

The design of every thing that flows and moves^{1,2}

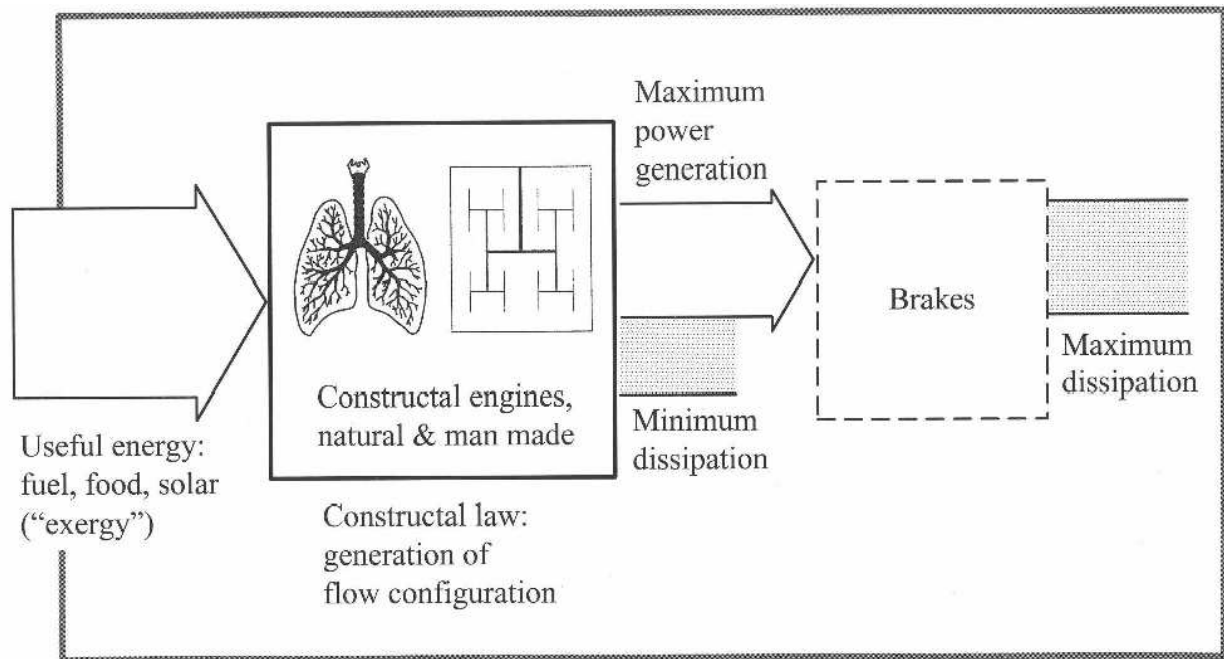


Figure 1 Every nonequilibrium (flow) component of the earth functions as an engine that drives a brake. The constructal law governs ‘how’ the system persists in time (how it survives): by generating a flow architecture that distributes imperfections optimally to fill the flow space. The ‘engine’ part evolves in time toward generating maximum power (or minimum dissipation) and, as a consequence, the ‘brake’ part exhibits maximum dissipation. Evolution means that each flow system assures its persistence in time by freely morphing into easier and easier flow structures under finiteness constraints. Evolution never ends because in nature the constraints (e.g. solar heating) change with the ages. The arrows proceed from left to right because this is the general drawing for a flow (nonequilibrium) system, in steady or unsteady state. When equilibrium is reached, all the flows cease and the arrows disappear, but the traces of the flow (erosion, skeleton, heterogeneity) remain.

Thermodynamics has reached an impasse similar to the development of the heat engine two centuries ago. The real world (nature, physics) has structure, organization, and pattern. Until now, thermodynamics was not concerned with the architecture (the drawings) of the systems that inhabit its black boxes. It should have been.

The tissues of energy flow systems like the fabric of society and all the tissues of biology, are special architectures. Not just “any” architectures, as in the black boxes of classical thermodynamics, but the optimal, or the near-optimal architectures. The climbing to this high podium of performance is the transdisciplinary effort—the balance between seemingly unrelated flows, territories, and disciplines.

No flow system is an island. No river exists without its wet plain. No city thrives without its farmland and open spaces. Everything that flowed and lived to this day to “survive” is in an

optimal balance with the flows that surround and sustain it. This balancing act—the optimal distribution of imperfection—generates the very design of the process, power plant, city, geography and economics.

We examined theoretically [1, 2] the largest flow system on earth from the point of view of the constructal theory of organization in nature [3], which now constitutes the thermodynamics of nonequilibrium (flow) systems with configuration [4, 5]. The news is that there are two time arrows in physics, not one. The old is the time arrow of the second law of thermodynamics, the arrow of irreversibility: every thing flows from high to low. The new is the time arrow of the constructal law, the arrow of how every flowing thing acquires architecture, configuration, drawing. The “how” is condensed in the constructal law: existing configurations assure their survival by morphing in time toward easier flowing configurations. The constructal time arrow unites physics with biology and engineering (engineering is the biology of “man + machine species”).

We see this union in Fig. 1, which expresses the vision proposed in Fig. 3.16 of Ref. 3 and earlier. The earth with its solar heat input, heat rejection, and wheels of atmospheric and oceanic circulation, is a heat engine without shaft: its maximized (but not ideal) mechanical power output cannot be delivered to an extraterrestrial system. Instead, the earth engine is destined to dissipate through air and water friction and other irreversibilities (e.g., heat leaks) all the mechanical power that it produces. It does so by “spinning in its brake” the fastest that it can (hence the winds and the ocean currents, which proceed along easiest routes). Because the flowing earth is a constructal heat engine, its flow configuration has evolved in such a way that it is the least imperfect that it can be. It produces maximum power, which it then dissipates at maximum rate. Maximum dissipation is being invoked *ad-hoc* in geophysics: all such talk applies only to what goes on in the brake.

The heat engines of engineering and biology (power plants, animal motors) have shafts, rods, legs and wings that deliver the mechanical power to external entities that use the power (e.g. vehicles and animal bodies needing propulsion). Because the engines of engineering and biology are constructal, they morph in time toward flow configurations that make them the least imperfect that they can be (Fig. 1). Therefore they evolve toward producing maximum mechanical power (under finiteness constraints), which, for them, means a time evolution toward minimum dissipation (minimum entropy generation rate).

Immediately outside an engineering or biology engine, all the mechanical power that the engine delivers is destroyed through friction and other irreversibility mechanisms (e.g., transportation and manufacturing for man, animal locomotion and body heat loss to ambient). The engine and its immediate environment (the brake), as one thermodynamic system, are analogous to the whole earth (Fig. 1).

When all is said and done, the flowing earth (with all its engine + brake components, rivers, fish, turbulent eddies) and all of us (the “man + machine” animal species), mixes the earth’s crust most effectively—more effectively than in the absence of the constructal phenomenon of generation of flow configuration. Dry river basins, Egyptian pyramids and junk yards are fossils of the constructal flow systems that once thrived.

Physicists have always been intrigued by the mystery of configuration generation, which is foreign to dynamics. Before the constructal law, no straightforward connection had been envisaged in order to bring together these two aspects (configuration and dynamics) in describing the evolution of the systems in space and in time.

The thermodynamics of non-equilibrium systems with configuration [4, 5] is an example of how science makes progress. It does, but in steps. The field reached an impasse because the scientists' knowledge and imagination raced well ahead of the concepts and language that are currently accepted. The knowledge and imagination consider "design" (order, optimization, maximization, etc.) as evident. The current language is stuck in the concept of 'entropy', disorder and the microscopic.

The word entropy does not appear in constructal theory. Entropy is the word and concept of the second law of thermodynamics, which it serves very well. The physics covered by the second law is the phenomenon of irreversibility: every thing flows from high to low (there are other equivalent statements [2, 3]). The occurrence of organization (configuration, macroscopic complexity) in nature is an entirely different phenomenon. This phenomenon calls for its own principle and concepts. The constructal law answered this need. The words that appear in the constructal law are the generation of flow configuration, in time.

References

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