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STRUCTURAL EDUCATION
A NEMESIS TO ARCHITECTURAL EDUCATION

by

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STRUCTURAL EDUCATION: A NEMESIS TO ARCHITECTURAL EDUCATION

INTRODUCTION

During this century, the study of structures has been a part of almost every architect's education. In the schools of architecture, the configuration of the structural curriculum has varied over the years, but there has always been a recognized need for the student to acquire some level of structural knowledge. The question which has been raised in recent years is not whether structural subjects should be a part of architectural education; rather, the debate centers around the subject's general content, the level of skill to be acquired, and the method of presentation.

Prior to the mid-nineteenth century, structural design was primarily empirical and intuitive. Structural knowledge was passed on from the experienced practitioner to the apprentice. Around the middle of the last century, the era of empiricism started to give way to the more formal theoretical approach of structural mechanics. This transition paved the way for the introduction of formal structural studies into the classroom. Most of the schools of architecture continued to place great emphasis on structural studies up until the 1950's. Generally, these studies were centered on the very formalistic theories of structural behavior. Due primarily to the rigor of the mathematical analysis of structural systems, very little time was devoted to the creative aspects of structural design.

During the last twenty-five years, the schools of architecture have attempted to break away from the formalized engineering approach, some-

times referred to as the "Theory of Structures," in search of a more creative approach to structural education. In most cases, the break away was complete, but the search goes on.

In this paper, I will attempt to identify the pertinent aspects of the problem of teaching structure to undergraduate students and propose a solution to the problem. The proposal is not necessarily unique. It has been heavily influenced by the thinking and experiences of others. This influence has been both positive and negative, but even negative results can lead to pedagogical progress.

My attitude toward structural education has been influenced by twenty years of engineering and teaching experience in the field of structural design and analysis. During this period, contact with engineers, architects and students of both professions has left me with strong feelings about the goals of structural education and the means through which these goals might be achieved. I do not wish to imply that the analysis and proposal presented in this paper is in no way errant. A workable solution can only be developed by application, evaluation and continual improvement through experimentation.

DISCUSSION

Structural Education: The Past and the Present

Before the middle of the nineteenth century, structures were designed and built on the basis of empirical information and intuition. Although I am sure that there were many catastrophic failures, there were also many beautiful and structurally correct buildings erected. Many of these buildings are still standing today.

During the middle and latter parts of the nineteenth century, statics and the theory of elasticity became more formalized and these subjects were introduced into the curricula of the schools of engineering. The need for structural training for architects does not seem to have developed until the early part of the twentieth century. This need arose out of the "modern movement" in architecture and the trend toward the exposure of structure in the buildings. The architectural schools borrowed from, or employed directly, the structural curriculum of the schools of engineering. The structural training during this period might have included physics, mathematics up through differential equations, statics, dynamics, two courses in the mechanics of materials and perhaps three or four courses in the design of steel, timber, and concrete structures. This series of courses constituted a very rigorous program of study which provided students with the structural knowledge needed plus the confidence necessary to apply the knowledge in the analysis of existing structures. Considering the society as a whole and the students in particular, this program of structural studies was appropriate for the time.

The period around the turn of the century and leading up to World War II was an exciting time from a structural point of view. New appli-

cations of materials and construction techniques were being developed by engineers and applied by architects. This, I am sure, made the rigorous study of structures very relevant to the students of architecture. There was obviously a need to know.

During the 1950's and 1960's, we entered the space age. A whole new glamorous frontier was opening up for the engineering profession. The emphasis in engineering education switched from pragmatism to theoretical analysis. Courses which had been taught from a practical point of view were reduced to mathematical exercises.

In the early 1960's the digital computer was developed to the point that it was convenient and simple to program and use. Vast new structural systems were subjected to computerized structural analysis. Complex structures, which once required expensive laboratory study, could now be analyzed theoretically through the use of the computer. The engineering faculty moved from the laboratory to the computer terminal.

This, in my opinion, was a very unfortunate transition. True physical experimentation in the laboratory requires a great deal of creativity; an intuitive approach to structural research. When faculty are involved in this type of endeavor, they cannot help but understand the reality in the mechanics of structure. The physical involvement and understanding tends to be carried over into the classrooms, and this makes the subject of structures come alive. On the other hand, theoretical research can become so sophisticated that the subject becomes incomprehensible to undergraduate architectural students.

At about the same point in time, the schools of architecture were becoming enthralled with the prevailing social revolution. The emphasis was shifting from the mundane subjects, such as structures and systems,

to the social and behavioral sciences. This period in architectural education has been called by some people the era of "talkitecture."

The result of the shift in emphasis on the part of the two schools in education has been to cause an increase in the schism between engineering and architecture; two professions that were once nearly synonymous. It was inevitable that the schools of architecture would take a close look at the relevance of the structural education being offered their students by the schools of engineering.

During the last two decades, many schools of architecture have established their own curriculum for structural education. In order to establish a structural curriculum, a choice had to be made: either stick with the traditional courses or develop a completely new course of study. Few schools of architecture were staffed with faculty able or willing to undertake the teaching of the traditional courses. Therefore, the development of a completely new curriculum was the most logical choice, a choice that offered the possibility of making the subject of structures more applicable to the architectural students.

A cursory survey of the curricula introduced in various schools of architecture indicates that a number of different approaches are being explored. Although these curricula vary in rigor, they have one thing in common: most schools have condensed what had been a seven or eight semester sequence of courses to a two or three semester sequence. This condensation has limited the amount and precluded the reinforcement of the material presented. Reinforcement is imperative if the students are to gain any confidence in the application of their newly acquired knowledge.

One popular method of presenting structural information has been survey courses. These courses treat the subject of structures in a superficial way. Words, pictures and diagrams are used in an attempt to describe structural action. Often these survey courses are presented without calculations of any kind and leave the students in a state of bewilderment. Structural decisions cannot be made by a person who has had nothing but a brief overview of the subject of structures. This is comparable to expecting someone to write poetry in French after one brief course covering the conversational beauty of that language.

At the other extreme is the "cookbook" method of teaching structures. This method requires a minimum of thought; only a set of formulae and a list of "rules of thumb" are required. The students learn to apply the proper formula or rule of thumb at the appropriate time and place. The cookbook method may be a valid approach to teaching structures in a technical school, but it should have no place in a school of architecture. This method requires no rationalization by the students. To succeed in the classroom they need only jump through the proper hoop at the proper time.

The formalistic approach to the teaching of structures used by the schools of engineering have been and are very rigorous in the textbook sense. The engineering approach is not appropriate for the architectural student who must learn to make preliminary design decisions involving function, aesthetics and economics, all of which hinge upon the definition of the structure. The architect must be able to explore various structural systems in terms of form, function and economy.

In an effort to develop an appropriate pedagogical approach to structural education in the schools of architecture, the student of archi-

ture and the architectural profession will be examined, and their needs and desired abilities will be reviewed. Faculty requirements will also be examined in light of the needs and abilities of the students. Based upon this review, a new approach to structural education will be proposed.

The Students

The students of architecture come from diverse backgrounds and have been exposed to a variety of experiences. Most of the students are products of the public school systems where they commonly have had little exposure to creative thinking and rationalization. Even though a student may have been exposed to courses in mathematics and physics in high school, he has a limited grasp of the subjects because of a lack of reinforcement through application. A beginning student should not be expected to have any appreciation for structural systems in buildings. Unfortunately, this lack of appreciation perseveres when the studio courses place little or no emphasis on the structural aspects of architectural design. The problem of appreciation and recognition can be easily remedied by making the students aware from the very beginning that a structural understanding is a necessary and important part of architectural education.

The faculty entrusted with the teaching of structural subjects must have great empathy with the students and with the subject matter. The students must be made to feel a physical awareness of structures and their application. The emphasis must be placed on creative thinking and rationalization.

In the past, and unfortunately still today, the subject of structures has been presented with an aura of mysticism. Students need to be made aware of the fact that man has struggled and continues to struggle in

an effort to understand and relate to the forces of nature. He must be made to feel that by learning about the inner workings of structures as we understand them, he is joining the struggle; he is becoming a participant instead of a spectator.

The Profession

It would be very presumptuous of me to try to express the desires and requirements of the architectural profession in regard to its need for structural education. My contact with the architectural profession over a period of years has left me with some strong impressions about its needs, and my association with the engineering profession over the last twenty years has exposed some very definite needs in its structural education. Since this paper deals with structural education in the schools of architecture, I will not attempt to expand this discussion into the area of engineering, but let it suffice to say that the problems and solutions expressed here would apply to both professions.

The architectural offices in this country vary in size from the one and two man offices up to the large corporate office employing hundreds of professionals of all types. The responsibilities placed on those employed by these offices will vary depending upon the organization and the type of work with which they are involved.

Based on my contact with the architectural profession, I can conclude that the aspiring new professionals graduating from the schools of architecture need to have a broad base of technical knowledge and the ability to think creatively in the application of this knowledge. Although a structural engineer may be called upon to perform the final structural calculations, the architect needs to have the ability to make preliminary

structural decisions.

During the creative phase of a design, it is important that an architect be able to make quick and simple structural calculations which will allow him to determine the feasibility of alternative structural systems. In order to do this, the architect must understand the inner workings of the various systems and be able to simplify the systems to the point that the possible structural requirements can be approximated. This process should be an integral part of the overall design sequence and, if properly applied, assist the designer in the execution of a complete work aesthetically, functionally, and structurally.

The development of this ability cannot happen in a short period of time, not even in the course of a five year academic program. The schools of architecture can, however, accomplish a great deal in the development of this ability and the necessary mental attitude. The approach taken must, I feel, be philosophical in nature. We must generate the ability to think creatively in all aspects of design.

In the writings of Pier Luigi Nervi and Felix Candala, the word "intuition" appears in regard to structural design quite often. This word should not be taken literally. What is meant by these men is that an architect should assimilate structural knowledge and practice the art of structural design until it becomes an integral part of his thinking; he acts in a seemingly intuitive way.

In this context, the goal of structural education should be to produce young professionals with an indepth knowledge of structural mechanics and systems, and with sufficient practice in the application of this knowledge to allow them to think "intuitively."

The problems which must be faced by the architect of the future promise to be the most challenging of any time in the history of man. The rapid population increase coupled with limited natural resources requires that future buildings be efficient in the utilization of these resources, and, at the same time, provide society with a pleasant environment in which to live and work. The pedagogical community must strive to provide the strong background necessary to enable their students to meet this challenge.

The Faculty

The faculty required to teach structures in the schools of architecture must be knowledgeable and creative, but, above all, they must have empathy with the students. They must have the patience to take the students from where they find them and move them toward specific goals in a logical way. The faculty must challenge the students to explore structural issues. They must insure that the students understand the assumptions made in the development of the theory of structures. They must remain aware that the students are young adults and, as such, they are trying to cope with a variety of problems over and above those presented in the classroom.

The requirements for the structural faculty seem to be the same as that which might be established for the teaching of any university subject. The difference lies in the subject matter itself, a subject which is as alien to an undergraduate student as is the theory of relativity. The faculty must accept the student's lack of understanding and search for ways to bridge the gap between ignorance and knowledge of the physical reality of structures.

The faculty must organize programs for structural learning which are integrated with the overall program of design education. The structural curriculum must be rigorous and demanding, and the commitment of the faculty must be equal to that expected from the students.

The major concern of the faculty in the schools of architecture must be with the strength of the educational program. To many contemporary educators, a rigorous course of study precludes popularity, which has become a very important issue to individual faculty members as well as to colleges who are trying to bolster sagging enrollments. To deny that popularity is an issue in higher education is a mistake, but to equate laxness with popularity is an even greater mistake. The future depends on the abilities of our students to solve the problems generated in the past and present, and this requires the best possible education. With the exception of a brief period in the 1960's, students have always come to the university seeking guidance and leadership from its faculty. This places the responsibility for developing a course of study which will equip the students to be creative in their chosen field squarely upon the shoulders of the faculty of the university and the schools therein.

A Proposed Solution: A Philosophical Approach to Structural Education

The goal of structural education in the schools of architecture should be to develop a competence in structural design. The students must understand the forces that are brought to bear upon a structural system and to visualize how the forces might flow through that system in an efficient way. Architectural students must understand the major structural systems, how they work and their limitations. They must have a basic knowledge

of the primary structural materials, as well as soils.

Without this basic knowledge, an architect will never be able to fully release his creativity in the search for better solutions to old and new problems. He must know his media and how to manipulate it in order to achieve the desired results.

To enable the students to achieve the desired capabilities, they must be encouraged to participate in the teaching-learning process. In the past, the presentation of the course material on structures has been very formal. Facts are presented, example problems worked, homework problems assigned, and finally, for the purpose of evaluation, tests are given over each block of material. At no time in this process is the student allowed to think, form judgements, ask questions, and draw conclusions. Since there are no real structural problems presented in the "FACT, EXAMPLE, PROBLEM, TEST" format, it is no wonder that the student cannot apply whatever knowledge that he may have gained.

In order that the graduates of architectural schools may achieve the level of ability that is desired, it is proposed that a philosophical approach be used in the teaching of structural subjects from the very beginning. This approach to the teaching of structures would require the students to learn the mechanics of structures in a rational way. With the guidance of the faculty, the students would explore and investigate the action of forces on structures and the way that these forces flow through a structure.

Before embarking on a series of courses in the philosophy of structures, the students should have at least one course in mathematics beyond college algebra, and a course in college physics. These courses would form the

basis upon which the philosophy of structures could develop.

The series of courses in the philosophy of structures would be broken down into three parts. The first part would cover the mechanics of rigid and elastic bodies. The second part would deal with basic structural systems, while the third would apply the knowledge gained in parts one and two in the design analysis of a variety of real structures.

In the beginning, the course format would be that of experimentation, observation and analysis. Rather than being spoon fed, the students would proceed under the guidance of the faculty to explore and rationalize the actions of forces on structures and the material of the structures.

For example, the concept of force could be introduced through a series of questions answered through experimentation and reasoning:

What is a force?

How does a force occur?

What effect does a force have on a structure?

Does a force occur singly or does it occur in pairs?

How would you graphically depict a force?

Questions such as these can be answered through simple experimentation and observation, such as pushing and pulling a book around on a desk top. Feeling the effects of forces acting on the human body is an excellent way to begin understanding structural response to forces.

All of the basic information can be presented and absorbed in this rational way. At first, progress will be slow. The students have had little experience in thinking for themselves. However, as they progress from the concept of a force to the moment of a force, to the equilibrium of a force system, the process will become more instinctive, and the pace

can be accelerated. A standardized vocabulary will be developed, verbal problems dealing with real structures solved, and mathematical and graphical descriptions of the verbal problems developed.

Only real physical problems will be introduced. If simplification of the real problem is required, the students must make the simplifying assumptions and be able to justify them.

Once the students have learned to cope with the external forces acting on structures, they will have a fairly good grasp of the MECHANICS OF RIGID BODIES. Next, the student will proceed to develop a description of the internal forces acting within the structural material under the action of various external force systems. Once again, experimentation and direct observation will be used to help develop the "theory of elasticity." In the early stages, the experimental models can be very simple: a rubber band, an eraser, a plastic ruler, a piece of sponge rubber, a paper clip. As the theory develops, more sophisticated experiments can be introduced using real structural materials in a laboratory setting.

Much care must be taken in the investigation of the mechanics of materials. The theory must develop in a logical way and any required simplifying assumptions must be thoroughly justified. The response of the experimental model must always be related back to the external force system.

Once the theory has been developed and is understood, the students will have reasonable understanding of THE MECHANICS OF ELASTIC BODIES.

Throughout the first part of the structural study, no textbook would be employed. The students will be writing their own book based on their experiences in the study of the Mechanics of Rigid and Elastic Bodies.

A syllabus of study would be presented for each phase of the program. The syllabus would contain the objectives of each phase, and it would also ask the questions that must be answered through experimentation before moving on to the subsequent phases of study.

Following the basic courses in the Mechanics of Rigid and Elastic Bodies, a study of Structural Systems would be undertaken. This course would explore the action of structural systems, both determinate and indeterminate. The study of structural systems could be accomplished in a more traditional manner, or the philosophical approach could be continued. This course would investigate all of the standard structural systems in use today.

The structural curriculum would be culminated by a two semester course in structural design and analysis. During this part of the program, the students would do the preliminary design calculation, consider various structural systems and decide on the system most appropriate to satisfy the functional, aesthetic and economic aspects of the proposed building. This analysis could be carried out on a student design project or on an existing building. Through this process, the students would gain confidence in their abilities, learn to use the structural parts of the building codes, and gain insight into the methods used in the solution to actual design problems.

Coordination of the Structural Curriculum

The study of structures must be coordinated and integrated with the design and construction courses within the schools of architecture. For example, a roof framing system discussed in Structural Systems should also

be covered in a course on construction technology. The design studio faculty should encourage the students to incorporate a proposed structural system in all the design proposals, show positions of the necessary supports and ensure that adequate depth has been allowed for the spans anticipated.

The fifth year studio courses should insist that structural design be an integral part of every project. The students of the upper level design courses should be encouraged to experiment with structural systems in their designs. They should become familiar with the literature on architectural designs and structural solutions of the past. Many of the past masters of architectural design were also masters of architectural structures, and they used the structural systems to enhance their designs. There is much to be learned from the experiences of the past.

Course Descriptions

The following are brief course descriptions for each course proposed in the structural curriculum.

1. Applied Mathematical Analysis of Curves, Surfaces and Volumes.
One course covering the development and evaluation of curves, surfaces and volumes. This course should require college algebra and trigonometry as prerequisites.
2. Physics. One course covering mechanics, heat, light, sound and electricity. At least one half semester should be spent on mechanics. A laboratory should be included.
3. Mechanics of Rigid Bodies. A one and one half semester course covering the mechanics of rigid bodies. Various force systems will be investigated and their effect of rigid bodies rationalized.

4. *Mechanics of Elastic Bodies.* A one and one half semester course covering the mechanics of elastic bodies. Various force systems will be investigated and their effect on elastic bodies rationalized.
5. *Structural Materials.* A series of mini-courses investigating the physical properties of the most common structural materials in a testing laboratory. Each mini-course would cover one material and would vary in duration from four to six weeks. The mini-courses would be taken concurrently and integrated with the course on the Mechanics of Elastic Bodies.
6. *Structural Systems.* A course designed to explore the action of structural systems, both determinate and indeterminate. The course would investigate various standard structural systems and explain the approximations that can be made in the analysis of each system. This course would also act as a staging ground for other courses. A course where many loose ends can be brought together and become relevant.
7. *Design Analysis.* This would be a two semester course bringing all of the previous courses to culmination. In this course the students would do the preliminary design calculations, consider various structural systems which might be appropriate, and make decisions on these systems and their components for existing buildings or for buildings designed by the students. The students should gain confidence in their structural design capabilities and gain insight into the methods used to develop a logical proposal. This course would introduce the students to the building codes in use today.

Sequencing of the Structural Courses

The following is the proposed sequencing for the structural and structurally related courses in a five year architectural curriculum.

<u>Semester 1</u>		<u>Semester 2</u>	
Applied Mathematical Analysis		Physics	4 hrs.
of Curves, Surfaces and		Physics Lab	1 hr.
Volumes	3 hrs.		
<u>Semester 3</u>		<u>Semester 4</u>	
Mechanics of Rigid Bodies	3 hrs.	Mechanics of Rigid and	
		Elastic Bodies	3 hrs.
<u>Semester 5</u>		<u>Semester 6</u>	
Mechanics of Elastic Bodies	3 hrs.	Structural Systems	3 hrs.
Materials Lab	2 hrs.	Construction Techniques 1	3 hrs.
Design 1	5 hrs.	Design 2	5 hrs.
<u>Semester 7</u>		<u>Semester 8</u>	
Design Analysis	3 hrs.	Design Analysis	3 hrs.
Construction Techniques 2	3 hrs.	Design 4	5 hrs.
Design 3	5 hrs.		
<u>Semester 9</u>		<u>Semester 10</u>	
Design 5	5 hrs.	Design 6	5 hrs.

SUMMARY

Throughout this report I have attempted to establish the fact that the study of structures is a necessary and important part of an architect's education. It has been emphasized that structural education in the schools of architecture should be design orientated. The traditional as well as the contemporary methods of teaching structural subjects have been examined in light of the needs of the students and the profession and are found to be inadequate.

The philosophic approach to the teaching of structures has been introduced. This approach requires the students to become actively involved in the learning process. Throughout the series of structural courses, the students are required to think, form judgements, ask questions and draw conclusions. No textbooks are used, and all of the problems to be investigated are drawn from the real physical world.

The approach proposed is unique. It would be difficult to implement, and the progress of the students would be slow *in the beginning*. The results, however, would more than compensate for the difficulties imposed. The students would, perhaps for the first time, understand the concept of structure and be able to apply the knowledge gained in a rational way.

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ABSTRACT

The goal of structural education in the schools of architecture should be to develop students with competence in structural design. The students must understand the forces that are brought to bear upon a structure and to visualize how the forces might flow through that structure in a logical and efficient way. Architectural students must understand the major structural systems, how they work and their limitations. They must have a basic knowledge of the primary structural materials, including the structural capacities of soils.

During the creative phase of a design, it is important that an architect be able to make simple and rapid structural calculations, which will permit him to study and determine the feasibility of alternative structural systems. In order that he be able to do this, the architect must understand the inner workings of the various systems and be able to simplify the systems to the point that approximations of the possible structural requirements can be made. This process should be an integral part of the design sequence. The architectural student should assimilate knowledge and practice the art of structural design until it becomes an almost intuitive process.

To accomplish these goals, a structures curriculum has been proposed. At the heart of the proposed curriculum is a three semester sequence of courses covering the mechanics of rigid and elastic bodies. These courses would be taught by what I have designated the "philosophical approach."

This approach involves the students in experimentation and rationalization. No textbooks would be used in this segment of the curriculum. A syllabus would be provided and the faculty would actively guide the students toward the established goals.

The proposed learning method should enhance the student's ability to think independently. Problem solving in the other areas of design will reinforce the reasoning ability of the student.

Finally, the study of structures must be coordinated with the courses in construction technology and with the design studios. The coordination of these courses will enhance the individual courses and show the relevance of structural decisions to the design process.