AC 2012-4325: BRINGING ENGINEERING INTO THE STUDIO: DESIGN ASSIGNMENTS FOR TEACHING STRUCTURES TO ARCHITECTS

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Bringing Engineering into the Studio: Design Assignments for Teaching Structures to Architects

1. Introduction

This paper describes an example of design education in architectural structures at Syracuse University. When architecture students choose a structural material for a design it is vital that embedded in that decision is an understanding of the scale of both the structural members and of the spaces that material supports. Understanding the forms required and the experiential quality of space (both in terms of scale and the interaction with non structural interior elements) that follows from structural material choice, allows for more control and precision in the design process. A capacity to size members (even approximately), similarly allows for a richer and more finely detailed representation of design work. In the studio design courses students are rarely held responsible for the finer detail in accuracy and validity of their structural systems, but are critiqued when the structural solution proposed is obviously problematic. In comprehensive design courses more attention is paid to structural systems and at Syracuse University many students request a structural consultation on their comprehensive studio design work. The assignments described in this paper represent an attempt to more directly tie the required structures sequence to the design studio, and to better prepare students to take comprehensive studio. This paper presents the results of the assignment and the student evaluation data for the course as whole and this assignment as part of an overall effort to understand the value of structural engineering in the architectural design process.

2. Background

The teaching of structures is often viewed as marginal in the overall architecture curriculum. A search of JAE archives produces very few articles devoted to the subject. When I survey my students on the first day of the first of the two required structures courses, less than 30% say they would take the structures if it were not required. I have found there is a wide range of preparedness amongst architecture students for mathematical learning. A lack of understanding of fundamental structural ideas can stymie the creativity of architectural design. But an aversion to mathematics does not preclude an understanding of, and an intuition for, how structures work. Plesums argued "knowledge of mathematical methods, however, does not assure a feeling for structural behavior."[1] Severud stated that it is more important for architects to have a sense of the basic fundamentals of how structures work and that the figures can be left to the engineers.[2] I further argue that it is this very intuitive understanding of structural form and its possibilities that newly-trained engineers lack, making it all the more vital that architects can argue persuasively and competently for innovative structural solutions in their design work.

The two required Structures courses for the BArch program at Syracuse University contain the standard NAAB required material, with the first semester focusing on analysis and the second on design calculations. In common with many other BArch programs Syracuse University teaches a comprehensive design studio in the third year. In this studio students are required to exhibit competence in issues of life safety, structures, mechanical systems, alongside the formal and aesthetic considerations of design. Over my first few years of teaching structures I was often invited to critique this work and to consult with students on their choice of structural systems. I became increasingly concerned that the more mathematical course work in the required Structures courses was not adequate to prepare students for comprehensive studio. No matter how many charts the students had seen about how far different systems can span, some students seemed wholly unprepared to even put together a layout of beams and columns, let alone negotiate a more complex layout to support more ambitious design intentions.

The assignments arose out of a concern for teaching the big-picture ideas about form, structural layout, material selection, and system selection in architectural design from the point of view of structures. In the typical structural engineering-style mathematical assignments for structures students most of the above facets of a design have already been determined. A typical exam problem on the first midterm for ARC311 Structures II is to "design" a timber beam. They are given the beam length, beam spacing, dead and live loads, and the elasticity of timber. They are then required to find a standard timber beam size that resists bending and shear, then check that deflection is under some given limit, and that the bearing capacity of the timber has not been exceeded at the connections. There are usually some follow up questions about construction of connections, or what might happen if the beam had to be longer, or where it would be best to put an opening for a pipe or duct. Homeworks and exams like these are very useful for teaching a certain amount of the mathematical subroutines required for a good understanding of structures, and some of the nuances of structural design. What they fail to do however, is to test things like material choice, system choice and structural layout. The assignments described here represent an attempt to address this imbalance and to better prepare students to engage with structural systems in comprehensive studio.

3. The Design Assignments

Over the course of the semester the students undertake three group project assignments in timber, concrete and steel respectively. In ARC311, Timber Design, Concrete Design and Steel Design are covered in that order. After students are finished with the lectures for each material, a project is assigned. For each project they are presented with a volume or series of volumes with a prescribed program (usually one that requires a mix of large and small structural spans). They are also provided with the relevant live load tables, snow load maps, some estimates of dead load, a chart with allowable spans for various systems, and any other background information that they might need. They are also given a list of steps to streamline the process.

The students work in groups of 3-4. They may alter the preliminary volumetric design that is given to them, but they are encouraged to spend minimal time on that aspect of the project. They must adhere to the free span lengths given in the project brief. They are also encouraged to take on one additional design constraint such as a green roof or a glass façade to enliven the design. They must chose an appropriate structural system and propose a framing plan. The project statement requires them to calculate the member size for a small but representative number of the structural elements, typically two shorter spanning elements (beam, slab, folded plate, etc), one longer spanning element, and one column. In addition to plans and sections the students produce representations to scale of the interior space that results. This is a particularly important aspect of the project intended to show the students how structural knowledge can add depth and control to their design representation.

For the timber project students were required to design a single story structure with dorm rooms with 14 ft spans and a higher ceilinged multipurpose room with a 50 ft span. The concrete project was a four-story building with a mix of gallery space with 50 ft spans and library space with 25 ft spans. For the steel project students were offered a choice between a small sports facility (with a large 120ft span over a basketball arena, and other associated program with 20ft and 50 ft spans) OR their studio project. They could submit a structural steel layout for their design, with associated calculations for a long span, two short spans, and a column.

After the projects have been turned in, they are very quickly read in order to identify the typical mistakes or misconceptions. A class wide critique, in the form of a review lecture, follows. This provides an excellent opportunity to teach some of the less mathematical aspects of structural engineering. For example, most students learn the very useful rule of thumb: beam depth = beam length /20. It is easy to remember and miraculously seems to work for all materials. But when the students attempted the timber project the most common solution for the 14 ft long beam in the dorm area was a 6x18! What happened to length/20? Well, it turns out it only works if you space the beams appropriately. Other typical mistakes included: students only showing structure in the direction of the main span, resulting in a series of domino-like frames; spanning the longer distance in a space rather than the shorter; inappropriate connections for frames; systems such as waffle slab or folded plates used without the appropriate edge beam or column configurations; transfer girders on the first floor without the appropriate size of beam to compensate; a Richard Serra Corten steel sculpture on the fourth floor! Many of these things have been covered in lectures in some way, but the students didn't pick up on them out of context. Others are difficult to cover in a lecture without it becoming a random list of things to remember. The critique model is familiar to architecture students and so this is an ideal way to discuss the more intangible aspects of structural engineering.

4. Student Work

Examples of the student work for the design projects are shown in Figures 1-8.

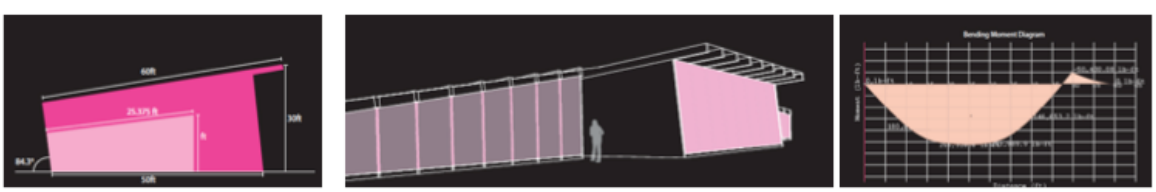

Figure 1: Images and Calculations from a Timber Design Project

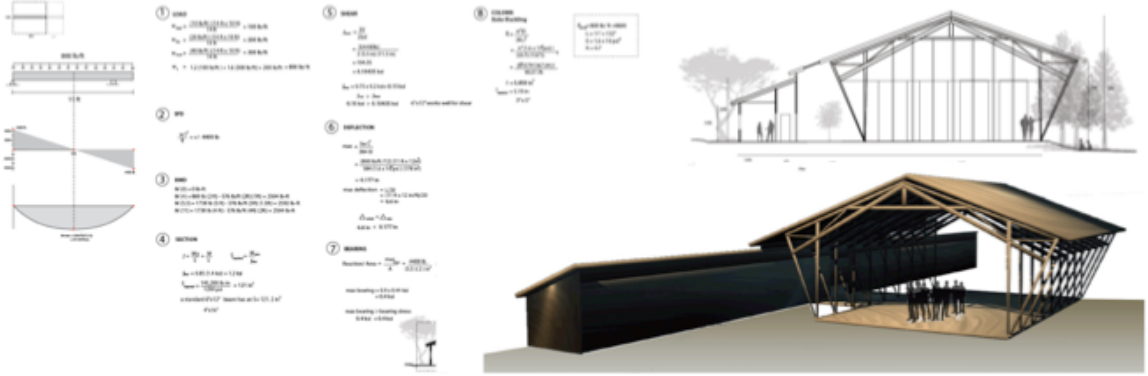

Figure 2: Images and Calculations from a Timber Design Project

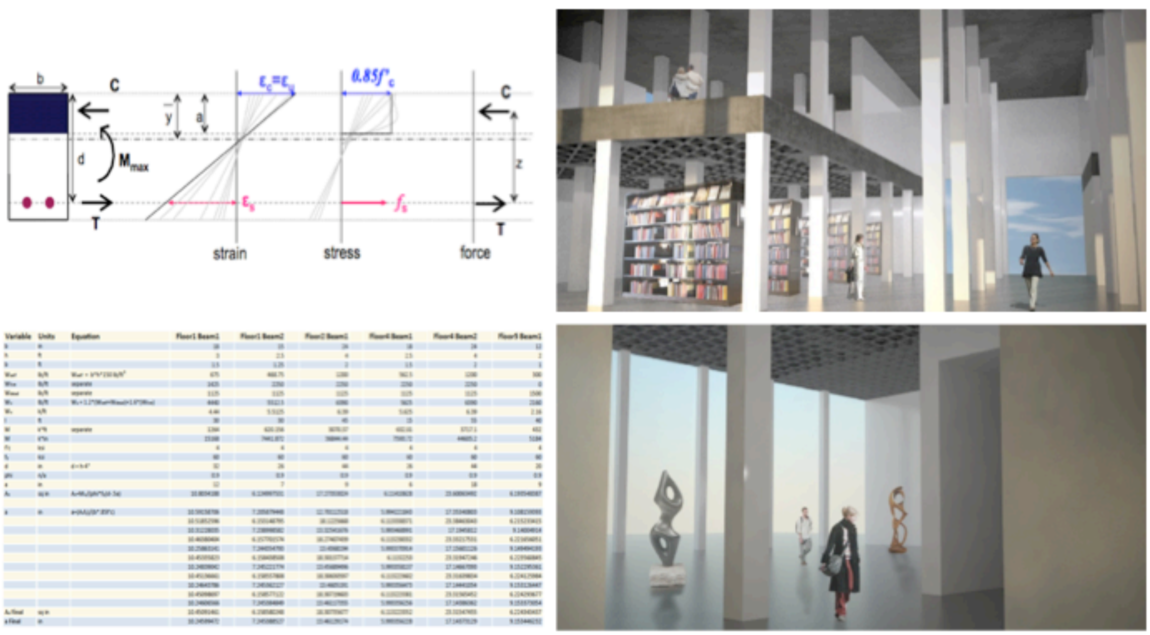

Figure 3: Images and Calculations from a Concrete Design Project

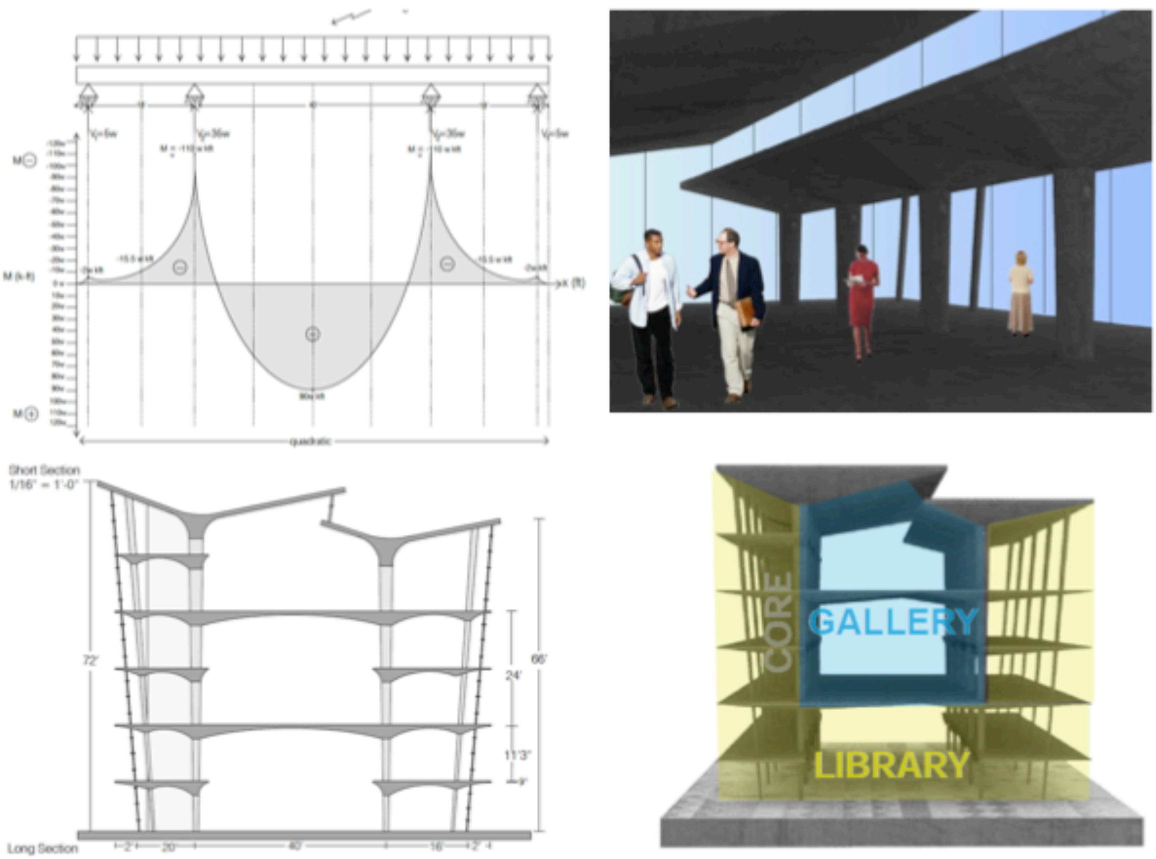

Figure 4: Images and Calculations from a Concrete Design Project

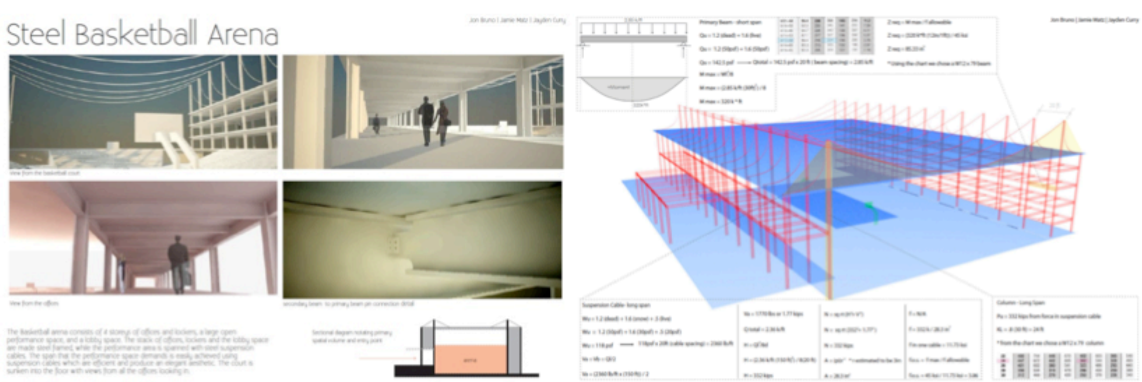

Figure 5: Images and Calculations from a Steel Design Project

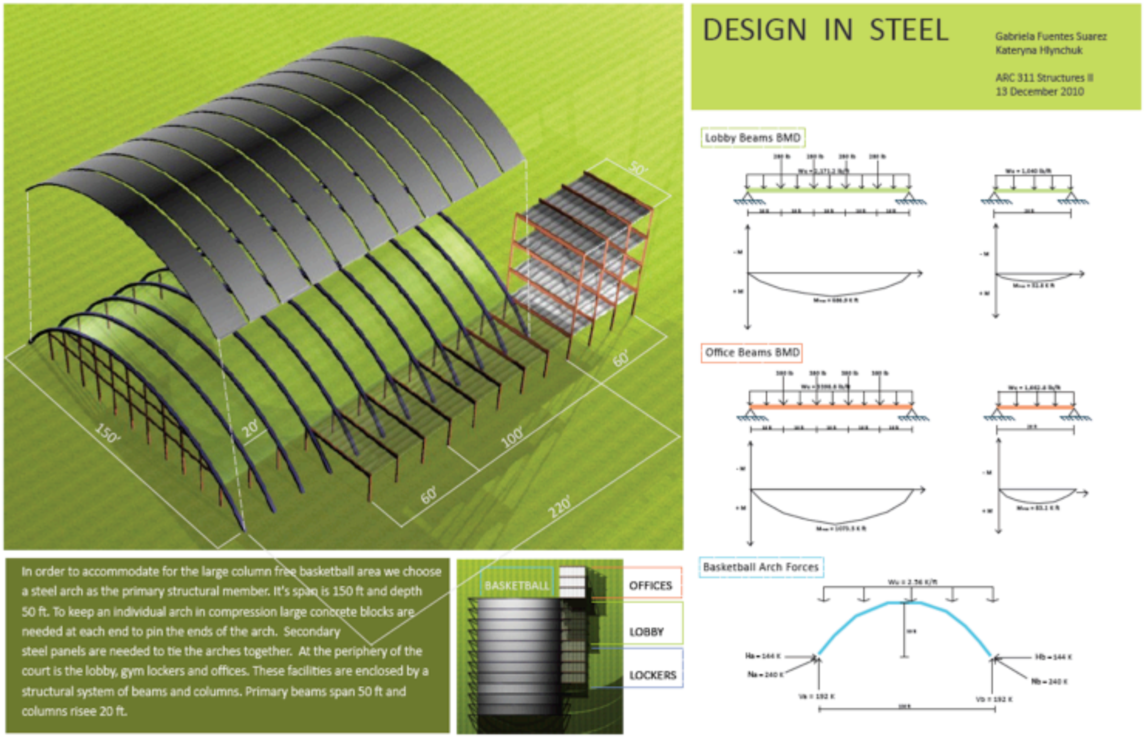

Figure 6: Images and Calculations from a Steel Design Project

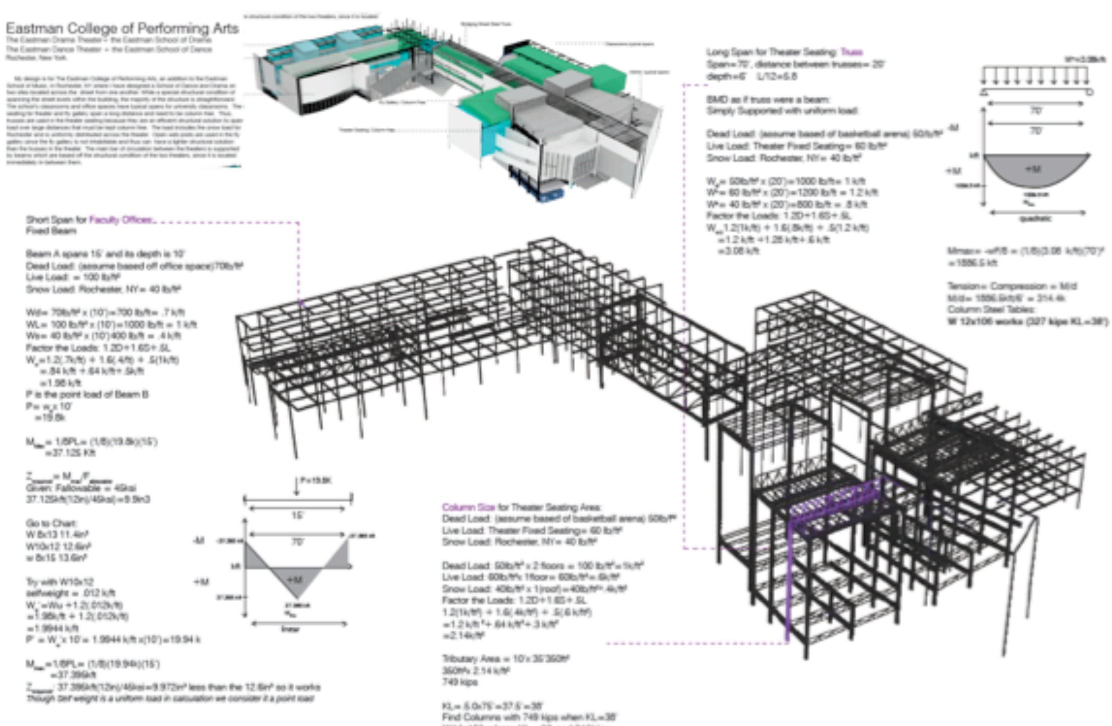

Figure 7: Images and Calculations from a Steel Design Project where the student used their studio project

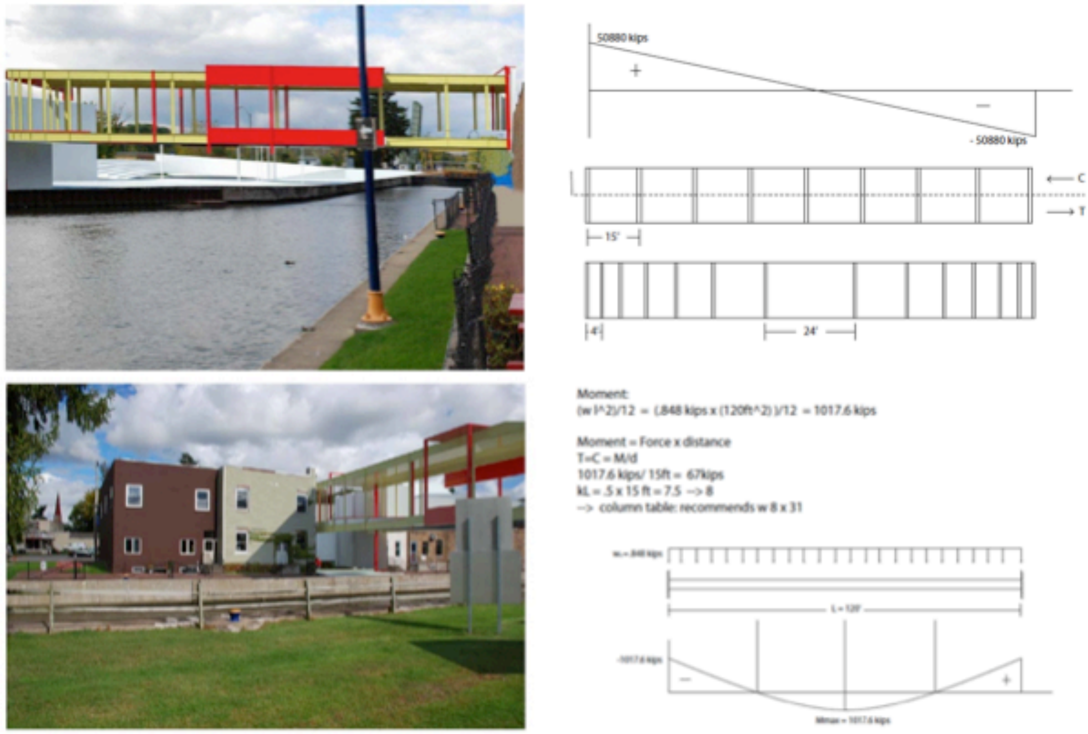

Figure 8: Images and Calculations from a Steel Design Project where the student used their studio project

5. Student Response

In order to evaluate the usefulness of this assignment, a survey was sent to both groups of students who had completed the assignment in Fall 2011 and Fall 2010. There were 60 respondents (approx 25% of the overall population). Two thirds of respondents took ARC311 in Fall 2011 and the remaining third are from the 2010 group. The full results of this survey are presented in Figures 9 and 10.

The results of the survey were overwhelmingly positive. Almost 90% of respondents agree that the design projects were useful in preparing for the exams in ARC311 and approximately 75% agree that the projects were useful in learning the non-mathematical aspects of structural engineering. Most importantly (with regard to the ultimate aims of the assignment) approximately 85% of the students agree that the projects are directly useful in their studio design work. Further, almost 80% of respondents agree that the projects engendered appreciation for the role of structural engineering in architectural design. Note that there was very little explicit disagreement with any of these statements (i.e. most of the non-agreeing respondents checked “neither agree nor disagree”) and no “strongly disagree” responses were recorded for any of these statements.

The students were also asked questions about the review lecture where examples of the most successful projects were presented and illustrative examples of the typical mistakes were also discussed. The results from these questions are also encouraging. When asked if the review lecture was useful for the exams in ARC311, 67% of respondents agreed, although it should be noted that this was not the primary purpose of the lecture. Over 75% of respondents agreed that the review lecture was useful in their own design work (which was the primary purpose of the lecture). A small number of students explicitly disagreed with these statements.

In addition to the statements in Figure 9 and 10, the students were offered the opportunity to add any other observations they had about the design assignments. Some students had positive comments on both working in groups and working in project form. This is not surprising as these are modes of learning that are very familiar to architecture students.

> *"Working in small groups allowed a large amount of discussion about the math involved in designing a structure. This was very helpful because discussing mathematical design aspects makes the process much more comprehensive as students touch on many subjects and variables relevant to the project rather than just the base equations or math necessary for the problem."*

> *"It is always better to learn how to calculate structures in doing projects."*

A number of students cited the less deterministic nature of the projects (as opposed to the other work in ARC311) as a strength of the assignment.

> *"Since it was very open-ended, it was tough to find which paths to take…… …..However as a result of that we gained a greater understanding of the process"*

> *"The Timber, Steel and Concrete Projects were a good addition to the recitations and homeworks, because while the recitations and homeworks were already predetermined systems, the projects allowed us to experiment with different systems and to construct from scratch all the math for it."*

> *"I feel that because these projects require design, it allows for us students to feel like it's not just math; actually designing and calculating each project helped enthuse not just me, but my fellow classmates as well."*

Other students had observations on the structure of the assignments and the review lectures, and suggestions for improvement.

> *"I liked the progression of these projects throughout the semester as it gave the class some consistency throughout in terms of reinforcing methods and the approach to structural design and consideration in architecture."*

> *"the concrete project seemed very long and challenging but it helped in understanding the math."*

> *"The most useful aspect of the projects was looking in hindsight at the mistakes we made. Attempting to correct our intuition when it comes to structural design is greatly enhanced through this process"*

"The Timber, Steel and Concrete Projects allowed us to really consider how a structure will be constructed, however, it would be better if there was some sort of example in order to figure out whether the dimensions found are good"

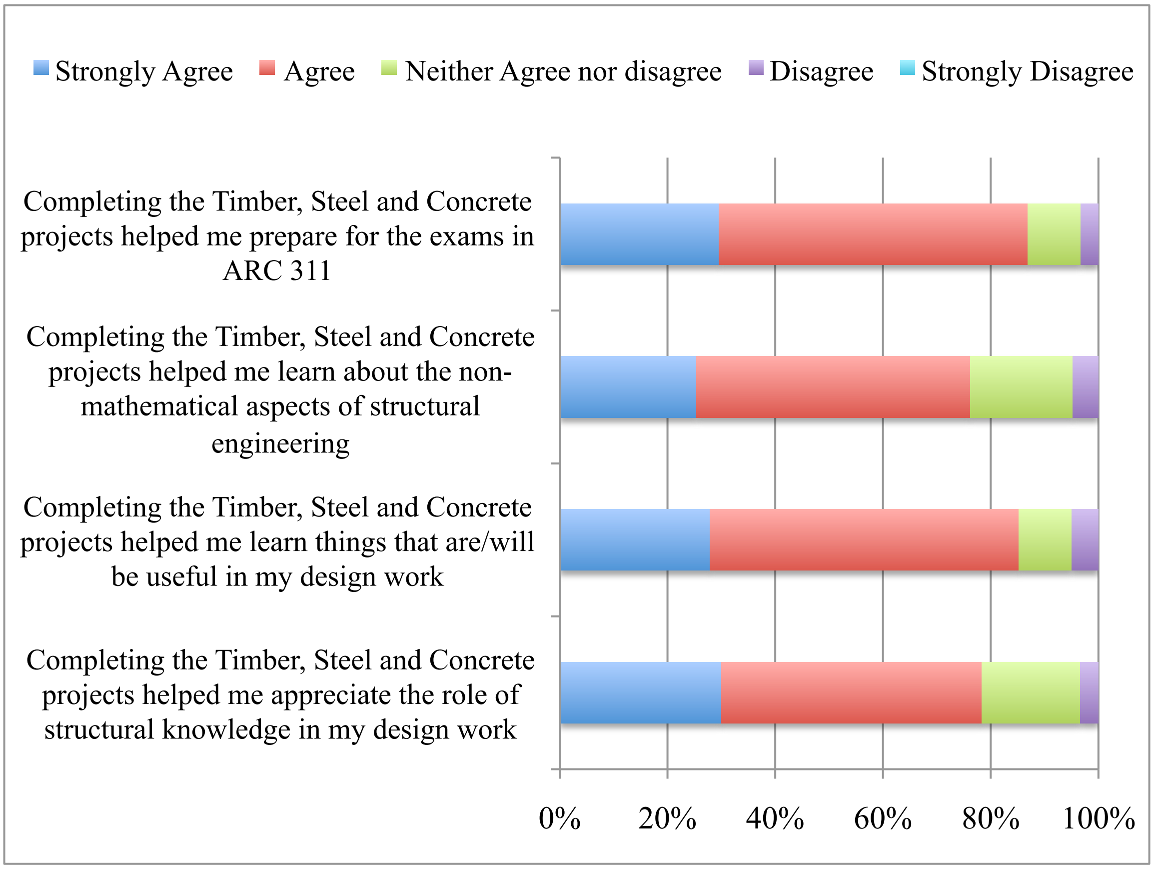

Figure 9: Student responses regarding the value of the ARC 311 structural design assignments in both to both structures learning and design education.

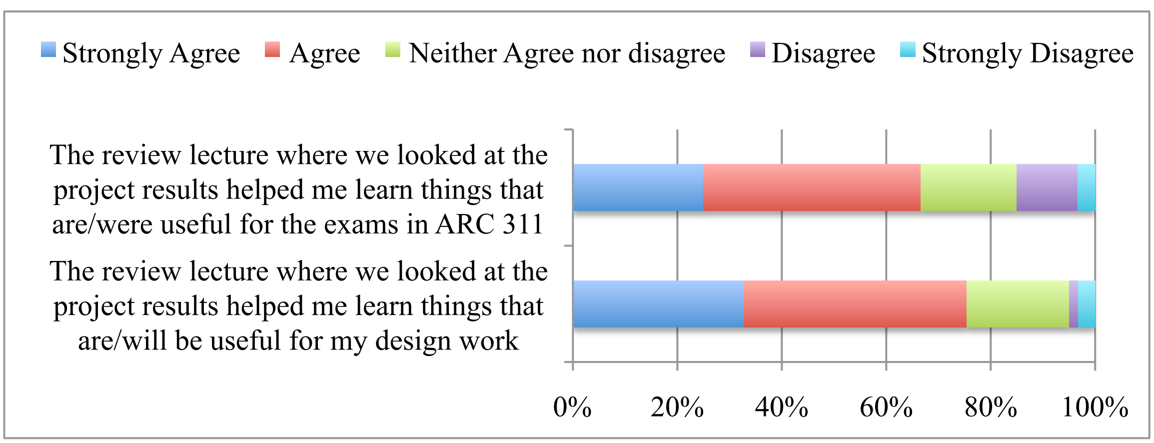

Figure 10: Student responses regarding the value of the ARC 311 structural design assignments in both to both structures learning and design education.

Those students who had completed comprehensive studio since taking ARC311 (the Fall 2010 group) were also asked about the usefulness of the design projects as preparation for comprehensive studio. Over 90% of respondents agreed that the projects were good preparation for comprehensive studio and 76% of respondents agree that the projects were *better* preparation for comprehensive studio than any of the other coursework in ARC311 (see Figure 11). These findings align very well with the pedagogical aims of the design projects.

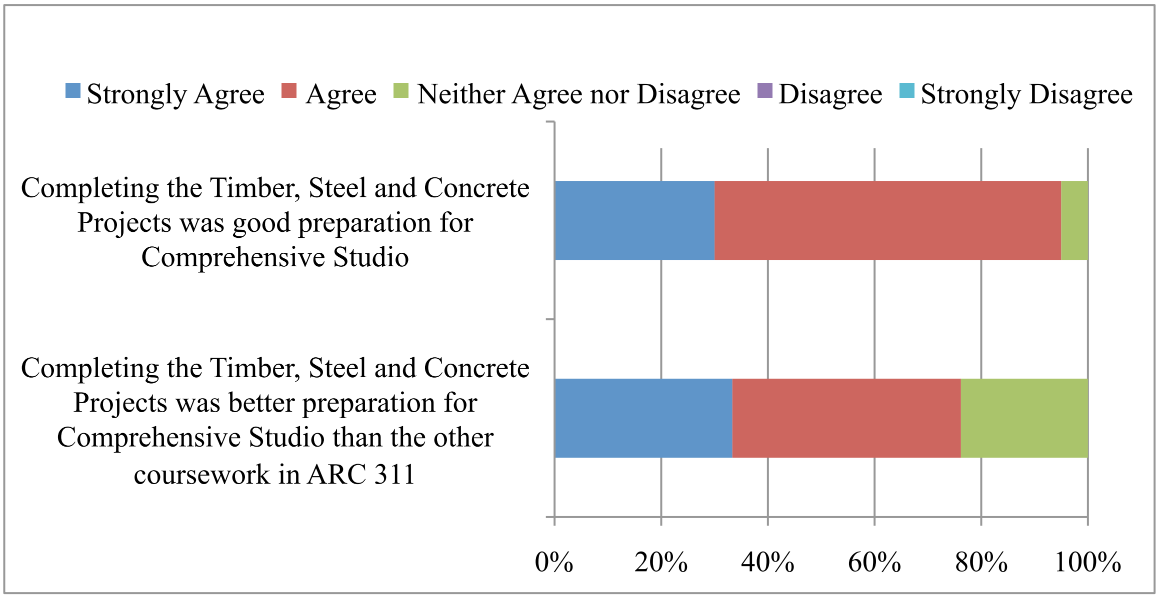

Figure 11: Student responses (from those students who have since completed comprehensive studio) regarding the value of the ARC 311 structural design assignments in preparation for comprehensive studio.

Those students who had taken comprehensive studio also offered these comments on the usefulness of the design assignments for their later design work.

> *"The Timber, Steel, and Concrete Projects were helpful because students had to choose their own parameters for the calculations that we learned to do in class. Through this application, students could better understand the influences of each variable and how to structurally maintain their design."*

> *"It was a great starting off point for potential workable designs. Structure is a big part of any design and is often neglected"*

> *"It was beneficial to be familiar with the differences between timber, steel and concrete buildings and how the structure worked in a possible project done in ARC 311 when deciding on a structural system that was appropriate, and figuring out how it would work with the design scheme. If we had just done tests and no design project in ARC 311 I feel that the connection to different systems would have been lost a bit."*

"Although the projects made us learn construction assembly, I don't think that a lot of the students will be using timber construction, but rather more inventive types of construction, like glass facades."

"The projects I did in this semester gave me profound information in using different kinds of material and structure type. Tutorial in SAP2000 would also helpful in calculating structures in 3D."

These comments are very encouraging and suggest that perhaps eliminating some exam work and homework in favor of another project in ARC311 might be a positive move.

6. Conclusions

Structures are a vital but oft overlooked part of a architecture education. Today's graduates will practice in an ever more technologically complex environment and it is critical that they be equipped with the skills to most effectively integrate technical knowledge into their design work. The projects described in this paper represent a useful pedagogical strategy to help students both learn the structures material and connect it to their design work. The student response data was overwhelmingly in support of this claim.

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[1] Plesums, Guntis. "On Teaching Structure Systems." *Journal of Architecture Education* 27, no. 4 (1974): 68-77.
[2] Severud, Fred. "Structures: The Feel of Things" *Journal of Architecture Education* 16, no. 2(1961): 18-22.