122nd ASEE Annual Conference & Exposition
June 14 - 17, 2015
Seattle, WA
Making Value for Society
Paper ID #11661

Structural Engineering Integration into Architecture Studios

Mr. James B Guthrie P.E., California Polytechnic State University

Structural Engineering Integration into Architecture Studios

Introduction

It is important that Architecture students graduate with a strong foundation in structural engineering. The College of Architecture and Environmental Design at California Polytechnic State University, San Luis Obispo (Cal Poly) has addressed this potential gap through extensive interaction between the Architectural Engineering (ARCE) and the Architecture (ARCH) Departments, two of five departments located within the college. The ARCE Department has traditionally taught a sequence of five structural courses to ARCH students with the goal of giving them structural engineering skills so that in their careers as project leaders they will better understand structural engineering systems and principles. With this ability they can better produce efficient integrated designs, collaborate effectively with their structural engineering consultants and lead more successful projects.

Although the five course structural sequence has been comprehensive and has given the Architecture students the skills needed to develop and design structural systems, some Architecture faculty observed that these lessons were not consistently integrated into the Architecture Department's design studios. It appeared that the building structure was a separate and isolated topic receiving inconsistent emphasis in the architectural studios. As part of a larger reconfiguration of the five course structural engineering sequence, a culminating structural engineering course was created that would directly provide this structural integration.

This new course, ARCE 316 *Structural Integration in Architecture*, has some traditional structural content. However the unique aspect of this course is the integration of ARCE faculty into Architecture studios. Each ARCE section is associated with two Architecture studio projects (typically a total of 35 to 40 students) and the ARCE faculty works with each Architecture student to develop structural systems for his or her studio project. The Architecture studios occur over two quarters and ARCE 316 occurs in the second quarter. During this second quarter, the structural systems are developed over the course of three project assignments. The gravity load system is developed first, followed by the lateral load resisting system. The third project assignment is the development of cladding system framing and connections that are coordinated with the building structure. The development of these structural systems can require significant ARCE faculty involvement and significant student time, especially if the building structure was not anticipated in the early architectural design. However the results were well worth the effort. An end-of-quarter student survey revealed very favorable results with the vast majority of students saying they thought "(their) architectural concept was improved by the integration of structure".

This paper presents the background of the course, its learning outcomes, content, teaching approaches and project examples. It describes how structural engineering was successfully integrated into the Architecture studios and lessons learned.

ARCE Sequence Background

The curriculum for the ARCH students at Cal Poly have, for many years, included a five course sequence of structural engineering courses taught by the ARCE department. This sequence of courses have also been taken by Construction Management (CM) students and so the content of the full sequence was developed to address both groups of students.

The benefits to ARCH students of understanding structural engineering principles are clear. Architects typically take a lead role in building design and so an understanding of structural principles can enhance their ability to produce design concepts that are coordinated with an efficient, well thought-out structural system. Understanding structural concepts and nomenclature allows the architect to more effectively communicate with their structural consultants and better develop the structural system. In addition, the architect, as team leader, often has the direct communication with the client or owner and a better understanding of structural principles allows them to better communicate structural principles and the implications of structural decisions to the owner. The decisions of an informed owner are more likely to result in a successful project. An understanding of structural engineering principles acquired as an architecture student can therefore be of great benefit in his or her career.

This course sequence has been recently reconfigured, in response to requests by the ARCH and CM Departments whose students they serve. The reconfiguration was in response to two specific requests. The CM Department needed to eliminate one course from the five-course sequence required of their students in response to a directive to reduce overall program units. The ARCH Department requested an explicit integration of structural engineering content into their upper division third year studios. The solution, which served both departments, was composed of two actions. One was to consolidate the content of the final two courses into a single abbreviated course entitled *Introduction to Structural Design*. This course is being taken by both ARCH and CM students. This created the opportunity to create a course integrated into the third year architecture studios and taken solely by ARCH students. This course, ARCE 316, is entitled *Structural Integration in Architecture*.

The new sequence for ARCH students is composed of five one-quarter courses. The titles and number of units and hours each week are listed below:

- *Structures I*, ARCE 211 - 3 units with 2 hours of lecture and 2 hours of activities per week
- *Structures II*, ARCE 212 - 3 units with 3 hours of lecture per week
- *Introduction to Structural Systems*, ARCE 226 - 3 units with 3 hours of lecture per week
- *Introduction to Structural Design*, ARCE 315 - 4 units with 4 hours of lecture per week
- *Structural Integration in Architecture*, ARCE 316 - 4 units with 4 hours of lecture per week

The first two courses, *Structures I* and *Structures II*, are rigorous courses that introduce statics and mechanics of materials. These two classes combine traditional lectures with activity sessions in which students build physical models to enhance their understanding of the content. *Structures I* is an introduction to statics and the creation of simple three-dimensional structures. Skills to analyze structures composed of axial force members are developed. *Structures II* is an introduction to shear and moment diagrams using the principles of statics and the application of the diagrams to simple three-dimensional structures. Skills to analyze structures composed of bending (beams) members, particularly, are developed.

Following *Structures I* and *Structures II*, are two courses entitled *Introduction to Structural Systems* and *Introduction to Structural Design*. In *Introduction to Structural Systems* the focus shifts from structural elements to building structural systems. Building on the skills learned in *Structures I* and *Structures II*, students develop the skills to analyze simple buildings composed of axial and bending members. They learn about structural stability, gravity and lateral loads, the development of framing plans, the behavior and comparison of structural building systems, framing schemes and building configuration related to vertical and lateral loads. *Introduction to Structural Design* introduces material specific content for timber, structural steel and reinforced concrete structures. Students learn the characteristics, advantages and disadvantages of different structural systems, how to evaluate different systems and how to develop the preliminary structural designs of buildings. Design projects are used to supplement and reinforce the lecture material. ARCE 316, *Structural Integration in Architecture*, is the culminating course and the subject of this paper.

Integration of structural engineering courses with architecture studios and the use of projects to supplement traditional structural engineering lectures is discussed in several papers.

Dermody, in a paper entitled *Get the Form Right*[1] describes and recommends the use of projects, such as pedestrian bridges and ice rinks, to explore structural solutions. He also recommends a studio setting as effective with this approach.

Bringing Engineering into the Studio: Design Assignments for Teaching to Architects, by MacNamara[2], reports supplementing traditional structural engineering lectures, in a structural engineering course for architects, with project assignments. In her case, project assignments used timber, reinforced concrete and structural steel and were assigned to students after completion of lectures on those materials. The goal was to move beyond the design of structural elements to the development of structural systems. The author reported positive results with students saying that the design projects better prepared them for exams and, more importantly, assisted them with their architectural studios.

The Structures – Design Studio Link, by Becker[3], describes bringing studio projects into her structural engineering course by requiring that student assignments be based on each student's studio projects. The benefits were described as introducing a “sense of reality” to their studio projects, providing students the tools to implement their designs and giving them greater confidence. The author also reported a significantly greater time commitment for the course because of the time required for individual consultation and stated that the approach was not suited to a large lecture format.

ARCE 316, *Structural Integration in Architecture,* is most like the last example and took a similar approach. It had similar gratifying and successful aspects. It also required a large time commitment.

Architecture Curriculum Reconfiguration

The integration of ARCE 316 into the third year architecture studios was part of a larger reconfiguration of the third year Architecture curriculum by the Architecture Department. A total of five courses make up their coordinated two-quarter long (Winter and Spring) studio sequence. The sequence includes two quarters of design studios, an environmental control systems course, an architectural practice course and ARCE 316. The explicit inclusion of the ARCE course within this coordinated architectural course sequence underlines the serious intent to integrate structural content into the third year studios. The integration occurs in the second (Spring) quarter design studio. The third year studio projects were previously one quarter long design efforts intended to develop an architectural design. The expansion to a two-quarter long effort was to facilitate further development of the architectural design and the integration of the major building systems such as structure, MEP and cladding. This reconfiguration was initiated in Academic Year 2013/14 and ARCE 316 was taught for the first time in Spring quarter 2014.

ARCE 316 Course Development

The learning outcomes, logistics and teaching approach of ARCE 316, *Structural Integration in Architecture*, were developed in coordination with the architectural reconfiguration and in consultation with the ARCH Department and the ARCE Curriculum Committee and faculty.

Two primary goals were identified in the development of the learning outcomes and content. One goal was to lead the ARCH students in the successful development of a conceptual structural system integrated into their third year studio projects. This was seen as both an opportunity to practice the structural engineering skills acquired in this and earlier courses and to address the previously expressed concern of some Architecture faculty that the structural engineering lessons were not consistently integrated into the ARCH Department's design studios. The second goal was to include structural content that was not able to be included with the predecessor course, *Introduction to Structural Design*. This content included tall building, long span and cantilever systems, foundations and the structural aspects in the design and detailing of cladding.

The catalog description and learning outcomes presented below reflect these two goals.

ARCE 316 – Structural Integration in Architecture

Catalog Description: Integration of structural systems into architectural design. Preliminary design of structures including the development of gravity load carrying systems and lateral load resisting systems. Introduction to tall building and long span structural systems. Introduction to cladding systems. Taken concurrently with third year architectural studios.

Learning Outcomes: Upon completion of this course, students should have the ability to:

1. Create preliminary vertical and lateral structural systems that are integrated with a comprehensive architectural design.
    a. Develop structural framing configurations based on conventional systems.
    b. Develop preliminary designs, integrated with studio

projects, for vertical and lateral load resisting systems including preliminary sizes for slabs, beams, columns, walls and braces.
   c. Develop structural concepts for long span and cantilever structures.
   d. Develop structural concepts, integrated with studio projects, for cladding jointing, framing and connections and describe structural issues associated with cladding systems.
2. Describe advantages and disadvantages of common structural systems relative to performance, cost and function.
3. Describe deep and shallow foundation systems and temporary and permanent retaining systems.
4. Describe structural systems associated with tall buildings.

Either of these two goals could have occupied an entire quarter and much discussion was had about how to achieve an appropriate balance between the two.

Based on the learning outcomes above, a course outline was developed and hours assigned to each topic. Forty percent of the 40 hours of class time were explicitly assigned to the integration of structural systems into the studio projects. These hours included individual review and consultation between the ARCE instructor and students and special topics related to the studio projects. The inclusion of this magnitude of time was a departure from the traditional lecture and activity teaching approach but was believed to be necessary for the success of the course goal. The remaining sixty percent of class time was assigned to general structural engineering topics: load flow, framing design, tall building, long span and cantilever systems, foundations and cladding. These topics assisted the ARCH students with their projects as well as providing general structural engineering information.

Logistics & Teaching Approach

Logistics and teaching approaches were developed to implement these dual goals of integration of structure into studio projects and instruction in general structural engineering topics. The approach for general engineering topics was traditional with structural engineering lectures and homework and exams for reinforcement and assessment. The first goal, integration of structure into studio projects, however had never been implemented before and required different logistical and teaching approaches.

ARCE 316, in its earlier configuration, typically had student populations of 35. To retain that efficiency, each section of the reconfigured ARCE 316, *Structural Integration in Architecture*, was associated with two twenty student architecture studios. Architecture students were assigned in blocks based on their studio section. This was a departure from the normal the practice of allowing ARCH students to select their own ARCE section, but it had several advantages. The first was that projects assigned in each studio are typically based on similar programs or assignments. In Spring quarter 2014, for example, one studio's projects were 40-story buildings and another studio's projects were high speed rail stations. Special topic lectures were able to be developed that focused on specific structural engineering issues associated with each studio's projects. Also, with two studios in each ARCE section, it was easier to coordinate the ARCE 316 schedules with the studio milestones and travel schedules. And last but not least, the students in each studio entered the class with relationships that made for a more cohesive class.

The teaching approach for integration of structural systems into each student's studio project, occurred in several ways: individual faculty consultation, special topic lectures and project assignments.

Structural systems for the studio were developed incrementally with three project assignments. The three project assignments were the development of 1) the gravity load carrying system (floor and roof framing), 2) the lateral load (wind and earthquake) resisting system and 3) the framing and connections required to support cladding. Assignment deliverables were typically composed of narratives, drawings and structural calculations. The narratives discussed system characteristics and decision making and described alternate systems and configurations considered and the basis for the selection of the proposed structural approach. The drawings were preliminary structural framing plans, three-dimensional images of the structure and wall sections. The structural calculations were intentionally limited with the intent of providing depths of framing and numbers of braces or shear walls. The purpose of the calculations was to provide a basis for the development of a conceptual structural system for the studio project and detailed structural calculations were not required. The assignments were typically individual reflecting the nature of the studio projects.

Special topic lectures were provided as appropriate to suit the studio projects. They included long span rail systems and tall building systems.

Formal structural consultation by the instructor occurred at several times during the quarter. An initial consultation was held at the beginning of the quarter to allow the instructor to understand each project and provide guidance as to potential structural approaches. A two-hour class period was devoted to the students in each architecture studio. These review sessions were held in the studios. This was done for convenience because the designs were often represented as physical models as well as drawing and electronic form. Two more sessions were held to review drafts of the first two project assignments. These were pin-ups on the ARCE 316 classroom walls. Guidance was provided by the instructor and student comments were solicited. Although the time allocated to project reviews was a significant portion of the total class time, providing enough guidance was a challenge. With 25 to 30 projects in each section, reviewing all projects in one class period meant only approximately 5 minutes per project. Additional guidance was provided during office hours and as written comments on assignments. Still, many of the projects were complex and did not start the quarter with a clear structural approach. The time allocated in class for these types of projects did not always seem adequate.

Studio Projects

Although the studio projects varied by considerably by size and type the approach taken to develop structural systems was similar and proved to be successful. Structural system material and type were first selected based on design requirements such as function, shape, spans and appearance as well as cost and environmental issues. Structural system layouts were then developed based on material appropriate spans and spacings, alignment, continuity and balance.

The goal was for the students to develop a structural system that were regular and efficient and were also consistent with the original architectural design intent.

The author taught two sections of ARCE 316 in Spring Quarter 2014. The two sections encompassed four architectural studios. The ARCH Department places some guidelines on the nature of the third-year projects, multi-story and of a minimum size. However each of the four studios had very different assignments. The project assignment in one studio was high school in the area. Another was a station for a high speed rail system. A third was a tall (40-story) building located in one of several cities world-wide. The fourth was for an open competition and each of the projects had a different function, scale, location and character. They also varied in the level of structural integration that had occurred before the start of the Spring Quarter. The high school projects had the beginnings of structural grids and the tall building projects had developed vertical cores. This initial structural integration provided a good starting point for the ARCE 316 preliminary structural design. Some projects however were more sculptural and developing a structural system was challenging.

Two projects are presented as examples.

One was a station for a new high speed rail system. The building is four stories high, has a floor area of 75,000 square feet and is located in an area of moderate seismicity. The building includes platforms, waiting areas, offices and retail. Figure 1 shows an architectural model at the beginning of the Spring Quarter. Figure 2 shows a representative floor plan and Figure 3 a structural model prepared at the end of the course. The student selected a structural system material and type and layout appropriate to the project and the area. She then prepared a preliminary structural design that was regular, efficient, met the heavy load and span requirements of the rail station and provided the lateral resistance appropriate to the area's seismicity. It can be seen that although the structural model does not include the canopies, screens and decoration of the original architectural model, it is consistent with the original architectural design intent.

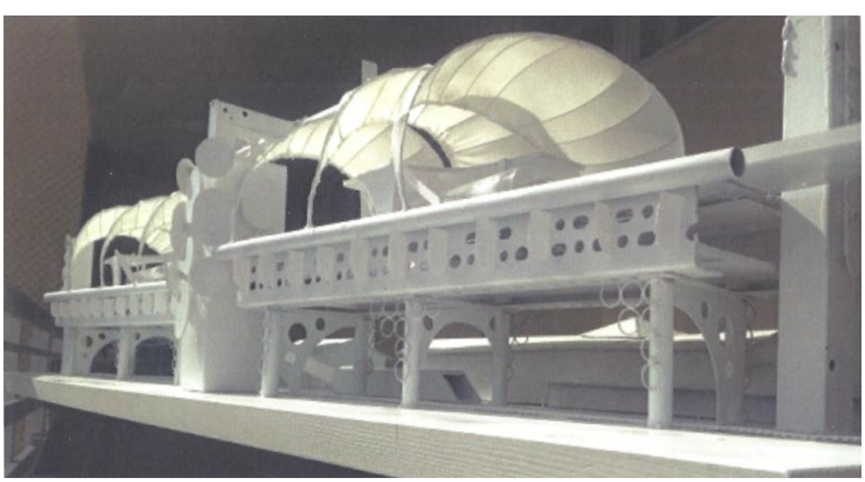

Figure 1. Rail Station Architectural Model

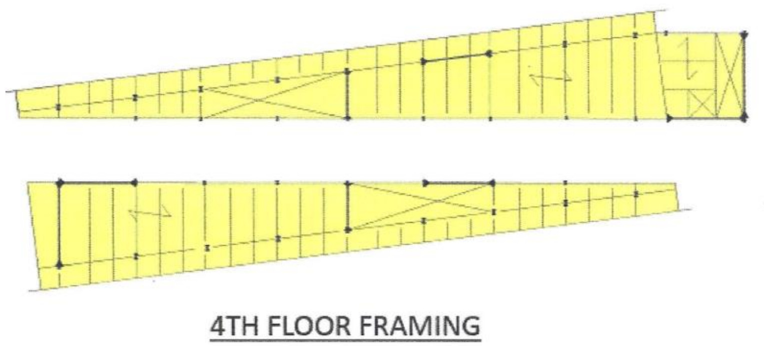

Figure 2. Rail Station Framing Plan

Figure 3. Rail Station Structural Model

The second project is a four-story, 127,000 square foot high school located in an area of high seismicity. The building is composed of four wings, overlapping and at non-orthogonal angles, with long spans for bridges and gymnasiums. Figure 4 show a three-dimensional image of the building and Figure 5 a representative framing plan. The students selected a structural system material and type appropriate to the project, developed the structural layout and prepared a preliminary design of the floor framing and lateral load resisting system. The structure successfully retains the transparency and openness desired in the original design.

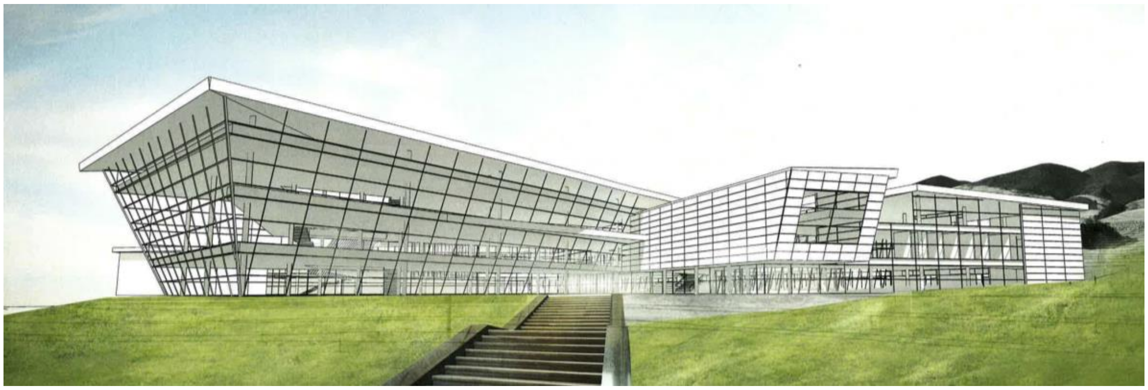

Figure 4. High School Three Dimensional Image

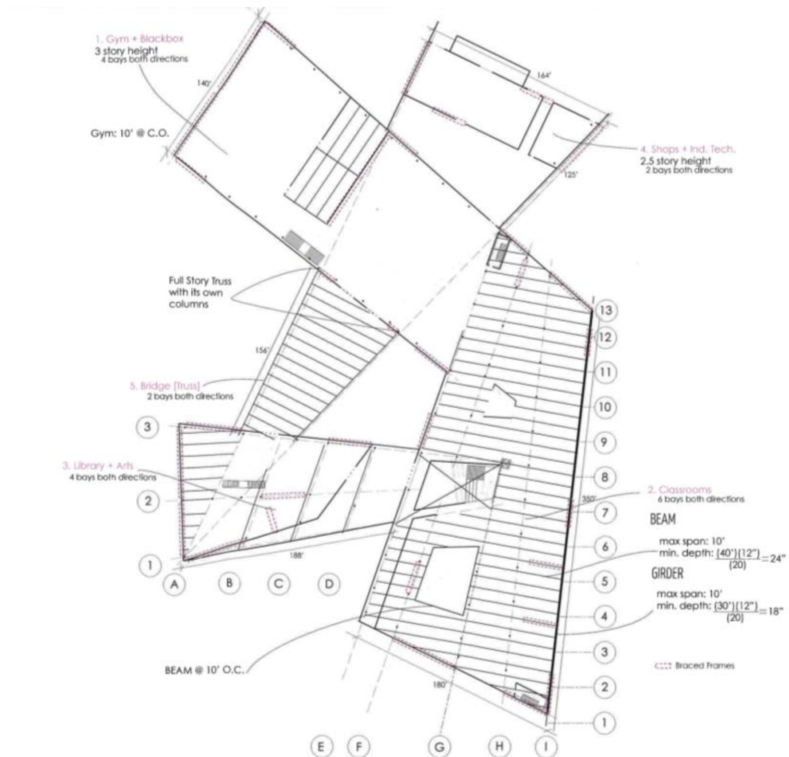

Figure 5. Framing Plan

Student Surveys & Lessons Learned

The course was formally offered for the first time in Spring quarter 2014. It was judged to be successful at several levels although with lessons learned that will result in improvements in the future. Its success was evaluated based the results of projects and exams, discussions with architecture faculty and an end-of-the quarter student survey.

The two projects, described above, are representative and demonstrate that building structures were successfully integrated into the studio projects and thus met one of the primary goals of the course. The student's performance on exams was good and thus met the other course goal.

An end-of-the quarter survey asked several questions of the students. One was whether they would have liked greater or less content in each of nine areas. The results are presented below.

ARCE 316 Student Survey (47 Responses)			
Which of the following content areas would you like to see more of, less of, or about the same?			
Gravity Framing System Types (45):	More 9%	**OK: 71%**	Less: 20%
Gravity Framing Configuration (45):	More 22%	**OK: 58%**	Less: 20%
Gravity Framing Sizing (45):	More 11%	**OK: 69%**	Less: 20%
Lateral System Types (46):	More 30%	**OK: 63%**	Less: 7%
Lateral System Configuration (45):	**More 51%**	OK: 44%	Less: 4%
Lateral System Sizing (44):	**More 50%**	OK: 43%	Less: 7%
Structural Connections (46):	**More 57%**	OK: 37%	Less: 7%
Structural Aspects of Cladding (46):	**More 76%**	OK: 24%	Less: 0%
Foundations (45):	**More 44%**	**OK: 44%**	Less: 11%

For most content areas, the students thought the level appropriate or their opinions were evenly divided. This is fortunate because there is little room to provide more content. The one area that jumps out is cladding and more content will be included in the future. In response to the question "Would you have appreciated more individual consultation on the development of the structure for your studio project?"' 64% said yes. This will be addressed. In response to the question "Was there sufficient coordination between the structural content and schedule of this class and your studio?" 74% said yes. Although this was a positive response, the author believes it could be improved.

Most telling and gratifying were the following two questions. Students were asked "Was it helpful to practice the structural design skills on your studio project?" and the response was 98% positive. Students were asked "Do you think your architectural concept was improved by the integration of structure?" and the response was 87% positive.

Studio faculty discussions, reflected the positive response of the students.

Several modifications are proposed for the future:

- Winter Quarter structural involvement. This was done by the author with one studio and was worthwhile. However it requires significant time of the ARCE faculty as well as coordination between each architecture studio instructor and the ARCE instructor. This involvement was done by the author in two studios in advance of Spring quarter 2015. However because at the present it is a volunteer effort by the ARCE instructor it may not be sustainable.
- Coordination between ARCE 316 and architectural studios and practice courses. Assignments in the two courses sometimes overlapped and could have been better coordinated.
- It would be beneficial to devote more time to individual project consultation. This is easier said than done.
- It would be beneficial to devote more time to cladding. This would also be valuable. Some additional classroom time and coordination with the architecture practice course might help.

Conclusions

ARCE 316, *Structural Integration in Architecture*, was introduced in Spring Quarter 2014. Significant effort was expended in the preparation of the course, including the development of goals, learning outcomes and content, frequent consultation and coordination with the Architecture Department and review by the Architectural Engineering Curriculum Committee and faculty. The effort paid off. Based on reviews of completed assignments and exams, discussions with architectural faculty and an end-of-quarter student survey the course is believed to have been a success and met its goals. There were several lessons learned that will be incorporated into the Spring Quarter 2015 classes however the basic approach to the course is not expected to change. We believe that each student's experience in integrating a building structural system into his or her studio projects has been very beneficial and will serve them well in their future careers.

<u>Bibliography</u>

[1] Dermody, R, "Get The Form Right!", 2010 ASEE Annual Conference and Exposition Proceedings.
[2] Mac Namara, S, "Bringing Engineering into the Studio: Design Assignments for Teaching Structures to Architects", 2012 ASEE Annual Conference and Exposition Proceedings.
[3] Hitchcock, H, "The Structure – Design Studio Link", 2013 ASEE Annual Conference and Exposition Proceedings.