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Interactive comment on “Constructal theory of pattern formation” *by* A. Bejan

Anonymous Referee #6

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This manuscript reviews work related to the author’s “constructal law", which holds that “For a flow system to persist... it must evolve in such a way that it provides easier and easier access to the currents that flow through it". This “constructal law" is advanced as “a single physics principle from which form and rhythm can be deduced, without any use of empiricism". The author clearly intends to advance this “law" as a universal principle that governs all flowing systems.

For such a scientific law to be scientifically useful, we need a clear sense of what it means, a clear statement of the domain to which it applies, and a clear rule for how to apply it. As the present manuscript demonstrates, the constructal law presents significant problems in this regard.

What does it mean for a flow system “to provide easier and easier access to the currents that flow through it"? The present manuscript appears to interpret this in several

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different ways. For example, blood vessels are said to be configured to minimize drag; presumably this is what is meant by “easier and easier access". But turbulent flow structures, on the other hand, are said to provide “the most direct path for the flow of momentum from the fast regions of the flow field to the slow regions" – to maximize momentum dissipation, or, in other words, to maximize drag. In the first case, “easier access" means that the flow of fluid is maximized in the downstream direction; in the second case, “easier access" means that the flow of momentum is maximized in the cross-stream direction. The definitions are mutually contradictory; in the first case, “easier access" means that drag is minimized; in the second case, “easier access" means that drag is maximized. The problem is that for the constructal law to be scientifically useful, in each specific case it cannot just mean whatever its author says it does.

Presumably the configuration of a flow system is ultimately determined by the processes and mechanisms that shape its evolution. Is there anything in the evolutionary mechanisms that shape flow systems that drive them to a particular minimum-drag configuration? A counter-example is illustrative in this regard. In travertine streams, calcium carbonate precipitates due to out-gassing of CO2, with the result that the geometry self-organizes into a series of dams and pools, with drag effectively maximized. Travertine streams are completely natural flow systems, but they starkly defy the constructal law. Thus the constructal law is not universal.

Even in cases where nature conforms to the constructal law, it may well be doing so for fundamentally different reasons than drag minimization. In the case of ducts such as blood vessels, their roundness is said to arise because flow resistance is minimized, but the resistance of a square duct is only about 9 percent greater. So are blood vessels round in order to avoid this 9 percent penalty? It seems far more likely that blood vessels are round – in evolutionary terms – because they need to carry fluids under pressure, and a round duct is vastly stronger than one with corners.

Another example given in the manuscript describes how logs (or ships) floating in water, and being struck by wind, will naturally settle into an orientation perpendicular to the wind, with the effect of maximizing the momentum transfer from the wind to the water. But they don't do this because it maximizes the momentum transfer; they do this because in any other configuration, the wind exerts greater drag on the upwind end of the log (or ship), and the water exerts greater drag on the downwind end, so the only stable configuration is perpendicular to the wind. The configuration of the system is determined by force balances, not by an optimization criterion. To see that this has fundamentally nothing to do with optimizing momentum transfer, note that if one puts a small sail on one end of the log and or small rudder on the other end, it will now float parallel to the wind, even though it would transfer more momentum in the perpendicular orientation. Indeed, sea anchors are used precisely to alter the force balance on a ship at rest in a stormy sea, so that it orients itself parallel to the wind rather than perpendicular.

The standards of proof that are adopted in some cases are surprisingly loose. For example, the branching networks shown in figures 6 to 8 are presented as bearing some resemblance to natural stream channels, but the resemblance will appear elusive indeed to those who have studied the configuration of real stream networks. As another example, constructal theory predicts that stream channels should have an optimized with-to-depth ratio of approximately 2. This prediction is simply wrong, by roughly a factor of 10-100, when compared to most natural stream channels. The manuscript fails to disclose this, noting only that “there remains plenty of room for the empiricism-based analyses of river bottoms proposed in geomorphology, in fact, their territory remains intact. They complement constructal theory." On the contrary, a fairer assessment would be that the observational data flatly contradict constructal theory. Given these sorts of problems, the self-congratulatory tone of the manuscript will surprise many readers. In section 6, we are told that “The support for the theoretical view of turbulence as a constructal configuration-generation phenomenon is massive. Table 3 is one example of how an entire chapter of fluid mechanics is replaced by a single theoretical formula, Eq. (5)." This entire section, and much that it implies, strikes this reader as misleading. Table 3 compares conventional Reynolds and Rayleigh numbers for the onset of instabilities, with the author's “local Reynolds number" (which depends on the viscosity, the far-field velocity, and the diameter of the first eddies). But this compares apples and oranges, in two ways. First of all, it combines combining Rayleigh numbers and Reynolds numbers as if they are somehow comparable. They're not; one predicts convective instability, and the other predicts the onset of turbulence. Secondly, it compares conventional Reynolds numbers, which predicts the onset of turbulence from independently measurable quantities (velocity, viscosity, and the diameter of the duct), with the “local Reynolds number", which requires that one already know the size of the eddies in the turbulent flow! The “local Reynolds number" is useless for the purpose of predicting the onset of turbulence, because one needs to first observe the onset of turbulence and measure the size of the first eddies. One can then observe that these eddies conform to the predictions of equation (5), but that's entirely different from predicting whether they will occur at all. The “local Reynolds number" is interesting, but to claim that it replaces the conventional Reynolds number is misleading.

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