Deformation Reformation

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Premise

This article presents an educational exercise titled Deformation Reformation that is an introduction to structures for beginning architecture students. Computation is an essential dimension of all structures curricula but the language of force, form and material is much more than quantitative in an architectural realm. Structural principles, concepts, poetics and integration strategies are of paramount importance. How does the architectural academy cultivate in students the structural knowledge, skills and sensibilities appropriate for architects, and how does it introduce beginning architecture students to the realm of structural behavior and design? The architectural structures curriculum of the School of Architecture at the University of Arizona employs the laboratory as the primary learning vehicle; emphasizing observation, experience and structural discourse to explore the functional / aesthetic dimensions of architectural structures. Computational exercises, lectures and readings are conceived and delivered in support of the laboratory experience. The Deformation Reformation exercise invites students to learn structural behavior and find structural form through the playful self-guided exploration of forces, conditions and materiality.

The Beginning

“In the beginner’s mind there are many possibilities, but in the expert’s there are few.”

“The mind of the beginner is empty, free of the habits of the expert, ready to accept, to doubt, and open to all the possibilities. It is the kind of mind which can see things as they are, which step by step and in a flash can realize the nature of everything.” As beginning architecture students embark upon the transformative journey from layperson to expert it is important that the introduction draw upon their innate intelligence, naïveté, and motivation to become architects; setting forth their education as a self-guided experience that allows them to engage in inquiry, interaction and invention. The beginning is precedence and sacred opportunity. Initial experiences have long-term effects. The Deformation Reformation exercise is the opportunity for beginning architecture students to establish an intimate rapport with structure considering it a creative technical endeavor that stimulates and draws upon the imagination; one that is pregnant with experiential, and therefore architectural, potential.

Pedagogy

“I never try to tell anybody else what to do, number one. And number two; I think that’s what the individual is all about. Each one of us has something to contribute. This really depends on each one doing their own thinking, but not following any kind of rule that I can give out, any command. We’re all on the frontier; we’re all in a great mystery — incredibly mysterious. Each one possesses exactly what each one is working out, and what each one works out relates to their particular set of circumstances of any one day, or any one place around the world.” The pedagogy of the Deformation Reformation exercise is to teach nothing but rather to allow the students to self-learn by exploring the realm of structures on their own terms; “to discover the nature of things, the secret is to be curious.”
“All our knowledge is born of experience, and it differs in its efficacy for each one of us according to the nature, for him, of that experience. If it is to serve as a spring board for imaginative creative thought, then at least part of the experience must be truly personal, like that through which we learn to speak our native tongue.”

This exercise employs empiricism and the scientific method to cultivate this kind of creative knowledge, the informed structural intuition. Empiricism is the philosophical doctrine that regards experience as the only source of knowledge, emphasizing the use of the senses to create broad, profound and innate understanding. Computational analyses and procedures are critical dimensions of a structural knowledge but are highly abstract. Structure is physical and requires an experiential, sensory-based foundation upon which the more abstract dimensions can be applied. The scientific method consists of systematic observation, measurement, and experiment, and the formulation, testing, and modification of hypotheses. The Deformation Reformation exercise employs the scientific method as an evidence-based process. Structural form finding begins with the observation and measurement of structural phenomenon (e.g. buckling and flexure), proceeds with the development of a hypothesis (a design intention such as restricting buckling by introducing lateral bracing), and then concludes with the testing of the hypothesis through physical modeling, an iterative conversation that cultivates structural understanding and intuition.

**Precedence**

Robert Le Ricolais was a French structural engineer that founded, in 1954, the Experimental Structures Laboratory at the University of Pennsylvania. Generations of architects cite his influence, acknowledging his ability to cross-pollinate the realms of engineering and architecture. He utilized rhetorical devices such as analogy and paradox to “illustrate things which are very difficult to comprehend.”

“The Order of Destruction Follows the Order of Construction” is a paradox originating in Le Ricolais’ development of the Isoflex System for the French Navy. The Isoflex System utilizes crosswise layers of corrugated material to render structural panels and tubes. These structures demonstrate periodicity and the repetition of form. Le Ricolais employed this concept in pursuit of an optimum design for columns, called “automorphic tubes.” These structures were comprised of inner and outer layers of parallel compressive tubes bound by a network of tensile diagonals, essentially a space frame wrapped in the form of a hollow cylinder. Fig.1 illustrates harmonic buckling in the pattern of failure under axial compressive forces. This precedent is utilized to introduce the phenomenon of buckling and the utility of physical testing. It most importantly illustrates the expression of forces through specificity of design and failure, a critical concept for integrating structure into an architectural language.

**Fig. 1: Automorphic Tubes [Robert Le Ricolais, Visions and Paradox]**

“The Art of Structure is Where to Put the Holes” is a paradox Le Ricolais used to define the strategy of building with things that have strength but no weight. He stated “that in the search for structures two opposed attitudes are possible: to start with a ‘block’ and work by means of excisions or, on the contrary, to start with a germinal cell in order to arrive at the definitive form by means of addition.”
Le Ricolais utilized excision in the development of the structural probes associated with this paradox. This class of probes employs the idea of the Funicular Polygon of Revolution (FPR) [Fig. 2]: to “weave cables and generate a tension network following a minimal surface, by rotating funicular strings around circular compression diaphragms and connecting the tension network to an axial compression member.”

Le Ricolais states “We treated the structural dissymmetry between tension and compression not by following the conventional differentiation of alternating members, common in trusses, but by decomposing the whole structure into two groups acting massively and brought into equilibrium by tensioning.” The FPRs are abstractions with speculative applications for conditions of flexure: horizontal span systems (bridges), or vertical systems subject to lateral instability (towers). This precedent is utilized to introduce the phenomenon of flexure as an expansive relationship between tension and compression, and structural conception strategies such as excision and addition. It is also used to illustrate structural language, the potential to express the implicit dialogue between forces, and to dissolve the paradigm of conventional structural systems.

**Project Proper**

The Deformation Reformation exercise aspires to cultivate structural intuition in two realms of knowledge: the technical realm of structural behavior and the creative realm of structural design. It utilizes a kinesthetic methodology, qualified by empiricism and the scientific method. Students work in teams of two to encourage the collaborative negotiation of individual experiences and ideas.

The exercise challenges students to analyze and interpret a structural condition. The conditions are categorized in two classes of structural phenomena: buckling and flexure. For the purposes of this exercise buckling refers to the condition, stresses and deformation resulting from the imposition of an axial compressive load on a linear member. Flexure refers to the conditions, stresses and deformation resulting from the imposition of a perpendicular load on a linear member.

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**Fig. 2: Funicular Polygon of Revolution [Robert Le Ricolais, Visions and Paradox]**

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**Fig. 3: Buckling schemes 1-5**

**Fig. 4: Flexure schemes 1-5**
Each phenomenon is configured into five schemes comprised of lines; geometry and buildable areas are prescriptively dimensioned. Students begin the exercise with the buckling conditions [Fig. 3] then repeat the exercise with the flexure conditions [Fig. 4].

Each team selects or is assigned a particular scheme. The diversity of schemes ensures a diversity of experiences and products. By juxtaposing the different schemes within the class students are encouraged to acknowledge the specificity of their particular scheme in comparison to others. Student teams analyze their prescribed abstract condition then assert ownership through the interpretative design and fabrication of a load frame. The line(s) must be rendered in piano wire; the load frame may be constructed of any materials as long as they are logically employed. The load frames are utilized to deform the wire; the deformation is recorded on paper that can be removed from the load frame. [Fig. 5]

The students then proceed to design by interacting with the observed deformation. Design materials are restricted to three gauges of piano wire and the method of connection is restricted to soldering. The design process inevitably involves imparting strength but not necessarily as the primary objective. The interaction is more of a conversation that takes the form of a structural narrative. The narrative may be resistant where deformation is limited or the narrative may be encouraging where deformation is allowed then constrained through strategies of form bias. The model illustrated in Figure 6 employs the form-bias strategy. The original line, defined by buckling scheme 1, is constrained by a series of triangular compressive diaphragms that rotate in plan and are bound by tensile lines that trace the rotation about the perimeter. When loads are imposed the deformation is torsional rather than planar.

Fig. 6: Buckling scheme 1 model [Chris Payne / Ian Viroslav]

Figure 6 depicts the structural design as an autonomous entity apart from the load frame. Although it is abstracted, one can imagine its function and perceive its derivation from its generative conditions. This abstraction is a demonstration of structural expression through specificity and legibility.

Figure 7 depicts a project where the abstract condition (buckling scheme 2) is comprised of two lines adjoined at the top and spread at the bottom. The load frame serves not only as a

![Fig. 5: Load frame and project evolution, buckling scheme 1](image_url)
testing device, but also, by virtue of interpretation and its cruciform configuration in plan, as unique generative conditions for the design.

The design takes the two original lines from the scheme and divides each into a set of two compression members bound internally with tension, rendering each element a lenticular plane. This initial step employs the structural proposition that $1 + 1 > 2$. The team then bound the two lenticular planes together with a central field of tension lines. This second step again employs the $1 + 1 > 2$ strategy, but this time to the system. The project deformed with torsion after steps one and two. The team then constrained the torsional deformation and constitutes the third and final step in this structural narrative. This project demonstrates structural dissymmetry by eschewing the convention of alternating members, as in common trusses, in favor of the more expressive grouping of tension and compression into fields.

Figure 8 depicts a project developed in response to the phenomena of flexure (flexure scheme 1) generated by three reactions and two applied loads. The design process began with introducing depth by locating compressive king posts at the internal reaction and applied loads, separating the lines of tension and compression previously embodied in the single line of the scheme. Once strength was offered in the load plane, the design deformed laterally, illustrating that force follows the path of least resistance.

The team subsequently increased the breadth of the design through a series of lateral struts bound by triangulated tension. Once the design was strengthened in two directions at the location of the internal reaction and loads, the design deformed laterally about the points of inflection, where the flexure shifts from positive to negative moment. The team then constrained this lateral deformation by introducing additional bracing in plan.

Reflective Diagramming

The design process does not precede the modeling; they are concurrent. The drawing and diagramming of the design/modeling evolution is performed afterward. They are considered reflective activities used to rationalize and document the kinesthetic design process. This
Reflection is intended to assist in transforming intuition into objective, rational understanding. Figure 9 illustrates the reflective diagramming of a structural narrative (buckling scheme 4). Three stages are indicated, each illustrating the geometric configuration, character of forces and the resulting deformation.

Conclusions

The explorations of the buckling conditions tend to be more creative and compelling than those of the flexure conditions. As students undertake the challenge of the phenomenon of flexure they seem to be overwhelmed by the complexity and essentially derive trusses from beams. This is a productive and intelligent activity but more toward the objective of cultivating the technical knowledge of structural behavior than the creative knowledge of structural design.

The Deformation Reformation exercise proves to be a genuine and effective learning experience for beginning architecture students; one that affords students the opportunity to formulate individual hypotheses, drawing upon their innate intelligence and curiosity to experience, explore and build an honest rapport with the potential of architectural structures.

Notes


8 Ibid., 77-78

9 Ibid., 43-44