

# Building Rammed-Earth Systems: Constructal Design and the Hierarchy of Energy in Earthen Architecture

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# 1 Function Follows Form Follows Function Follows Energy: Steampunk to Cyberpunk

Observation: Figurative lines of design between engineering forms with regard to scientific reasoning and designing forms with regard to artistic reasoning—philosophical, historical, practical, semantic, and neurological lines probably reckoned by the human capacity to reason in both domains—puts designers in a steep quandary. On one hand, applying mathematics and physics to models of the world enables forms and formalities that achieve desirable states of operation with relatively high fidelity and invariance. On the other hand, the capacity to qualitatively reason about the world in all its chance and weirdness also permits the ability to bring about form by appealing to unquantifiable design factors such as the historical, intuitive, religious, or somatosensory.

Three lenses: structural art of the industrial revolutions, twentieth century Modernism, and Eli Attia's framework of *Engineered Architecture*, illuminate epistemological and technical evolutions reflected on historical interplays between scientific and architectural design, computation and intuition, artificiality and naturality, technology and society, being and not-being. Considering a low-order trajectory of designed forms across these worlds is to presuppose a grounds for building presently, by tracing the complex knot of building's past as it leads into the potential to design and build one way or another.

*"In his 1957 book The Reason of Structural Types, Torroja wrote that "Vain would be the enterprise of somebody who would propose himself to design a structure without having understood to the backbone the mechanical principles of inner equilibrium." Being an engineer, he saw those principles and their interiorization as something that was independent from history. I would like to challenge that position. For in the understanding of the backbone of the mechanical principles of inner equilibrium we are necessarily indebted to the way we perceive our body and its movements. In the past decades, cultural historians have multiplied studies showing that this perception is to a certain extent a social construct. Gravity, just like a certain number of fundamental natural constraints, is always perceived through the prism of our body, a historically determined body."*

— Antoine Picon, *Construction History: Between technological and cultural history*

Before looking back, it is important to note that the lines of construction history also extend to a number of theoretical histories and to an infinitude of real histories. History is also only tenuously relevant to contemporary engineering design, and moreso but diminishingly so to contemporary architectural design. At an even higher level, authors of construction history are usually also engineers and architects, with doctrinal responsibilities to write building history one way or another. [1, p14] Consulting history to presuppose the grounds for building rammed-earth systems is here more concerned with the flux of ideas than stylistic or technical precedents.

Furthermore, setting one endpoint in the early twenty-first century and expecting some level of detail permits only a sliver of continuous building history. Ancient building methodology, the most relevant to earthen architecture, is postponed to a later section. But a latent technical continuity may remain if the eras prior to the eighteenth century possess the truly polytechnic heritage Lewis Mumford claims:

“Because the era before the eighteenth century is mistakenly supposed to have been technically backward, one of its best characteristics has been overlooked: namely, that it was still a mixed technology, a veritable polytechnics, for the characteristic tools, machine-tools, machines, utensils, and utilities it used did not derive solely from its own period and culture, but had been accumulating in great variety for tens of thousands of years. . . . The introduction of new inventions like the clock did not necessitate on principle the discarding of any of these older achievements.” [6, p134]

## 1.1 Function Follows Form

Designer, engineer, historian of technology, and professor David Billington provides an account of “structural art” in *The Tower and the Bridge*. According to Billington, structural art is a form of building tall structures, bridges, towers, long-span roofs, and the like originating in late eighteenth-century Britain around the industrialization of iron and this phenomenon’s reflexive imperative to build more robust infrastructure. [2, p7] From this alone, the subject of structural art is narrowly concerned with the physical object of design; belonging to a certain typology, material, location, and scale. In this sense structural art begins as a realistic, empirical way of building, transitioning through the inertia of rigorous analysis. “The works of structural art have sprung from the imagination of engineers who have, for the most part, come from a new type of school—the polytechnical school.” [2, p14] It is not far to recognize Giedion’s schism of architecture and technology characterized in France’s Ecole des Beaux-Arts and Ecole Polytechnique. [5]

A compressive generation of art and science (e.g. Lord Byron, the poet, and Ada Byron, the computational mathematician) and a tensive divergence of engineering and architecture (the machine and the structure [2, p11]) elicited a pro/anti-technological milieu embodied by the British industrialists and the Luddites. The second epoch of structural art occurred in the 1880s with the explosion of steel and reinforced concrete. The Eiffel Tower (1887), a canonical example of structural art, was lambasted by French artists offended by its industrial, mechanistic aesthetic looming over Paris’ normal architecture [4]. Eiffel responded in the character of a structural artist:

“For my part I believe that the Tower will possess its own beauty. Are we to believe that because one is an engineer, one is not preoccupied by beauty in one’s constructions, or that one does not seek to create elegance as well as solidity and durability ? Is it not true that the very conditions which give strength also conform to the hidden rules

of harmony? (...) Now to what phenomenon did I have to give primary concern in designing the Tower? It was wind resistance.

Well then! I hold that the curvature of the monument's four outer edges, which is as mathematical calculation dictated it should be (...) will give a great impression of strength and beauty, for it will reveal to the eyes of the observer the boldness of the design as a whole. Likewise the many empty spaces built into the very elements of construction will clearly display the constant concern not to submit any unnecessary surfaces to the violent action of hurricanes, which could threaten the stability of the edifice. Moreover there is an attraction in the colossal, and a singular delight to which ordinary theories of art are scarcely applicable." [4]



Figure 1: Katsuhiro Otimoto and Sunrise's rendering of the Crystal Palace in the film *Steamboy*, 2004. In quest of a revolutionary technology within, the British army destroys the palace. Similarly, in *The Difference Engine*, a 1991 science-fiction novel by Gibson and Sterling, a Victorian-era warehouse is destroyed in quest of a set of computer punch-cards thought to predict gambling outcomes. Obviously, the potential for artistically representing this world is strong.

Innovation driving structural art followed from "stretching" iron, steel, and concrete beyond successive limits, "just as medieval designers had stretched stone into the skeletal Gothic cathedral." [2, p5] Doing so enabled a rapid and reciprocating techno-social progress not unlike the motions of a steam or internal combustion engine. However, this elasticism was not actually calculable until Claude-Louis Navier's theory of elasticity in the 1820's. [3, p73] Therefore, Billington claims that the engineering involved in structural art initially denied stress-related analyses for empiricism as its primary science. [2, p43] In light of Mumford's conception of true polytechnics, the structural artists of the eighteenth century polytechnical school appear to be **the entrance for analytical rigor in building design.**

To handle the ethical pressures of government, shareholders, and industrialists idealizing the conservation of natural and public resources, in addition to the physical demands of building, three disciplines of structural art emerged to cover three dimensions of structure

proposed by Billington. “Efficiency, economy, and elegance” address the scientific dimension, the social dimension, and the symbolic dimension. [2, p5,16,17]

Billington provides a discernible order of engineering/technology, science, structural design, and architecture summarized in the following:

**Engineering and Science:** “There is a fundamental difference between science and technology. Engineering or technology is the making of things that did not previously exist, whereas science is the discovering of things that have long existed. Technological results are forms that exist only because people want to make them, whereas scientific results are formulations of what exists independently of human intentions. Technology deals with the artificial, science with the natural.” [2, p9]

**Structures and Architecture:** “Structural designers give the form to objects that are of relatively large scale and of single use, and these designers see forms as the means of controlling the forces of nature to be resisted. Architectural designers, on the other hand, give form to objects that are of relatively small scale and of complex human use, and these designers see forms as the means of controlling the spaces to be used by people.” [2, p. 14]

**Structures and Machines:** “As intimately connected as they are, structures and machines must function differently, they come into being by different social means, and they symbolize two distinctly different types of designs. Structures must not move perceptibly, are custom-built for one specific locale, and are typically designed by one individual. Machines, on the other hand, only work when they move, are made to be used widely, and are in the late twentieth century typically designed by teams of engineers. General statements about technology are frequently meaningless unless this basic distinction is made.” [2, p13]

It is conclusive from these propositions of the structural art that science and engineering are separate but parallel disciplines, similarly, structures and machines are separate but parallel objects, and structural design and architecture are separate but parallel disciplines as well. If the conversation between engineering and science is marked by conceptions of the artificial (variable) and conceptions of the natural (invariable), then a rift appears along the **system boundaries** of a model. System boundaries conceptually determine which quantities are of analytical concern and which are to be assumed external to the function of the system. If the conversation between structural design and architecture is marked by a physical object’s magnitude and use, then a rift appears at **scaling**.

“The prototypical engineering form—the public bridge—requires no architect. The prototypical architectural form—the private house— requires no engineer. We have seen that scientists and engineers develop their ideas in parallel and sometimes with much mutual discussion; and that engineers of structure must rely on engineers of machinery just to get their works built. Similarly, structural engineers and architects learn from each other and sometimes collaborate fruitfully, especially when, as with tall buildings, large scale goes together with complex use. But the two types of designers act predominantly in different spheres.” [2, p14]

## References

- [1] In:
- [2] David P. Billington. *The Tower and the Bridge. The New Art of Structural Engineering*. Princeton University Press, 1983.
- [3] Philippe Block. “Retrofitting and Redacting Masonry Engineering”. en. In: *Building systems : design, technology, and society*. Ed. by Kiel Moe and Ryan E. Smith. Routledge, 2012, pp. 73 –85.
- [4] Socite d’Exploitation de la tour Eiffel. *Origins and Construction of the Eiffel Tower*. [Accessed 03/20/2018]. URL: `\url{https://www.toureiffel.paris/en/the-monument/history}`.
- [5] Sigfried Giedion. *Space, Time, and Architecture. The Growth of a New Tradition*. Harvard University Press, 1982.
- [6] Lewis Mumford. *The Myth of the Machine. The Pentagon of Power*. Columbia University Press, 1970.