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

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“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.”

— Lewis Mumford [7, p.134]

“. . . the history of rammed-earth and the contemporary experience of the experimenters will hold a great value to the builder until the material enjoys the same commonplace security of the clay-fired brick, a building unit which no amateur questions but which is far more vulnerable to faulty manufacture and inexpert handling than rammed-earth could ever possibly be.”

– Anthony F. Merrill [6, p.xvi]

This thesis intends to derive epistemic and technical grounds for designing and building rammed-earth systems. “Rammed-earth”/“pisé de terre”/“hāngtǔ” is an earthen building material generated (and semantically inseparable) from a particular mechanical process. It is archaic, sourced globally, and reappearing in modern technological/architectural domains. Given its general disappearance from modernity, at least in the West, on what grounds does and can it reappear? This turns out to be a reflection of the material and modern building itself.

Part I deliberately follows a historical trajectory of building from eighteenth-century industrialism, through twentieth-century modernism, and into the contemporary mode in order to contextually rationalize Mumford’s pre-eighteenth-century “veritable polytechnics” in light of modernized polytechnics. Through building on pithy principles of these three eras, it is argued that the efficacy of modern rammed-earth design relies on a balance of low-tech, veritable polytechnics and high-tech, modernized polytechnics.

Part II considers a modern physical law about architecture and a modern architectural theory about physics that together extend to a potential ground for designing and building rammed-earth systems.

Part III summarizes an implementation of this ground.

1 Function Follows Form Follows Function Follows Energy: Iron to Silicon, Steam to Bits

Observation: "Form Follows Function" is a well-known principle of modern architecture, uttered by an architect. "Function Follows Form" is an alternative to this principle in pre-modern/modern structural art, uttered by a professional engineer. "Form Follows Energy" is a contemporary iteration of the principle, uttered by a building scientist. "X follows Y" seems to function as a sentential trace through the epistemological and technical knot of building towards a ground for building in some way, in light of the infinitude of other ways. There is, apparently, a polytechnical collective around this singular phenomenon.

In search of ground for building rammed-earth systems, each of these three building principles becomes a lens for envisaging epistemological and technical appearances during their time. "Function follows form" in structural art of the modern industrial revolutions, "form follows function" in twentieth century modernism, and "form follows energy" in the contemporary building mien. Considering a rough trajectory of design and designed forms across these worlds is to presuppose some historical ground for the present potential to build in one way or another.

Metamorphic boundaries between 'engineering' or 'designing' forms (as verbs) with regard to reasoning 'scientifically' or 'artistically' (as adverbs)—philosophical, historical, technical, semantic, or neurological boundaries probably reckoned by the capacitity to reason in both domains—puts potential designers in a steep quandary. On one hand, applying mathematics and physics to modeled systems enables forms and formalities capable of achieving desired states with relatively high fidelity and invariance. On the other hand, the capacity to intuit the world in all of its chance, variability, and quality also permits an ability to bring about form, appealing uniquely to semi-unquantifiable design factors such as the historical, visual, spatial, or somatosensory.

Before looking back, it is important to note that the lines of building history cross with contruction history, technological history, a number of other theoretical histories, and an infinitude of real histories. Theorizing about history seems only tangentially relevant to contemporary technological design, and moreso but seemingly diminishingly so to contemporary architectural design. At an even higher level, authors of building history are usually also engineers and architects, with doctrinal responsibilities to write about it one way or another. [1, p14] Here, consulting history to presuppose a grounds for building rammed-earth systems is directed towards the evolution of building concepts and causalities through ideological and technical lines.

Setting the origin of this timeline in the eighteenth century and leading into the early twenty-first century consciously withholds any history of rammed-earth building to be elaborated in a later part of this text. The argument behind this supposes that the "veritable polytechnics" of rammed-earth cultures around the world, and earth-builders in general, derived their art from a form of thinking virtually lost to the modern era. Considering that history

and withholding facts and speculation about rammed-earth building history to a later point is a deliberate design decision. It is an attempt to clearly separate the "veritably polytechnic" from the modern polytechnic. As an ancient building method (having been dated to the Neolithic Era in the East [8]) and a somehow innate method (having been found on every continent besides Antarctica), drawing rammed-earth out from its origins is

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 similar objects in this class, originating in eighteenth-century Britain. A first epoch of structral engineering began with the industrialization of iron and this phenomenon’s reflexive imperative to build more robust infrastructure, and concluded around the ironed construction of the Eiffel Tower as the explosion of steel and reinforced concrete overran the iron world. A second epoch of structural art began in the late nineteenth century and concluded whenabouts W.W.I. appeared on the horizon and building stalled. [4, p7]

To place structural art among other subjects and objects, Billington writes of discernible relationships between engineering and technology, structural and architectural design, and structures and machines, 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 fomulations of what exists independently of human intentions. Technology deals with the artificial, science with the natural.”[4, p9]
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> **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.” [4, p. 14]
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> **Structures and Machines:** “As intimitely 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.”[4, p13]

The first distinction between science and engineering/technology has a basis in classical philosophy. Aristotle distinguishes between *episteme* and *techne* in *The Nicomachean Ethics*; they are respectively “demonstrative knowledge of the necessary and the eternal” and “knowledge of how to make things.” [3, p104, 105] From these capacities for pure knowledge comes the ability to act deliberately in one mode or another. Science would then follow as an application of reasoning about eternal physical laws. Similarly, *techn*ology/archi*tec*ture follow as applications of reasoning about making.

The second distinction between the role of structural designers and architectural designers concerns scale and system boundaries. That is, the act of making structures is determined by the large-scale structural function as its use case and structural building forms as its language. The act of making architecture is about the human-scale and concerns myriad physiological, visual, spatial, and social forms as its language.

The third distinction between structures and machines is the most dividing as "they symbolize two distinctly different types of designs." This is tied to the second distinction and they are both far more subjective than the first distinction. The latter two are quite subject to change.

> "The first principle of structural art is that **the form controls the forces.** In general terms, this means that **function follows form**" [4, p87]

rationalize these boundaries emerging through lens of structural art, Tom F. Peters' *"How the introduction of iron in construction changed and developed thought patterns in design"* is broadly referenced here as a source for epistemological and technical patterns moving through this era. Three modes of thought: 'overlay' thought [2, p. 36] of pre-modern design, 'model' thought [2, p. 37] developing under the influence of the Enlightenment, and 'kit-of-parts' thought [2, p. 53] leading into the twentieth century, generally discern the pre-modern to modern transition in building.

Overlay thought appears between the "veritable polytechnics" of pre-eighteenth century thought and the nucleation of a more structured, analytical form of polytechnics. It is a pre-theoretical idea, relying on a collective of experiential and experimental forms rather than conscious analysis of structural behavior. 'Overlay' implies the superposition of invented and analogous building forms and methods, directed towards the progression of grander and more capable structures. The absence of conscious analysis allows "more flexible and redundant" designs to fit a particular materiality, location, and construction method; compared to calculated, deterministic, and isolated designs derived from an abstract model. [2, p36, 37] In turn, it lacks a robust arithmetic language, but embraces a geometric one.

Model thought, **the generally accepted form of contemporary building thought** [2, p38], "[makes] objects by synthesizing analytical thinking and a clear split of empirical knowledge into the experiential (learning from direct knowledge, which [is] considered a lesser process), and the experimental, or learning by introducing a variable into a normal situation, which was considered a more reliable way to gain knowledge." [2, p39] By deconstructing experimentally validated forms known to work reliably for a certain purpose into a hierarchy of parts susceptible to conscious analytical functions, builders are able to solve various problems with rigorous [1] and standardized means *if they assume a host of non-realistic conditions in the analysis.*

Kit-of-parts thinking appeals to a more dynamic mode of building inspired by the building process rather than end form. It is proposed to be, in part, a reaction to the mobilization of war-machines at the onset of W.W.I.. "Assembly" is a critical notion that enables a "design-matrix of structural constants and variables" capable of organizing finite *systems* and their corresponding forms, mechanics, and functions. Peters implies a semantic separation from construction ("putting together", creating, changing, and manipulating interfaces and connections by altering components") to assembly ("one degree removed from manufacture, fitting together without alteration, minus adaptation") [2, p53]

The technological innovations 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." [4, p5] Doing so enabled a rapid and reciprocating techno-social progress. However, this elasticism was not actually calculable until Claude-Louis Navier's theory of elasticity in the 1820's. [5, p73] Therefore, Billington claims that

[1] De Toffoli claims that sentential logic is regarded in the modernizing traditions as the proper means towards mathematical proof, as compared to diagrammatic/visual logic.

the engineering involved in structural art initially denied stress-related analyses for physical intuition and empiricism as its primary science. [4, 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. [4, p5,16,17]

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**.

References

[1] In:

[2] In:

[3] Aristotle, W. D. Ross, and Lesley Brown. *The Nicomachean ethics*. Oxford University Press, 2009.

[4] David P. Billington. *The Tower and the Bridge. The New Art of Structural Engineering*. Princeton University Press, 1983.

[5] 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.

[6] Anthony F. Merrill. *The Rammed Earth House*. Harper and Brothers, 1947.

[7] Lewis Mumford. *The Myth of the Machine. The Pentagon of Power*. Columbia University Press, 1970.

[8] Nancy Shatzman. Steinhardt. *Chinese architecture*. Yale University Press, 2002.