Architectural Reinforced-Concrete Building Technology: Teaching Through History, Theory and Practice

EUGENIA VICTORIA ELLIS
University of Idaho

HISTORY

> There is also a kind of powder which, by nature, produces wonderful results. It is found in the neighbourhood of the Bay of Naples and in the lands of the municipalities round Mount Vesuvius. This being mixed with lime and rubble, not only furnishes strength to other buildings, but also, when piers are built in the sea, they set under water. Now this seems to happen for this reason: that under these mountainous regions there are both hot earth and many springs. And these would not be unless deep down they had huge blazing fires of sulphur, alum or pitch. Therefore the fire and vapour of flame within, flowing through the cracks, makes that earth light. And the volcanic clay which is found to come up there is free from moisture. Therefore, when three substances formed in like manner by the violence of fire come into one mixture, they suddenly take up water and cohere together. They are quickly hardened by the moisture and made solid, and can be dissolved neither by the waves nor the power of water.
>
> - Vitruvius, *De Architectura,*
> "On Pozzolana," Book II, Chapter VI, 1

This passage by Vitruvius was written almost two thousand years ago, and yet there is still an element of truth to what he wrote. He describes the process of curing in which concrete transforms from a plastic state to a solid state, however, he attributes this change to the latent heat he believes to be inherent in a material which was formed through volcanic action rather than the chemical process we now refer to as hydration, which was unknown at the time. The most amazing thing is that the use of concrete completely died out at the end of the Roman Empire around 600 AD and was not used again until after the discovery of Vitruvius' manuscript in the fifteenth century. The use of concrete for buildings was not again popularized until after the development of Portland Cement in the nineteenth century. This backdrop of history is used in a metaphorical sense to introduce the students to the materials science of concrete and to describe its physical properties.

Fig. 1. Giovanni Battista Piranesi, Roman concrete infill construction, *Antichità Romane*, 1756.

The beginning of the course is an interweaving of history, and the materials science and physical properties of concrete. Through slide presentations, the students are introduced to significant works of architecture and structure from antiquity to the twentieth-century and to the differences between concrete which is cast-in-place and that which is pre-fabricated. Techniques of storytelling and metaphor are used to unlock the students' imaginations so that they can begin to "picture" concrete as a material in preparation for understanding it as structure. The Pantheon is used as a vehicle to divide the history of concrete into two analogous time periods: ancient and post-nineteenth century.

Through Hadrian's Roman Pantheon (118-128 AD) significant points regarding the materials science of concrete and its use as a structural material are addressed. Early Roman concrete was unreinforced and generally consisted of mortar-cemented rubble used as "infill" construction with the form-work being provided by exterior wythes of brick or, in the case of vaults and domes, was cast-in-place using temporary timber centering to contain the concrete mass until it hardened sufficiently to stand on its own. The dome's construction is used to discuss the relationship between concrete mix design and the distribution of forces within a structure. The Pantheon's dome was cast-in-place, or ***in situ,*** and was hand-layered using aggregate which varied from large tufa stones at the base which carry the heavier loads to pumice and hollow clay jars at the top of the dome where the loads are lighter and the stresses are less; to compensate for the internal stresses developed, the dome's thickness varies from 23 feet at its base to two-feet thick at the 30-ft diameter oculus. The technology used to create the 142-ft clear span of the Pantheon's dome was unmatched until well into the fifteenth century, around the time of the discovery of Vitruvius' manuscript.

Although mid-eighteenth century and not a concrete construction, Jacques-Germain Soufflot's Pantheon (ca. 1764) is used to introduce the subject of post-nineteenth century concrete which is reinforced with steel, and ***in situ*** versus precast concrete. The Paris Pantheon is significant because the entrance portico is constructed of iron-reinforced stone in such a way as to ***anticipate*** the steel-reinforced concrete construction to be developed during the twentieth century. The positioning of the iron-reinforcing to compensate for tension stresses developed within the stone lintels is compared to François Hennebique's patent (1892) for steel-reinforced concrete beams. Hennebique's design is the first example of positioning steel reinforcing for tension correctly within a concrete beam: at the tops of columns and at the bottom of beams at mid-span, with stirrups placed incrementally closer toward the supports. The work of two engineers, Robert Maillart and Pier Luigi Nervi, is used to explain the differences between in situ and precast concrete and to demonstrate the connection between concrete as a material and as a structural system. For example, the timber centering used to construct Maillart's cast-in-place Fliegenbach Bridge (1923) is used to illustrate how in some instances it is necessary to build a temporary structure in order to build a more permanent structure for sitecast concrete construction, and the positive and negative moment diagrams of the Salginatobel Bridge (1930) are used to show how moment diagrams might literally be added together to determine a structural form. Nervi's *ferro-cemento* projects are excellent examples of both sitecast and pre-fabricated concrete systems and innovations in structural design such as isostatic concrete slabs. Nervi is particularly significant because he was both an engineer and a contractor, which means that he built what he designed.

THEORY

> The creative act of the designer, in our age as in ages past, is an act of pure intuition guided by an understanding of statics, and neither can nor should be the fruit of a theory or an impersonal technical formula, nor derived from a preconceived formalism.
>
> \- Pier Luigi Nervi

Due to a legacy set up by Durand and passed down to us through the Bauhaus, design itself has become a method of computation and, at times, may even be reduced to simple formulae. This is particularly apparent in engineering, and as a result is evident in most of the structures sequences taught in our schools today. Most of what we term knowledge is based upon a tradition of rational or scientific reasoning; so much so that we have reduced Roger Bacon's sequence of experience, experiment, mathematics to the single step of mathematics. As a result, most structures courses consist of derivative formulae without real-life application and succeed in obfuscating the subject matter more than developing the student's abilities. Typically, structures is a course most students have to ***endure*** in order to get through an architecture program.

In this course concrete structural design is taught through theory and application. The students are introduced to vertical shear and beam bending moments in preparation for the method of moment distribution and moment estimating commonly used by architects in the preliminary design of reinforced concrete structures. The students are taught the design of concrete beams, columns, footings and foundations through concurrently drawing architectural construction details and calculating member sizes and reinforcing. There are three drawing exercises: 1) Beam, beam-and-slab framing system and beam-to-column connection; 2) Columns, footings and foundations; and 3) Architectural precast-concrete wall cladding. The three drawing exercises together comprise a small set of construction drawings for a two-story plus basement office building. In this manner, the students learn about reinforced-concrete structural technology through reinforced concrete building technology and the process of learning becomes a tangible one, rather than an abstract one.

There was a time when theories of structure were derived from simple laws of equilibration based on geometry, calculation and the observation of the principles of statics. With the advent of descriptive geometry came the architectural drawing and building became a science because the architect could then describe methods of construction without actually having to be involved in the craft of making the building. Because so very few architects in the past two hundred years have constructed their own buildings, most architects today regard drawings as substitute buildings. The experience gained from the direct experimentation with materials by "getting one's hands dirty" and the observance of results obtained by con-

Fig. 2. Students assembling precast concrete wall

structing is difficult to achieve only on paper. The intuition guided by an understanding of statics of which Nervi speaks is one which can only be acquired through the continued and familiar practice of making tangible constructions.

PRACTICE

> Ist, We must know at the outset the nature of the materials to be employed; 2dly, We must give these materials the function and strength required for the result, and the forms which most exactly express that function and strength; 3dly, We must adopt a principle of unity and harmony in this expression,—that is, a scale, a system of proportion . . .
>
> - Eugene-Emmanuel Viollet-le-Duc, "Lecture X: Importance of Method"

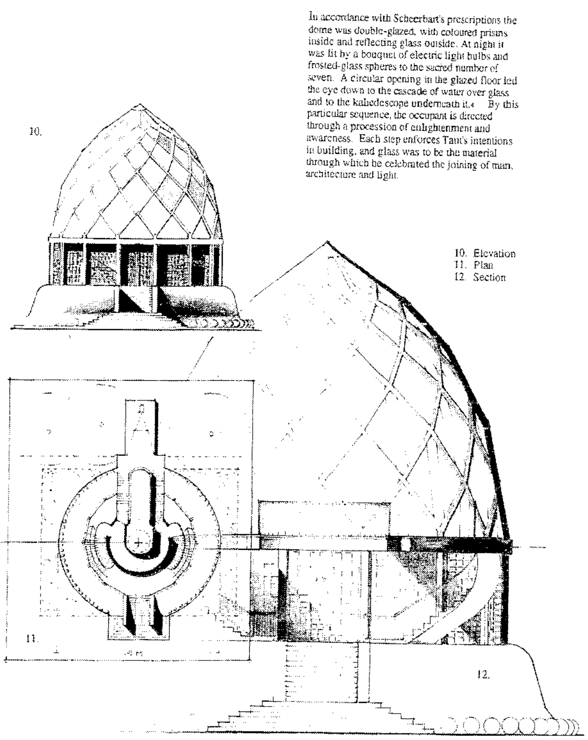
Viollet-le-Duc's definition of architecture was divided into two parts: *theory*, which deals with principles of geometry and laws of statics, and practice, which adapts these principles and laws through continued and familiar service by the hands in such a material as is necessary for the purpose of a design.

In order for the students to acquire a "feel" for the material concrete they are required to participate in a laboratory experiment to design and construct an architectural precast-concrete panel which can be joined with others from the class to build a wall. The objective is to familiarize the student with the materiality of concrete through the design and construction of a 2' x 2' precast concrete panel. This laboratory experiment prepares the student for an understanding that construction itself is the basis of architectural design: 1) by knowing the nature of the material; 2) by using the material according to its nature; and 3) by utilizing a system of proportion to establish a harmonious relationship between all the parts. The laboratory experiment is in two parts: 1) Drawing Exercise which describes the design of a precast concrete panel through dimensioned plans and sections, placement of reinforcement and concrete mix design; and 2) Field Experiment which includes the mixing and placing of concrete and reinforcing, the casting of the panel, and the assembly of all panels to make a free-standing wall. The difference between this lab exercise and the more conventional engineering model is that the emphasis is on what the students can make with the material in lieu of the scientific capabilities of the material. Most importantly, the students have the opportunity to actually construct what they have visualized in their minds and drawn on paper.

ARCHITECTURE (RE)PRODUCTION

> . . . invention no more depends on imagination than imagination has the ability to create anything whatever. The fact is, production of the new - and imagination - are only productions: by analogical connection and repetition, they bring to light what, without being there, *will* have been there. . . Imagination is what retraces, what produces as reproduction the lost object of perception. . .
>
> - Jacques Derrida, "Imagining"

History, theory and practice are combined in the Case Study Project. This project is an in-depth study of an historically relevant building in the use of material and the detailing of the material to reveal and express its nature. The document produced is an exercise in detailing which contains both historical background and significant details. It involves the research and drawing of a completed building in light of the increased understanding of its structure and construction gained in class. The objective is for the student to observe how the character and quality of a building is both a consequence of the methods and materials used in its construction and simultaneously how the desired and achieved character of buildings affects and determines the materials and technology used, with the following emphasis: 1) To conceptually identify the detail with the making of the joint and to recognize that details themselves can impose order on the whole through their own order; 2) To investigate the joining of materials in order to discover how the detail can give character and style to a work of architecture; 3) To investigate the joining of materials in order to discover how the detail can reveal and express the true nature of a material; 4) To investigate methods of construction in order to dis-



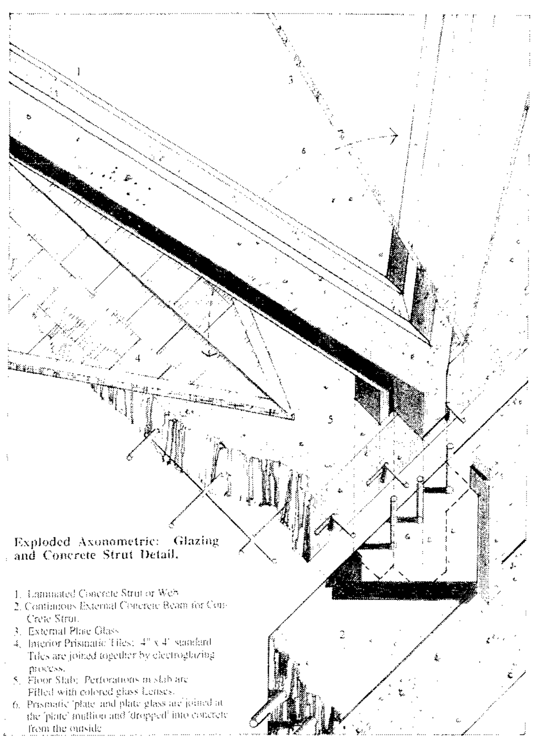


Fig. 3 and Fig. 4. Bruno Taut: Glass Pavilion, Justin J. Rumpeltes, student

cover ways in which available technologies affect the joining of materials; and 5) To speculate on the architect's design objective through discovering a detail(s) which speaks of the work as a whole and captures the essence of the architect's intention. The goal of this project is to familiarize the student with the methods used to express architecture through detail, and subsequently how the detail makes architecture.

An architectural drawing is not a picture of a building but is a "picturing" of the architect's imagination; nor is it a substitute building. Ideally, architectural production is a mimetic process which copies the procedure of production rather than the product. Architects characteristically learn from other architects, however in mimetic imitation it is not what a building "looks" like which is copied but how that building was constructed. The detail is always a joint, a joining of materials, and it is the methods by which the materials are joined which give style and character to an architectural project. The Case Study is a type of architectural (re)production through which the student can construe architecture as construction: a process of making rather than a product made. Through this understanding the student is prepared to translate, transform and invent original works.

REFERENCES

Allen, Edward. *Fundamentals of Building Construction.* New York: Wiley & Sons, 1990.

Architectural Precast Concrete. Chicago: Precast/Prestressed Concrete Institute, 1989.

Billington, David P. *Robert Maillart and the Art of Reinforced Concrete.* Cambridge, MA: The MIT Press, 1990.

Ching, FDK. *Building Construction Illustrated.* New York: Van Nostrand Reinhold, 1990.

Corkill, P.A., H. Puderbaugh and H.K. Sawyers. *Structure and Architectural Design,* 4th edition. Davenport, Iowa: Market Publishing, 1993.

Elliott, Cecil D. "Reinforced Concrete," *Technics and Architecture.* Cambridge: The MIT Press, 1992, 165-197.

Ford, Edward R. *The Details of Modern Architecture.* Cambridge: The MIT Press, 1990.

Frascari, Marco. "A New Angel/Angle in Architectural Research: The Ideas of Demonstration." *JAE* 44/1 (November1990): 11-15.

Guedes, Pedro, editor. "Structural Design, etc," and "Building Materials," *Encvclopedia of Architectural Technology.* New York: McGraw-Hill, 1979, 166-197, 252-263.

Mainstone, Rowland J. "Structural Actions" and "Structural Materials," *Developments in Structural Form.* Cambridge: The MIT Press, 1983, 31-62.

Mark, Robert. "Reinterpreting Ancient Roman Structure," *Light, Wind, and Structure.* Cambridge: The MIT Press, 1990, 49-89.

Perez-Gomez, Alberto. "Architecture as Drawing." *JAE* 3612 (Winter 1982): 2-7.

Polonyi, Stefan. "The Concept of Science, Structural Design, Architecture." *Daidalos* 18 (15 December 1985).

Nervi, Pier Luigi. *Buildings, Projects, Structures 1953-1963.* New York: Frederick A. Praeger, Inc., 1963.

Nervi, Pier Luigi. *Process: Architecture* 23 (April 1981).

Salvadori, Mario. *Why Buildings Stand Up.* New York: WW Norton & Company, 1990.

Shaeffer, R.E. *Reinforced Concrete: Preliminary Design for Architects and Builders.* New York: McGraw-Hill, Inc., 1992.

Viollet-le-Duc, Eugene-Emmanuel. *Lectures On Architecture, Volumes I and II.* New York: Dover Publications, Inc., 1987.