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Culture, history, technology and American timber architecture

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A liberal arts framework is formulated to teach structural engineering design and explicitly integrate architecture and structure. The first element of the curriculum presents and investigates architecturally and structurally significant buildings in their historical and cultural contexts. The second element is the analysis of these buildings to identify the reasons for their form, construction technology, and successive transformations or adaptations as the technology evolved over time or toward different cultures. The third component is devoted to qualitative methods of engineering analysis and form-finding to deal with the abstract nature of incompletely defined structural design problems. The fourth component teaches various design theories and approaches to the integration of architecture and structure. The whole curriculum is presented in a Beaux Arts studio format.

WCTE'98 - 5th World Conference on Timber Engineering

Sous ce titre, la chaire de l'EPFL IBOIS organise sous la présidence du professeur Julius Natterer la 5e conférence mondiale sur la construction en bois, qui se déroulera du 17 au 20 août 1998 à Montreux.
A cette occasion, nous présentons ici un exposé sur un mode de construction qui a connu et connaît encore une grande faveur sur le continent nord-américain.

Rédaction

1. Introduction

1.1 Object

The attempt over the past three years to develop a consistent series of structural engineering courses for the graduate program of a department of architecture led to a curriculum to teach and practice structural design using a liberal arts framework that explicitly integrates architecture and structure. For the purpose of this paper, these curriculum elements are presented within the context of wood buildings representative of typical American timber architecture.

1.2 Liberal Arts Framework

The liberal arts education framework in this case means including the historical, cultural, and social significance of buildings in the design of their structure, as well as the traditional topics of a normal engineering curriculum.
Qualitative and intuitive methods of design and analysis are taught in conjunction with traditional analytical approaches of structural analysis. These are more appropriate and often more powerful than analytical methods when dealing with abstract structural concepts or incomplete problems such as encountered in design. A liberal arts framework places structural engineering clearly in a social context, giving it more significance. It broadens the palette of structural design tools available and increases the potential for integrating the process and results with other design professionals – thereby increasing the probability of success and acceptance of the buildings.
These issues occupy that critical interstitial space between engineering and architecture, covering such issues as aesthetics of structural form, efficiency of the structural function, and constructibility.
The key elements of the curriculum are as follows:

- historical and cultural influences that shape the architecture and structure of important buildings
- evolution of construction technology in history and culture
- qualitative engineering methods
- design theories or approaches.

These are taught using a Beaux Arts studio approach.

2. Components of the curriculum

2.1 Historical and cultural influences shaping structure and architecture

The historical significance of buildings is presented simply and factually to help students learn to see the relationships among architectural elements and understand the structural parameters relevant to various construction technologies. These include form, span, order, safety, loads, materials, environmental conditions, and long term preservation and protection. The historically or culturally significant buildings used as examples help orchestrate the subsequent analyses according to methods relevant to the design process. Many of these buildings illustrate their designer's ability to investigate the extremes of simplicity of form and construction - a simplicity resulting from an excellent understanding of engineering mechanics and construction technology.
Much of contemporary engineering teaching focuses on the mechanics of primary structural forms such as the beam and the column, or the evaluation of spatial structural systems with nonlinear theories. Most textbooks for so-called "structural design" courses parallel the content of engineering design codes instead of further developing the knowledge of engineering systems and their design. It is therefore not surprising that most engineering students have little awareness or affinity for designing and building advanced structural systems.
Engineering students must learn to be aware of the context in which their engineering work will be placed and that the results will be evaluated by society at large. For engineers to be a proactive part of a successful "builders culture", they need to be exposed to a larger number of important buildings within their cultural context, and recognize the role of these buildings in the transformation and evolution of societies.
Students need to understand why and how different cultural, social, religious, and physical environ-

ments lead to different architectural statements and building forms and must, therefore, be designed according to different structural systems.

Fay Jones' Gothic-inspired Thorncrown Chapel (fig. 1) was built in 1980 in Eureka Springs, Arkansas, and earned a Gold Medal from the American Institute of Architects. His architecture makes specific references to Frank Lloyd Wright's organic Prairie Style. By using the simplest possible wood structural element, the 2 x 4, the chapel bears Fay Jones' highly personal and undeniably American signature. The project is internationally known because of his ability to express a "sacred structure ... a space that is not just physical, but metaphysical." [1][1]

Fig. 1. – Thorncrown Chapel by Fay Jones, 1980, Eureka Springs, Arkansas

The following example shows the corresponding religious architecture of two religious communities, Quakers and Shakers. The Meeting House (fig. 2) for a small Quaker community was built around 1900 in West Branch, Iowa - the birthplace of Herbert Hoover, the American president during the 1930s depression (and an engineer).

This simple two-room worship building has a removable central partition to separate women and men.

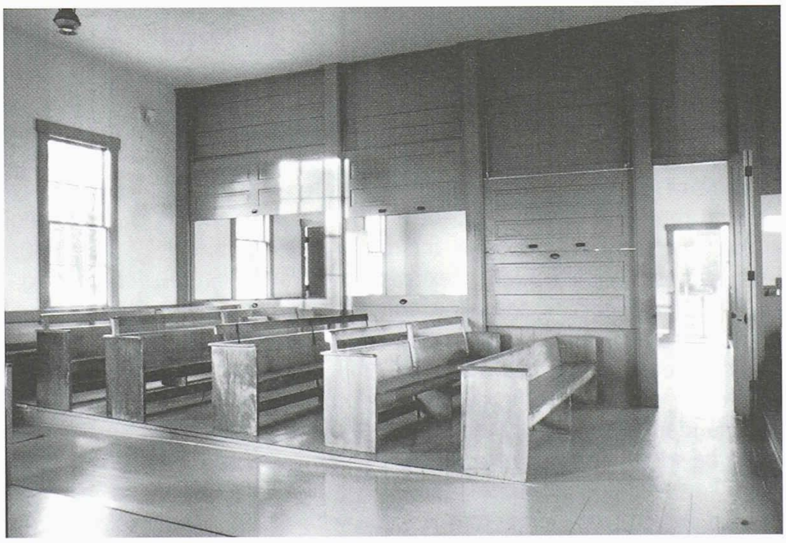

Fig. 2. – Quaker Meeting House, c.1900, West Branch, Iowa

The Quaker worship consists of prayers, meditations, songs, and directed discussions with the elders sitting with the congregation - hence the pew arrangement.

Although the Shaker religion and worship were derived from the Quakers, their sometimes very dynamic religious dances necessitated a large, open worship place with no obstructions. In the 1822 Meeting House (fig. 3) in Pleasant Hill, Kentucky, the entire first floor is devoted to the worship and has a free space of ±12,5m by 18,5m. The second-floor apartments for

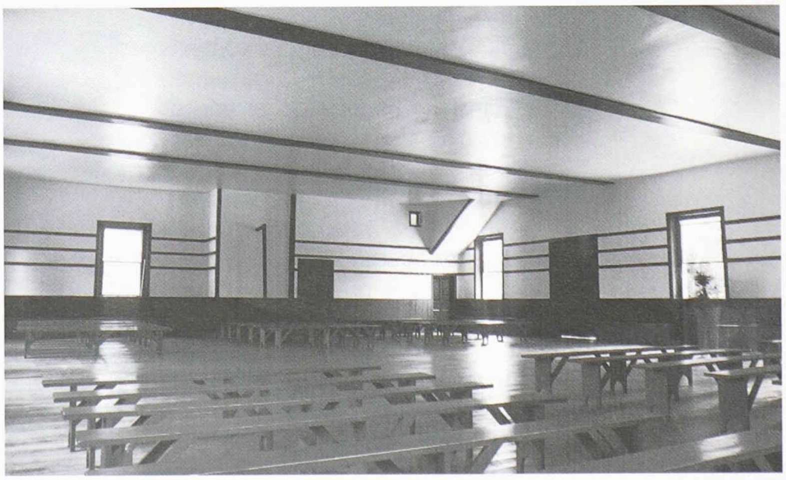

Fig. 3. – Shaker Meeting House, 1822, Pleasant Hill, Kentucky

[1]See the bibliographical references at the bottom of this contribution

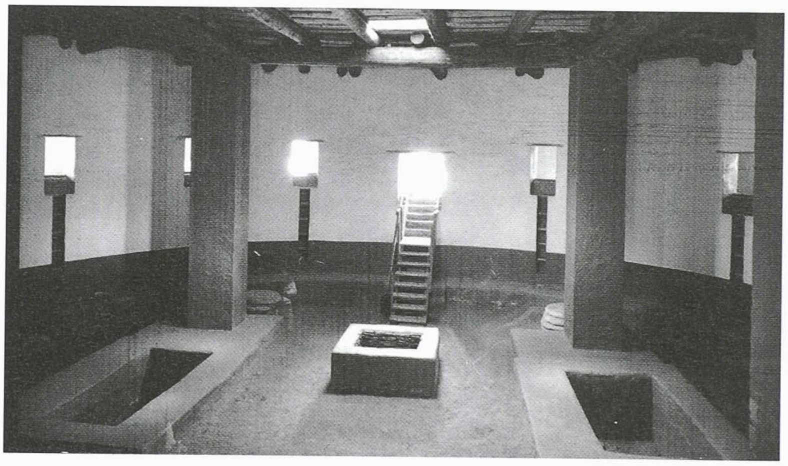

Fig. 4. – Reconstructed kiva, Chaco Canyon, New Mexico

the Shaker elders literally hang from the attic's full-span oak trusses to eliminate intermediate supports on the first floor.
While students must understand that different cultures and religions require different architectures, it is also important for engineering and architecture students to realize that in spite of local influences, basic structural systems are repeated all over the world - structure could be used as a great unifier and description of architecture. It can organize architectural thinking and design because it adapts itself to different architectural styles, while mandating that all built architecture be sound and safe.
The form and use of basic structural systems, for example, may persist in one geographic region for many different types of structures, even as the cultural contexts evolve over time. Vigas (i.e., purlins) are an example of this, as shown in the following two religious examples from the Anasazi culture and the Spanish missions, both in New Mexico but several centuries apart.
The Anasazi pueblos in Chaco Canyon, New Mexico, were built from 800-1100 A.D. on high desert plateaus. The Anasazi used locally cut stone and medium and large logs brought by foot from 150-300 km away. The kiva roof (fig. 4) was typically made with evenly and closely spaced vigas resting on larger girders and columnar logs, supporting small twigs and willow mats covered with sand and gravel [2]. (Similar systems were used by the native Kwakiutl on the northwest coast and the Mandans on the North Dakota plains.)
The earliest Spanish missions go back to the mid-1600s. The Spanish colonial and religious architecture in New Mexico was similar to its Renaissance counterparts. As in the Chaco Canyon kivas, the roof of the Santuario in Chimayo, New Mexico (fig. 5) is made with large, regularly spaced logs, still called vigas in the region [5]. These were brought by horses, however, instead of by foot; the roof is made with planks sawn from the large logs.

This kind of presentation helps architectural and engineering students understand the crucial role of culture in integrating architectural and structural design. It also helps architectural students realize that design concepts must go beyond the rules of aesthetics to account for the complexity of structural requirements and constructibility.

2.2 Construction technology

The examples of history and culture for the structural design course are selected to assemble a knowledge base of facts, principles, and methods to analyze both architecture and structure and consequently, design.
The first part of the analysis correlates the culture, time, and geography to the choice of structural system and material, and includes the description of the origin or inspiration of the structural form. Round barns, for example, were commonly built in the eastern and central regions of the U.S. through the 1930s. The roof of a round barn (fig. 6) from Cedar Falls, Iowa, was built to sustain 2 kN/m^2 of snow and 130 km/h winds. The roof is 4 cm thick and covers a 20 meter circular span.
In the second part of the analysis the students analyze the structure of a typical system and verify the sizes of members. This step correlates the actual sizes to the com-

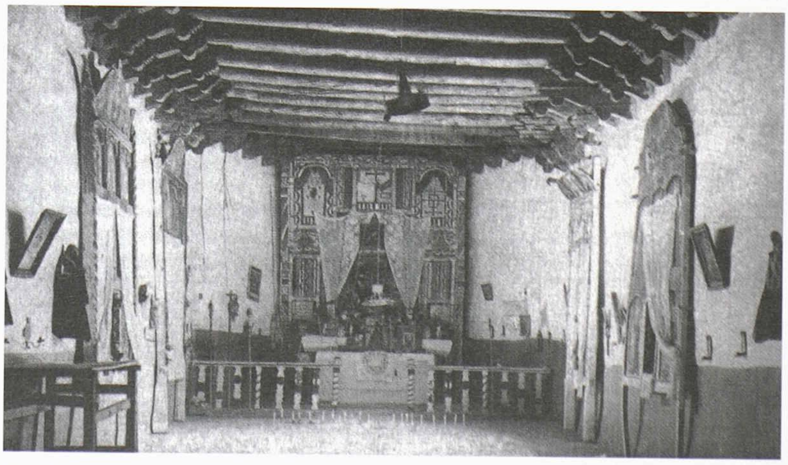

Fig. 5. – Santuario del Seva, Chaco Canyon, New Mexico

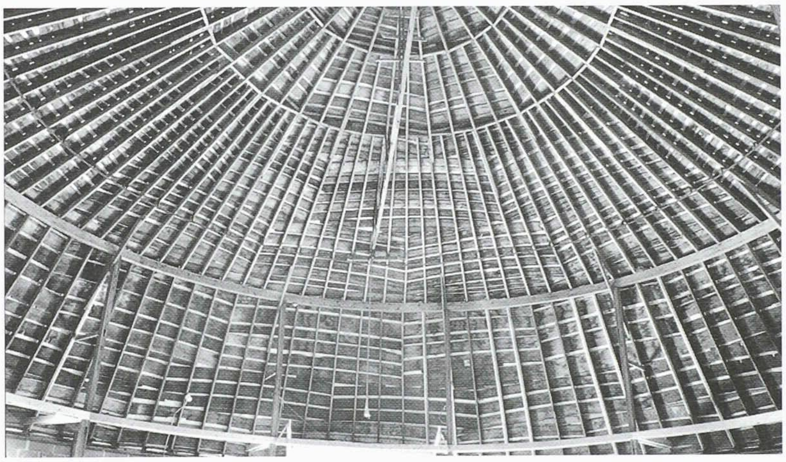

Fig. 6. – Roof of round barn, Cedar Falls, Iowa

puted ones and helps students fully grasp the structural principles.

The system descriptions include discussions of one type of architecture or technological adaptations to different geographic locations. For example,the architecture of Acadian constructions with so-called Norman trusses was common along the Mississippi River and is easily traced to its European roots. The two adaptations below are both original Acadian structures built near St. Louis, Missouri between 1700 and 1800. The small farm (fig. 7) in the sandy plains near the Mississippi River illustrates the use of "poteaux-en-terre" construction, with vertical posts closely spaced with dried mud and straw infill.

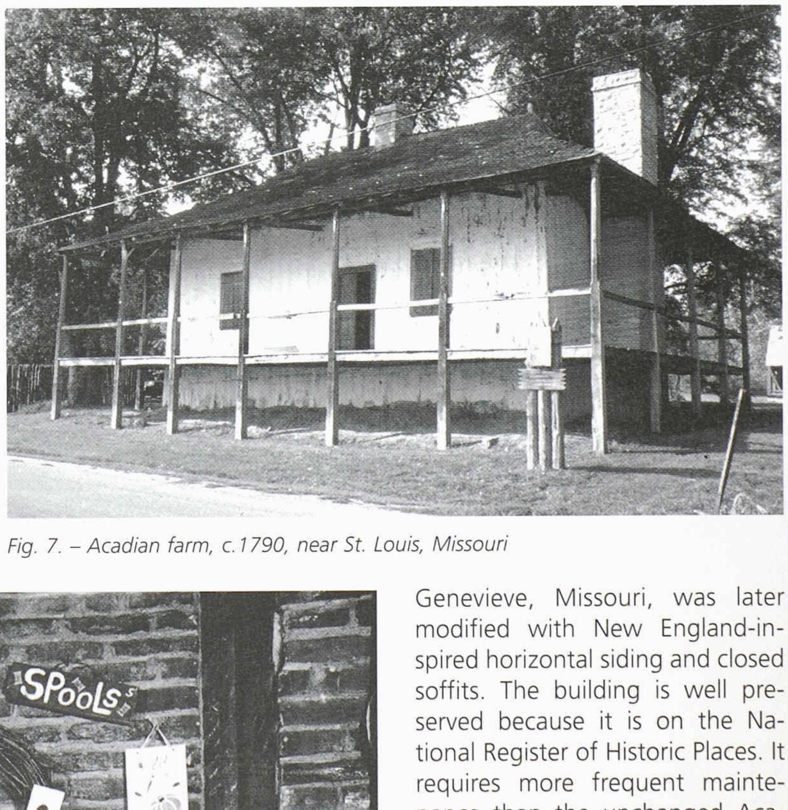

Fig. 7. – Acadian farm, c.1790, near St. Louis, Missouri

The prosperous little town of St. Charles, Missouri, was home to a significant brick factory. In this interior detail (fig. 8) from a tourist shop, the original 1800 brick infill is still visible between the rough-sawn timber posts.

The adaptation of technology can lead to transformation, improvements, or degradation from an ideal system. An original Acadian construction (fig. 9) in Sainte Genevieve, Missouri, was later modified with New England-inspired horizontal siding and closed soffits. The building is well preserved because it is on the National Register of Historic Places. It requires more frequent maintenance than the unchanged Acadian farm shown in fig. 7, however, because the subsequent style modifications promote rotting of the lumber which is completely encased inside the walls and therefore unventilated.

Fig. 8. – Acadian structure, 1800, St. Charles, Missouri

2.3 Effectiveness of design

Some of the examples of precedents provide specific information about the design philosophy of the architects or engineers. Fay Jones, for example, designs ac-

Fig. 9. – Guibourd-Valle house, Ste. Genevieve, Missouri

cording to two principles: Operative opposites, i.e., do the inverse or opposite of the inspiring precedent, and absolutely minimal explicit structure, i.e., every structural element is exposed and functional [1]. His Thorncrown chapel (fig. 1) shows the Gothic-inspired architecture realized with tension elements, which implies that the stabilizing trusses are inside the building instead of outside like their flying buttressed counterparts; all 2 x 4s are essential to the integrity of each truss.

Minnesota architect David Salmela's houses are inspired by Scandinavian architecture, a heritage common to the majority of people living in this region near Lake Superior. This influence is clearly illustrated in his design (fig. 10) for the Brandenburg residence in northern Minnesota.

Saimela's designs are based on what we call "apparent omission." The structure is always apparent, but unlike its timber-framed vernacular counterparts, there is always one crucial element which seems to have been omitted: the tension tie of a truss is replaced by an horizontal beam at the top of walls, the lateral bracing for a wall is replaced by hiding a rigid column in the framing, or a ridge beam is removed by using compression rafters. An example of this is in the top floor attic (fig. 11) of the Brandenburg home [4]. It is framed with conventional dimensional lumber, but is full height because the tension ties of the roof trusses also serve as floor joists.

2.4 Qualitative engineering

Design entails a mode of thinking and problem solving completely different from analyzing or diagnosing problems. Analyzing a specific engineering problem with an identified set of well-defined parameters leads to a unique solution. By contrast, a design problem leads to successive generation of unknown parameters, and from there often to a multiplicity of acceptable solutions which meet the requirements of the intended structural function.

While the skills associated with design thinking can be acquired only by experience, the methods of "design" can be systematically taught. The first condition of "design think" is to transition from a quantitative or mathematical mode to a qualitative or conceptual mode. For example, the correct size of a cable element can be found only by computing an actual tension stress; yet the design solution provided by a cable is only appropriate if pure tension is the primary mode of resistance and lateral deformations are not necessarily detrimental. By contrast, if lateral deformations must also be limited, a truss is probably more appropriate. Deciding between the cable or the truss is more conceptual than analytical, but the decision can be reasoned with the

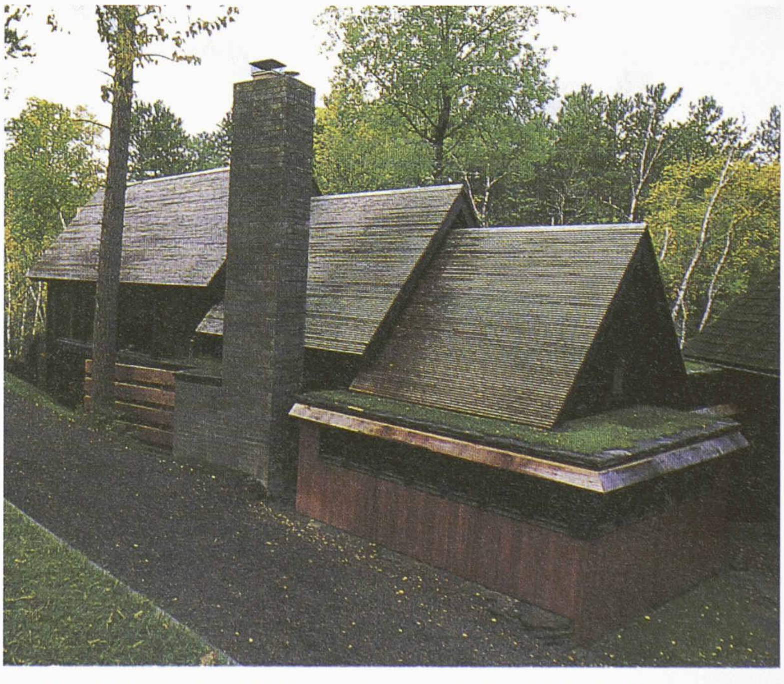

Fig. 10. – Brandenburg residence: living quarters, by David Salmela, Minnesota

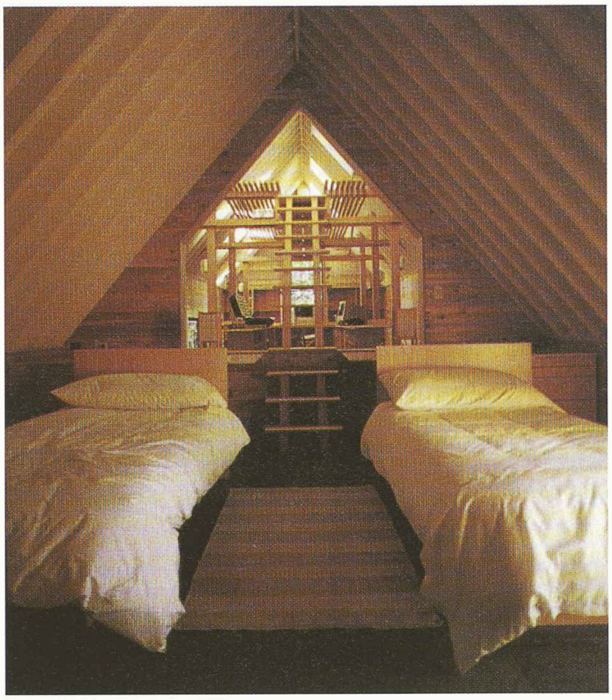

Fig. 11. – Brandenburg residence: attic, by David Salmela, Minnesota

same scientific rigor as the actual computation of stresses and cross-section. Several techniques of qualitative engineering can be taught in an engineering curriculum.

The general form of a structural system may be prescribed by aesthetic requirements or derived from issues such as clearance needs. The actual geometry of the form can be investigated using the methods of graphic form-finding derived from graphic statics. (See Zalewski and Allen's *Shaping Structures - Statics* [3] for more information on specific methods.) These methods are very effective for vector active structural forms, especially funicular forms. Graphic form-finding makes it easy to generate and analyze a series of possible structural forms, allowing it to be a useful bridge between purely numerical and more abstract methods of representing problems.

The discussion of precedents highlights the essential elements of architecture and structure that have led to the success of structures. When dealing with a design problem, these same precedents are used to generate forms and adapt them based on a qualitative understanding of the new problem. This qualitative ability has its roots in the understanding of fundamental structural mechanics and the experience that builds the intuitive component of the knowledge.

As structural engineering leads to the construction of a building, the teaching should ideally also lead to the construction of models. The ability to build appropriate structural forms and structurally correct models can come only from a hands-on approach in which the model builder must understand the material and how to make connections with it. This model-building ability provides a second very powerful way for students to experiment with structural design without having to rely on the analytical methods of engineering. Eiffel, Isler, Freie, Candalebra, and Rice are just a few of the great engineers who have used this method very successfully.

3. Beaux Arts Studio – Teaching Structural Design

The Beaux Arts studio provides an excellent environment to teach engineering in a context that draws material from social responsibility, cultural sources, and technological achievements, and touches on the art of engineering design. The studio format can form the bridge between teaching conventional structural analysis and design problem solving.

A typical design studio revolves around solving a complex problem, over a period of time, using a mix of applied methods and investigative research, with a combination of individual and team work, and with project deliverables corresponding to those seen in typical consulting work. The relatively long-term nature of a studio problem allows the students to be taught how to take a complex, abstract, or incomplete problem formulation and tackle it in successive steps; apply techniques and expand upon them as they go along; view and structure the entire design process as iterative; and integrate design requirements in cultural, architectural, and technological contexts.

4. Conclusion

Teaching a series of structural engineering courses within an architectural curriculum mandates rethinking engineering teaching to facilitate the integration of structure and architecture. It yields teaching facts and methods to develop structural forms that are sensitive to culture and aesthetics, and architectural forms that reflect an inherent understanding of structural and construction requirements.

A Beaux Arts studio frames the issues and philosophically anchors the understanding of the implications of dealing with abstract and complex engineering design problems. A studio efficiently organizes the teaching of qualitative and quantitative techniques more effectively than traditional engineering curricula. It allows students to better grasp the significance of their studies and future professional work by giving them the chance to work through problems in a comprehensive context, thereby gaining a greater appreciation of the broad spectrum of issues.

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Rédaction