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Book Review

Design in Nature
Anchor Books, New York, 2013, ISBN 978-0-307-74434-0
By Adrian Bejan and J. Peder Zane

Bjarne Andresen

Design in Nature is a fascinating elaboration on how many structures in Nature as well as in civilization resemble each other. The author does not make any distinction between natural systems and man-made systems and argues forcefully that man is part of Nature and hence our systems are as natural as a river system. I fully agree and thus will not make a distinction either. The thesis is that everything of importance in the world are flow systems: Flow of water in rivers, of electricity in lightning, of people around the globe, of ideas between cultures, and so on. The argument for this is a little artificial and strained at times, but what the heck, let's give the man some rope. The idea is truly thought provoking. The claim is that all these flow systems will then naturally evolve over time in such a way that resistance decreases and consequently the flow increases.

The reasoning is interesting and gives a new perspective on the many similarities. However, I lack any explanation of why *all* these flows *must* evolve this way. It is simply postulated or argued with the words "in order to", i.e., Nature must do things this way in order to achieve a certain effect. But to a-religious scientists, and Bejan claims to be one, Nature has no purpose, it follows the established laws of physics and of probability, but it does not have any higher goal. Therefore any argument using "in order to" is non-scientific.

The realization that so many phenomena look alike in Nature – e.g., the shape of river systems, of tree branches, tree roots, lightning bolts, blood vessels, lung airways – has probably occurred to most of us sometime without thinking too deeply about why. Bejan's primary accomplishment is providing a framework for thinking about this 'why.' He does it in terms of what he has dubbed the 'constructal law' which he claims is a primary law of physics, not in need of experimental proof, not to be questioned, it is just there, ex cathedra. That is where I have serious misgivings.

In physics 'laws' are relationships between quantities or concepts or ideas which have been defined independently from each other and which often have been distilled out of endless numbers of experiments and which are seemingly not violated, at least not within the universe we are considering. We have energy conservation (the First Law of Thermodynamics), non-decrease of entropy (the Second Law of Thermodynamics), charge conservation, and we have mass conservation as long as speeds are not relativistic. *All such 'laws' are true only as long as nobody has managed to produce an experimental counter example.* I.e., they are experimentally based, and they are under constant attack by probing experimentalists. Consequently they are upheld only until they are disproven. They are not absolute and God-given with the ability to predict rather than explain experiments as Bejan repeatedly claims for his 'constructal law.' His 'law' can at most be called a principle or a rule of thumb, something which works most of the time with reasonable accuracy, but not exactly all the time. That is one of the major differences between the modes of operation of engineering (Bejan's background) and physics (mine). This difference does not belittle the significance of this 'constructal principle,' but it is an important one.

Design in Nature is not accidental nor does it follow a particular higher principle. Rather, it emerges as being the path of highest probability. Out of the many (infinitely many) structures, which one will we see the most often? The one which has the largest chance of establishing itself. By the same token, the Second Law of Thermodynamics is not a first principle or a matter of design (p. 49); it is the consequence of systems preferentially moving to states of highest probability. There are more microstates available to a system at high entropy than at low entropy. This does not happen all the time, but preferentially. Small systems have been experimentally observed to violate the Second Law occasionally. Thus such statistical behavior, or "chance" as Bejan calls it, is not a result of too many conflicting pieces of information (p. 78) but the normal random evolution of systems. Total and exact predictability is the realm of traditional classical mechanics, while modern physics, e.g., quantum mechanics and chaotic behavior, is inherently statistical.

Next, what about the 'constructal' concept itself, law or no law? The idea is that large flows split into two smaller flows, each of which again splits into two still smaller flows, and so on, like streams in the delta of a river or a tree trunk into branches and eventually twigs. The splitting may also run the other way, i.e., merging, like creeks merging into rivers or the electricity generated in solar cells merging into larger and larger conductors before finally being connected to the inverter and then the power

grid. Some physical systems contain both splitting and merging, e.g., our blood system which splits from arteries to arterioles to capillaries in the tissue and then merges back to veins. Is this self similarity of constant binary splitting a new concept? No, it is a special case of fractals, so named by Benoît Mandelbrot almost 40 years ago but as a concept much older. A fractal is the repeated operation on a structure making the fractal self similar on all scales. Bejan's fractal is that of binary splitting, such that an overall map of the Mississippi River is indistinguishable from a map of its tributary Ohio River. Consequently, there is no need for a new name or a new concept. All his designs are fractals. Further, nowhere does he argue why evolution should always produce binary splits rather than, say, ternary or some random number. Nor does he explain why his designs should do the splits at right angles (most engineering designs) or at a more acute angle (most natural structures). For a claimed predictive 'law' there are many unanswered questions.

The book is oratorically well written and thus a fruitful attempt at explaining his ideas in layman's terms. One consequence is that it is rather longwinded for my taste. I am sure Bejan could have explained everything in certainly less than half the 300 pages which are used here. We do not need to hear the same arguments about rivers over and over again, nor do we need repeatedly to hear about his disdain for communism; it is irrelevant. By the same token, it is cute to learn about his father's attempts to survive under communist regime and his advice to his son, but what is the relevance to the structures of Nature? On the positive side, it is delightful to see that Bejan is not afraid to take up politically incorrect examples (race, gender, etc.) and attempt to give rational explanations of differences.

Another consequence of the very free flowing words is that many of the explanations come out like a horoscope: They are based on sweeping statements which on the surface sound true, statements which everybody can relate to but which are not unique and disprovable. This overwhelming case for a 'constructal law' reads like astrology, based on some improvable claims garnished with many examples and approximate statements. Every time some phenomenon does not turn out to follow the 'law' exactly, it is quickly dismissed as the exception which proves the rule or that it will work eventually, we just haven't gotten there quite yet.

Another point of friction in my mind while reading the book is Bejan's total lack of humility. He repeats the words 'constructal law' well over 1000 times in the book and the word 'I' even more often, even though it is a two-author book. It is hammered in again and again that "I did," "I discovered," "I published," "I made great drawings as a kid," and so on.

Bejan is indeed an accomplished researcher who doesn't need all this self-promotion. A more low-key attitude would have left a far more positive legacy.

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Author information

Bjarne Andresen, Niels Bohr Institute, University of Copenhagen,
Universitetsparken 5, 2100 Copenhagen Ø, Denmark.
E-mail: andresen@nbi.ku.dk