Teaching Structures Online: Finding Opportunities for Tangible Engagement

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Abstract

Faced with increasing demand but limited flexibility within the academic year, the School of Architecture at Clemson University developed and delivered an online version of its undergraduate Structures 2 course during the summer of 2018. This shift in timing and format presented a range of challenges, most significantly the compressed schedule (six weeks to deliver fifteen weeks of content), and the desire to maintain engaged, experiential learning despite the detachment and asynchronicity introduced by the online setup.

With respect to this remoteness, it proved fruitful to turn the challenge on its head and instead identify opportunities afforded by the geographic distribution of the students. This resulted in a unique case study project devised to capitalize on diverse summer experiences and dovetail with student internships. The project aimed to develop a clearer understanding of the collaborative relationship between practicing architects and structural engineers through shadowing and interviewing both parties. In conjunction, students identified a current project in the office of these professionals as a reference point for the interactions being described. This provided a foundation for discussions of scope, contracts, design stages, workflows, and special coordination. The case study also provided a vehicle for integrating basic course content relating to material systems, hierarchy, load path, and connections, all while developing other key competencies ranging from interpreting construction drawings to synthesizing architectural and structural information.

This paper details the first offering of the online Structures 2 course at Clemson University – its organization, its content, and the unique project devised as a thread tying everything together. The paper considers the scope of our students' unfamiliarity with the architect / engineer relationship, and how a project like the one described can address this need. It is punctuated throughout by examples of student work, and includes detailed student feedback concerning the course and its methods.

Keywords: Structures, Online Instruction, Pedagogy, Professional Practice

Introduction

The undergraduate Architecture program at Clemson University consists of a four-year Bachelor of Arts degree, in which students are required to complete a minimum of 122 credit hours. This number is comparable to other B.A. programs across the United States, and it has been in place at Clemson since the 2005-'06 academic year, prior to which the program required 141 credits. The most significant cuts were made in the area of requisite building technology courses, which were reduced from five to two.[1] Within this number, Structures 1 is required for all students, and a second technology course must be completed from among a list of options, including Structures 2. Almost all of the students complete their second technology requirement in the form of field studies or maker courses offered during a compulsory off-campus-study semester. This effectively relegates the Structures 2 course, then, to being an extra elective rather than required material. As such, it has been traditionally offered once per academic year, in a single section.

This changed in 2018, when a second section was offered over the summer to keep up with growing demand among students. While it was always recommended as a valuable course, the urgency with which our academic advisors have promoted it recently increased in response to the growing number of M.Arch programs requiring the equivalent of Structures 2 for admission. The summer offering was seen as both a pressure relief valve, managing the enrollment in the normal Spring semester section, and as a unique opportunity for students desiring more flexibility in their course schedules.

One significant constraint to a viable summer section, however, comes with the fact that many students pursue professional internships and other opportunities during these windows. It was determined, therefore, that an online version of the course would be necessary to allow for wide participation, and that an asynchronous format would best accommodate varying schedules.

Contents, Setting and Participants

The Structures 1 course at Clemson focuses primarily on the related topics of load path and statics. As a compliment to the quantitative dimension of basic statics, students are challenged to develop an intuitive sense of structural behavior through numerous tactile modeling exercises. Along the way, a variety of overarching structural typologies are introduced in service of highlighting the range of systematic approaches and their distinctions. Structural materials are discussed lightly and mostly in the context of presenting these typologies. The topic of Strength of Materials may be introduced, but is increasingly relegated to Structures 2.

Structures 2 delves into internal stresses and deformations and the impacts of material and cross-sectional properties. Beam theory is a central topic for the demonstration of these lessons, and students go in-depth through the analysis and design of steel, timber and reinforced concrete systems. The topical outline for the standard 15-week course (two periods per week, each 1.25 hours) is as follows: Review of fundamental principles, including equilibrium, load path, and reaction forces (3 weeks); strength of materials (1 week); beam theory (3 weeks); structural steel (1 week); structural timber (1 week); reinforced concrete (2 weeks); lateral forces (1 week); column design and stability (1 week); foundation systems (1 week).

Summer courses at Clemson are generally organized into 6-week terms. While it is possible to create longer-running summer courses, as needed, the decision was made to stick with the 6-week format for the inaugural summer version of Structures 2, allowing students and the instructor more flexibility with the rest of their summer schedules. The course was positioned in the second half of the summer (June 27 – August 7), allowing students time beforehand to gain their footing with any internships or other opportunities.

Eight students enrolled in the course, exceeding the university's required summer minimum of six. Of the eight, four were rising 3rd-year students, three were rising 4th-years, and one was an outgoing 4th-year, set to graduate upon completion of the course. Two of the rising 3rd-years and all three of the rising 4th-years were engaged in professional summer internships. Only one student was spending the summer in Clemson, as she was simultaneously enrolled in a summer Studio course. The others were spread across six different cities and two time zones.

Challenges and Opportunities

Given the condensed, 6-week time frame for the course, the organization and scheduling of content delivery was one central concern at the outset. A second challenge involved finding a way to promote active learning in a course taught online. It is evident from previous experiences teaching Structures at all levels, that students benefit greatly from project-based applications of the lecture topics. In addition to cementing the lessons of the lectures, such projects are avenues for new knowledge and synthesis across concepts. So, while physical, model-based approaches would be infeasible in this case, some other form of central project would be essential for providing tangible engagement with the course material. Moreover, a well-devised project could turn a constraint into an opportunity by taking advantage of the fact that students were living and working in a wide variety of different settings.

Course Organization and Delivery

The summer course kept the same topical outline described above, but featured up to five lectures per week, rather than two, in order to fit the 6-week timeframe. This equated to 25 core lectures in the following sequence: review of loads, spanning strategies and statics (5 lectures); strength of materials (2 lectures); beam bending and shear (6 lectures); structural steel properties and methods (1 lecture); beam deflections (1 lecture); timber design (2 lectures); reinforced concrete design (3 lectures); column buckling and stability (2 lectures); lateral forces (1 lecture); retaining and foundation systems (2 lectures). As with the normal 15-week course, the opening period for review is included with the 4th-year students in mind, as it may have been two years since they completed Structures 1. It is also important to mention that the various subjects are not as discretely separated as they may appear from the outline. Lateral stability, for example, is discussed throughout the entirety of the course, though it is only the principle topic of a single lecture.

In addition to the core content, one additional mini-lecture was provided in the first week, addressing the topic of structural documentation and coordination between architectural and structural drawings. In the traditional course format, this important topic would be informally covered in discussions surrounding class projects, such as those in which students are asked to work from as-built drawings to model and analyze structural systems of existing buildings. However, without such face-to-face interactions for the online course, this content was instead packaged as a pre-recorded add-on lecture.

Lecture Delivery

Each of the lectures has the format of a slideshow with audio narration, and each was simply recorded in PowerPoint and delivered as a pptx file, as PowerPoint is a program that is freely available to all students at the university. The lectures averaged 61 minutes in duration, but were broken up into shorter modules to better hold students' attention and allow more flexibility in the way they consume the content. The modules varied in duration, depending on content. One may contain an entire subtopic, while another may contain a complete design problem. The average module duration was 10 minutes. This is somewhat longer than examples gathered from colleagues[2], or even recommendations from Clemson's own online education department, each of which favor five-minutes or less. However, in this case, longer modules resulted from an effort to err on the side of subject continuity rather than breaking at places that could disrupt a theme or idea. That said, some selective editing in future iterations could break up certain longer modules, such as those featuring example problems that are divisible into discreet steps.

The course was administered through two cloud-based tools. Canvas, a learning management system, was used for course communications and for posting grades, while Box, the university's cloud storage service of choice, was used for uploading and sharing the lecture modules because of its ample space. Most lectures were recorded in advance of the course, allowing for batch uploads. In an earlier interest meeting, prospective students indicated that posting multiple lectures at once, at the beginning of the week, for example, would afford more flexibility for their schedules.

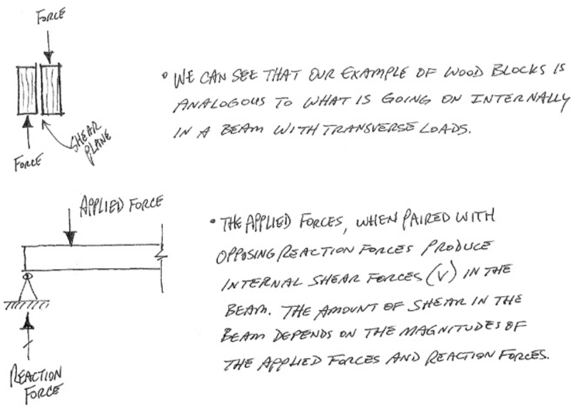

Fig. 1. Lecture slide example

The lectures generally fell into two categories. Some were image-based, such as discussions of structural materials and their applications, which tended to involve illustrated case-studies. Others, in particular those featuring more quantitative content, were heavier on written notes, diagrams and calculations. In these cases, the decision was made to stick with handwritten notes and sketches (see Figure 1 above). This method followed examples gleaned from a colleague who has found that handwritten content provides a better "sense of connection" with a remote instructor.[3]

Graded Assignments

The course contained three types of graded assignments. The first were homework problem sets, in which students could leverage lecture notes, the textbook[4], or even each other's help to solve a range of structural analysis and design problems. There were two total problem sets, scanned and submitted by students via email. Each was followed within a few days by an exam, one at the midterm and one at the end of the course.

The exams were designed to cover the same quantitative content as the problem sets, but also address the more qualitative matters of the course. This might include making comparisons between structural materials and systems, or even sketching illustrations of key concepts, such as different types of retaining walls. For these reasons, both exams were written exams, presenting challenges for coordination and administration. Computer-based remote proctoring programs were considered as a measure for exam security, but the unique, paper-based aspects of the tests, led to a different solution.

In the weeks leading up to the course, students were contacted and asked to identify a suitable setting and proctor. Suggestions included testing centers, public libraries under staff supervision, or at their summer firms under a senior mentor. Once identified, these proctors were contacted, provided with guidelines for administering the exams, and asked to sign off on their willingness to serve in the role. On the mornings of each exam date, the tests were simply emailed to the proctors, along with any approved reference tables, and instructions regarding time limits and permitted materials. The proctors printed and administered the exams and scanned and emailed them back to the instructor, once completed. The physical copies were also mailed back via stamped envelopes provided by each student.

The third type of graded assignment, the course project, is described in the following section.

The Project

A multifaceted project was devised as a thread to knit together and apply the course's central lessons. The project took the form of a building case study, but with a twist. Taking advantage of their various summer situations and locations, each student was to perform their case study while shadowing an architectural professional and consulting structural engineer. This wrinkle was aimed at addressing a knowledge deficit concerning the practical relationship between these parties.

Knowledge Deficit

A survey of 4th-year architecture students at Clemson University was recently conducted to gauge the level of familiarity with the working interactions between architects and structural engineers.[5] At the time of the survey, these students were in their final academic semester, twelve weeks from graduation. Of the 42 respondents, 37 reported that they intend to pursue architecture as a career. 31 reported having some prior experience interning in an architectural office, and the average length of experience among those that had any was 6.4 months. Interestingly, 40.5% of all respondents indicated that they had observed a coordination meeting between architects and structural engineers.

However, when asked to rate their level of "familiarity with the typical working interactions" shared between these parties, the majority of respondents reported little or no familiarity (see Figure 2). Additionally, only 23.8% reported that they could say with confidence how the content of these interactions changes over the course of a typical project.

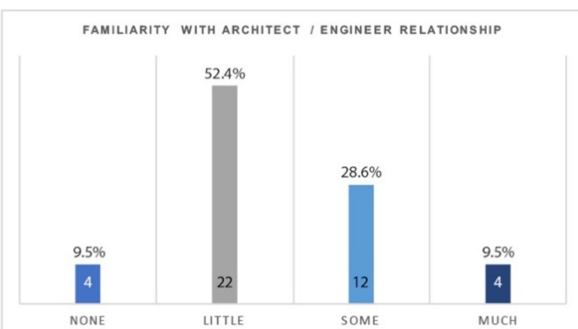

Fig. 2. Student familiarity with architect / engineer interactions

Taken together, these results indicate a clear knowledge deficit among students, and even among those who have had exposure to professional practice. One is left to conclude that summer internships and related experiences, while helpful for offering some awareness, are not consistently providing lasting insights into the architect / structural engineer relationship. One is likewise left to conclude that students have not learned about this topic in their academic coursework.

Project Setup

Aimed at tackling this blind spot, the course project required that students identify a partnering architect and engineer and invite them into conversation about their working relationship. Likewise, students were asked to select a particular case study building as a vehicle for mapping out the collaboration, and, if possible, try to attend a project coordination meeting between both parties. Given the short, 6-week duration of the course, there was no time to waste in selecting professionals and a building. Therefore, a draft description of the project was sent to each student five weeks before the course began to get them started on planning these connections. Students engaged in professional internships were invited to work within their own firms for the project, and all five ultimately took this route. The remaining three students were encouraged to find architects and engineers close to where they were spending their summers.

Once the course did begin, and within its first few days, all students were required to make an initial progress report to the instructor (via phone call), during which they confirmed that they had found willing professionals and had access to a promising case study project, including the project drawings. It was at this stage that two students reported challenges in finding a participating architect. The instructor was able to step in in both cases and help make the necessary arrangements through personal contacts. This worked out easily enough, as both of these students were somewhat local, but it could have proven more challenging in other circumstances. In addition to verifying access to professionals and case study resources, the early progress report also provided a good opportunity to confirm that students understood the project goals and requirements, and that they had a well-defined path for completion. A second progress report was required at the midterm to verify that students were still on the right track.

Project Goals and Parameters

Through conversations with professional architects and their partnering engineers, students were asked to construct a detailed picture of their interactions and what they look like at the various stages of a project. The selection of the accompanying case study project was, therefore, a critical decision, as this would serve as the lens for understanding the working relationship. As a guide to beginning fruitful conversations, and as a measure to ensure quality control in these engagements, the students were given the following questions as starting points. Additionally, they were encouraged to add their own questions to this mix.

- Where is each of the professional firms located? What are their histories?
- How are the contracts between architects and engineers structured?
- What are the various stages of a design project, and how do the architects and engineers practically interact at each stage? Can this be mapped out as an illustration?
- What tools (software or otherwise) assist in coordination between these parties? What opportunities or limitations are imposed by these tools?
- What tools are the structural engineers using to make the necessary calculations to size the structural elements? What does this workflow look like?
- Does each party feel that the typical measure of interaction on a project is adequate? Are there opportunities for operational improvements to be made?
- What attributes are architects looking for in an ideal structural engineer?
- What attributes are structural engineers looking for in an ideal architect?
- With respect to the selected case study project, are there any specific areas in the design that require special attention and coordination? If so, what do these interactions look like and what was the result?

More than just a reference point for mapping professional interactions, the case study project was also intended to be a tool for developing three key competencies among the students. First, they would practice reading and understanding construction drawings, including coordinating between the architectural and structural sets. Second, through drawing and diagramming, students would gain a greater appreciation for the hierarchy and interdependency among structural members. Third, through close study and re-representation, students would better understand the structural materials at work and, in particular, the details of their assembly and connection.

Project Deliverables

The final submission of the project took the form of a comprehensive report addressing the architect / engineer relationship and the accompanying case study project. Students were advised that the report should be more than a perfunctory listing of facts. It was each individual’s responsibility to be curious and creative in order to elicit compelling information that effectively told the story of these professional collaborations. Students were asked to include dates and times of conversations, as well as the names and roles of the individuals interviewed and observed. Photos and other images, such as example drawings of the case-study projects themselves, were to be included, as were any photos from in-person visits or diagrams made to illustrate the collaborative process.

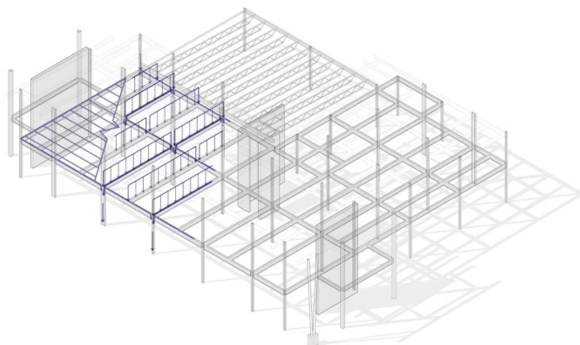

Fig. 3. Load tracing diagram (by Harrison Novak).

Students were required to make and include a series of analytical drawings, each pertaining to the selected case study project. The first was an axonometric diagram illustrating the load path at work in a given portion of the building (see Figure 3 above). For reference, the selected portion of the building was to be highlighted in the accompanying set of plan and section drawings.

Each student was also required to produce axonometric drawings articulating the assembly of at least three distinct structural joints. If a given case study project was not far enough along in its development for defined connection details, then students were asked to make drawings of representative joints from a similar project. The drawings were to be annotated so as to identify all of the key elements and their dimensions (see Figure 4). Students were informed that all drawings would be evaluated on thoroughness, accuracy, clarity, and graphic quality.

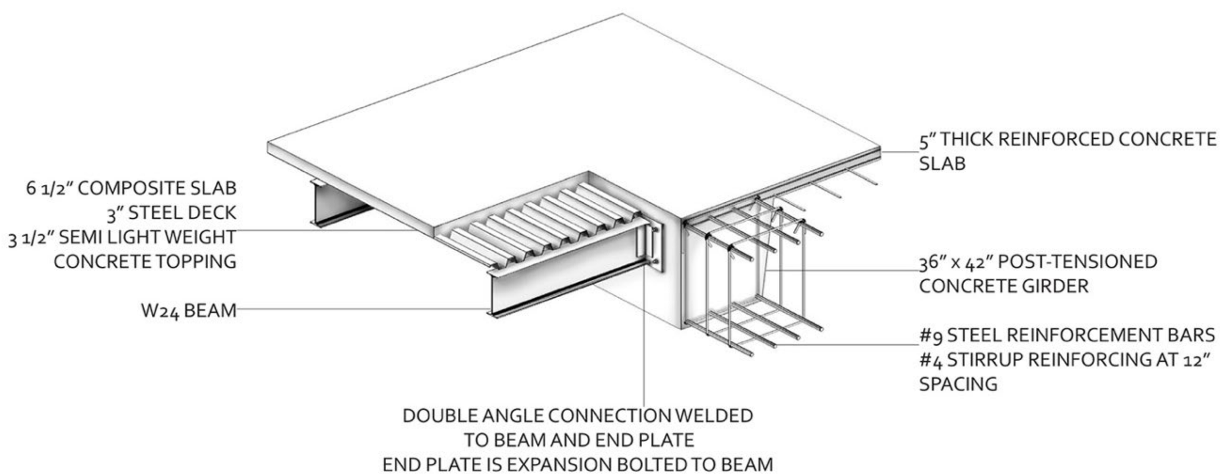

Fig. 4. Structural detail drawing (by McKenna Tiley).

Project Outcomes and Observations

As a set, the projects covered a lot of ground, owing to the diversity of the professional mentors, their practices, and their work. From the metropolitan offices of large, international firms, to a three-person practice a mile from our campus, each student had unique experiences to report. The case study buildings, by extension, ranged in scale and scope, from a small commercial renovation to a new 45,000ft^2 (13,700m^2) office building to a 370,000ft^2 (112,800m^2) conference center expansion. They also ranged in their states of completion, from the design stages to buildings under construction (see Figure 5). Relative to the questions posed by the project, this diversity presented a welcomed breadth of lessons. On the other hand, certain common threads were present, cutting across scale, location and complexity.

Fig. 5. Bracing detail during construction (by Kevin Crumley)

As expected, one of the more interesting topics to surface was the contractual variations and hierarchies associated with differing project delivery methods. Based on her interviews and case study, one student reported matter-of-factly that "typically, an architectural firm and a structural engineering firm work together in conjunction with a contractor with whom they both enter into a contract for the project." [6] Others described the engineers as consultants hired by the architect, and, in some cases, through competitive bid scenarios. These varying takeaways, fragmented as they were, led to productive teaching moments, in this case concerning design/build versus design/bid/build arrangements and their impacts on the architect / engineer relationship.

The diverse case studies also proved successful at highlighting the sorts of situations that may require special coordination. One student reported:

"I had the opportunity to discuss specific areas of the project that required special attention and coordination with [The Engineer] during our meeting…. Due to the building's location… along the river, there has been a lot of coordination and discussions, between structural, civil, and geotechnical about the poor soil. Due to the ballroom's large size, they have to account for a large amount of people in that area. There is coordination with a vibration consultant, who will help design the structure to limit the impact of all of the movement." [7]

Some of the lessons common to all the students included an appreciation for project workflows and the various levels and tools of collaborative engagement that are typical at different stages. In fact, a basic awareness of customary project phases was new knowledge for some of the younger students. Insights such as the following statement were common:

"[The Engineer] mentioned that, (from) the end of DD's all the way through CD's, the architect is in communication with an engineer several times a week. Usually there is a consultant meeting once a week ... During the CD phase, structural will send their updates on Tuesday while [The Architect] will send their updates and changes to the Revit model on Friday. This allows for quick and organized workflow." [8]

Another universal takeaway from the interviews was an appreciation for the "soft" skills that are most desirable across both parties – namely, the critical importance of good communication. Comments like the following were common:

"Good structural engineers are good communicators; they keep their partnering architect up to date on the progress and value an architect's project no matter the size. Good architects are also good communicators; they have the ability to convey their design clearly and have the understanding that structure is important and can aid with the organization of their building." [9]

Beyond the interviews, the project's required diagrams and drawings (see Figure 6) were shown to be a beneficial addition, in particular in their value for making tangible connections to the course's lectures on subjects such as load path, and material systems and their joints. The task of reading, interpreting and applying construction drawings was instrumental in these lessons. Even among students that had previous experience, the project provided a new and helpful lens. In feedback gathered after the course, one student reflected: "I got accustomed to going through CD's at my first summer internship, however I hardly ever looked through the structural drawings. I would fix and edit architectural drawings and that was the extent of my experience."

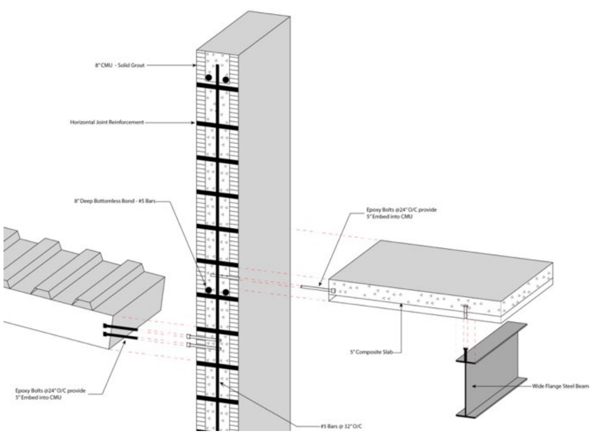

Fig. 6. Structural detail drawing (by Kaleb Mercer)

The quality and insight of the drawing studies varied among the students, with the older, more experienced students generally outperforming their counterparts. This was not unexpected. Beyond simply having a more developed skillset, these advanced students tended to have higher-level responsibilities in their summer internships, leading to more sophisticated approaches to the course project. That being said, it was evident that the project held much value for all students, in that it was broad enough to offer points of engagement across all skill and experience levels.

Student Feedback

Student course evaluations were helpful for assessing the strengths of the course, as well as possible areas for improvement.[10] Students felt that the course was "well organized" (4.43 rating out of 5), and were satisfied with the "availability of the instructor outside the class room" (3.86 rating out of 4). Students offered more modest assessments when asked to rate the "effectiveness of the instructor's teaching methods" for helping them "understand the course material." Their rating of 3.86 (out of 5) is consistent with the mean across courses in the discipline (3.89), but lower than the instructor's typical evaluations in comparable courses. By way of comparison, this same question garnered a rating of 4.78 in the graduate version of the course, offered in-person during the previous Spring. The content of these two courses was nearly identical, with the recorded lectures being prepared directly from the notes for the live course. The lower mean for the online course may stem, in part, from the smaller number of respondents (7 versus 18), which increases the impact of a single low rating. It may also underscore that student performance in the online setting is even more dependent on each individual's self-discipline and their ability to work independently and stay on schedule with the content, which can be challenging with a compressed schedule.

The intensity of the schedule was a common thread in the student comments. One respondent stated: "It was hard to have a full-time internship and make sure that I was keeping up with the lectures every night. It made for a long, tiring day. There were a couple of days where I missed the lectures and that made it hard for me to catch back up." Another suggested stretching the course out over a "slightly longer span during the summer."

Relative to the course project, students again mentioned the timeframe, stating: "Due to architects' and structural engineers' working schedules it can be hard to get ahold of people quickly and it would be good to have more of the summer to work on the project." Another critique came from a student who felt the project favored intern experiences with larger offices. There is some validity to this, in that a small, residential practice may feature limited and distinctly different interactions with structural engineers. This was acknowledged at the outset by the instructor, and students were presented the option of approaching an architect outside their firm, if necessary.

Otherwise, the projects were very well received. One respondent noted: "Prior to this class, I had never spoken to a structural engineer before about what they do," and "I believe I am now able to read structural drawings, and my understanding of the consultant process is much better than before." And, commenting on the building case-study: "It helped narrow the focus on one building that allows you to dive into details that you might miss with an expanded scope. Especially when it came to looking at connections." Commenting on the "greatest strength" of the project, a respondent noted: "I think the fact that it uses our summer internships as an access point into the communication of the architect and structural consultant is very strong."

Conclusions

Based on student evaluations and the instructor's own observations, it appears that the inaugural online Structures 2 course at Clemson University was largely successful. Student learning objectives were met, and exam averages were on par with comparable courses taught in-person by the same instructor. Based on student feedback, future versions of the course and its project may be stretched out over a longer period – perhaps eight weeks instead of six.

The course project proved to be an effective vehicle for synthesizing and cementing the lecture content, including specific material systems and the hierarchies and load paths among their respective components. Additionally, while different than the model-based approaches employed in an in-person setting, the course project successfully fostered new and applied knowledge through its own form of active learning. By incorporating the diverse locations and summer experiences of its participants, it resulted in a wide variety of practical lessons among the students. This demands a healthy measure of flexibility on the part of the instructor when it comes to managing and evaluating the project. It is important to embrace the variety and encourage the specific opportunities afforded by each unique experience. For example, the differing timelines of the case study buildings may result in early design meetings in one case and on-site construction visits in another. This should be viewed as a strength of the project, and future versions of the course will explore the best ways that each student's research can be disseminated to the whole class.

Notes:

1 A more detailed history of this credit hour reduction and its impact on required building technology courses can be found in an earlier paper: Albright, D. "*Action and Reaction: Balancing the Dual Challenges of Breadth and Depth in Undergraduate Structures Instruction.*" In Proceedings of the 2015 Building Technology Educators' Society Conference. Salt Lake City, UT. 2015. p 233-239.

2 Sprague, Tyler S. "Watch/ Respond/ Act/ Solve: A Hybrid Approach to Architectural Structures Education." In Proceedings of the 2015 Building Technology Educators' Society Conference. Salt Lake City, UT. 2015. p 223-229.

3 Ibid.

4 Onouye, Barry and Kane, Kevin. "Statics and Strength of Materials for Architecture and Building Construction." Fourth Edition. Prentice Hall, 2011.

5 This survey was conducted in January 2019, five months after the completion of the summer Structures 2 course. The survey results confirmed the author's suspicion that students generally lack knowledge of the typical architect / structural engineer relationship. The questions and results of the survey were as

follows: (1) *Including any past or current internships, how many months (total) have you worked in a professional architectural office?* Average duration = 4.675 months. This number included 11 participants that reported zero experience. (2) *How much familiarity do you have with the typical working interactions shared between architects and structural engineers over the course of a project?* None = 9.5%, Little = 52.4%, Some = 28.6%, Much = 9.5% (3) *Could you say with confidence how the content of interactions between architects and engineers changes over the course of a typical project?* 23.8% Yes, 76.2% No (4) *Have you ever observed or participated in a project coordination meeting between an architect and a structural engineering consultant?* 40.5% Yes, 59.5% No (5) *Do you intend to pursue architecture as your profession?* 88.1% Yes, 11.9% No.

6 Quoted from final report by student, Rachael Jackson.

7 Quoted from final report by student, McKenna Tiley.

8 Quoted from final report by student, Kevin Crumley.

9 Quoted from final report by student, Harrison Novak.

10 Course evaluation data was based on a survey participation rate of 87.5% (7 out of 8 students).