of a rigid frame under lateral loads transposed on the top. Figure 3-b and 3-c show the deflection diagrams of the frame. As evident in the images, the frame has its maximum mass at the corners where the moment is maximum and where the deflection curve changes its direction. The frame tapers towards the connections at the base where the bending moment is zero.

Center, Wiltshire, 1983, Norman Foster and Associates

The Renault Center is a car manufacturing facility. In order to accommodate change and future growth, Foster and Associates selected a square modular building system that could be expanded and assembled in a variety of configurations. The structure of the unit module is a steel frame with four pre-stressed masts located at each corner and tapered arched beams supporting the roof. The masts are composed of circular steel tubing that is tensioned by steel rods. The roof beams are continuous elements, which are supported on the top by the steel masts at quarter points. Each side of the square module is about 80 feet long and the column masts rise to a maximum height of 53 feet³. There are 42 modules constructed in the first stage of construction.⁴

The images in Figure 4-a, 4-b and 4-c show the structural module and the load distribution path to the four columns located on the corners. The corner columns are laterally supported by perforated steel members that connect to the top and bottom of the column with cables. The perforated steel bracing and the cables act together to reduce the buckling length of the column thus allowing the column to extend much higher. Although this lateral bracing system primarily has structural function, it creates expressive elements that create undistinguishable form.

Figure 4-e shows three frames of the animation showing the buckling or deflection of the column without the lateral bracing system and how the addition of the bracing stabilizes the column. Figure 4-f shows other possible profiles and column forms that enhance the column performance.

² Alexander Tzonis, Santiago Calatrava: The poetics of movement, Universe publishing, NY, New York, 1999, p.156

³ Chris Abel, Modern Architecture in the Second Machine Age-The Work of Norman Foster, Architecture and Urbanism, 1988, pp.170

⁴ Foster and Associates, Norman Foster, International Academy of Architecture Varese, Italy,, 1991, p.95

Freestanding Structure: Rennes viaduct, Rennes France, 1992, Norman Foster and Associate.

This project is a design for an elevated inner city viaduct transit system. One of the critical design considerations was to devise a light structural system that imposed minimal intrusion to the fabric of the city. The proposed design was a structure consisting of tall steel pylons that hold up the pre-cast concrete deck units by suspension cables. The deck units are connected to the pylons by rigid connecting elements that act as cantilevered beams extending out from the pylon. The structure extends over 2000 meters.⁵

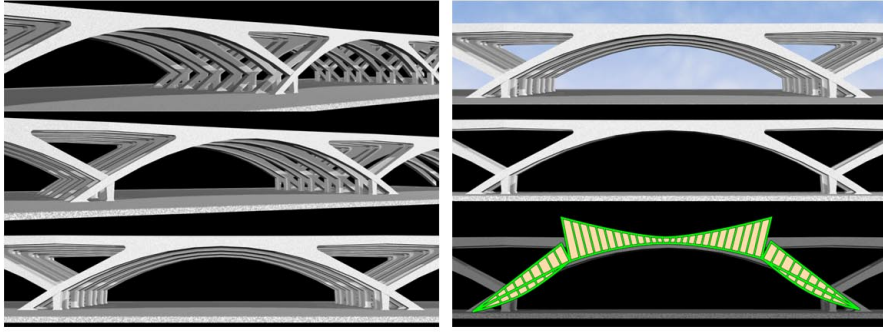
When observing the form of the steel pylons, it is evident they are designed to withstand lateral loads. As the bending moment produced by wind load accumulates toward the base of the pylon, the pylon profile becomes larger to provide adequate stiffness for resisting stresses. The tapered form of the precast deck units are a response to the gravity loads. Larger stiffness is required at the fixed end of the deck to support the weight of the entire deck.

Figure 5 uses three frames of the animated model to demonstrate these concepts. The first frame, figure 5-a shows the overall structure and identifies the various structural members; Figure 5-b superimposes the moment diagram of a pylon for lateral load. The last frame of the animation focuses on the form of the pre-cast deck units. The corresponding moment diagram of the deck is drawn for two cantilever beams thus clarifying the formal relationship.

Closing Remarks

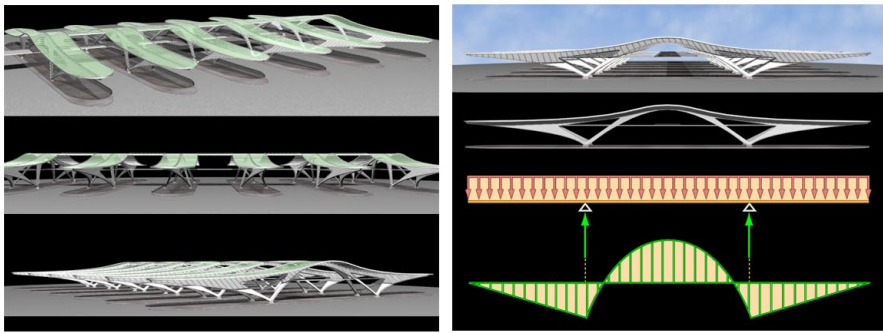
The possibilities for using digital modeling to effectively teach and investigate structural concepts used in architectural design are encouraging. Use of the E-Book so far have shown that the use of digital models and highly visual graphics as an alternative instructional delivery system can better meet the needs and capabilities of architecture students and improve their understanding of the subject matter. While digital technology is by no means a panacea for the difficulties in learning how form and structure can be integral parts of the design process, it can be an effective teaching tool. Further work on the project is aimed at expanding the library of architectural case studies and providing interactive characteristics to the computer-generated models.

⁵ Norman Foster, Architectural Monographs No. 20: Foster Associates Recent Works, Academy Editions, London, 1992,



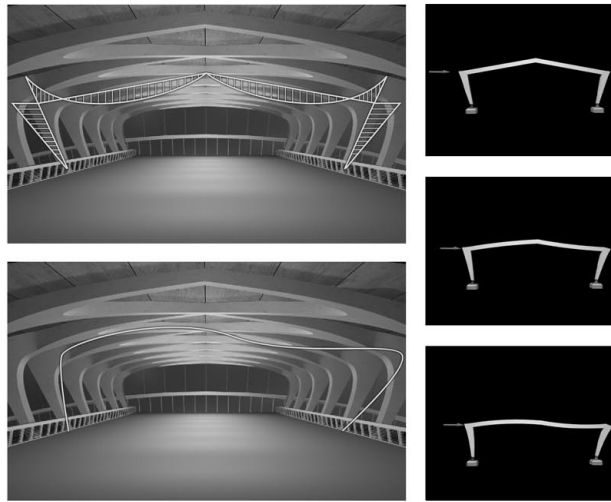
1-a

1-b



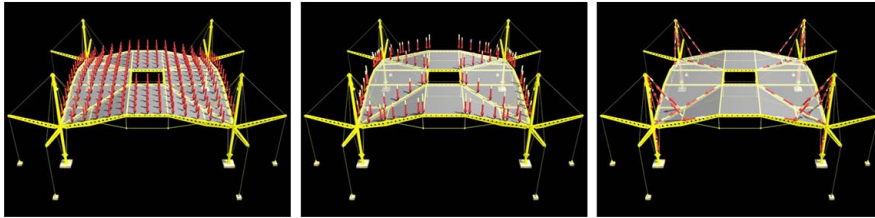
2-a

2-b



3-a & b

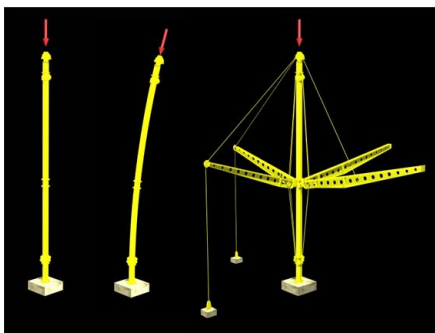
3-c



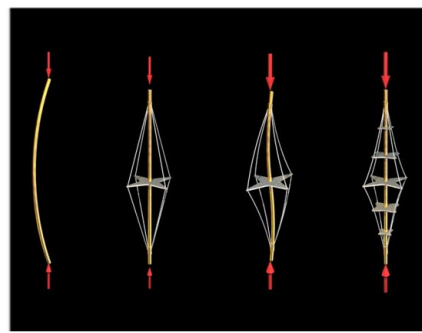
4-a

4-b

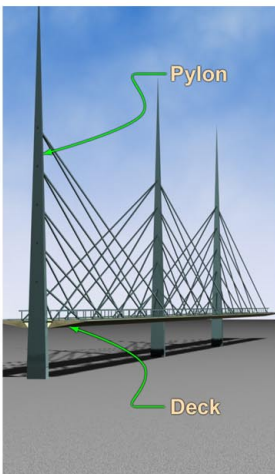
4-c



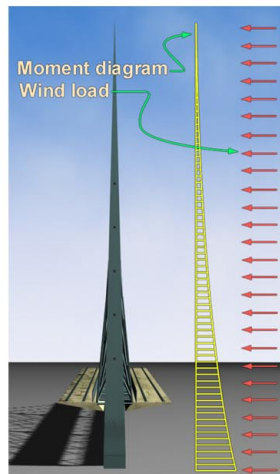
4-e



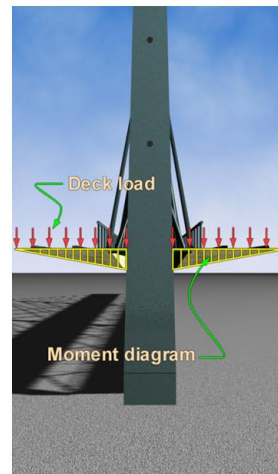
4-f



5-a



5-b



5-c