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The four functions of elementary pipe design from constructal law

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Abstract

Constructal law explains the sense of evolution (morphing to improve flows) of beings, but paradoxes do exist as not all vegetables have a tree form. Also, not all animals are optimized for displacement. This work aims at identification of the design functions or objectives that guide evolution under the overall statement of constructal law. This work adopted the system engineering technique of segregation between functions (abstract objectives) and solutions (physical entities). Further, this work introduced the assumptions of flow under external threats and pipes subject to leakages. Results showed that there are always elements doing four functions in pipe element: to reduce flow entropy, to protect flow channel, to retain flow content and to increase flow drive. Although the four functions are always present, natural systems typically privileges some functions over others, depending on environmental pressures. As a solution to improve flows, animal brains also fit in the model of four functions. Human mind seems to have groups of instincts associated to each of the four pipe design functions (fear, attachment, curiosity and greed). Finally, the four functions model unified physics and animal psychology.

Keywords: constructal law, system engineering, unifying theory, animal design, gamification, human centred design.

1. Main text

Constructal law states that beings morph in the sense to give greater access to the flows needed to their survival or existence [1]. Adrian Bejan also stated a case of the constructal law as the tendency to minimize flow resistance (or entropy generation) in a pipe given pipe length and volume are fixed. Adrian Bejan also enumerated the flow problems, which are: flow from point to point, flow from point to curve, flow from point to surface, flow from point to volume. The best solution for flow from point to point is the round cross section straight pipe [2]. The best solution for flow from point to many points (curve, surface or volume) is a tree, which is in fact a structure composed by a set of pipes.

However, at first glance, in nature, many structures or life forms seem not fit in the constructal law, like cactus (mostly a single trunk), turtles (not mobile at all) and sloths (evolved into a slow creature). This work aims at creating a model to explain such singularities or paradoxes by adding the assumptions of flow risks and pipe imperfections. The first step is to enumerate this work assumptions:

- Every aspect of design serves to the constructal law statement: beings morph to improve flows;
- The elementary pipe is base to solve every flow problem (point to point, point to curve, point to surface and point to volume) as trees are also composed of pipes;
- The environment of the flow system contains sources of disturbances or threats that may cause flow interruption (total or partial);
- Imperfections are always present in pipe construction, meaning that a perfect round form cannot be achieved in practice nor perfect tightness, as order requires energy application (perfect form requires infinite energy);
- Probabilistic approach: threats events and intensities are not deterministic but occur following a probability density function. The same goes for the pipe construction, as forms are never perfectly replicated;
- Real-life flow systems (for instance, animals) may need many simultaneous flows to exist, like water, food, sun bath, sex;
- A single flow interruption may destroy the system. For instance, block of airways for animals.

The first aspect of the method is the formal segregation of objectives (abstract functions or realized actions) and solutions (physical entities). Functions are typically expressed in the form verb plus substantive, optionally adding some semantical complement. Functions are abstract objectives perceived by human mind and are different from (but related to) the material entity realizing it. Solutions are physical entities that have mass, volume and physical properties. Such state of mind helps to understand systems and it is adopted in system engineering for many reasons. Taking the enumerated assumptions into account, to establish flow from one point to other, and to improve it over time, the following functions are necessary:

- to reduce flow entropy. This function is the objective of reducing entropy generation or power requirements of the flow, as stated by [2]. Due thermodynamics second law, every movement implies in entropy generation. For fluids, due the viscosity property, part of the energy is irreversibly lost. A solution for this function is the round shape of pipes;
- to protect flow channel. This function is the objective of availability of the channel for the flow, preventing plugging. This function is a response to the assumption of external threats. An example is a protective shell against external aggressions;
- to retain flow content. This function is the objective of reduction of loss of part of the content or keeping the same flow at inlet and outlet. Forms cannot be perfect by assumption, so a pipe needs to mitigate losses or leaks. An example is electric insulation on electric cables; and
- to increase flow drive. This function is the objective of increasing the magnitude of the driving force of the flow. For instance, increasing the electric tension on power lines or increasing hydraulic fluid working pressure.

Animal brains and associated instincts are solutions (from the point of view of constructal law) to facilitate access to flows. Animals have the urge to get food even if they are not hungry, giving rise to greed which seems to be consequence of the function of increasing the flow drive. Many species get attached to other individuals or an environment which seems to be the function of retaining flow content. Most animals also feel fear, which seems to be a solution to protect the flow channels. Some species have the urge to get new information, to go to unknown places which leads individuals to reduce the overall effort and risk to get access to flows (food, water, shelter). Curiosity seems to be an answer to the function of entropy reduction. Table 1 presents some examples of the proposed functions for each domain of nature or human-made machines.

Table 1. Examples of functions across domains

Domain	to reduce flow entropy	to protect flow channel	to retain flow content	to increase flow drive
Fluid	reduce pressure loss	prevent the entrance of foreign material in the channel volume	prevent leakages	increase working pressure
Electric	reduce heat losses	prevent electrical discharges	prevent leakage currents	increase electrical tension
Mechanical	reduce mechanical losses	prevent corrosion	reduce flexibility	increase mechanical stress
Thermal machines	reduce entropy generation	reduce of fouling	reduce heat losses to environment	increase temperature difference between sources
Information systems	reduce spent energy per bit	reduce noise	reduce data loss	increase data flow and bandwidth
Animal body	reduce energy for displacement	protect against aggression	retain body components, mainly water and blood	increase muscle power
Animal mind	desire changes	fear aggression	attach to known entities	desire flow increase
Vegetables	reduce energy for driving water and minerals from roots to leaves	prevent attacks	retain nutrients like water	increase growth rate

Although all four functions are always present, environment may impose more mass and energy investment in one function than the other functions. When this happens, there is a dominant function while the other three remain recessive. In an experiment involving human players, it was found that there are four types of players, encompassing about 88% of population: trustful, pessimist, envious and optimist [3]. Other 12% did not present a dominant behaviour. Table 2 presents some examples of natural systems design according with the respective dominant functions.

Table 2. Examples of natural systems and their dominant functions in design

	Dominant function in design			
Natural system type	to reduce flow entropy	to protect flow channel	to retain flow content	to increase flow drive
Vegetables	tree	thorn tree	cactus	grass
Animals	birds	turtle	camel	horse
Player types	trustful	pessimist	envious	optimist

The analysis of functions (objectives) of the elementary pipe included the identification of particularities for a set of domains. This work presented a finite induction from many domains (physical, vegetal, animal and social), relating the proposed functions with the physical properties. The model of four functions seems to be adherent and quantifiable. A key finding was that addressing the four functions is key to design balanced solutions. In engineering, designers need to balance the four functions to reduce life cycle costs. Another key finding is the relation of the four objectives with animal brain and instincts. Understanding the drivers behind human mind evolution is the key to design information systems and games. Future work consists in exploring human mind drives in engineering information systems using human-centric design (gamification techniques). Such approach may improve productivity and personnel satisfaction.

References

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