Construction Principles: An Introduction to Architectural Technology

JORI ERDMAN
Drury College

technology — the body of knowledge available to a civilization that is of use in fashioning implements, practicing manual arts and skills, and extracting or collecting materials // Greek — tekhnologia, systematic treatment of an art or craft; tekhne, skill // teks — to weave, to fabricate, especially using an axe

Construction Principles, a course offered in the second year of a professional five year architectural program, provides students with their first approach to concepts of technology as they relate to architecture as well as their first formal educational experience with full-scale construction. The course is taught by myself, an architecture professor, together with the school's wood shop supervisor. The methodology of the course promotes an understanding of tools, materials and construction methods through a format of lectures and lab work, culminating in the full-scale construction of an architectural detail. Fundamental to the course is the belief that architectural education must provide ways for students to experience the act of building and think about the technological questions of building as part of the design process.

Our approach to and understanding of technology is framed through the above definition as well as Heidegger's essay, "The Question Concerning Technology," to be fundamental to the making of architecture, as well as many other applied arts. Architectural education inevitably addresses technological issues directly and indirectly through courses in structures, materials and methods, mechanical systems, history/theory and design. Unfortunately, the more specific idea of "tectonic," or the art of construction, gets lost in the consideration of technology as a purely practical and pragmatic issue. As Kenneth Frampton points out in *Studies in Tectonic Culture*, architecture in its built form is one of the most powerful indicators of our culture and spirituality as humans. Therefore, it is imperative for architectural education to begin to address the ways of making buildings directly, through physical contact with actual building materials and processes, in order to develop architects trained in ways of thinking about the act of construction.

construct(v): -ed, ing, s1. to form by assembling parts; build. 2. to create (an argument or sentence, for example) by systematically arranging ideas or terms (n): 1. something formed or constructed from parts. 2.a. a concept, model or schematic idea. b. a concrete image or idea. the latin root is ster — meaning to pile up

construction: 1.a. the act or process of constructing. b. the art, trade, or work of building. 2.a. a structure, such as a building, framework or model b. something fashioned or devised systematically. c. an artistic composition using various materials; an assemblage or collage. 3. the way in which something is built or put together

principle — 1. a basic truth, law or assumption. 2.a. a rule or standard, especially of good behavior. b. the collectivity of moral or ethical standards or judgments 3. a fixed or predetermined policy or mode of action 4. a basic or essential quality or element determining intrinsic nature or characteristic behavior 5. a rule or law concerning the functioning of natural phenomena or mechanical processes

The course was developed as an experiment in a "hands-on" learning approach. This attitude developed as a reaction to the oft-heard complaint from recent architectural school graduates that their training and education in school did not prepare them for the "real world" of schedules and construction documentation. Many architects practice architecture as a primarily cerebral exercise, rarely finding an opportunity to actually participate in the physical act of constructing the edifices they spend months and sometimes years drafting, editing and re-drafting. Of course, it is easy to rationalize why this has happened and one can only speculate that as information technology becomes faster and more powerful, that the architect will become yet further removed from the construction process. As Edward Ford has stated in *The Details of Modern Architecture*, the evolutionary loss of the craft of architecture is a complex series of events, no one more to blame than the others. Yet he goes on to say that the architects from history whom we agree have contributed the most to the study of form and design, have all also had an implicit or explicit philosophy of building as well, such as Mies van der Rohe and Frank Lloyd Wright. We learn not only from their successes, but their failures as well. For instance, we study the inconsistent results R.M. Schindler achieved when trying to mix local sand with Portland cement for the concrete in his Pueblo Ribera project in La Jolla, California.

Principles of construction were investigated through the course in lectures, demonstrations and lab exercises. Based on the exercises suggested in Mario Salvadori's book, *Building: The Fight Against Gravity*, students performed assignments demonstrating the basic structural principles behind certain shapes and forms, such as the arch and the serpentine wall. Group exercises included working to form a human flying buttress and building models of tensile structures using straws, string and paper. They also observed the appropriate use of various structural systems while on field trips to local building sites and fabrication shops. Once a basic understanding of certain fundamental structural principles was achieved, the remainder of the course was organized around a study of the primary materials used in construction and the principles of their usage and development as building components.

MATERIALS AND TOOLS:

material: greek root is mater or materia—meaning tree trunk, as in hard wood or carpentry, i.e., building

tool: 1. a device used to facilitate manual or mechanical work. 4. something used in the performance of an operation; an instrument

Throughout the course we focussed on primary materials historically used in building, including masonry, wood, concrete, steel and glass. Each material was introduced to the students through lectures and readings, presenting both historical and specific technical perspectives, including cultural and geographical effects on the development of technology and the spatial implications of various materials. There was a conscious effort throughout to expose the students to both typical building practices as well as to expose them to examples of the ways in which architects have thought about and manipulated these materials in less typical applications. Through this introductory component of the course, the students could develop the framework for a working knowledge of accepted practices, as well as begin to think about how their preconceived notions of technology and construction could be challenged and improved.

The physical properties of the materials and tools were explored by the students through the lab exercises. For instance, one exercise involved framing a wall using basic wood stud construction techniques. In this exercise the students were also exposed to different tools through an impromptu race between a normal hammer and an air powered nail gun. Another exercise allowed the students to mix mortar and lay brick in low walls forming a corner. They quickly learned that there is an art to keeping mortar on a brick that they had previously under appreciated. They also learned there is a significant difference between mortar and cement when we realized we had gotten bags of cement, without any sand, instead of pre-mixed mortar. All students participated in lab exercises, thus ensuring that each individual student developed an appreciation of tools and materials. An additional benefit of these exercises was that they could all see the inevitable failures of unskilled laborers and poor craftsmanship, a necessary component of working with any material. Most importantly, it allowed them to begin developing ways of thinking through the construction process logically and productively.

DETAIL CONSTRUCTION:

After the completion of the materials lectures and exercises, the students divided into groups to study different materials in relation to specific buildings and architects as follows:

1. Brick — Louis Kahn — Exeter Library
2. Steel — Frank Lloyd Wright — Fallingwater
3. Steel — Charles and Ray Eames — Eames House
4. Concrete — R.M. Schindler — King's Road House
5. Wood — Greene and Greene — Gamble House

The architects and projects were chosen for several reasons other than their use of the specific materials. American projects were chosen based on the idea that there is a cultural value to place and tectonic expression. It was also hoped that materials consistent with those used in the buildings would be available to the students. Modern works were chosen for their worth as architectural artifacts and would be used in preparation for the History of Modern Architecture course which is taken in the following semester. By studying and reconstructing details from architectural masterpieces, the students were exposed to an understanding of materials and construction techniques which have been subjected to the highest level of thought by great architects and master builders.

Working in groups of six and seven each, the students prepared a 10-page research paper for each project, focusing on issues of construction and materiality, more specifically, in terms of tectonic, and historical significance. By studying the primary materials in depth, they became aware of the ways in which each architect deviated, rejected or developed new ways of looking at standard building practices through the projects. Students then chose wall sections that expressed the essence of the building and the architect's approach to materials and construction. Upon completion of the research component, each group presented their work to the class as a whole, thus allowing everyone to see the comparative value of each architect's approach.

This research allowed the students to appreciate the architect's approach to materials and building processes. This appreciation informed the student's decisions throughout the detail development and construction. For instance, the group studying Louis Kahn and the Exeter Library fully embraced Kahn's famous conversation with the brick wherein he asks the brick what it wants to be and the brick replies, "I like an arch." This lead them to the decision to construct one half of a jack arch from the library. In this section the brick is three rows thick but when it was suggested that they might ease their work and the structural load by creating a "false-front" to the arch by building a boxed out frame and cladding it with one layer of brick, they summarily rejected the suggestion as untrue to Kahn's principles. The impact of the this decision was great as they realized through studying Kahn's actual drawings from the library that each brick had been specially cut at different angles to create a smooth arch, not just one row but all three. Still they persevered and built the arch as intended because of their desire to pursue Kahn's principles; a desire which developed as a result of their research.

Fig. 1. Students cutting brick for Exeter Library jack-arch.

The process of getting the students to arrive at a final solution to the problem of building one half of Kahn's jack-arch illustrates one of the intangible yet key components of the entire course, or in fact, any educational endeavor. This key component consists of asking the right questions and allowing the students to solve the problems which occur throughout the process. For instance, in the Kahn project, in addition to the question of the bricks in the half arch, the students also had to consider the structural integrity of the resultant cantilever. We, as instructors, brought this to their attention. The students proposed a method of reinforcing by placing steel all-thread within the arch as they laid the brick and tying it back into the filled concrete block pier. They proposed that this would provide sufficient structure without further support and wanted to leave the arch as a cantilever to more fully express it as a section. We asked them what they would do if this didn't work and where the possible failures would be. As they worked through these questions, they also realized that there was no way to support the concrete lintel behind the brick, which was also a part of the section. They then came to us with the solution of a stainless steel plate to which the all-thread in the arch and lintels could be bolted and the loads transferred to the pad.

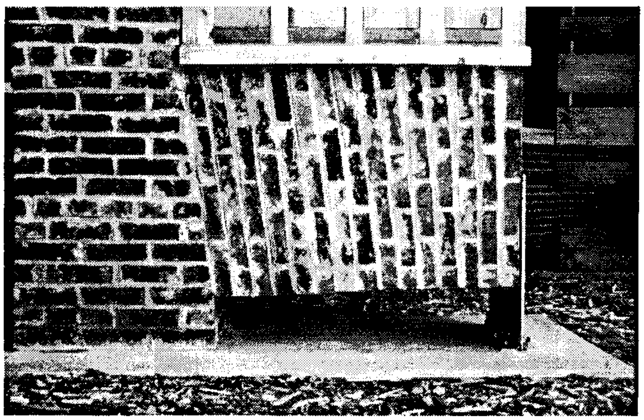

Fig. 2. Completed Exeter Library arch assembly.

By arriving at this solution on their own, with minimal interference by the instructors, the students "own" the knowledge and confidence gained in solving their own problems. This is just one example of our way of getting the students to be responsible for their projects and education. Important to recognize within this as well, is that despite our reticence about giving answers, we were always there to help them think through the issues when they arose.

Simultaneously with the research paper, each group prepared fully detailed drawings and a study model of the wall section they had chosen to build. They prepared lists of materials, tools, and outlined construction schedules required for each wall section. Each wall section is constructed in actual full size materials, coming as close to the reality of the actual building as physically possible. Donations from the local building community supplied the majority of our building materials but when necessary we were able to purchase them with school funds. Through this part of the process, they became aware of the compromises inherent in any built work, for instance, lack of access to redwood for the Gamble House resulted in a compromise on cedar. As the materials were being gathered for the construction process to begin in earnest, preparations were made to the site.

The details were constructed in a planting bed directly next to the northwest entry of the school of architecture, within the area of a covered walkway. This protected area allowed construction to continue in inclement weather and also ensured light for work done at night. Each wall section was approximately 4 feet wide by 8 feet tall and of a thickness which varied from project to project, based on the construction type and materials. The sections rest on 6-18" deep site-cast concrete pads.

Due to the fragmentary nature of the sections, the concrete pads became a small design project for each of the groups. They had to solve the problem of connecting each section to the pad, providing as inconspicuous of a connection as possible, while also providing a solid structure. Two of the groups, Fallingwater and Gamble, made this connection by placing j-bolts in the concrete, onto which their sections, constructed off-site, would be placed. The other two, Kahn and Schindler, placed rebar in the concrete which would be embeded in the piece itself as it was constructed. In order to ensure proper placement of the steel connections, each group constructed templates to be placed over the forms of the pads. The concrete pads follow the outline of each wall section, allowing an additional foot of concrete around the perimeter for structural integrity.

Again, the inevitable unexpected occurrences made the students quickly react and compromise in order to complete the projects on time. For example, the Gamble House group realized as they tried to place their section on the bolts that they had inadvertently misplace the template by four inches. Their solution to the problem was to add an additional piece of wood to the major cross-beam resting on the pad, made of the same wood and treated the same. This solution is invisible to the unaware observer, yet those students will undoubtedly always double-check their measurements in any future construction project.

Fig. 3. Gamble House beams with additional pad attachment.

As the building and construction process unfolded, the students quickly became aware of the limitations of the drawings and models they had previously believed to be complete representations of the details. For example, the Fallingwater team (working in steel to reconstruct the original Hope windows) realized that the hinges were not going to be commercially available so they spent hours designing and making prototypes of approximations of the actual hinges. In the end, their hinges were virtually identical to the originals. In addition, the entire piece had to be constructed of stock steel angles and flat stock so their previously "completed" drawings, in the form of blueprints in the shop, became an inscrutable Rosetta stone of calculations and drawings and re-drawings of each section they had to construct. These tattered blueprints remain the true testament to the thought process they went through as they built the piece.

The students also learned the necessity of improvising tool use and inventing new tools when needed. The Schindler House group, executing a corner of the tilt-up concrete system that Schindler devised for the house, came up with one of the most ingenious and humorous examples of an improvised tool. The process of construction of this corner was to pour three slabs and tilt them into place with two adjoining, parallel pieces on one side and one perpendicular to the others to form the corner. These pieces were bound together with pre-placed rebar which was then cast into place, necessitating

Fig. 4. Completed Exeter Library arch assembly.

additional form-work and a system for bracing the form-work in place. In thinking through the process, they discovering that they would have to develop a way to tamp down the concrete to form the approximately eight feet tall by six inch square corner. This corner was also filled with rebar and even more complicated by the fact that they had approximately eighteen inches between the top of the form-work and the ceiling of the overhang. Finding it impossible to obtain a length of material which was both flexible enough to bend into the form, as well as being stiff enough to actually work, they devised a tool similar to a carpenter rule which had two bolts at each pivot point, which got locked into place as the stick, now dubbed "The Wonder Stick," was bent and lowered into the form. As the pour began, The Wonder Stick was worked fine, until the moment, about 14 inches deep into the pour, when its bolts got tangled on the rebar and summarily became a permanent part of the wall section. This anecdote is not only very humorous, but also demonstrates the students willingness to problem-solve and think through the process.

The Gamble House wall section, which was built in the school's wood shop was the first to be completed and installed. Next came the Schindler House with its tilt-up concrete panels. The Fallingwater detail was constructed in a welding shop off of the school grounds and had to be transported via trailer once it was completed and then the split-face block walls representing the original stone were laid.

The Exeter Library detail, the most complex as it consisted not just of the half-jack arch but also one of the teak carrels, was the last to be completed. Unfortunately, the Eames House wall section was never completed as the students in this group could never agree to proceed.

The final step in the process, which allowed the students a certain amount of time for reflection and provided a framework for that reflection, was the development of an exhibition of all of their process work and documentation. The exhibition, entitled "1:1 Constructed Historic Details," was constructed and opened the semester following the completion of the projects. Through the development of their individual presentation spaces, the students had the opportunity to realize just how much they had learned and to frame that process accordingly. It also allowed the rest of the community to see that there was more involved in these projects than simply the building of artifacts.

Due to the success of the construction project, we will be continuing with the project for the next few years. We project that eventually the continuation of the constructions will move beyond wall sections as the mode of expression. For instance, we may spend one semester exploring the construction of stair details, or roof to wall connections, or column to beam connections. However for this year we are continuing with the construction of wall sections which include: The Millard House (concrete blocks) by Frank Lloyd Wright, The Brion Cemetery (concrete) by Carlo Scarpa, Villa Mairea (wood) by Alvar Aalto, St. Mark's Church by Sigurd Lewerentz and Maison de Verre (steel) by Pierre Chareau.

Fig. 5. Schindler-Chase House detail under construction.

FINAL THOUGHTS

The ultimate success of the course rests in the knowledge gained by the students in going through the process. While the hands-on approach to learning is not necessarily unique, we have found this model to be particularly interesting and successful in getting students to think and feel confident in the knowledge gained by going through this process. Part of the unique quality to the course is the combination of historical significance and construction, with minimal design decisions to be made. We would argue that this is particularly appropriate for Foundations level students and that potentially this project may take the form of a more traditional design-build project later in their architectural education. We would hope that the heightened tectonic sensibilities of the students will stay with them throughout their careers.

In a more far-reaching view, the projects which formed the culminating experience of the course provide invaluable examples of construction principles and building of Modern architecture for all students. This approach to technology through the process of construction has proved to be one of the most invigorating experiences the school has had in years. In fact, the faculty recently agreed to adopt the paradigm of construction as a guiding force for the restructuring of the entire curriculum. One possibility for this may be incorporating more materials explorations in the Foundations

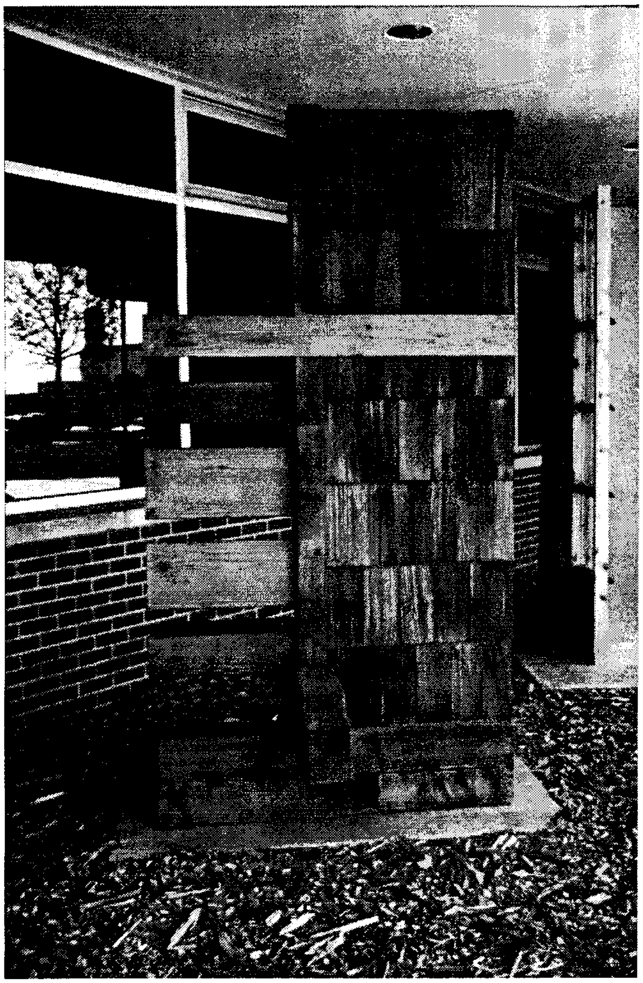

Fig. 6. Completed Gamble House wall section.

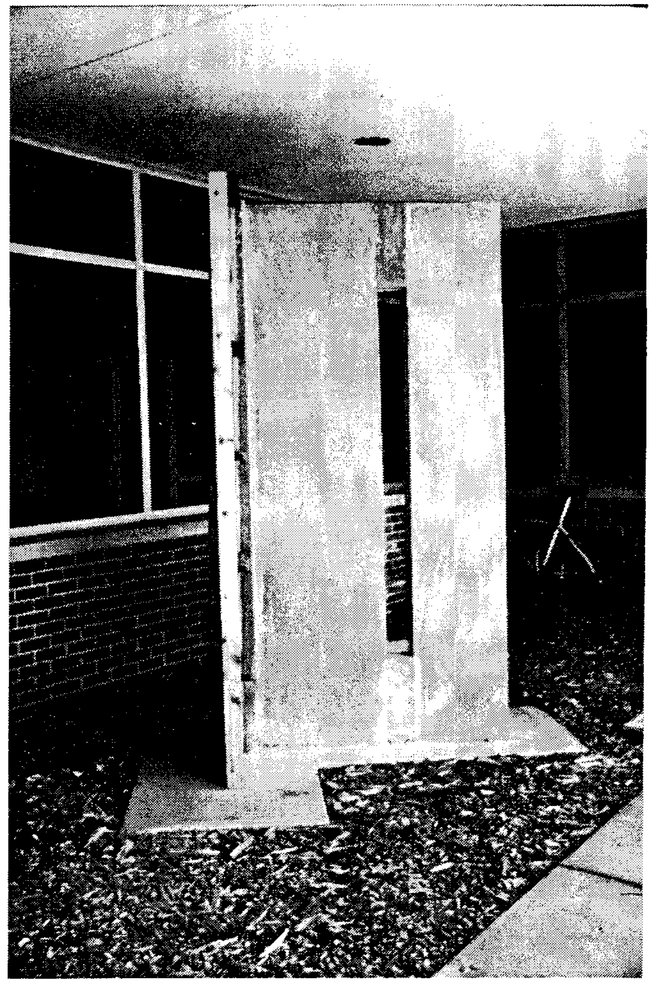

Fig. 7. Completed Schindler-Chase House wall section.

sequence. Another possibility may be that language used in the curriculum would reinforce notions of construction, such as "building a concept, or curriculum." It remains to be seen how the continued and growing interest in this area will shape the education of students, but already the students from last years Construction Principles class, now in their third year, are showing signs of a heightened thought process towards the making of architecture and the effects of technology in the process.

BIBLIOGRAPHY

The American Heritage Dictionary of the English Language. 3rd ed. 1992.

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

Ford, Edward. *Details of Modern Architecture, Volume 2: 1928 to 1988*. Cambridge: MIT Press, 1996.

Frampton, Kenneth. *Studies in Tectonic Culture*. Cambridge: MIT Press, 1995.

Frascari, Marco. "The Tell-the-Tale Detail." *VIA* 7 (1984): 22-37.

Heidegger, Martin. *Basic Writings*. Ed. David Farrell Krell. San Francisco: HarperSanFrancisco, 1993.

Sekler, Eduard. "Structure, Construction, Tectonics." *Structure in Art and in Science*. Ed. Gyorgy Kepes. New York: George Braziller, 1965. 89-95.

Fig. 8. Completed Fallingwater wall section.