Montreal
Architectural
Review

Bridging Engineering and Architecture

David Leatherbarrow
University of Pennsylvania

However useful the task of the grammarian, his contribution to the world's literature is small.
— *Paul Philippe Cret*

"In order to be an engineer, it is not enough to be an engineer." This quotation from the philosopher José Ortega y Gasset is simple to say but not simple to understand. Initially, I would like to approach the question it poses from a teacher's point of view. Anyone who has spent more than a little time in a university, especially teaching a subject such as architecture—which has always had a strained relationship with the university—will have realized that what students need most is what their teachers cannot give them: understanding of their untaught but deeply held convictions, *the culture* that both sustains and limits their projects. Ironically, students possess this understanding before they enter school but often neglect it while enrolled. Teachers can give students skills, concepts, and examples, but not the foundation on which decisions about their use can be made. I believe it is this non-technical frame of reference that Ortega meant when he pointed to what the engineer needs.

My opening quotation comes from a book by José Ortega y Gasset called *History as a System*, the contents of which are broadly cautionary. Ortega warned that

> this magnificent and miraculous technology of ours [is] endangered and might crumble between our fingers

> and vanish faster than anybody had imagined. Today [1940] I am more than ever frightened. I wish it would dawn upon engineers that in order to be an engineer, it is not enough to be an engineer. While they are minding their own business history may be pulling away the ground from under their feet.[1]

My concern, like Ortega's, is with the "ground" beneath the engineer's feet, a foundation he suggested is non-technical.

Ortega had expressed similar alarm ten years earlier in *The Revolt of the Masses*, a book that gave him international fame. There, too, the harvest of European civilization was judged to be unhealthy. He spoke of the seeds of barbarism in the techno-science of the 19th century and suggested that it is illusory to expect anything better from those who

> disregard science as such. . . [as do the] mass of technicians themselves – [the] doctors, engineers, etc. who are in the habit of exercising their profession in a state of mind identical . . . to that of the man who is content to use his motor-car or buy his tube of aspirin without the slightest intimate solidarity with the future of science, of civilization.[2]

Even so, unease about the technician's limitations should not cause us to denounce science, he said, but to seek it more energetically and discern its limits more exactly, which means distinguishing its *kinds*, because *natural* science is only one among many. This, Ortega's most significant point, is one to which I will return at the end of this study. Again, the warning: contentment with past technical achievements quickens culture's atrophy, for

> technology . . . will irretrievably empty the lives of those who are resolved to stake everything on . . . it alone. To be an engineer and nothing but an engineer means to be potentially everything and actually nothing. Just because of its promise of unlimited possibilities technology is an empty form. . . unable to determine the content of life. That is why our time, being the most intensely technical, is also the emptiest in all human history.[3]

Devastating as it is, I would like to take this indictment seriously.

Ortega's chapter title, "Man the Technician," suggests that the problem he confronted is not only historical but also constitutive of the human being as such. He was in fact deeply worried about the global transformation of society after the age of the revolutions (the end of the *ancien regime* and the birth of the industrial period), for that period gave birth to a new type of person, called the mass man. Ortega also charted the growing secularization of society and the increasing disenchantment of the world; see, for example, his text on *The Dehumanization of Art*. But as one reads him further, history gives way to ontology. The tension between freedom and necessity, which is also a conflict between mind and body, or possible realities (such as an engineer's mathematical projections) and real possibilities (say, an architect's cultural engagements), can be discovered in the make-up of each of us. Ortega introduced a curious symbol to characterize this conflictual anthropology; the person, he said, is an

> ontological centaur, . . . one's being and nature's being do not fully coincide . . . [each of us] is partly akin to nature and partly not, at once natural and extra-natural . . . half immersed in nature, half transcending it . . . a boat drawn up on the beach with one end of its keel in the water and the other in the sand.[4]

The image should be familiar to architects: Vitruvius sketched not the centaur, but an equivalent image of a person being in between—the story of Aristippus on the shore of Rhodes after a storm had wrecked his ship, taking delight in the geometric marks he found in the sand because they were signs that he had landed among civilized people, despite the fact that the tide would soon wash them away as had the storm his ship.

One of Philadelphia's greatest architects, Paul Philippe Cret, cited Ortega's arguments in a paper he wrote in 1933 on the progress of modern architecture. Although he introduced Ortega's topic under the heading "barbarism," Cret was prompted less by events in Germany at the time—events that led to a measure of barbarism previously unknown in the whole of human history—than by the difficulty of developing good taste in his students, especially the young talents who accepted modernism's supposed rejection of the past. In response he advocated a "new classicism." In a number of papers from those very same years he took up issues related to the design of bridges.[5]

These texts also sound cautionary notes. After recommending the great bridge builder Paul Séjourné's summary motto, *On croit inventer, on retrouve*, he noted a fallacy that had become common among contemporary designers—"that engineering or architecture is an exercise in a mathematical text book, where, given the premises and following prescribed rules, there is only one correct answer."[6] The truth is there are always many mathematically correct solutions to design tasks. The chief difficulty is one of choice, and with the matter of choice, Cret said, "we enter the domain of art."[7] Speaking of choice in the paper called "Bridges," he suggested that preference should be given to the scheme most likely to give distinction and significance to the work. Put in reverse, a correct solution—correctly calculated—may also be unremarkable or insignificant. Thus Cret affirmed Ortega's assertion that to be an engineer one must be more than an engineer. In what, then, does this "more than" consist? If aesthetic concerns are key, project development would allow choice. If, however, the non-mathematical foundation is ethical, design requires decision making—taking a stand. Perceived from this second point of view, the bridge builder is not a poet with a slide rule.

Bridge design concerned Cret throughout his career, from the time of his collaboration with engineers in the design and construction of his first bridge, the Delaware River, or Benjamin Franklin Bridge, to his work on many others. His interest was hardly academic. Intense and acrimonious debate accompanied the development of the Delaware River Bridge from the moment the Pennsylvania Department of Works announced their intention to have an architect lead the project. For engineers, that suggestion was outrageous. The following judgment, published in the *Engineering News-Record*, exemplifies the controversy: "[S]trength is measurable and definite; beauty is neither, but too often only lies in the eye of the beholder . . . The engineer's instinct for simplicity [unlike the architect's for beauty, is] indisputably sound."[8] While Cret tried to keep out of the fray, he did take part in the project as a collaborator with the engineers who were eventually put in charge of the design. Construction started in 1922 and was completed four years later. In fact, the professional correspondence shows entirely productive collaboration between Cret and the engineers. He summarized his arguments on the subject in an important essay from 1927.

Several significant points are contained in that text. First, the divorce between architecture and engineering appeared to have been relatively recent. Cret saw its beginning in the second half of the 18th century. Before then, in France at least, bridge designers were also schooled in architectural ateliers. Architectural training was not optional but essential for a young engineer. Second, and with the controversy concerning the Delaware Bridge fresh in his mind, Cret observed that by the beginning of the 20th century the divorce between the two fields was definite; the unity of the old profession had, he maintained, been completely severed. Largely because of professionalization, reunification was impossible. Complementarity was the only alternative. Its achievement assumed a three-part intellectual task—distinguishing the unique contributions of the two fields, demonstrating their joint necessity, and explaining the manner of their correspondence. Citing Hippolyte Taine, he argued that "the strength and dignity of design were attained, not by dissembling, but by emphasizing structural purpose."[9] The idea of emphasis was not new. Before the Victorian period architects knew that there were "possibilities of beauty latent in the sheer mechanical frame of construction."[10] The architect's task, then, involved amplifying, heightening, or accentuating structural solutions, i.e., making what was latent patent. Without this, with calculation only, there would be intellectual satisfaction but no emotion. Cret's summary is as follows: "Logic and clarity and strength, although they are elements of the beautiful, are not all there is to beauty. Until they are emphasized by subtle modification of lines and structural proportions—until a sense of harmony, of rhythm and accent fuses them into an aesthetic unit, they remain mute; they are seen, but they are not felt;"[11] "However useful the task of the grammarian, his contribution to the world's literature is small;"[12] "Constructive necessities . . . will never create a building really worth while, because these elements have only a limitative and corrective value."[13] Artistic judgment is as essential as engineering logic. On this point, Cret cited his most well-known source: "Art begins where calculation ends."[14]

Le Corbusier's aphorism, famous as it is, concluded an account that must be seen as contradictory, or at least not simple. He did, indeed, give the architect disposition over our emotions:

> Architecture is a thing of art, a phenomenon of the emotions, lying outside questions of construction and beyond them. The purpose of construction is to make things hold together, of architecture to move us . . . Architecture is a matter of 'harmonies,' it is a 'pure creation of the spirit.'[15]

Yet earlier in the text he spoke of an engineering sensibility that sounds remarkably similar to the architect's. He admitted that

> engineers produce architecture, for they employ a mathematical calculation which derives from natural law, and their works give us the feeling of harmony. The engineer therefore has his own aesthetic, for he must, in making his calculations, qualify some of the terms of his equation, and it is here that taste intervenes.[16]

This explains why architecture can be found in the Parthenon and the telephone, also why engineers "find themselves in accord with Bramante and Raphael." How, then, are the architect and engineer different? Are they? Can the second substitute for the first, or are the two distinct but complementary, as Cret argued?

Le Corbusier's most sustained treatment of the problem can be found in a text entitled *The Home of Man*, written in Vichy in 1941, and published the next year. The architect supplied the drawings and captions for the book, while François de Pierrefeu, a hydraulics engineer and supporter of the Saint Simonian Catholic right, supplied the text. Joining the architect and engineer, a third player appeared on stage in their account: the humanist. The virtues these three represented were put together in the make-up of what was alternately called the "master of works" or "cathedral builder." His profile was as follows—"The ideal master of works should be a humanist [and] accommodate within himself . . . two distinct actors, an *architect* and an *engineer*." Then, restating Saint Simonian ideas of the technocrat as a secular savior, this new trinity was offered as a replacement for its Christian antecedent, a new power of world construction. We are told that the humanist should possess "a sense of [the] *oneness* of [all] existing [things, the] variety of forms."[17] The vision of the whole, of harmony, or of wide proportionality, was not, however, achieved by, or evident in, calculation. Instead, intuition was required. Intuition was also the mental faculty that could bind the architect and the engineer together in their shared concern for "*the well-being of man in pursuit of happiness and fulfillment*."[18]

A diagram Le Corbusier developed summarizes this division and complementarity of tasks. Circles above and below its central fan-shaped figure show the relative proportions of sentiment and technique in the work of the architect and engineer. Two kinds of knowledge are represented by the red and blue, knowledge of man and knowledge of physical laws. The first includes understanding of all manner of human needs (spiritual, intellectual, civic, social, domestic, physiological, and material), and the second, physical constraints (those of raw material, gravity, material resistance, and mathematics). Each is also a tendency, represented by the two axes, one toward creative imagination, beauty, and free choice in the vertical direction, the other towards material constraints and calculation along the horizontal line. While both kinds of knowledge are necessary, the architect and engineer are allotted different measures of each. The fan at the center proportions these powers to the several building tasks, each with coupled blue and red triangles, variously bridging sentiment and technique. Reading from left to right, the tasks consist of monuments and temples, civic buildings, hospitals, recreation facilities, the home, administrative offices, workshops, factories, and infrastructural works. The home is at the center because architects and engineers, mediating spiritual and physical needs, contribute equally to its design. The family it houses serves as the nucleus of society, or the germ of the common good. Here, then, the accent is not on the designer, still less on the profession, but on the task, and different tasks require different kinds of knowledge, with less sentiment for the hydroelectric dam, more for the chapel.

Le Corbusier and Cret were not the only architects to discuss the architect/engineer dichotomy. In 1933, the same year that Cret cited Ortega's anticipation of barbarism, Auguste Perret, an architect to whom Le Corbusier often referred and for whom he worked, also addressed this opposition. Like Cret and Le Corbusier's, Perret's ideal architect is endowed with what seem to be extra-mathematical faculties of intuition, judgment, and perception. According to Perret, "the architect must be able to perceive the elements of beauty in his work before he can present and display them, [and] make them sing."[19] Perret explained himself with a counter-example, the Eiffel Tower, which is over-decorated in detail and structurally redundant, its designer having been tone-deaf. His second counter-case referred to Orly airport. There, thankfully, the hangars by Freyssinet (1921) were not spoiled by art. But despite their economy they were not quite architecture. What they lacked, Perret said, what stopped them from being expressive works, even though they worked, is "scale, proportion, harmony and humanity."[20] Were they qualified through these measures the result would have been musical: architecture, he said, "is the art of making supports sing."[21] This is much like Cret's notion of emphasizing the action of structural elements. One of Perret's most famous lines, that "Technique, spoken in poetry, brings us to architecture," makes the same point.[22] Less philosophical than Le Corbusier, Perret did not try to explain the sort of knowledge that allowed the architect to transform calculation into expression.

The entire problem disappears if one assumes that engineering works are beautiful in themselves, and that mathematical thinking is sufficient for aesthetic pleasure. Is that true? Can we end the question by ignoring the distinction? Is the structurally determined "equipoise" of a bridge by Robert Maillart as beautiful as a painting by Picasso, as Sigfried Giedion maintained in his paper "Construction and Aesthetics?" What Le Corbusier hinted in his praise of the engineer's aesthetic was in fact maintained by earlier writers. Already in 1910 the Austrian Joseph Lux, for example, had argued that the true architect of modern times was the engineer. Lux's sense of a new epoch was hardly tentative: "nowadays," he said, "technology is more important than Plato."[23] Although Lux's engineer developed his solutions without reference to historical models, such an engineer was not blind to aesthetic concerns, for indeed there was a process through which right sensibility was acquired. First, one must see that calculation does not exclude considerations based on empirical experience. Next, the accumulation of experience gives the engineer a kind of judgment, something Lux called "the sense of form" (*Formgefühl*), which for Lux was a kind of aesthetic sensitivity or eye for visual harmony. In fact this sense of form pre-existing in the engineer's mind was for Lux "the precursor" to "mathematically hardened construction."[24] The surprising point here is that qualification *precedes* calculation. This is just the opposite of Cret's history of the project in which accentuation followed calculation. This accentuation was governed by the principle of eurhythmy, according to which symmetries were adjusted to make a seemly appearance, as in Vitruvian optical correction. The example Lux cited was Paxton's Crystal Palace of 1851, which represented form first—the famous tablecloth metaphor—then calculation.

Two years before Lux's *Ingenieur-Aesthetik* another German language theorist, Adolf Gotthold Meyer, argued in *Eisenbauten* that engineering involved "pictorial thinking." To explain this he presented a brief history of the modern approach. The new way of building dated from the time of Jean-Baptiste Rondelet, who "treated the structural calculation for the first time as an essential part of the discipline of construction."[25] Rondelet's discovery was also the moment when two approaches to design, one based on mathematical rules and calculation and another on artistic genius, went their separate ways. But more interesting is Meyer's account of the origin of the engineer's pictorial thinking. Its formation involved a two-step development. First there was the transposition of problems of mechanics into arithmetic and algebraic formulae, and then there was the transfiguration of those two into a *vision of graphic form* (*ein Anschauung graphischer Gebilde*). His epistemology was not explained more fully, but this vision of form developed in each engineer and in the profession, Meyer concluded, is the means by which the right calculation is selected, there being, as Cret also observed, many possible solutions to any given problem. According to this perception as well, calculation is something that occurs 'after the fact' of a designer's intuition.

In 1909, one year before Lux's text and one year after Meyer's, the German art historian and philologist Carl Watzinger offered a striking reading of the Vitruvian eurhythmy, mentioned above with regard to Cret. Among the elements of order essential to architecture, Watzinger said, eurhythmy was the one that governed the optical effect or appearance of the work. This would mean that it was categorically distinct from the principle of symmetry with which it had been associated. Ancient, like modern, design was thus a two-step procedure in which symmetries were calculated, then modified. Pleasant or appropriate appearances resulted from the adjustment of pre-conceived arrangements. We have seen that modern architectural theorists also envisaged a two-part process—visualization before the calculation, in the arguments of Lux and Meyer, and adjustment after it, for Perret, Le Corbusier, and Cret. Leaving aside the distinction between the engineer and architect, the key is that adjustment and anticipation give the work its significance, appropriateness, and beauty. There are two important premises in this account. In one, insignificance is likely in purely symmetrical design or narrowly mathematical thought, and in the other the risk of insignificance arises from the relative autonomy of mathematical modeling. Un-interpreted calculation might be described as meaningless certainty. And in all of this, poeticizing is no help.

Jean Ladrière, the great historian of science and mathematics, once observed that mathematical thinking seems to be both constructed and given at the same time.[26] He meant that according to one view mathematics is a generalization, idealization, or representation of the phenomena that present themselves in given reality. According to a second view, mathematics presents itself with its own objects—highly abstract, approximating a system, and very largely formal—something like a bridge without abutments. Adjustment and attunement are necessary in architecture precisely because of the tendency toward formalism in mathematical modeling. As a style of thought, interpretation develops in the opposite direction—not horizontally, as a system, but vertically, into pre-existing conditions. Moreover, attunement is optical, not conceptual, intuitive not logical, circumstantial not abstract. If we grant the complementarity of these two styles of thought, both can be seen to be required in the architectural project; again, one kind of thinking calculates the internal coherence and self-sameness of the design, and another intuits the ways that arrangement will appear as part of a wider situation it cannot control. Their internal or essential complementarity is what Cret said results from collaboration and Le Corbusier illustrated in his diagram.

Aristotle, in *Nichomachean Ethics* observed that a mark of a wise man is to know the degree of exactitude required for a particular inquiry, project, or subject. His advice emerged in consideration of the different kinds of science required for productive work in physics and ethics—each a science in its own right. He cautioned: "the same exactness must not be expected in all departments of philosophy alike, any more than in all the products of the crafts."[27] Next follows an admonition: "it is the mark of an educated mind to expect that amount of exactness in each kind [of science] that the nature of the subject admits."[28] Again, the focus is on the task, which always plays itself out in a specific cultural context. An illustrative distinction would be between the conclusions of an orator and those of a mathematician, with suitable yet probable arguments in the first case, exact demonstrations in the second. Similarly, the geometrician and the carpenter might both be seeking the right angle, but in different ways, for the former would be looking for the essence, while the latter would be content with that approximation to it which satisfies the purpose of the work.[29] Both kinds of reasoning are required for the development of an architectural project—in the first case, knowledge of the laws of nature and techniques of calculation, in the second, knowledge of human affairs, the habits, symbols, and institutions of a culture that give life its pattern, purpose and beauty.

Notes

1 Ortega y Gasset, José. *History as a System.* (New York: W.W. Norton & Company, 1961), 103.

2 Ortega y Gasset, José. *The Revolt of the Masses.* (New York: W.W. Norton & Company, 1957), 87.

3 Ortega y Gasset, José. *History as a System.* (New York: W.W. Norton & Company, 1961), 151.

4 Ibid., 111.

5 In one text from 1930 titled “Bridges,” and two others from 1936, one called “The Design of Bridges,” the other “Bridge Architecture.” I have consulted the original manuscripts of these talks, held in the Annenberg Rare Book & Manuscript Library, University of Pennsylvania.

6 Design of Bridges, 2.

7 Cret, Paul Philippe. *Paul Philippe Cret, Architect and Teacher.* ed. Theo B. White (Philadelphia: Art Alliance Press, 1973), 70.

8 “What Is Art?,” *Engineering News-Record* 85 (16 September 1920): 531; cited in Farnham, Jonathan. “Staging the Tragedy of Time: Paul Cret and the Delaware River Bridge,” *Journal of the Society of Architectural Historians* (57:3, September 1998): 261.

9 Cret, Paul Philippe. *Paul Philippe Cret, Architect and Teacher.* ed. Theo B. White (Philadelphia: Art Alliance Press, 1973), 63.

10 Ibid., “The Architect as Collaborator of the Engineer,” 63.

11 Ibid., 64.

12 Ibid., “Design and Construction,” 71.

13 Ibid., 71.

14 Ibid., 69.

15 Le Corbusier. *Towards a New Architecture.* trans. Frederick Etchells (New York: Payson and Clarke, Ltd., 1927), 19.

16 Ibid., 15.

17 Le Corbusier and Francois de Pierrefeu. *The Home of Man*, trans. Clive Entwistle and Gordon Holt (London: Architectural Press, 1948), 32.

18 Ibid., 33.

19 Perret, Auguste. *Contribution à une Théorie de l’Architecture* (Paris: André Wahl, 1952), 22. See also: Britton, Karla. *Auguste Perret.* (London: Phaidon, 2001), 242.

20 Ibid.

21 Perret, August. “L’Architecture,” *Revue l’Art et l’Esthétique*, 1/1-2 (June 1935), 49.

22 Britton, Karla. *Auguste Perret.* (London: Phaidon, 2001), 213.

23 Mallgrave, Francis and Christina Contandriopoulos, ed., *Architectural Theory, Vol. 2* (Malden, MA: Blackwell Publishing, 2008), 105.

24 Ibid., 106.

25 Giedion, Sigfried. *Building in France, Building in Iron, Building in Ferroconcrete.* trans. J. Duncan Berry (Santa Monica, CA: Getty Center for the History of Arts and the Humanities, 1995), 33.

26 Kockelmans, Joseph J. and Kisiel, Theodore J., ed., *Phenomenology and the Natural Sciences* (Evanston: Northwestern University Press, 1970), 457.

27 Aristotle. *The Nicomachean Ethics*, 1.3.1, trans. H. Rackham (London: Heinemann, 1956), 7.

28 Ibid., 9.

29 Ibid., 7.

About the Author

Dr. Leatherbarrow supervises research and directs the architecture Ph.D. program at the University of Pennsylvania. He has taught theory and design at the Polytechnic of Central London and Cambridge University, England, and maintains a private practice with Lauren Leatherbarrow. Dr. Leatherbarrow was the recipient of the Visiting Scholar Fellowship from the Canadian Center of Architecture (1997-98). Books include: *Topographical Stories*, *Surface Architecture* (with Mohsen Mostafavi), *Uncommon Ground*, *Roots of Architectural Invention*, *On Weathering: The Life of Buildings in Time*, and *Masterpieces of Architectural Drawing*. He has done research on history and theory of architecture and the city.