Bejan 2.0: Toward a More Refined Constructal Law

Bert G. J. Frederiks[a,1,*]

[a] *Independent, The Hague, The Netherlands*

Abstract

Other than Bejan's constructal law predicts, evolution of flow-systems (or life) goes with ups and downs. Essential for evolution are physical processes of *trying*. The better access 'only' needs to come before death or extinction. The process of dying gives time for this. Lowering access may even need to precede the better access.

The freedom law predicts how and when new systems or life emerge through reductive freedom, and it shows how evolution works through changing freedom. Reductive freedom itself evolves, and is co-created top-down, because of higher life-forms needing it for their survival. Yet reductive freedom is not always 'accessed' immediately.

I suggest an *evolved* version of both the constructal and the freedom law*:->*

Keywords: constructal law, freedom law, life, reductive freedom, evolution

1. Introduction

I want to argue that Bejan's *formulation* of the constructal law does not *strictly* and *completely* match *his own* ideas behind it [1, 2, 3] — it is correct in spirit, but not in letter. My theory on reductive freedom will need some additions too. Changes to my own theory have to do with "potentiality"; that is of things not *always* and not *continuously* being necessary or causal [4].

1.1. Ups and downs of easier access

This is the original constructal law:

> For a finite-size system to persist in time (to live), it must evolve [freely] in such a way that it provides easier access to the imposed currents that flow through it [1, 2, 3],

Interpreted strictly, the law states that access to the flow of a system has to grow *always* (through evolutionary means). But we know from biology and engineering that, in practice, such goes with ups and downs — with a rhythm even. This is an undeniable falsification of the law, and very interesting. One cannot say that "easier access" is not to be taken strictly because the word "evolve," meaning 'evolution,' is used too. Yet, indeed, access must certainly grow '*in time*,' i.e., *before life dies*. But dying and extinction are *processes*. Dying and extinction *give* time. A physical law should catch these 'ripples of time' within the law. So, the constructal law itself will have to evolve*:-)*

1.2. The birth of laws from concepts or insights

The constructal law is entangled with, what I call, "reductive freedom" [5, 6]. From the easy to show *existence* of reductive freedom, *necessarily* follows 'my' freedom law. This law is about life *coming* into existence. It is the law of *emergence*.

Bejan's constructal law is about life *being* and *staying* in existence. It is the law that *necessarily* follows from his physical concept of *life* and the real *existence* of that: Physical life is anything that both flows and has a persistent but evolving design or configuration, for example, a river. Therefore I also call his law "the law of life" — ipso facto the law of death.

1.3. Life and death from the constructal law

As stated in [5, 6], the constructal law can be reformulated starting with an "if": "If a system is to persist in time (i.e., if it lives), it must evolve freely in such a way that it provides easier access to the imposed currents that flow through it." This formulation more clearly shows that the constructal law is not only about *life*, but also about *death*. I have shown how the type of death that 'bricks,' 'solidifies,' or 'fixates' configurations is fundamental to the construction of the universe. Regarding biological systems, a 'dissolving' or 'destructive' kind of death is more important, since biological evolution spreads through offspring, so parents have to die — but much of such life is fixated in DNA.

1.4. Life creating freedom and 'higher level' life

In [5, 6] I explain how life builds itself up out of reductive freedom of other living or (relatively) death systems. Life "supervenes" on other lives and deaths [7].

Reductive freedom means that the parts of a system do not fully determine the state of that system. They, so to

*BGJFrederiks@gmail.com

[1] Author Homepage and News: `http://www.bertfrederiks.nl`

· This is a follow-up on my peer-reviewed paper published at `https://doi.org/10.1016/j.icheatmasstransfer.2024.107516` · This preprint is available at http://dx.doi.org/10.2139/ssrn.4991994

say, submit themselves and wait for 'input,' i.e., they show a certain 'behavior.' Here *reductionism* ends, and a new system or being *emerges*, for which the constructal law applies again — this is a 'newborn' universe with its own time and space, though the time and space of its constituents is not lost, e.g., our thoughts (mental time-space) living in our brain (physical time-space) [5, 6]. Some examples in [6] are: The moment people start behaving habitually or predictably, a social structure will emerge. Regarding physics, atoms are largely dead structures, but they do have chemical freedom, which may create all kinds of materials. In an inviscid jet, the compressibility of air molecules (=freedom) within a cylinder, makes that its output behaves as a column under pressure, and therefore it creates a sound with a frequency determined mainly by the exhaust's diameter.

2. A better freedom law and theory

In [5, 6] the freedom law states:

> When and only when reductive freedom arises, life *can* cause new natural systems or beings to come into existence, that is to emerge.

Mimicking Bejan's formulation of the constructal law, a more clear formulation of the freedom law may be:

> For a new being or natural system to come into existence, i.e., to emerge, reductive freedom must arise.

When energy starts to flow, then (by definition) a flow-system will arise. As the first law of thermodynamics states, energy cannot just disappear with no effect, though it may end up as entropy, i.e., inaccessible energy; see [4].

2.1. Life co-creating its own freedom

In [5] and [6] I take freedom itself to be determined only by reductionist principles. That was the aim of these articles: to prove *to reductionists* that irreducibility and the *emergence* of new beings *exist*. Now that we understand that, we can take the next step: top-down (co)creation of reductive freedom.

My earlier articles introducing the freedom law assume reductive freedom to arise *first*, with (higher level) life emerging from this. However, and more complex, a *partial* freedom may arise first, which may get ever more free in the process of the emerging and evolving life *because of this life* — i.e., non-reductionist. The evolving life may *need* the evolving freedom and *thus choose* it to evolve, like with DNA, i.e., a molecule, evolving under environmental pressure. This is 'top-down' co-creation of freedom. The evolution of our intelligence is also an example of this. Humans *need* free intelligence for survival, so that is what our (cultural, lingual, biological, and personal) evolution is 'aiming' at. In [5, 6] I did realize how life *uses* a *provided* reductive freedom, and how it *itself* forms or creates new, reducible, 'bottom-up,' reductive freedom, but I more or less 'forgot' how this life itself may co-create this freedom 'top down,' because of freedom being beneficial or even essential to this life.

2.2. Potential, accessible, and accessed freedom

I at first thought that reductive freedom would *always* cause a new natural system or being to come into existence. But then I thought of a battery. A battery has a *potential* to provide 'action,' i.e., it is *accessible*. But one *need not* use or access it. There is a *freedom* to connect to the battery's current or not, as many electronic circuits are switching between continuously. Isn't there actually always first a *potential* or *accessible freedom* or use, which is then, or in the end, ((almost) always), accessed? — in the end, any battery will drain. Isn't that the essence of time and finiteness? Such a potentially usable, but momentary inaccessed or inaccessible force, in fact is a relativistic form of entropy, as I explain in [4].

Introducing 'potentiality' makes that we take *time* and *configuration* into account more explicitly. The freedom is double free; it is both *reductively free*, and it is 'potential,' 'accessible,' or 'optional,' i.e., '*free to use*.' These, in fact, are the same freedom, but the first is as seen from 'the inside,' i.e., the (reducible) design and cause of the freedom. The second is as seen from 'the outside,' i.e., its praxis, usability, and behavior. The constructal law adds a third: *evolutionary* freedom through change in configuration or design.[2] In [4] I delve deeper into potentiality, freedom and energy.

3. A better constructal law – a better law of life

Evolution is not, as the constructal law in a (semantically and syntactically) strict reading presumes, an *ever-and-always* rising access. In nature, there are examples of animals, or parts of animals, that have not changed for millions of years. Think of mitochondria or chlorophyll and the processes around it. Even if these will *some day* evolve, *there is a long period in which they need not or do not evolve*, yet in which they are alive for sure. Bejan certainly came to realize this too, but he did not adapt the constructal law to it.

3.1. Constructal law requirements

Let me sum up what the better constructal law should take into account... (1) Like not every reductive freedom *immediately* leads to the emergence of life, so *life* does not

[2] I would have liked to note here that evolution is to change the superversal or extraversal *usage* of more subversal or intraversal systems. But I have experienced that reviewers who have not read my earlier work will not accept this. Since I do not want to repeat my arguments, I will not use these terms here, except in footnotes.

continuously and at every moment *evolve*. It is not required to do so because dying and extinguishing are *processes*, so it *gives* time to not evolve and to make errors. (2) Since the process of evolution is seldom perfect, i.e., it goes with ups and downs, access will not even (need to) *rise* always. Only in retrospect it will, if you take a 'long enough' period of time. I think the prototypical example is this: A big DNA mutation may be quite destructive for an individual, but if it gets into offspring, one 'good' mutation in it might select out. For instance, human beings likely have evolved into having ever better access from *neoteny*, i.e., loosing evolved traits, becoming ever more juvenile, and ever more flexible and playful in our behavior. Engineers do not always immediately make the best choices either*:-/* (3) Wrong choices are often even necessary to get at the right ones, for instance, making up a 'first' constructal law*:-)* Creativity, in general, goes with ups and downs. (4) Although, in a strict interpretation the constructal law is not fully correct, the idea of 'on average' gaining ever more access is true and very important. How to formulate that? And, less 'critical,' (5) what if the accessed flow, as provided by the environment, diminishes? Then, probably, *absolute* access to it lowers with it, but *relative* access maybe does not — taking "relative" to mean relative to competitors and relative to the diminished flow. (6) The constructal law should state that all life must have the *potential* or *freedom* to evolve, not that it *must* evolve at any and every moment. But, (7) there are situations in which, in order to survive, it indeed *must* evolve, including because competitors evolve better, and (8) it usually has to do so *in time*, thus (9) *quite* continuously, to survive in times of hard competition. (10) This will go with ups and downs, with a certain rhythm, the frequency of which is partly determined by external forces, i.e., top-down causality. Furthermore, (11) isolated and closed systems, such as the universe or the earth's economy as a whole, may not *for ever* need to raise their access in order to survive and live on; at a certain moment, keeping access may be good enough. Lastly, (12) the updated law should predict more (and more precise) than the original.

3.2. Law of life and death — randomness, uncertainty, and selection

To meet all these criteria one may change the constructal law as follows:

> For a finite-size system to persist in time (to live), it must *keep trying to evolve (its freedom)* in such a way that it provides easier access to the imposed currents that flow through it.

But I prefer the following, as it is more specific:

> For a finite-size system to stay alive (i.e., to persist in time), it must access and keep *trying* to evolve its freedom (i.e., its 'internal' and 'external'[3] possibilities) in such a way that it accesses the imposed currents that flow through it ever better.

In this, "keep trying" provides the '*direction*,' or even '*intention*,' of development and evolution, yet it allows for 'ups and downs.'

A physical definition of "trying" is not only possible, it is used extensively already. It means 'to do, but to stop, return, die ("selection"), or do something else if not successful.' We find this in stochastic or statistical interpretations of physics and reality. Then "trying" relates to randomness and uncertainty. We find this in biology (random mutations in DNA) and in quantum mechanics. In the psychic and social domain possible operationalizations of 'trying' are, for instance, playing, arousal, and searching.

Remark that 'ever better' does not *guarantee* survival; others might do even better. But it does define an aspect of life, while it is still alive. Regarding the constructal law, death and dying are usually forgotten, though it is essential in many ways.

3.3. Trying without "trying"...

Some readers may nevertheless protest against the term "trying" in this context. Then they must try to*;-)* leave it all to the meaning of "to evolve," as in Bejan's formulation. "Evolution" is more correct than "evolving." This tried*;-)*, I think *syntactically* "evolution" is not enough, for the law still suggests that access should always improve. "Enough access not to die" instead of "easier access" would be better, but this predicts less than the original law:

> For a finite-size system to live (to persist in time), it must access its ('internal' and 'external')[3] freedom, and there must be evolution of this freedom in such a way that it provides enough access, to the imposed currents that flow through it, to stay alive.

This version does not show that, in the end, access must ('on average') be ever better. "Keep trying" really says it all and points at what is actually and really happening.

3.4. Flowing and flowable freedom

Flowability or *movability* is a special form of reductive freedom, i.e., some systems have the (reductive) freedom to *flow*. The direct environment determines where the flowable stuff will move to, the stuff itself does not. *Movement* is much like such flow in the context of this article. Typically this is the stuff that runs through the flow-systems that the constructal law is about.

[3] Hereby we mean, of course, subversal (or intraversal) and superversal (or extraversal) freedom.

Anything (physically or non-physically) flowable is a carrier of (physical or non-physical) *energy*. Anything flowing *physically*, including heat, also has *physical* energy — and generates entropy.

Although special, flow is just one example of reductive freedom. The other way round, in any configuration, *freedom itself can be seen as a 'thing' or behavior, i.e., an abstraction comparable to energy, that can flow through this configuration*. For instance, thoughts and knowledge can flow in our brain and between people. They even have energy, though not physical. Historically flowing gasses gave us these insights. I thought of one example where the flow more or less is the configuration: Domino toppling*:-)*

Statements and Declarations

The author declares no competing interests. No funding was received either. I am not a physicist. Physics came to me in me explaining consciousness [5, 6].

References

[1] A. Bejan, Adrian Bejan & Constructal Law (Aug. 2022). URL `https://mems.duke.edu/research/energy/bejan-constructal-law`

[2] A. Bejan, S. Lorente, The constructal law of design and evolution in nature, Philosophical transactions of the Royal Society of London 365(1545) (2010) 1335–47. doi:10.1098/rstb.2009.0302.

[3] A. Bejan, The Physics of Life, the Evolution of Everything, St. Martin's Press, New York, 2016.

[4] B. G. J. Frederiks, The Single Pole Battery: A Relativistic Understanding and Generalization of Clausius' Concept of Entropy (Apr. 2025). doi:10.31219/osf.io/skphf_v1. URL `https://osf.io/skphf_v1`

[5] B. G. J. Frederiks, To Emerge or not to Emerge, Reductive Freedom creates Life, Being and Death (Feb. 2023). doi:10.31219/osf.io/dy69c. URL `https://osf.io/dy69c`

[6] B. G. J. Frederiks, The freedom law, International Communications in Heat and Mass Transfer 155 (2024) 107516. doi:10.1016/j.icheatmasstransfer.2024.107516. URL `https://linkinghub.elsevier.com/retrieve/pii/S0735193324002781`

[7] E. Vintiadis, Emergence (Aug. 2019). URL `https://iep.utm.edu/emergence/`