# The Structures - Design Studio Link

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*Teaching structures to architects is a juggling act between the technical and the creative. It is not enough to teach statics and strength of materials. Architects are creators of space and as such they must also understand the inherent strength and weaknesses of the vast array of structural systems at their disposal. There are three topics often debated between structures educators. The first is the question of what should be taught first. Can one understand structural systems without first understanding the fundamentals of forces, load tracing, stress, and deflection? On the other hand, can one readily grasp the fundamentals of analysis and component design without understanding the concept of a structural system as an assembly of components working together to transfer all loads safely to the ground? The second topic of debate, stemming from interpretation of NAAB requirements and differing philosophies of architecture education in general, centers on the question of how much structural knowledge the architecture student really needs. The third topic is the integration of structural design in the architecture design studio. It is not so much a question of if the integration should occur as of how the student is expected to apply newly learned structures knowledge to projects in the design studio.*

*This paper posits that the application of structural knowledge in design studio is essential to an integrated design approach and as such, the structures curriculum should be directly linked to individual studio projects. Through analysis of the structural debates listed above, the paper discusses flexible curriculum components and multiple half-term courses to suit the needs of individual student schedules and correspondence to design studios. It also discusses strategies toward developing studio links that reinforce the design of structural systems from the concept phase of a project.*

**Structures and the Architect**

Architects do not strive to become structural engineers. On the contrary, many architects would rather relegate all notion of structure to an engineer. There is a rather tired quip that resurfaces periodically amongst architects: “The only structures number I need to know is the number of my engineer.” The statement avows the disdain of computation by a large number of architects. And yet, architecture is steeped in the art of mathematics albeit through patterns, scales, spatial relationships, and slopes or pitches; and in a very practical nature through dimensioning and calculating area and volume for the former. Throughout history the master builder designed both form and structure without a separation between the two. Good structure led to good form and good form led to good structure. At some time during the industrial revolution, when Portland Cement and Structural Steel were still in their infancy, architects began to relegate component design to engineers. Whether the decision was a conscious effort by instructors from schools such as L'Ecole Beaux Arts or out of the necessity to transfer responsibility of design to the engineers who developed and worked with new materials, the result was a gradual shift in the definition of architectural design from a practical or applied expression of form to the purely aesthetic expression that many architecture faculty embrace through design studio pedagogy today. William Braham[5] places the establishment of discrete courses in structures for architecture students separate from studio as taking place in the 1940's and 50's. This implies that educators today were educated themselves in a curriculum that sequestered structures away from the design studio.

In the defense of the shift in design thinking, it is true that with an understanding of structural concepts, an architect may design a space without ever calculating a size. But, in reality, a space designed without the ability to at least estimate component size will, in all likelihood, become a very different space once an engineer has finished the working drawings. Control of design is essential to the architect as is the ability to communicate with engineers and contractors, the ability to economize by designing components on small projects and the ability to see that structure is fully integrated with other building systems.

Architects must be able to communicate effectively with contractors and engineers. Without an understanding of the structural system and the stresses it experiences, an architect cannot participate effectively in decisions regarding structural design or grasp the implications of problems encountered. This does not imply that the architect should replicate the work of the engineer, but rather understand in general terms why a concern has arisen, or why an alternate strategy might be better suited to a project. Moreover, the architect must be able to discuss structural strategies competently to preserve the design intent.

Designing components for small projects without the help of an engineer is essential to the livelihood of any architect. If an architect must defer to an engineer for the size of a lintel or similarly simple component, the cost of the engineer could make the bid too large to be considered, or consume all profit on the project.

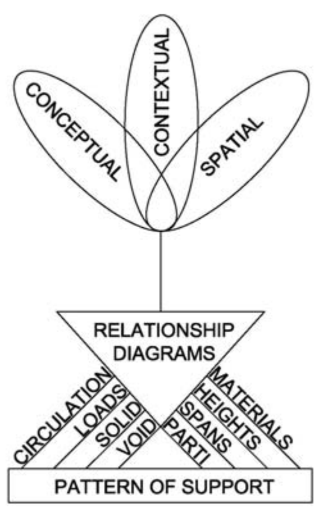
Architects should understand how the structure relates to all other building systems. Consider something as essential as a floor system. The horizontal spanning system has a direct influence on a number of future decisions. The depth of the structural members affects the depth of the interstitial space between levels. As a result, the overall building height can change or the number of levels may be forced to be reduced. The type of spanning component, I-beam or open web joist, or the like, determines the pattern and placement of ventilation ducts; and again affects the height if ducts must run below structural members. Choices made for other building systems affect the structural design. Consider a roof designed to collect rain water. The slope of the roof, the weight of the water, and how the water drains to a collection tank affect the size, and placement of structural components.

As important as communication, economy and integration are to achieving a good result, it is control of design that will always have the most impact on the architect. To understand structure and integrate structural design in the conceptual phase of every project is essential to control over the design intent.

## The timing and order of structures education

Alberto Campo Baeza once told me that to conceptualize architecture without structure is like giving birth to a baby without bones and then trying to insert the bones without affecting the relationships of the organs. And yet, most architecture students do exactly that. In many NAAB accredited curriculums, students do not receive any instruction in Structures until after several design studios. The result is that the average second year student tends to conceive space through the stacking of solids and voids modeled as boxes without consideration of the transfer of loads to the ground. To avoid the stacked box syndrome, structures should be taught as early as possible in the architecture student's curriculum and it should be intimately connected to the design studio beginning with studios that define a program and site.

Architectural Design begins with patterns that relate to the contextual, spatial and conceptual information analyzed at the pre-design phase of any problem. Contextual information such as site placement in relation to other buildings, solar orientation, circulation patterns on and around the site, the height of other buildings, topography and hydrology of the site are combined with programmatic information that defines the spans and heights of particular spaces as well as the relationship of internal to external circulation to develop a parti or design solution scheme.




A pattern of support may be developed with little or no understanding of the limitations on materials and loads. The spacing of columns and beams, the depth of joists or the thickness of slabs may be estimated from various tables provided in books and manuals. But the pattern of support cannot be well developed as a structural system without an understanding of how it works.

The structures curriculum typically includes statics and strength of materials, an overview of structural systems, and in advanced classes, component design for steel, wood and concrete materials. The conundrum is which to teach first: statics and strength of materials or structural systems. In a perfect world, the two would be taught simultaneously, but that scenario rarely fits the already overcrowded architecture curriculum.

The first thing every student needs to understand in structures is how things break. When, at the outset of the structures curriculum, five volunteers are asked to demonstrate different ways to break a piece of basswood, the first student invariably bends the piece and snaps it. The second student crushes it. The third student pulls it. The fourth and fifth twist and chop it. To these strategies, the names of flexure, compression, tension, torsion and shear are introduced. To understand how a structure will stand, one must understand how it will fail.

The second thing every structures student needs to understand is the concept of a structural system. A system is a set of inter-related components that serve a common purpose. In the case of structural systems the common purpose is to transfer all loads safely to the ground. How a system transfers loads to the ground depends on its configuration, which in turn depends on the pattern of support.

From this point, the structures student may learn statics and strength of materials concepts or may study structural typologies. The advantage to teaching statics and strength of materials before teaching structural systems is that statics is based on Newton's Third Law of Motion: an object at rest when subjected to a force will have an equal and opposite reaction. The idea that everything at rest is in balance is a simple one. Every child inherently understands that the heavier child sits closer to the pivotal support of a see-saw than the lighter one. Every teenager who has helped to move a heavy object knows the person supporting the heavier end carries more load. Likewise, the idea that Moment of Inertia is the ability of a cross-section to resist bending can be intuitively observed while bending a ruler. Because the ideas presented in statics are encountered in daily life, it is easy for the student to grasp the idea. This is not to say that the student will grasp the math; indeed many architecture students are right-brained thinkers gifted in spatial thinking, but not comfortable with the sequential thinking required by simply math equations.

Strength of materials brings a sense of scale to statics. Principled by Hooke's Law, the relationship between stress and strain defines the influence of materials on static conditions and thus the limitations of various structural systems. From calculating simple stress and strain to designing components for allowable stresses and deflections, students become able to choose components shapes and materials to serve a specific purpose. By understanding statics and strength of materials, students are better prepared to understand the thinking behind structural systems as a whole.

The study of structural systems is an opportunity for the architecture student to discover new ways to think about structure as a designer. Structural systems cannot be taught solely as a lecture based class. While lectures are necessary to show precedents and introduce the logic behind a system, it is ultimately the use creation of a system using a specific typology that allows a student to understand how it works and how it fails. Whether exercises involve the creation of cable systems, folding plates, trusses, a moment frame, or strategies for high rise typologies or any other exploration, they can be linked to the design studio. The studio does not have to modify its schedule to embrace the various exercises; rather the exercises will serve to augment the studio experience by requiring the student to explore the studio problem through the lens of a specific structural typology. At the same time, the application of a specific structural typology to a studio problem creates a unique set of parameters for each student, gives the student a sense of design purpose and allows the student to decide whether a typology is suitable for the problem at hand.

**The structural problem in design studio.**

Design Studio projects can range from the basics of drawing and diagramming to a comprehensive studio demanding some form of construction document. The general idea is that every studio will build upon knowledge gained in the previous. But there is often a debate over at what point, if any, structure should enter the design studio project. The answer is simple: earlier is better. Once programmatic elements are established in a studio project, the project becomes about architecture, not drawing, and all architecture contains structure.

The studio pedagogy is based on a dialogue between the student and a critic. The student alternately explores a design issue individually or through peer-group work and then refines, rethinks or advances exploration based on a dialogue with the critic. Julia Williams Robinson, in her essay *Form and Structure of Architectural Knowledge* [6] recognizes the tendency in design study to "apply abstract formal organizing principles… without being encouraged to link the principles to existing research or to their own daily experience." This tendency is indicative of a growing dichotomy in architecture education thinking: professional versus purely academic design thinking. The divide exists between schools as well as between faculty members within schools, complicating the efforts of building a uniformly rigorous studio experience at any given studio level.

NCARB[4] defines five levels of five levels of Design Studio learning as part of the educational standard for licensure. The first level does not specifically require understanding of structure or structural systems. It does, however, require "user consciousness with a familiarity of spatial analysis, natural and formal ordering systems, design process methodology". Students typically fulfill the structures course prerequisites of physics and calculus while at Level I in design studio. Yet, while structures instruction may not be possible simultaneously with Level I Design Studio, the ideas of natural and formal ordering systems are a good prelude to structural systems and as such should be emphasized within the Level 1 studio.

NCARB requires an introductory understanding of structural systems in Level II Design Studios, a general proficiency in the complete design of simple buildings in Level III and a general proficiency in the total synthesis of complex buildings including structural systems in Level IV. Since these studios take place in the undergraduate architecture curriculum and in years two, three and four, respectively, it is logical that structures should be taught in years two and three of the undergraduate architecture curriculum. Once students understand the basics of statics and strength of materials, the typical design studio mistakes such as paper-thin slabs and 80 ft. concrete overhangs tend to disappear. Once structural systems are understood, students tend to incorporate structural system thinking into every project.

The structures – design studio link does not need to be uni-directional. The design studio may also become a precursor to structural understanding. Most structure classes are in a lecture format due to the limited time allotted to the three credit course. Students briefly discuss assignments and then listen to new information necessary to complete the next assignment. Thus, exploration of structures is completed as homework without interaction with the instructor. The advantage of the design studio is that two-way communication exists during the exploration. Design studio instructors mentor students on a one-to-one basis and students peer-review each other’s work. If studio instructors discuss structure with students, the idea is more readily absorbed because it has a direct implication on the final goal for the student.

One difficulty with embracing structural concepts within the studio lies in the fact that many design studio instructors have little or no structural skills or feel studio is not the place to discuss structure. An easy solution to both scenarios is to coordinate structural consultations in studios so that the structures instructor can discuss design strategies directly with each student. This requires extra time on the part of the structure’s instructor, but ultimately lends a better understanding to the students.

Level V must show a comprehensive design with an understanding of the basic principles of structural design. Many schools defer a third structures course that focuses on the specifics of wood, steel and concrete design until the graduate level. Level V studio students should be capable of achieving the NCARB Level V requirement based on the structures instruction received at the undergraduate level and the application of such knowledge in previous design studios.

If the design studios in Level II through V strive to fulfill NCARB requirements towards a professional degree, it is logical to directly tie Structures classes with the studio. The dichotomy between professional and academic design thinking directly affects how the student views the role of structure in design studio. Students often have a disconnection between design studio and the technical courses offered in the architectural curriculum. Many view the design studio as purely an expression.

David Nicol and Simon Pulling, in their book, *Changing Architectural Education: Towards a New Professionalism*[3], identify five key principles of effective learning . First: "Learning is an active rather than passive process." This idea is true in all education, but for architecture students it is most important and can be interpreted on two levels. At the most basic level, students learn structures by solving problems better than by listening to lectures. Because statics and strength of materials deals with hypothetical loadings on diagrammatic representation of structural components, students have difficulty making the connection to design scenarios even if they are capable of solving assigned problems. By linking the studio with the structures class, students learn to design systems and components for a given set of parameters over which they have control. When the student owns the design, there is more interest in finding the solution and there is a complete understanding of the problem. By designing the entire system, rather than a single component, the student understands the relationships between components.

Second: "Reflection on learning develops wisdom and artistry in practice." Reflection is more than nostalgia or assessment of the personal experience. Reflection infers a revisiting and reuse of the skills and knowledge gained in new ways. Design studio is the perfect opportunity for students to reflect on what they have learned from Structures Class.

Third and Fourth: "Collaborative learning enhances individual learning." and "Self- and peer-assessment develop skills for lifelong learning." Design studios often use group projects. One problem with group efforts in design studio is that groups often divide the work in such a way that the responsibility for structure falls on one person. Group projects in the structures class can foster the same type of collaborative learning experiences, but the studio culture brings collaborative learning to a new level even with individual structures projects. The peer-review process in studio allows students to compare strategies in problem-solving and design in an open and encouraged forum.

Fifth: "Authentic learning tasks develop professional competencies." Design studio is the best place for mimicking real world situations in design. Authentic learning tasks can be attempted in the structure's class by incorporating codes and hypothetical situations. For example, a student may be asked to compare the design of a roof located in Miami, FL with one located in Bethlehem, NH, with the snow and wind loads being the main differences. But this type of problem, informative as it is, does not embrace the full spectrum of influences of a particular site, program and most of all concept or design intent.

In his book *Grown Up Digital* [8],Don Tapscott offers seven tips for educating the net generation. Among them, he suggests cutting back on lecturing, empowering students to collaborate and focusing on lifelong learning. Carlson reports in *The Net Generation Goes to College* [1] from *The Chronicle of Higher Education* that teachers find attention spans are so short that students lose focus on lectures longer than fifteen minutes. Given the short attention span of students, either the student or the lecture format needs to change. It has been argued that net generation students are multi-taskers, capable of watching videos, e-mailing and reading assignments at the same time. But there is debate whether the combination of activities is multi-tasking or attention-deficit. When challenged with true multi-tasking scenarios such as juggling the completion of multiple projects with pressing deadlines, these same students display few time management skills. Collaboration and the relevance of learning to the students' long term goals help students to focus on the task at hand.

Another of Tapscott's seven tips for educating the net generation suggests that adding technology to the classroom is not a stand-alone strategy. Technology, especially digital design tools, allows students to fabricate designs without accountability for its structural integrity. The complexity of component design for parametric structures is typically beyond the capability of the student. This is not a problem in reality, however, as architects collaborate with engineers in such cases to design the details of the structure. Ove Arup and Bjorn Utzon collaborated for nearly three years to solve the problem of how to design the shells of the Sydney Opera House [2]. Norman Foster and ARUP experimented with structure and form in the design of the Swiss RE Building, London [7]. In the design studio, students using digital technology to create complex curvatures and indeterminate irregular structures need only understand the inherent nature of the structure: how it will fail.

## Results of integrated curriculum

As an experiment while teaching at Kent State University, I was allowed to limit the student enrollment during one semester to students from particular Design Studio sections with the same studio syllabi. As a result, every assignment directly related to the studio project. Students benefited in two ways. First, they were forced to consider the structural implications of their design and as a result their designs gained a sense of reality often missing in early studios. There were none of the typical 50' concrete cantilevers that young students often draw. The primary fear the design studio instructors had was that the need for structure would limit or detract from the creativity of the designs. In reality, it proved quite the opposite. Rather than pull back and adapt form to suit a limited structural knowledge, the students remained true to their design concepts and expanded their structural thinking to meet the challenges of the design. Second, the students were able to incorporate the structures assignments into their studio presentations, showing the jury the structural thinking behind the design and allowing for a discussion of structure during the review. Students expressed satisfaction with the integrated process stating that they felt more confident with their designs and more interest in the Structures class during that semester compared with students from other sections of Structures class.

The following year, I integrated the structures course with design studio again, but was also teaching Design Studio. I found both positive and negative effects of teaching a student both Structures and Design Studio simultaneously. On the positive side, the structural critiques that require one-on-one conversations could become part of Design Studio time, but on the negative side, I felt that some students focused too much on the structure and were reluctant to push design exploration. And while these students were not the majority of the class, it made me realize the importance of having two separate instructors for structures and design studio.

From an instructor point of view, the integrated class takes more than double the time commitment of a non-integrated course. Every assignment has a unique solution requiring individual consultation. Teaching Assistants often feel overwhelmed by the individualized nature of assignments and as a result, the burden falls on the instructor. Still, the benefit to the students outweighs the added time and effort required by the instructor.

The unfortunate reality is that although this experiment was a huge success, I am unable to implement it in my position at The Catholic University of America due to the large lecture size of the class populated with students from various studios. Most universities today have large structures classes. This choice is either from financial necessity or from a pedagogical choice. I have found that students in classes of twenty or less gain a better understanding of structural thinking than students in a large lecture format. I believe that, while the material may be delivered exactly the same, the nature of a large lecture format is such that students may choose to sit far away, concentrate on other work on their laptops or simply catch up on sleep. To keep students on task requires in class problem solving which is difficult in the auditorium seating style of large lecture halls. With Professional Architecture curriculums over-packed to meet NAAB criteria, structures courses are often placed in inconvenient places in the curriculum where they do not occur at the same time as studios that would benefit most from structure-studio integration.

## Curriculum recommendations

Statics and Strength of Materials should be taught before structural systems, and simultaneously with Level I or II studios.

Structural Systems should be taught simultaneously with Level II studios. By following Statics and Strength of Materials immediately with Structural Systems the student sees the logic of structural principles applied to real life examples and may transfer that logic to the studio project.

With Statics and Strength of Materials and Structural Systems as a prerequisite, students are free to take half semester courses on various topics, such as design components in wood, or designing components in some other material, designing tall buildings, designing buildings of reclaimed materials, structures of shipping containers or reciprocal frames. The half-semester course would be offered to correspond to specific studios and may be a required component of that studio.

When a direct studio link is not encouraged or allowed, classes should be tied to design studio when possible through the use of the studio project as the basis for individual assignments. For example, after a beam design exercise for a given span, loading and material, the next assignment might be to design the longest span beam from the floor of the studio project. Obviously, this approach creates an enormous workload for the instructor and teaching assistants as there is never one solution to a problem to grade. But the benefit to the student makes the effort worthwhile because it creates the real-life scenario memory upon which the student can draw in future endeavors outside of the realm of the university education.

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