2012 Hawaii University International Conferences
Education, Math & Engineering Technology
July 31st to August 2nd
Waikiki Beach Marriot Resort & Spa
Honolulu, Hawaii

Hands-On Approach to Cross-Disciplinary Teaching Challenge

Dr. Ivan Markov

Associate Professor,

School of Architecture,

Rensselaer Polytechnic Institute

ABSTRACT

This paper proposes strategies to overcome challenges in cross-disciplinary teaching. It describes the advantages of building and load-testing physical models in structure classes of architectural curricula. The School of Architecture at Rensselaer Polytechnic Institute offers two required structural courses, each with distinct projects and objectives. In Structure 1, students examine the performance of a linear structure in the form of a pedestrian bridge constructed as an assemblage of mass-customized modules. Students are required to resolve the module topology and test the performance of the assembled structure. In Structure 2, students investigate the performance of a volumetric structure—a multistory building with a cantilevered volume. In both projects, architectural creativity is integrated with structural logic, with both aspects being of equal importance in assessing the students' performance.

KEYWORDS

cross-disciplinary pedagogy, structure, architecture, physical models, load-test

INTRODUCTION

Challenges in teaching cross-disciplines are the global in nature, rather than local subject related. The teaching of structure to architects is such example because teachers are not trained to teach in disciplines other than their own specialty. Thus, the teacher must decide whether to accept this restriction or take up the challenge to overcome this limitation. In making this choice, there are several key factors to consider.

First, there exists the risk of not taking full advantage of the discipline of structures if the teacher is not a specialist in this field. I cross-disciplinary experience is highly desirable.

Second, a teacher must have a good sense of reality and feasibility resulting from professional experience on construction sites, full-scale load testing of structures, and to have design practice in buildings and bridges. This experience helps to make teaching relevant to students.

Third, different students learn differently, and they come to architecture with different backgrounds and skills. This context gives rise to challenges in teaching to large compulsory classes. Pedagogy needs to take in account that students in architecture learn better visually and that they need to be aware of analytical validations to justify their intuition, to foster creativity and to avoid repeating existing designs.

To overcome these challenges a careful specific teaching strategy needs to be developed. In teaching structures to architects here three types of modeling investigations are proposed: physical, computer-based, and analytical. Each approach informs the others, thereby fostering intuition.

A structural analyses program can be used to perform analyses and to enable the visualization of deformation, from which the behavior of structures can be understood conceptually. Yet they are not be sufficient and best learning tool for architects.

Hands-On approach and physical modeling is in the hart of design studio culture. The same approach can be used in teaching structures. In this way, students learn by making models, choosing connections and supports, and observing deformation under load; they also experience high levels of excitement at moments of failure, leading to discovery. The students have an extremely high retention rate of knowledge gained through “gaming” and competitions from load-testing models. Moreover, the models require the integration of the language of expression with structural performance.

HANDS-ON APPRACH

In the current era of an enormously large number of digital design tools, physical modeling remains indispensable in testing not only spatial organization but also structural concepts. This paper shows the benefits of HANDS-ON approach and strategies involved in building integrated physical models and subjecting them to load tests.

Advances in digital technology have provided additional tools for the exploration of architectural designs and the means with which to challenge existing practice, leading to the emerging tectonics of buildings expressed by articulation of details, materials, structural systems, and production technologies.

New tools, based on parametric modeling, allow architects and engineers to investigate the design of forms, spaces, and context of previously unseen complexity. The latest developments in rapid prototyping and Computer Numerical Control (CNC) techniques offer new means of studying the tectonics and spatial qualities of structures with a complex geometry, yet these “new” geometries, if they are ever to be realized, must respect the constraints of structural and constructional realities.

Digital designs have their own limitations because they remain two-dimensional. Therefore, physical models remain indispensable in testing architecture and understanding structural concepts; indeed, architecture can be perceived by simply observing such models. Structural concepts are best visualized by subjecting physical models to load tests.

There are many superficial ways to test physical models by pushing or pulling, thereby yielding information on structural performance; however, this approach can be grossly misleading. The adoption of a more rigorous scientific testing method would yield more reliable information. A suitable approach in this regard is to test models in a load-testing frame and to monitor the load–deformation curve. In this way, students can learn a great amount about model performance. Information on factors such as stiffness, linear vs. nonlinear behavior, excessive deformation, failure sequence, and weak links is essential to understanding and improving the structural performance of the architectural intent.

Another advantage of using a load-testing frame is that the experiments are performed in a controlled environment, making it possible to control the speed and to stop the test at any point to assess the model performance. By physically touching various members in the model, students can assess which members are taking the loads first. Any cracks or redistribution of the load in the model will affect the load–deformation curve and could be easily noticed. We can also evaluate the load level the model stays in the desirable linear domain and the corresponding amount of energy needed represented by the area under the load–deformation curve. The slope of the curve indicates the stiffness of the model: the steeper the slope, the greater the stiffness. The curve also reveals the manner in which the model begins to fail. Brittle modes of failure are not desirable, given the absence of warning signs prior to failure.

In such a set-up, students can analyze the load–deformation curve, which enables them to study the behavior of the model and seek improvements to the structural system. They also view a real-time video of the model test on one monitor and the development of the load–deformation curve on another monitor. The major benefit of this approach is that students are fully engaged in the whole process and highly motivated to improve the design. The learning occurs by a combination of applying basic principles, visual observations, and trial-and-error. Evidence of learning is apparent in the design studios, where students commonly develop their designs using principles with which they became familiar during load testing of their models.

The School of Architecture at Rensselaer Polytechnic Institute offers two required structural courses, each with distinct projects and objectives. In Structure 1, a pedestrian bridge is designed using mass-customized modules. The students are required to first resolve the module topology and then test the modules when assembled in the structure as a whole. In Structure 2, the students design a multistory building with a cantilevered volume, and propose an efficient structure to support the volume. For both projects, architectural creativity and structural logic are assigned equal value in assessing the students' performance. The courses typically attract 50–70 students, who work in groups of 3–5.

PEDESTRIAN CROSSING

The first challenge is in the Structure 1 class, where the students design, analyze, construct, and test an urban pedestrian crossing. The urban setting means that tectonics and visual expression pose an additional challenge. The structure of the bridge is designed using repetitive components (modules). A module is defined as a unique topology that repeats itself with the same size or with variations in its size. The students are required to use 6, 12, 24, or 48 modules in the design.

The span of the bridge between supports is scaled to 18 in and the total length of the deck is no more than 22 in. The maximum height between the lowest and highest points on the bridge is 12 in. The lowest point of the bridge must be at least 5 in above the ground plate. The students are required to design their own supports, attached to the foundation plate. The width of the bridge is required to be between 3 and 5 in and the bridge must have a walking deck, which in plan view has an offset at the mid-span that is equal to the width of the bridge at that point. Thus, the bridge structure must respond to twisting forces. Models must have a detachable foundation to enable the bridge to be weighed without the foundation.

The bridge is required to have a site, well-defined architectural articulation, an interesting and iconic form, and a creative structure to support it. Each group of students is required to study at least one precedent case and to build two study models. Group constraints for the number of modules used to build a bridge are as follows: (i) 6 modules, (ii) 12 modules, (iii) 24 modules and (iv) 48 modules.

The bridge can be constructed from any material or combination of materials. Any structural system or “no system” is allowed.

It is left to the groups to find the best way to test the modules and acquire information for the final design. Consequently, it is not enough to simply develop a structurally sound module: it is necessary to understand how it will perform when assembled as part of the overall structure. Based on the information collected during testing of the study modules, the student groups consider their final designs. The final physical model is tested by compressive force from above or tensional force from below. This option in the testing procedure is important because it allows the designs to take advantage of a potentially integral and structural roof. The load–deformation curve is monitored in real time during the tests. Failure is defined as deformation greater than 1.0 or any load causing high nonlinearity.

On the day of testing, groups present their projects on 4 x 3 ft panels in 5-minute slots, being required to outline their architectural and structural concepts, and predict the ultimate load borne by the bridge and the likely location of failure. A short discussion follows the load tests as shown in Figure 1.

Figure 1: Students’ presentations of the projects followed by actual real load testing experiment.

Student performance is assessed based on structural logic, efficiency, and creativity of the design. Efficiency is estimated as the ratio of failure load to model weight, and contributes partially to the final grade. As mentioned above, the foundation is not part of the model weight. Thus, the students are required to produce the details of the foundation connection. The creativity component of the assessment is related to the degree to which the design is visually pleasing, spatially attractive, and structurally innovative.

The figures that follow here show different design solutions proposed by student groups. Figure 2 shows an interesting consideration for the pedestrian bridge based on 48 modules. A space frame truss is introduced to resist loads. In the process of design students used computer simulations to calculate the magnitude and the nature of the internal force in the members. Figure 2 shows the magnitude of the force by different colors and actual model during the load-test. The deck itself transfers the force to the truss joints. This particular solution did performed reasonable well since additional it takes advantage of the arching form of the truss.

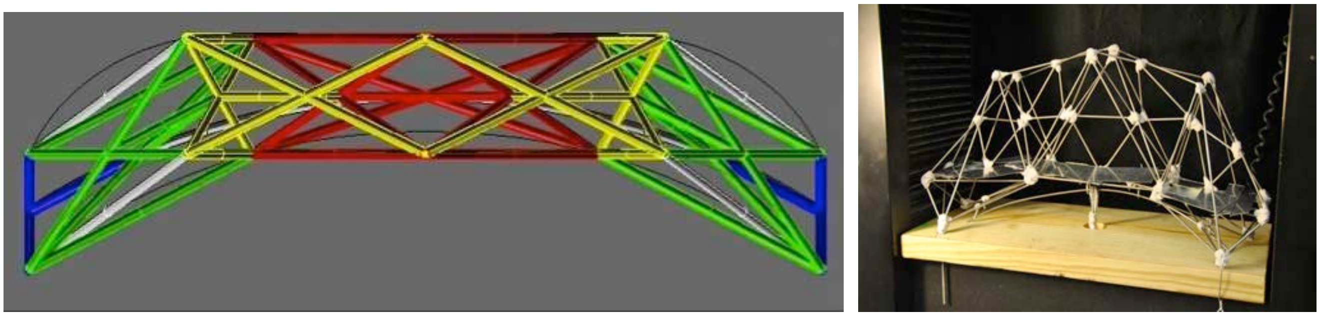

Figure 2: Computer simulation of distribution of internal forces and the actual load-test of the model

Figure 3 shows amazing creativity of students in responding to challenge. Assemblage of perforated polyhedral modules in Figure 3a created a feasible bridge because it enabled a strong connection between the modules. A bowed vierendeel truss show in Figure 3b is another example of innovative approach. Use of transparent material for architectural expression and for double cantilever structure in Figure 3c shaped to resist the moments demonstrates students' full understanding of the system.

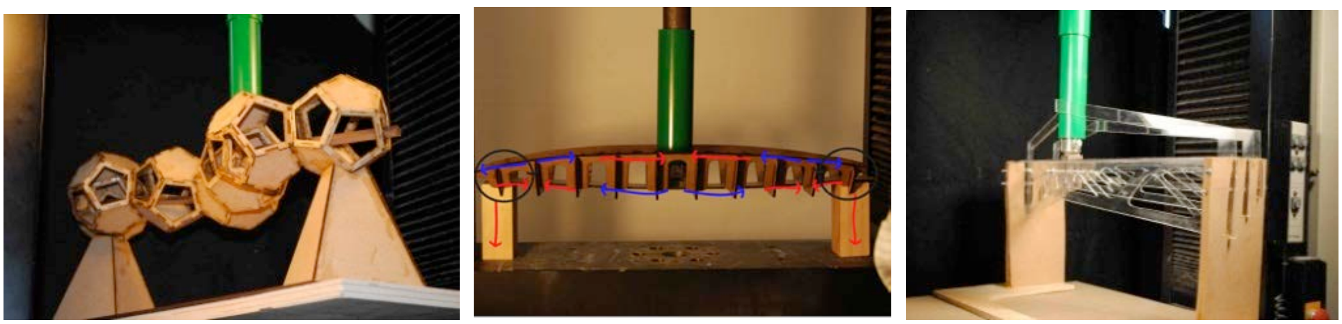

Figure 3: (a) Poluhedarl modules, (b) Bowed vierendeel and (c) Doble cantilevererd sytem

Figure 4 illustrates in depth understanding of structure and distribution of internal forces. The design solution is inspired by Ferris Wheel system. The cables are fanned from the middle of the bridge where the point load is applied to distribute the forces to the arch, which in turn brings them back to foundation. Additional refinement is in using arched deck to reduce bending force to compression force. Connections were smartly design to carry forces by shearing action which contributed to exceptionally well design and strong load resisting bridge.

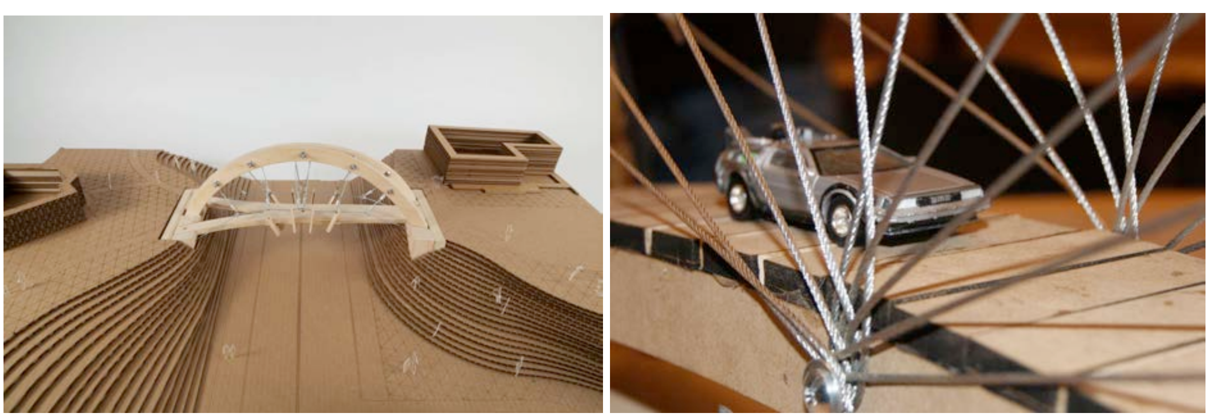

Figure 4: Ferris wheel concept for the pedestrian bridge

The exercise calls for more than just design of structurally sound model of the bridge. The issue of the site and how bridge will be functionally embedded and visually addressing the site had to be considered as well. Figure 5 shows a model addressing those issues and the performance of the model during the load-test.

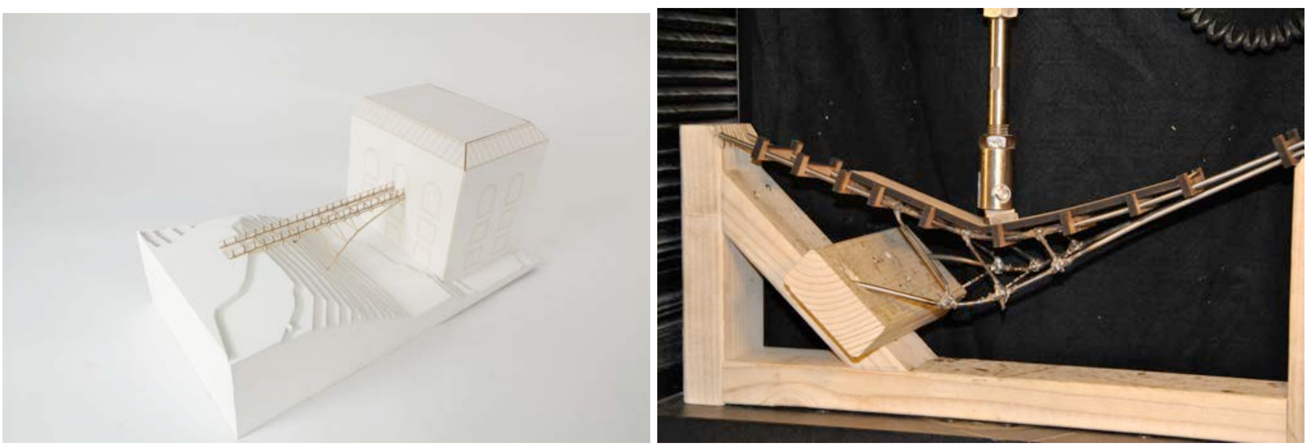

Figure 5: Site model and load-test of the pedestrian bridge

OVERHANGED SPACE

More advanced challenge is in the Structure 2 class where is required a greater integration of architecture and force transfer system. Students are asked to design, analyze, construct, and test a model of a building. Each floor plan is required to have 100 in^2. The footprint is of a free form. One third of the second floor plate, to which the point load is applied, should not have any support and is to act as a cantilever. This restriction does not apply to the overlying floor plates. The floor-to-roof height is 1.5 in.

The number of building floors and the cross-sectional area of the first-floor columns varies among the groups as follows: (a) one story + 1 in^2 area, (b) two stories + 1.5 in^2 area, and (c) three stories + 2 in^2 area.

These restrictions are aligned with the need for a larger support area and greater structural depth in the case of multistory buildings. The final physical model is tested either by compressive force from above or pulling by tension force from below, using the load-testing frame. The remainder of the project is similar to that for the pedestrian bridge.

Figure 6 shows a proposed design for a zoo-aquarium. The program is well defined and organized. Structurally it is an ingenious concept of using rigid floor plates and transparent cylindrical hollow columns. In this case, the students took full advantage of the restriction regarding the sectional area of columns. With a minimum amount of material, they were able to maximize the resting force. Cables were introduced to transfer force back to the floor plates but not to the ground, resulting in undesirable large rotation of all floor plates.

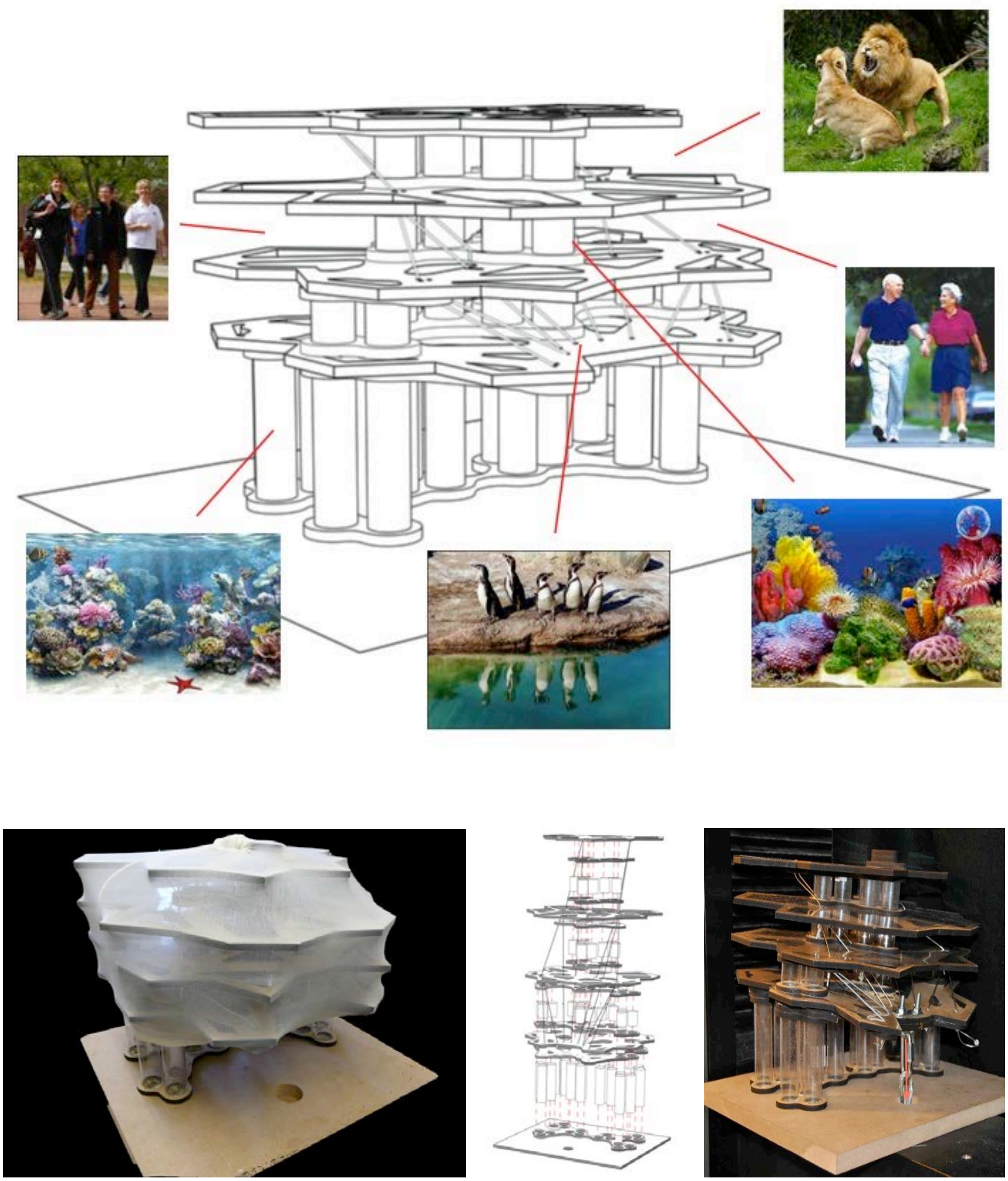

Figure 6: Architectural and structural design concept of a zoo-aquarium

Figure 7 shows a model of a three-story building designed by one of the student groups. The design idea was comprehend from boat concept. Cables are used to distribute the tension force to each of the floors connect three platforms. The figure also shows the load-testing and corresponding load deformation curve. The overall form and shape of the structure correctly follows the force flow. The solution is extraordinary integration of architecture and structure

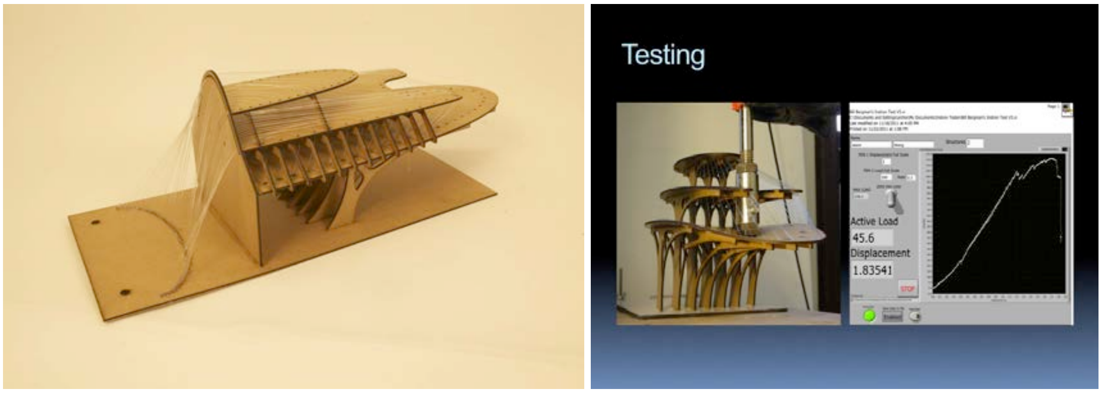

Figure 7: Boat concept applied to building form and model test with coresponding load-deformation curv

Figure 8 shows a several model that demonstrate enthusiasm, involvement, motivation, innovation and creativity of students participating in these projects.

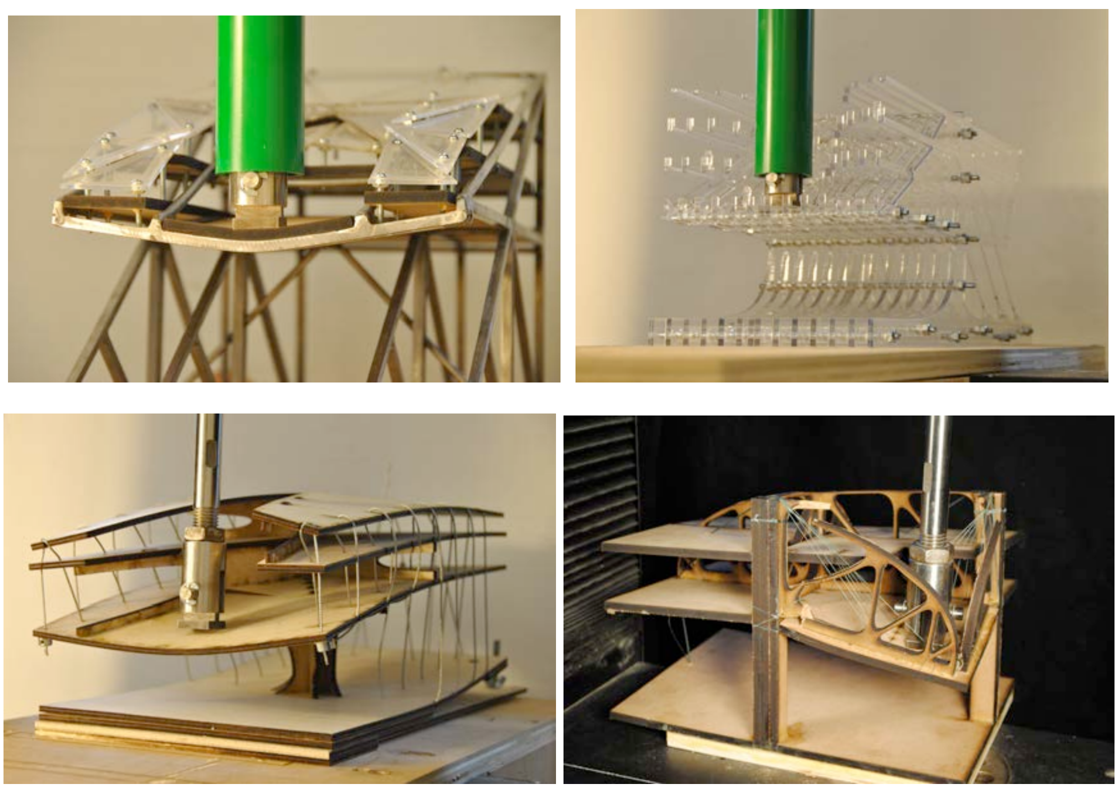

Figure 8: Various solutions for the over hanged structural model

SUMMARY

Creativity at the School of Architecture at Rensselaer Polytechnic Institute have always been encouraged to go beyond conventional solutions in both architectural and structural designs. Although digital design is clearly gaining momentum, its impact on the promotion of structural creativity remains unclear. Developing and refining the formulation of a problem and ideas for a solution, involving iterations of analysis, synthesis, and evaluation, lead to successful designs. Physical modeling remains an indispensable tool in testing integrated structural and architectural ideas. Learning gains are maximized in the case of load testing in a controlled manner. Students are enthusiastic about load testing of their physical models, and the exercises described in this paper generate large amounts of positive energy. Knowledge of the basic principles is then carried through to the design studio. Use of hands-on approach to resolve the cross-disciplinary teaching challenges is one of the solutions.

REFERENCES

Markov, I., “Structural Harmony in Cultural Discourse”, Proceedings, Building Technology Educators Symposium, Maryland, August 2006.

Markov, I., “Performance Test of Structural Architecture”, Proceedings, Building Technology Educators Symposium, Convergence and Confluence, Toronto, August 2011.