PROCEEDINGS OF THE 12th CONSTRUCTAL LAW CONFERENCE

Freedom, Design and Evolution

Editors:
Umit Gunes
Adrian Bejan
Umberto Lucia
Giulia Grisolia
Alexandru Morega

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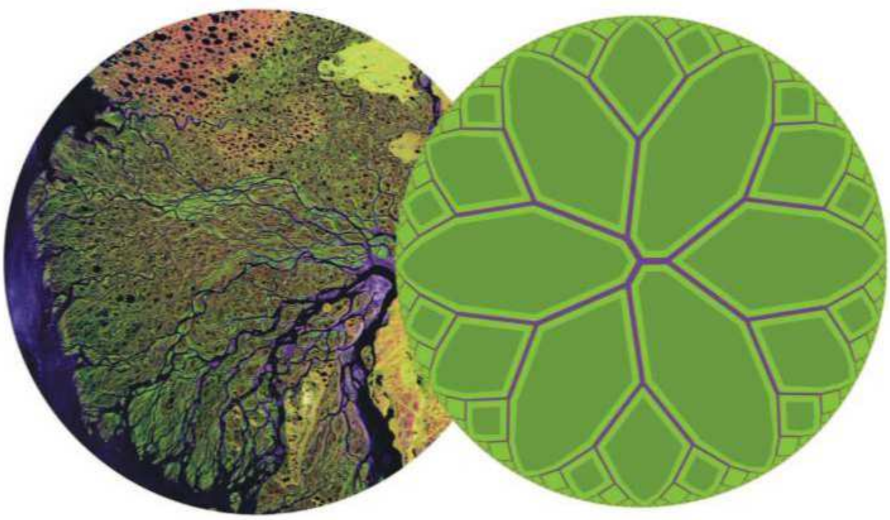

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Constructal Law Conference (CLC 2023)
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Vascular Design: Predicting Evolution

Adrian Bejan [1]

Abstract

Porous media are usually thought of as amorphous mixtures of two or more things, solids, fluids, and voids. The research field started that way, and so did my own activity in it. Along the way, I was drawn to the part of nature (the physics) that was missing from the amorphous view: the structure, flow, direction, configuration, drawing (design), purpose, and evolution [1-8]. The lecture is pictorial. It begins with defining the terms, vascular, design, evolution, and prediction (theory). Next, the lecture shows that vascular (tree shaped) architectures facilitate flow and movement. The tendency to evolve with freedom toward flow configurations that provide greater access is universal in nature, bio, and non-bio. This tendency is the *Constructal Law* of evolution in nature, which empowers us to predict the evolution toward flow access, miniaturization, high density of heat transfer, and the scaling up (or down) of existing designs. The future of evolutionary design everywhere points toward hierarchical flow architectures that endlessly morph toward freedom and access.

Keywords: Evolution, Freedom, Vascular, Prediction, Design, Constructal

1. Vascular flow configuration

Words have meaning. Vascular is an adjective. It refers to a feature of the image that suggests the presence of vessels conveying blood or lymph. This word does not come from biology. It comes from the Latin language, which is so old that it has been imported in many domains, as you will see

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throughout this lecture. Design is also a Latin word, both a noun and a verb, referring to how to make a sketch, a pattern, an outline, or a drawing. *Dessin* in French means drawing, as does *disegno*in Italian. The two images in Fig. 1 make the point that vascular design is present at all scales that we can perceive. The river delta and the human lung convince us that vascular design is everywhere.Consequently, vascular design is uniting the animate with the inanimate. Therefore, vascular designrepresents all nature, which means physics [1-8].

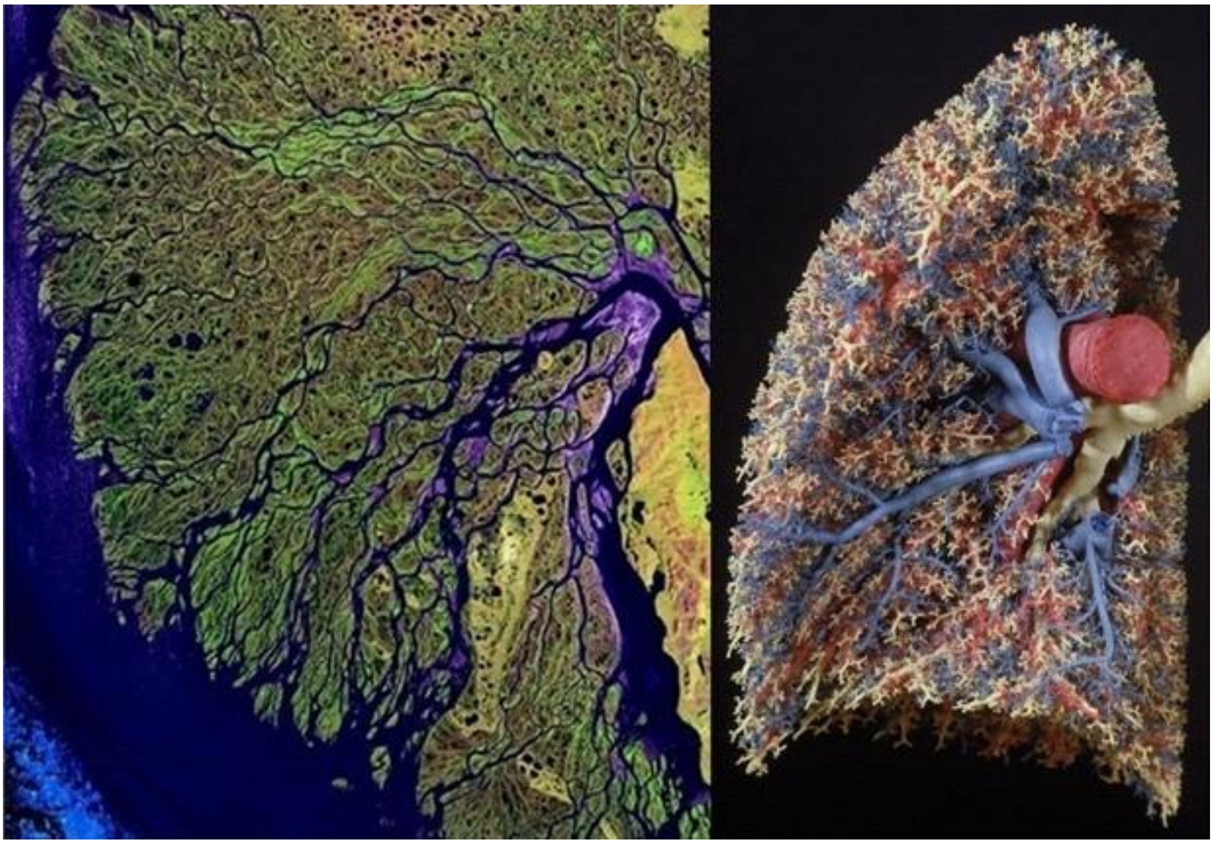

Figure 1. The flowing and evolving configuration unites the river delta with the human lung. The birth and evolution of flow configuration is a universal phenomenon in nature, bio, and non-bio.

Predicting design evolution begins once again with the meaning of the words. To predict, one needs a reliable mental viewing, which is called *idea* (a mental viewing) of how something *should be*. It is very important to know how something should be, that is the future of that something, before youlook at it. For that you need a reliable principle, a law. To predict is theory, and theory is not to be confused with empiricism or mathematical analysis.

One aspect of the physics of evolution is that nothing moves unless it is pushed. From the engines in the blue domain, the work (or power, per unit time) is responsible for moving something on earth.The movement dissipates the power. You can see the conservation of energy (the first law), from left to downward in the drawing. You do not see the second law, but you notice that the movement from left to right proceeded to a distance proportional to the work that was delivered to the mover.

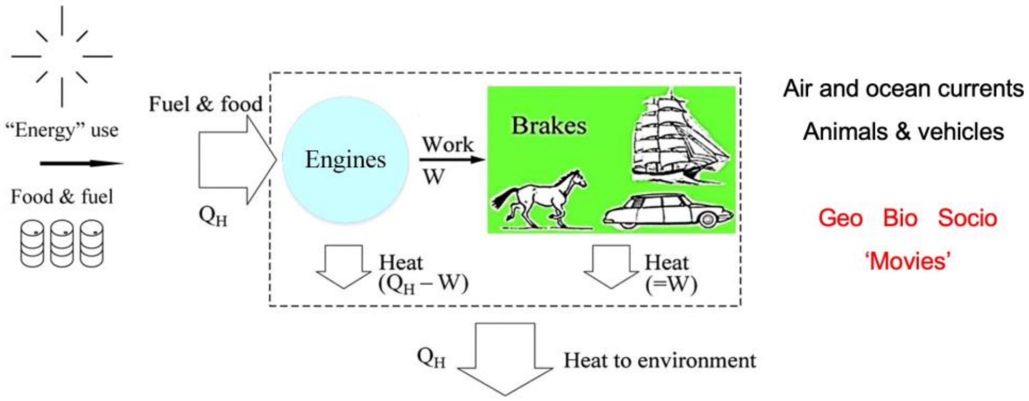

Figure 2. Nothing moves unless it is being pushed. The power comes from 'engines' fed by useful energy from a variety of sources. Power drives movement horizontally, against the ambient.

Another aspect of the physics of evolution is that from time to time the configurations that populatethe blue and green domains are morphing. They are evolving, changing all the time. What I sketchedin the rectangular dashed box is true of everything that a human being can perceive. The movementthat is driven by power with freedom and evolutionary design unites the geophysical with the biological and with the social dynamics.

Design in nature is not still life, not one image. Nature is a tapestry of 'movies' that are running simultaneously in the cinema of the mind of the observer. This reality has a concise summary, the Constructal Law of design evolution in nature: "for a flow system to persist in time (to live, in thermodynamics), it must evolve with freedom such that it provides greater access to what flows."

2. Predicting evolution

Vascular design is useful because it facilitates the flow (or transfer, diffusion) of something on areas,in volumes, and in societies of animals and people. The flows in the examples of this lecture are arborescent: heat conduction, fluid flow, urban traffic, point-area flow, point-volume flow, point- line flow, line-line flow, etc.

Theory is predictive. The principle is evolutionary design with freedom and directionality, objective,purpose, or goal. The evolution of the flow design has no end. With the mental viewing of facilitatingflow of access by morphing the architecture, the designer can fast forward the design, for example:

Vascular, arborescent architectures are everywhere. Every living organ (e.g., muscle) is a volume bathed by one stream entering as arterial blood and exiting as venous blood, as shown with red andblue in Fig. 3. The body is inhabited by two trees matched canopy to canopy. Imagine, two trees sharing the same canopy. That is the vascular design of the living organ, and it is predictable.

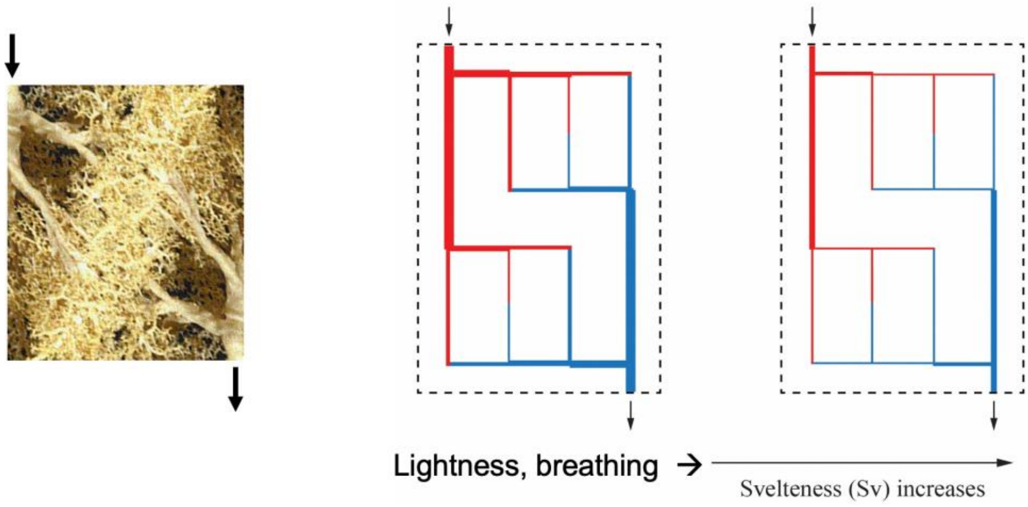

Figure 3. Living organs are vascular flow architectures, predictively. They should be configured astwo tree-shaped flows matched canopy to canopy, i.e., two trees sharing the same canopy.

Here is another benefit from getting to know vascular design in evolution. In the news there is a constant surprise that species vanish, and new species appear. This means that evolution, mostly inthe imagination of the biologist, is of two kinds: gradual changes, often imperceptible changes, which are accompanied by dramatic changes. Imagine two square specimens of trees matched canopy to canopy. Each specimen is swept (nourished) by one stream. In one specimen the channels are orthogonal, and in the other specimen the channels are diagonal. The measure of performance (flow access) of each of these organs is the pumping power or the pressure drop across the square. The better performance belongs to the specimen that requires less power. The complexity (graininess) of the specimen is indicated as the number of elemental squares (N^2) that reside in the square specimen. When $N < 7$, easier flowing is offered by the orthogonal design. When $N > 7$, there is an abrupt change to the diagonal design when the graininess of the of the specimen is sufficientlygreater.

The lecture continues with evolutionary designs such as flow volumes with spacings and inserts, multi-scale designs, electronics cooling by natural and forced convection, and the size of an organ on a mover, animal, or vehicle. It is important to question why we do things unwittingly [6,7]. The answer is that ‘organs’ are useful on something much bigger: the mover, animal, and vehicle.

3. Perfection is the enemy of evolution

With freedom comes the diversity of organ sizes that enable the greater system to exhibit essentially the best performance possible [8]. In evolution what works is kept. With imperfection comes significant freedom to identify sizes that assure high performance (not the highest, mathematically, but very close to the highest).

We arrive unwittingly at the physics basis of 'diversity', this time along the dry path of pursuing animal and vehicle design evolution. People talk a lot about diversity because its presence is obvious.People do not question why diversity must happen naturally. I marched against this method in chapter 8 of the book *Freedom and Evolution* [6] by predicting that diversity should be an essentialcharacteristic of the population on the globe today.

Diversity is one way that nature tells us how she works. Nature is not math. Nature is an immense superposition of flow designs, all evolving toward easier access, keeping what works, and going with the flow.

Driving the evolution of the mover is the tendency commanded by the constructal law: in this case,greater access means the need to cover a distance by consuming less food or fuel. This is the reality,it is on display everywhere, and covered in my books [1-7].

Acknowledgement. This lecture is supported by the Kimberly-Clark Distinguished Lectureship Award 2023 from the International Society for Porous Media.

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A tree-shaped constructal design with phase change material: A novel cooling strategy

Adeel Arshad[1]

Abstract

This study explores the heat transfer enhancement of a tree of conductive fins, as a constructal design, in a phase-change material (PCM) based heat sink. The effect of fin heights is investigated numerically at constant heating flux to study the transient temperature-time and natural convective heat flow phenomenon within the fins and PCM.At constant volume fraction of tree-shaped fins, the fin heights are varied as 0, 10, 15 and 20 mm. A commercially available PCM, RT-35HC, a grade of paraffin wax is employed with fins-based heat sink. The results of temperature-time variations and melting faction ofconductive trees in PCM are evaluated with a base-line case without conductive fins. Thereis a reduction of ~8% in heat sink's base temperature with 20 mm fin height filled with PCM compared to the 0 mm fin height case. The melting time is reduced with the increaseof fin height from 0 to 20 mm because of higher surface area of tree-shaped conductive fins. A more uniformity is observed in PCM melting, enhanced heat transfer rate with the increase of fin height. It is suggested that a heat sink with fully filled with PCM and equallyheighted to the heat sink of tree-shaped conductive fins has the better thermal cooling performance for electronic devices.

Keywords: Tree-shaped, Constructal Design, PCM, Heat Sink, Electronics Cooling.

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1. Introduction

The designing of electronic packages has been compacting with advanced and smarter features. This is only possible by choosing such a *design* or *geometry* judiciously so that components relative to coolant and each other can be arranged in fixed space. A modern electronics industry can only compete and hold the market if it promises the cheaper, faster, and high-performance technical features in a miniaturized electronic device. Conventionalair-cooled method uses the forced flow of air through package which is less effective. However, the convectional cooling methods are less effective because of bulky in volume, more noisy and unable to dissipate the excess heat from high-heat-flux electronic devices [1]. Phase-change material (PCM) cooled thermal management techniques are highly active from last decade because PCM can absorb or release heat during the phase-transition(solid-to-liquid) process at a constant temperature. The lower thermal conductivity of PCMs minimizes its rate of heat transfer, thus various techniques have been adopted integrated with PCM to enhance the heat transfer [2]. Xie et al. [3] studied the different volume fraction of 5%, 10%, 15% and 20% of PCM in plate-fin and tree-shape heat sink computationally. The results revealed that tree shape PCM-based heat sink significantly improved the melting rate of PCM in comparison with plate-fin heat sink. Khedher et al.[4] conducted a numerical study using solid-solid PCM and CuO nanoparticles in a plate- fin and tree-shaped heat sinks. A higher melting rate of 50% and 25% was obtained in caseof plate-fins and tree-shaped structure fins. Leong and his co-authors [5] carried out an experimental and numerical studies based on topology optimized tree-like structure. The authors found that tree-like structure heat sink exhibited a 4 ℃ lower heat sink temperaturecompared to fin structure heat sink at the same input heat flux. The current study exploresa tree-shaped constructal design heat sink with PCM of different volume fractions and fin structure heights for the first time through numerical method. Three different volume fractions and heights of tree-shaped constructal design heat sinks are chosen of 0%, 10% and 20%. The detailed melting phenomenon and natural convective heat transfer performance are investigated to determine the effect of PCM, optimum volume fraction and height of tree-shaped fin structure on thermal cooling performance.

2. Physical Model and Mathematical Formulation

The computational domain of tree-shaped constructal design filled with phase change material (PCM) having boundary conditions is shown in **Fig. 1**. Different volume fractions (γ = 0%, 10% and 20%) and fin heights (hf = 0, 10, 15 and 20 mm) are varied. The RT-35HC is usedas PCM and copper is used as thermal conductive material (TCM) for fins. Table 1 lists the thermophysical properties of all materials used

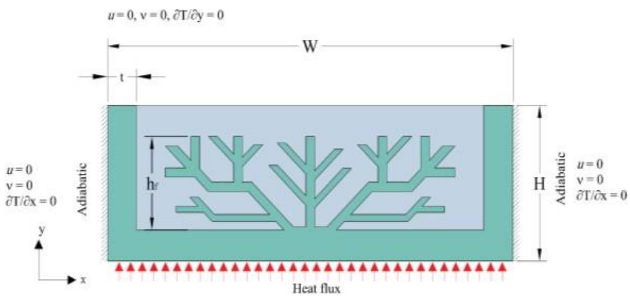


Fig. 1: Schematic description of computational domain.

in current study. A conjugate heat transfer condition is considered of heat flow for solid-liquid phenomena of PCM. The constant thermophysical properties of all materials are considered.The liquid PCM is considered as laminar,incompressible, and subjected to

Boussinesq approximation. The enthalpy-porosity method is adopted to model phase-change phenomenon in PCM based finned heat sink. The conjugate heat transfer model is solved using continuity, momentum, and energy equations as follows:

$$\partial\rho/\partial t + \nabla\cdot(\rho\vec{u}) = 0 \qquad \text{Eq. 1}$$

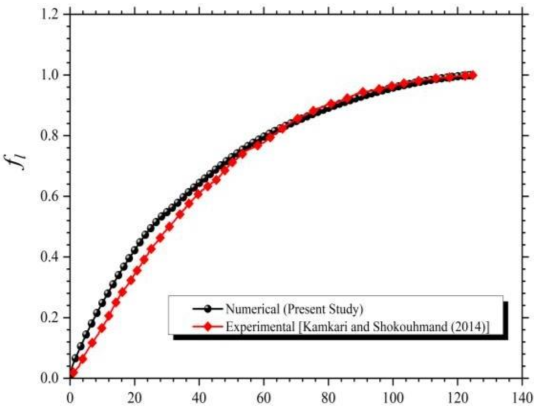
$$\partial(\rho\vec{u})/\partial t + \nabla\cdot(\rho\vec{u}\vec{u}) = -\nabla p + \mu\nabla^2\vec{u} + \rho\vec{g} + \vec{S}_{\vec{u}} \qquad \text{Eq. 2}$$

$$\partial(\rho H)/\partial t + \nabla\cdot(\rho H\vec{u}) = -\nabla\cdot(k\nabla T) \qquad \text{Eq. 3}$$

In Eq. 1, Eq. 2, and Eq. 3, the ρ, μ, k, and H are the density, viscosity, thermal conductivity, and total enthalpy of PCM. The phase transformation during melting/solidification of PCM is characterized by liquid-fraction (*fl*) during the temperature $T_S < T < T_l$. The governing equations are solved using ANSYS-FLUENT and SIMPLE algorithm is used for pressure-velocity coupling. For the pressure correction equation, PRESTO scheme is used while QUICK scheme is employedfor the momentum and energy equations. The present numerical results are validated with experimental results by Kamkari and Shokouhmand [6], (**Fig. 2**).

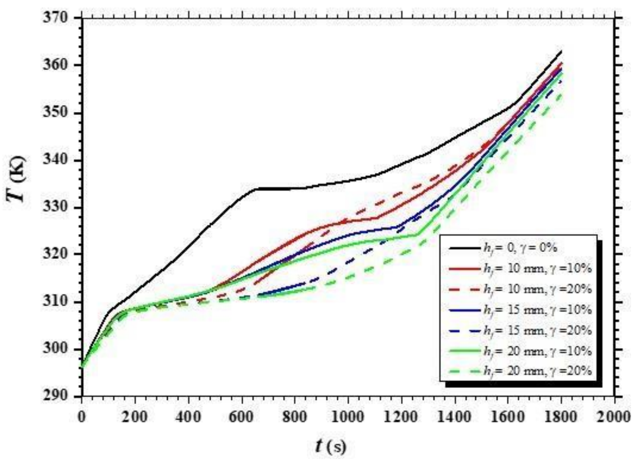
Table 1: Thermophysical properties of materials usedin current study.

Properties	RT-35HC	Copper
Tm (°C)	34-36	-
λ (kJ/kg)	240	-
Cp (kJ/kg.K)	2.0	381
μ (Pa.s)	0.0235	-
β (1/K)	0.0006	-
k (W/m.K)	0.2	400
ρ (kg/m³)	880 (s) 770 (l)	8978



3. Results and Discussion

The results of average temperature (*T*) distributionand liquid fraction (*fl*) are shown Fig. 3. A higher *T* is observed in case of γ = 0% or *hf* = 0, howevera lower *T* is achieved in case of γ = 10% and 20%.A uniform temperature distribution is achieved in case of add fins and lower heat sink *T* is attained athighest *hf* of 20 mm followed by the 15 and 10 mm*hf* either for γ = 10% or 20%. More precisely, it is revealed that a heat sink filled with PCM having 20 mm *hf* has the lowest the heat sink *T* and also achieved the lowest maximum temperature compared to all other cases. The



results of *fl* shows that the highest *fl* is obtained in case of of γ = 10% and 20% at *hf* of 20 mm. This shows that a heat sink with highest fins numbers or fin length has more capability to transfer the heat from heat sink to the ambient. In case of 15 and 10 mm *hf* there is still higher *fl*, however the rate of PCM melting is less than for *hf* = 20 mm. The total melting time (*t*) in case of γ = 10% and 20% can be seen in Fig. 4. The higher *t* is obtained in case of *hf* = 0 which shows that PCM is not melting uniformly andthere is a local heating occurring. In case of fins 10,15 and 20 mm *hf* either for γ = 10% or 20%, there is adecrease in *t* due to the addition of fins in heat sink which helps a rapid and uniform heat sink inside the heat sink through the PCM. The comparison of γ = 10% and 20% shows that there is a very slightvariation in *t* individually of any *hf* especially for 20mm. Therefore, the optimum fin height plays a keyrole to enhance the rate of heat transfer and dissipate the heat more effectively through the PCM.

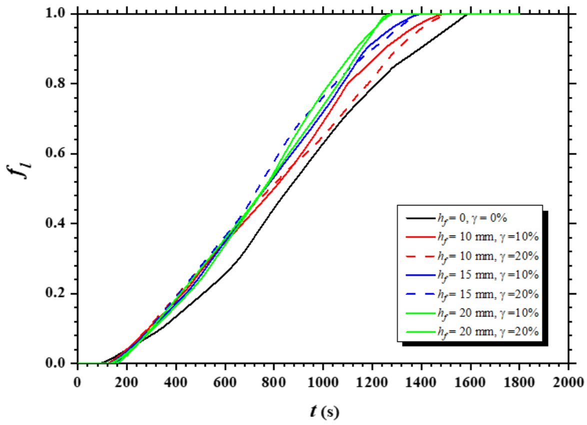


Fig. 3: Transient distribution of (a) T and (b) fl.

4. Conclusions

The present numerical study explores the optimized heat transfer enhancement of a novel constructal design tree-shaped structure heat sink filled with PCM at different γ and *hf* of fin structure. Results demonstrated that a tree-shaped structure fin enhances the heat diffusion rate from the heat source, provided at the base of heat sink, towards the top of heat sink though the PCM. The rate of heat transfer is mainly depending on the height of the fin structure.

The higher the *hf*, higher the heat transfer rate is obtained especially at 20 mm which is mainly because of conduction heat transport at the start of interfacial boundary layers. Thus, it is highly recommended that tree-shaped PCM-based heat sink having γ = 20% and 20 mm hf has better thermal cooling performance

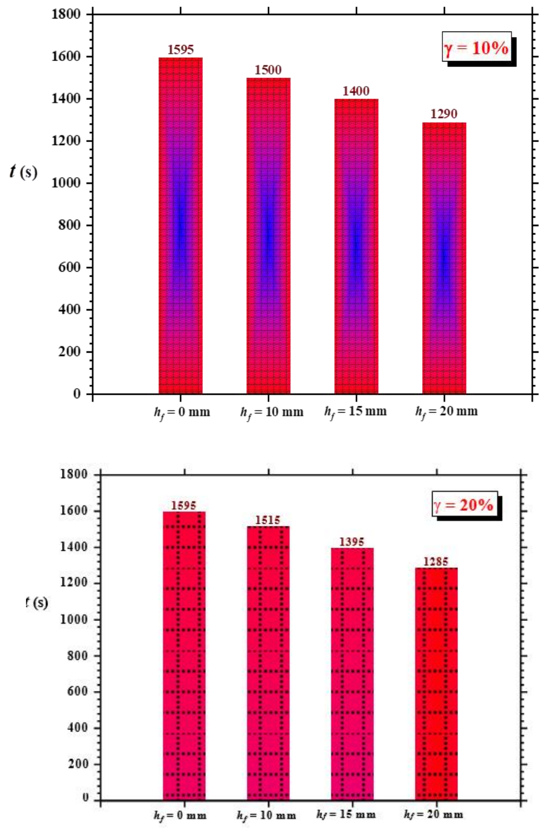


Fig. 4: The comparison of latent-heat phase melting time (t) (a) γ = 10% and (b γ = 20%.

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Constructal Law Conference (CLC 2023)
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Constructal Design of Circular Fins Row in CrossFlow

Ahmed Waheed Mustafa[a], Usam Abullah Sulaiman[a], Mohamed M. Awad[b*]

Abstract

A row of circular fins in cross flow is designed by means of the constructal design method. Two degrees of freedom are available between the fins, the transversal spacing and the spanwise spacing between the fins. The constraint is the outside diameterof the fin. The ratio of the fin to tube diameter is constant and set to 0.5. The circular fins and the tubes are maintained at uniform temperature and cooled by cross air flow. The cross flow is generated by constant pressure drop, the dimensionless pressure drop number (Bejan number) is ($Be = 10^3$). The three-dimensional equations of continuity, momentum, and energy are solved for incompressible and laminar flows by the finite volume method. The results reveal that there are two optimal spacings between the fins. One optimal spacing is in the transverse direction and the other is in the spanwise direction.

Keywords: Constructal Design, Circular Fins, Forced Convection

1. Introduction

Constructal designs of single finned tube were investigated for circular fins in forced convection by **[1]**, and for pin fins in forced convection by **[2]**. This paper presents the constructal design of circular fins row in forced convection. Two degrees of freedom are considered in the design; the transversal spacing and the spanwise spacing between the fins.

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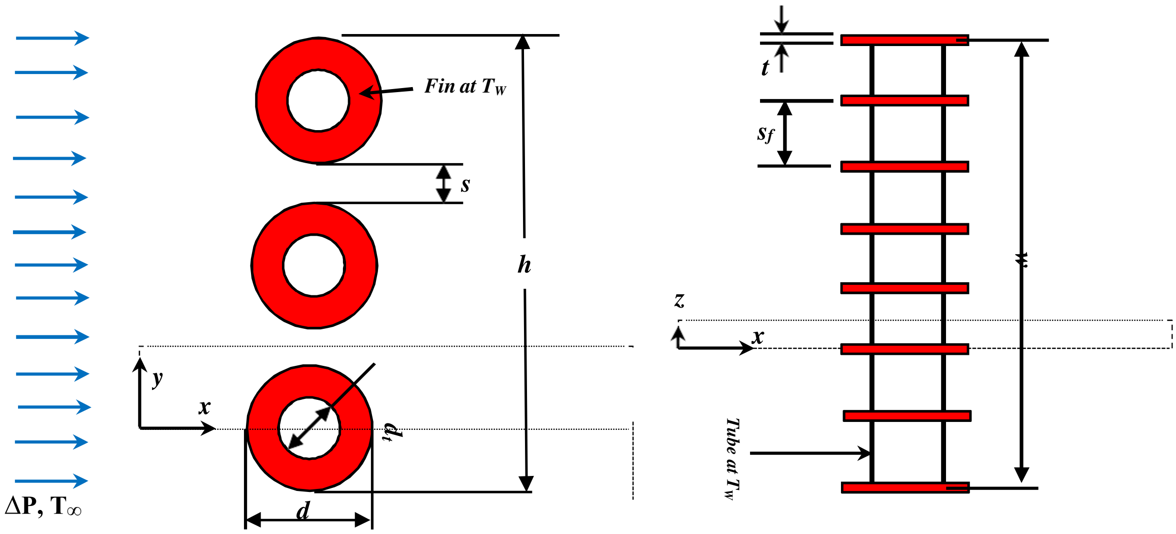
2. Mathematical Model and Constructal Design

A row of tubes of diameter (d) and finned with circular fins of diameter (d_f) and thickness (t) is shown in **Figure 1**. The tubes and the fins are cooled by a cross flow of temperature (T_∞). This cross flow is created by the constant pressuredrop (ΔP). Both fins and tube are heated at constant temperature (T_w). The finned tube is to be designed by applying the constructal law on the flow system for two degrees of freedom. The degrees of freedom are; the spacing between the in the transversal direction (s), and the spacing between the fins in the spanwise direction (s_f). The finned tubes are constrained by the fixed volume (d × h × w). The heat transfer per unit volume (heat transfer density) from the finned tube is to be maximized for the above mentioned degrees of freedom.



The three dimensional, steady, and incompressible flow equations (continuity, momentum, and energy) are to be solved by the finite volume method. The dimensionless continuity, momentum, and energy equations can be written as;

$$\frac{6U}{6X} + \frac{6V}{6Y} + \frac{6W}{6Z} = 0 \qquad (1)$$

$$U\frac{6U}{6X} + V\frac{6U}{6Y} + W\frac{6U}{6Z} = \frac{-6P}{6X} + \frac{\sqrt{Pr}}{Be}\left(\frac{6^2U}{6X^2} + \frac{6^2U}{6Y^2} + \frac{6^2U}{6Z^2}\right) \qquad (2)$$

$$U\frac{6V}{6X} + V\frac{6V}{6Y} + W\frac{6V}{6Z} = \frac{-6P}{6Y} + \frac{\sqrt{Pr}}{Be}\left(\frac{6^2V}{6X^2} + \frac{6^2V}{6Y^2} + \frac{6^2V}{6Z^2}\right) \qquad (3)$$

$$U\frac{6W}{6X} + V\frac{6W}{6Y} + W\frac{6W}{6Z} = \frac{-6P}{6Z} + \frac{\sqrt{Pr}}{Be}\left(\frac{6^2W}{6X^2} + \frac{6^2W}{6Y^2} + \frac{6^2W}{6Z^2}\right) \qquad (4)$$

$$U\frac{6\theta}{6X} + V\frac{6\theta}{6Y} + W\frac{6\theta}{6Z} = \frac{1}{\sqrt{BePr}}\left(\frac{6^2\theta}{6X^2} + \frac{6^2\theta}{6Y^2} + \frac{6^2\theta}{6Z^2}\right) \qquad (5)$$

$$\text{Where } X,Y,Z = \frac{x,y,z}{d},\quad U,V,W = \frac{u,v,w}{(\Delta P/\rho)^{1/2}},\quad P = \frac{P}{\Delta P},\quad \theta = \frac{T - T_\infty}{T_w - T_\infty},\quad Be = \frac{\Delta P d^2}{\mu\alpha},\quad Pr = \frac{\nu}{\alpha} \qquad (6)$$

The computational domain is shown in Figure 1 by the dashed lines in the xy and xz planes. The dimensionless inlet boundary conditions are (P=1,θ=0, ∂U/∂X=0, V=W=0), the tube and fin surface dimensionless boundary conditions are (θ=1,and U=V=W=0), the outlet dimensionless boundary conditions are (P=0, and ∂(U,V,W, θ)/∂X=0). On all other surfaces the symmetry boundary conditions areimposed. The finite volume method is used to solve the above equations. All details of computations, validation, and grid independence test can be seen in [3]. The dimensionless heat transfer density which is to be maximized under volumeconstraint is given b

$$Q = \frac{-\int \frac{\partial\theta}{\partial n} dA}{S_f(1+S)} \qquad (7)$$

3. Results

Figure 2 shows the temperature contours in two planes. The first plane is the fin-plane at (Z=0), and the second plane is at mid-distance between the circular fins ($Z=S_f/2=0.1$). These contours are shown at four selected transversal spacings (S= 0.2, 0.4, 0.48, and 1.6). At spacing (S=0.2), the air around and downstream the circular fin is at the hottest temperature (θ=1) in both planes (Z=0, and Z=0.1).This is because that the circular fins are very near to each other at this transversal spacing. As the transversal spacing increases to (S=0.4), the air around and downstream the fin becomes cooler than in the spacing (S=0.2). In addition, it can be noted that the temperature contour at the mid-plane (Z=0.1) takes the same circular red spot of the fin because the fins are very near to each other in the spanwise direction. More increase in the transversal spacing leads to the optimal transversal spacing as shown at (S_{opt} =0.48). In this optimal transversal spacing, the heat transfer density rises to be maximum. Beyond the optimal transversal spacing at (S=1.6), the cold air at (θ=0) occupies the central region between the circular fins and the heat transfer density becomes below the maximum value. Figure 3 shows the temperature contours at the planes (Z=0, and Z=0.3) for selected transversal spacings. In plane (Z=0.3), and in contrast to plane (Z=0.1), the circular red spot does not appear because the circulars fins are spaced more. Figure 4(a) shows the heat transfer density with the transversal spacing between the fins for different spanwise spacings. It can be noted that there is a maximum heat density for each spanwise spacings. From other side, the heat density can be optimized again with the spanwise spacing between the fins as shown in Figure 4(b).

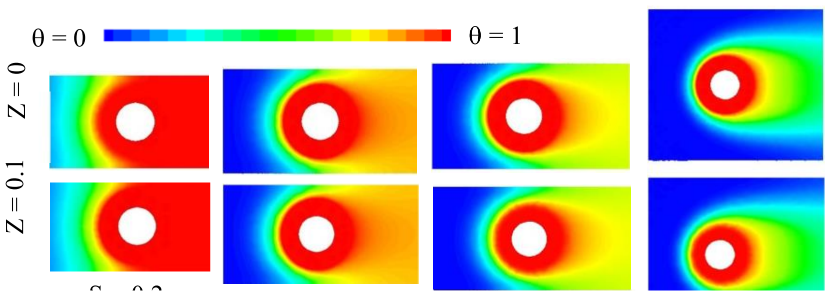


Figure 2. Temperature Contours for Different (S) and (Z=0, and 0.1) at ($Be=10^3$)

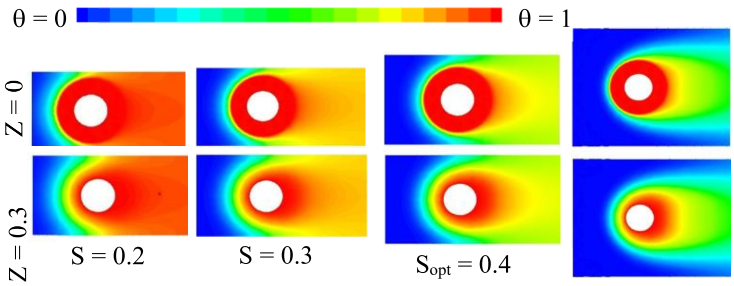


Figure 3. Temperature Contours for Different (S) and (Z=0, and 0.3)

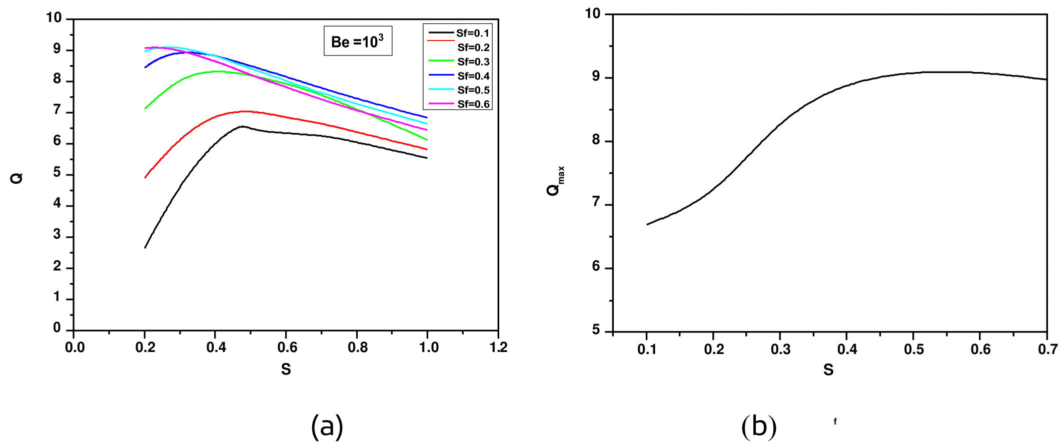


Figure 4 (a) Heat Transfer Density with Transversal spacing at different Spanwise spacings (b) Maximum Heat Transfer Density with Spanwise spacing

4. Conclusions

Constructal design from a circular fins row in forced convection at (Be=10^3) is investigated in this paper. The results reveal that there are two optimalspacings between the fins. One optimal spacing is in the transverse direction and the other is in the spanwise direction.

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Constructal Law Conference (CLC 2023)
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Constructal flow of constructal thinking

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Abstract

The constructal law was first formulated at Duke University in 1996 [Bejan 1996]. Since then, it has spread around the world. Thousands of researchers have written about the constructal law, and many more have heard about it. This process of dissemination and reception can be interpreted as a point-to-area flow. The point of origin is Duke, while the area of destination is the entire world. Here, we study this point-to-area flow through computer-aided textual analysis. We identify hotspots of constructal thinking, we study their evolution in time, and we reveal active channels of communication between them. The point-to-area flow that we are able to quantify and visualize can be interpreted as a constructal point-to-area flow. We therefore decide to call it a constructal flow of constructal thinking. Our results presented in this extended abstract are preliminary.

Keywords: Geospatial analysis, Geospatial discovery, Constructal thinking.

1. Introduction

The term "constructal" was coined by Adrian Bejan in the mid 1990s [Bejan 1996]. Since then, it has gained increasing popularity. It is used in phrases such as "constructal law", "constructal approach", "constructal design", "constructal evolution", "constructal principle", "constructal method", "constructal tree", or "constructal theory". All of these phrases are part of a larger body of constructal

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thinking that has kept growing over almost three decades. We call this larger body of thought “constructal thinking”. The overall growth of constructal thinking is quantifiable for example through Google Books Ngrams, 2019 English corpus.Our main interest is to explore how constructal thinking has spread geographically. Here we present preliminary insights. Other researchers have reported insights similar to ours in a previous study, which was performed in 2017 based on a smaller dataset [Razera, Errera, Dos Santos, Isoldi, Rocha, Proc. Rom. Acad. Ser. A 2018, 105-110]. Our work replicates those earlier findings independently and with a larger and more recent dataset.

2. Materials and Methods

To study how constructal thinking has spread around the world, we begin by collecting 6,785 publications. This corpus is generated through an advanced search for the term “constructal” in the Scopus database.
We proceed by geocoding author affiliations as well as textual content taken from the abstracts. For the latter, we employ a self-developed method of geographic information retrieval published elsewhere. After removing all records that have nogeocodable material, we remain with 6,619 documents.
To study geographical distributions, we employ an interactive interface that we previously developed for other research. This interface is designed to help us identify hotspots of research activity and discover and visualize active channels of communication between them.
In our visual, we draw each publication as a gradient line on the map. The line starts white in the place of the first institution that the publication is affiliated with. It then continues through all institutions that follow, becoming gradually darker. Finally, the line becomes green and goes through all geocodable content from the abstracts. Only little geocodable content was found in the abstracts, specifically. An interactive visual is available at bit.ly/constructallaw.

3. Results

Our five main preliminary insights are visualized in the five following figures.

1

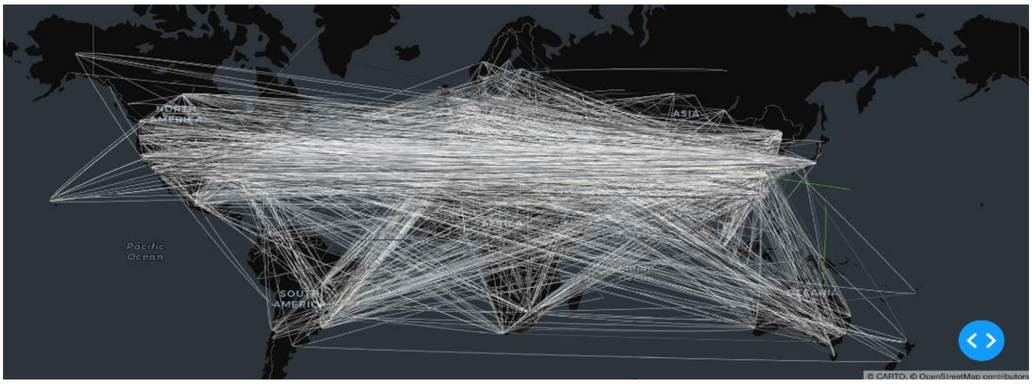

Figure 1. Constructal thinking has spread all over the world, including India,Australia, Asia, South America, and Sub-Saharan Africa. The visual speaks for itself.

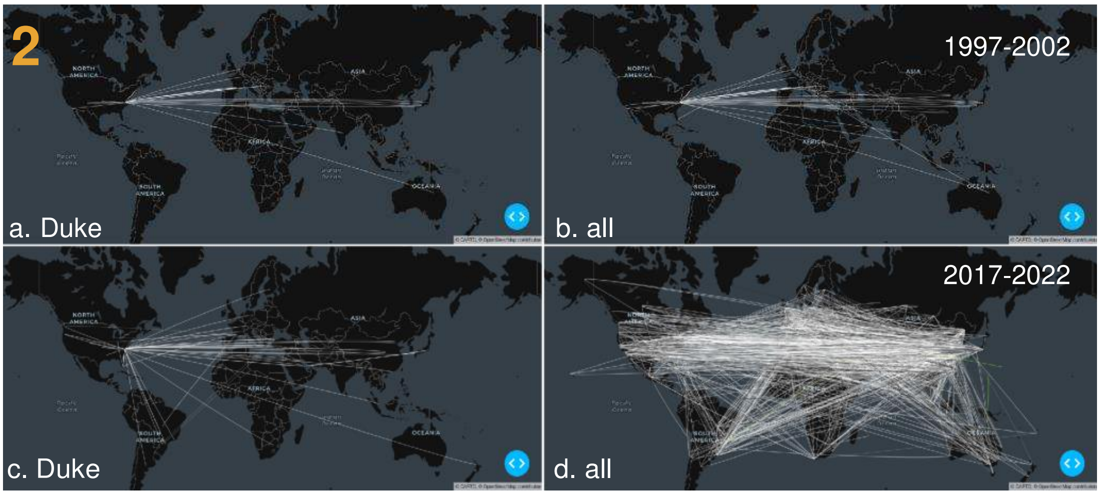

Figure 2. Constructal thinking has started at Duke University. Initially, most activitywas seen at Duke, but the activity outside Duke has grown very much faster.

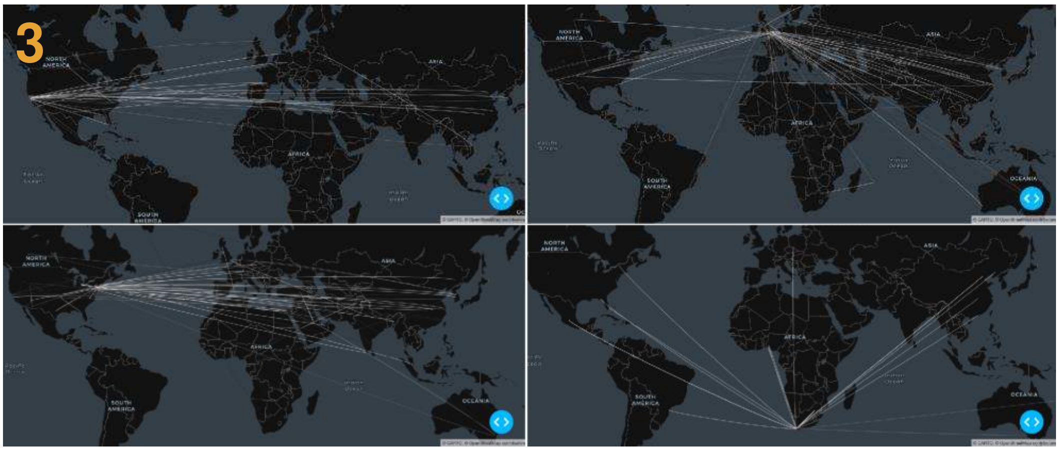

Figure 3. There are highly active centers of activity. The visual shows: San Francisco, New York, Cambridge, and Cape Town (50 km selection window around each).

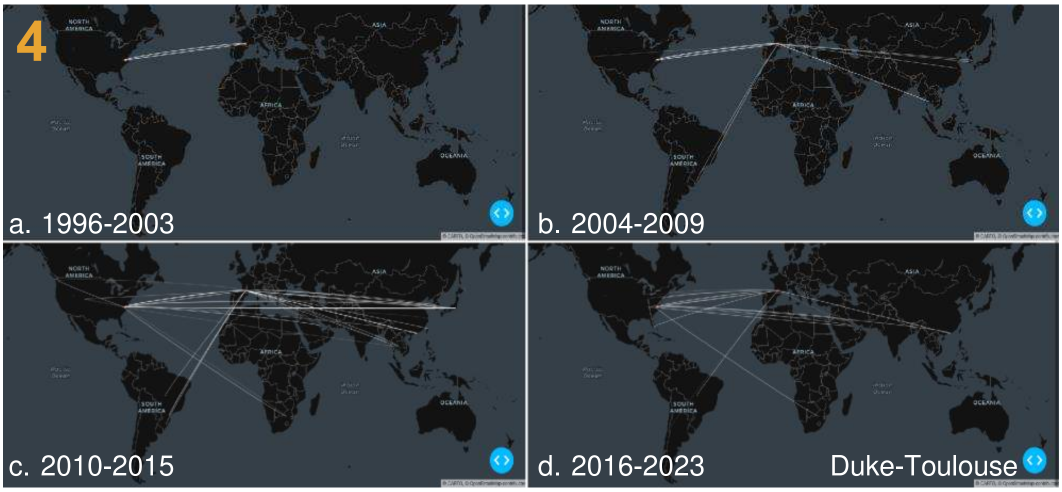

Figure 4. There are highly active paths of communication. The visual shows Duke-Toulouse, which has stayed active since the 1990s, reaching a peak in 2010-2015.

Figure 5. There may be breakaway groups. For example, from the many publications affiliated with Beijing none are affiliated with either Duke or Toulouse.

4. Discussion

Constructal thinking brings authors together, uniting them in an evolving network. As the network evolves, hierarchies with highly active centers of research and highly active paths of communication become increasingly apparent. These hierarchies may help authors gain increasing access to the information that flows through the network. At the same time, the shape of the network branches out to allow for an increasing amount of freedom. This evolution towards both clearly pronounced hierarchies and increasing freedom is what the constructal law has been formulated to describe [Bejan 1996, 2019, 2023]. Thus we can say that we observe a constructal flow of constructal thinking.

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Numerical Modeling for Volumetric Solar Receiver toward Enhancing its Thermal Performance

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Abstract

The transition from fossil fuels to low-carbon energy resources is continuously occurring worldwide. One of those vital energy resources is solar which is utilized through concentrated solar power (CSP), in which the energy conversion efficiency reaches 25%. The efficiency of solar tower technology, which is mainly CSP, is associated with the performance of its central element known as the open volumetric receiver. This volumetric receiver is a porous medium, made from metals or ceramics, heated by concentrated sunlight and through which air or steam/water flows. The design and configuration of these volumetric receivers play a key role in transferring the thermal energy of solar radiation into the working fluid. Therefore, the main goal of this work is to review the existing receiver designs and develop new designs for a homogeneous solar receiver using the concept of Constructal Design . The thermal and flow analysis of various solar volumetric absorbers having silicon carbide (SiC) open-cell foam structures are numerically conducted considering several variables, such as solar concentration and foam characteristics. The approach used in this study is based on porous continuum (macroscopic) model in which the volume of the receiver has effective properties determined experimentally and numerically in the open literature. This macroscopic model facilitates to consider novel configurations considering the constructal design approach. The novel design of the volumetric receiver enhances the overall thermal performance of solar thermal power plants.

Keywords: open-cell foam, volumetric solar air receiver, evolutionary design, thermal enhancement, local thermal non-equilibrium (LTNE) model.

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Introduction

Globally, energy demand is growing, however fossil fuel plants are still responsible for the majority of today's generated power. The downsides of fossil fuels are well-known through their scarce recourses, price increase and environmental impact, mainly CO_2 emissions. One of these crucial renewable technologies is concentrated solar power (CSP) which has recently captured more attention of researchers due its strong potential [1]. The main element in this technology is the open-cell volumetric receiver which is a porous medium, made from metals or ceramics, heated by concentrated sunlight and through which air or steam/water flows [2]. The air temperature reaches between 800ºC and 1000ºC in metal foams, 1200ºC in ceramic foams and up to 1700ºC in silicon carbide foam [3-4]. In this work, silicon carbide is selected as solar absorber material in which heat transfer analysis is numerically performed for the air and the solid domains using local thermal non-equilibrium model (LTNE). This model was broadly used to study the temperature field within porous medium [5-7]. More specifically, the flow and heat transfer performance of radiation participating media, namely volumetric solar receiver was numerically investigated using LTNE [8]. This macroscopic model enables to consider novel configurations for the open-cell foam by considering the constructal design approach [9]. The main idea here is, instead of using a uniform cylindrical solar absorber, to distribute (to morph the design) the total volume of the porous material in a way that the thermal performance of the flow system is enhanced.

Volumetric solar receiver modeling

The flow system of the solar volumetric receiver considered in the current study is shown in Fig. 1. The thermal and flow analysis are numerically conducted for a cylindrical cone (frustum-shaped) porous domain. Flow and solar radiation are allowed to pass through converging flow path having a homogeneous SiC porous as solar volumetric receiver. A fully developed flow profile is applied at inlet boundary condition (at x = 0).

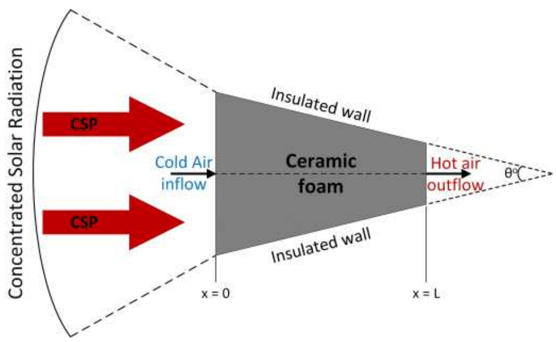

Fig. 1 Demonstration of the air solar receiver, including the variables considered in simulation work.

The heat transfer modes that coexist within the volumetric receiver are conduction heat transfer in porous SiC, convection heat recovery for fluid and radiation is considered as a heat source. The approach used in the current study is based on porous continuum model in which the receiver has an effective thermal conductivity determined experimentally in the literature [10] as $k_{eff} = k_{eff,f} + k_{eff,s}$. The governing equations used are the mass, momentum (Forchheimer-extended Darcy Flow), and energy conservation equations with LTNE approach. The LTNE is recommended when an internal heat source, which is the volumetric heating effect, occurs and when the interest is to find the thermal behaviour of the fluid and the solid distinctly. Thus, two energy equations are to be solved simultaneously: one for the fluid domain and one for the solid domain which are linked by the interfacial heat transfer coefficient between the fluid and the porous structure (h_v). Due to complexity of the computational domain, the main assumptions considered in this numerical work are 1) The fluid is air (treated as an ideal gas), and flow is laminar and 2) the Ceramic foam is an absorbing, emitting and isotropic scattering media, has homogeneous and gray radiative properties, and is optically thick media.

Numerical Solution

The parameters and equations needed to solve the governing equations used in this modeling are presented in Table 1. The radiation source term ($\nabla \cdot q_{rad}$) is calculated using the Discrete Ordinate (DO) model. The solar intensity is assumed to be 600 kW/m² and modeled as a uniform distributed incident radiation. This investigation is conducted to optimize the fluid domain configuration using the Constructal design bases. The constraint is the total volume of the foam. The cone angle (θ) and the ratio ($r = d_{in}/d_{out}$) are the degrees of freedom while the total length (L) of the solar volumetric receiver varies accordingly.

Table 1. Parameters/expressions for the simulation work.

Parameter	Value or Expression	Parameter	Value or Expression
Porosity, φ	0.8	Mean void diameter, d_c	1.5 mm
Permeability, K	$\frac{d_c^2}{1039 - 1002\phi}$	Inertial Coefficient, F	$\frac{0.5138\phi^{-5.739}}{d_c}$
Absorption coefficient, κ	$1.5\alpha\frac{(1-\phi)}{d_c}$ where α is the absorptivity	Scattering coefficient, σ	$1.5\,(2-\alpha)\frac{(1-\phi)}{d_c}$
$\mathbf{k_{eff,f}} = \boldsymbol{\phi k_f}$		$\mathrm{k_{eff,s}} = \frac{(1-\phi)}{3}k_s$	
Energy equation for fluid phase: $\nabla \cdot \left(\rho_f\, c_{p,f}\, u_D \langle T_f\rangle\right) = \nabla \cdot \left(k_{eff,f} \cdot \nabla \langle T_f\rangle\right) + h_v\,(\langle T_s\rangle - \langle T_f\rangle)$			
Energy equation for solid phase: $0 = \nabla \cdot \left(k_{eff,s} \cdot \nabla \langle T_s\rangle\right) + h_v\,(\langle T_f\rangle - \langle T_s\rangle) + \nabla \cdot q_{rad}$			

Results

The preliminary results presented in Fig.2 indicates improvements in thermal performance of the considered models compared to the uniform solar receiver designs.

Higher temperature is attained at r = 1.6 and θ = 30. Also, thermal equilibrium between solid and fluid domains occurs closer to the inlet of the ceramic foam (solar receiver) when the inlet-to-outlet ratio (r) is larger. The converging shape of the solar receiver led to increasing tendency of both temperatures along the flow path as compared to previous studies. More investigations are needed to address the effects of the new configurations on the fluid flow performance and to find the optimum design that would achieve high thermal effectiveness and low flow resistance, simultaneously.

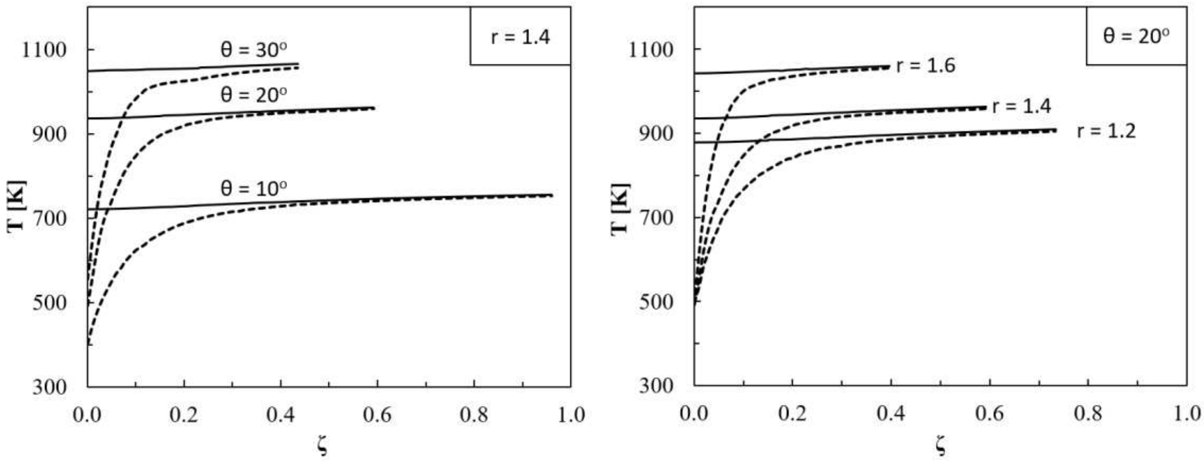

Fig. 2. Effect of (a) funnel angle (θ) and (b) inlet-to-outlet diameters ratio (r) on the air (dashed-lines) and the ceramic (solid-lines) temperatures inside the solar absorber.

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Diesel/biodiesel/biogas Mixtures Driven Compression Ignition Internal Combustion Engines Constructal Design

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Abstract

This paper introduces a first and second law based transient mathematical model for 4-stroke compression ignition internal combustion engines (CI-ICE) driven by diesel/biodiesel/biogas mixtures, and minimizes system total entropy generation, subject to physical constraints, according to constructal law. The impact of geometric and operating parameters are part of the model equations, so that their impact on performance could be assessed.

Keywords: Renewable energy, Minimum exergy destruction, Constructal law analysis.

1. Introduction

CI-ICE modeling and simulation has been extensively studied [1,2], and the code KIVA [3] has been one of the most used tools by car manufacturers. Alternative fuels (e.g., microalgae derived biofuels) need to be investigated to determine the impact on CI-ICE. Only a few fast and accurate CI-ICE models with alternative fuels (including combustion) are available [4]. In such scenario, constructal law [5] fits perfectly. As a result, the objective of this study is to introduce and test a mathematical model for the constructal design of ICE engines powered by alternative fuels.

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2. Materials and Methods

A mathematical model introduced and validated experimentally by Graciano et al. [3] is amended to quantify the CI-ICE entropy generation. The time dependent admitted air/exhausted products mass flow rate to (admission valve orifice) or from (exhaust valve orifice) the cylinder, and fuel injection are calculated with:

$$\frac{dm_i}{dt} = \dot{m}_i = (-1)^j C_d A \sqrt{2\rho_{air}\left|p_0 - p_{cyl}\right|}_{min} \quad \text{and} \quad \frac{dm_f}{dt} = \dot{m}_f = \frac{\dot{m}_{air}}{AFR} - \tag{1}$$

All parameters are input data, except $p_{cyl} = m_{gm}R_{gm}T_{cyl}/V_{cyl}$, with $\mathrm{m_{gm}} = \mathrm{m_f} + \mathrm{m_{air}}$, $\mathrm{R_{gm}} = \mathrm{c_{p,gm}} - \mathrm{c_{v,gm}}$, in which $\mathrm{c_{p,gm}}$ and $\mathrm{c_{v,gm}}$ are the weighed averaged gas mixture specific heat at constant pressure and volume, respectively, j = 1 (exhaust; i = products) and 2 (admission; i = air). Taking K_1 as an adjustment parameter, $\dot{Q}_w = -(\dot{Q}_{conv} + \dot{Q}_{rad})\,K_1$, with $\dot{Q}_{conv}$ and $\dot{Q}_{rad}$ by convection and radiation, respectively [3], and the 1st and 2nd law for:

- Admission

$$\frac{dT_{cyl}}{dt} = \left(\frac{\dot{Q}_w - p_{cyl}\frac{dV_{cyl}}{dt} + h_{f,in}\dot{m}_f + h_{air,in}\dot{m}_{air} - c_{v,air}T_{cyl}\dot{m}_{air} - c_{v,f}T_{cyl}\dot{m}_f}{c_{v,air}(m_{air}+m_{prod}) + c_{v,f}m_f}\right) \tag{2}$$

- Exhaust

$$\frac{dT_{cyl}}{dt} = \left(\frac{\dot{Q}_w - p_{cyl}\frac{dV_{cyl}}{dt} - h_{prod,out}\dot{m}_{prod} - c_{v,air}\,T_{cyl}\dot{m}_{prod}}{c_{v,air}m_{prod}}\right) \tag{3}$$

$$\dot{S}_{gen,k} = \left(\frac{dS_{cyl}}{dt}\right)_k - \frac{\dot{Q}_w}{T_w} + \dot{S}_{flow} \geq 0 \tag{4}$$

in which subscript k = admission, compression, combustion, expansion or exhaust, $\mathrm{dS/dt = d(ms)/dt = m\ ds/dt + s\ dm/dt}$ and $ds = c_p dT/T + R dp/p$, so that for the second law of thermodynamics in the admission and exhaust strokes, low temperature and pressure changes indicate that $dS/dt << -\dot{Q}/T_w + S_{flow}$, with $\dot{S}_{flow} = -\dot{m}_{gm}s_R$ or $\dot{m}_{prod}s_P$ for the admission (reactants) or exhaust (products) stroke, respectively, thus $dS_{cyl}/dt \rightarrow 0$ in Eq. (4).

- Compression, combustion, and expansion

In the compression and expansion strokes (first equation), the balance of energy is written for the temperature, and in the combustion (second equation), for the pressure, and the combustion reaction for any given fuel mixture (diesel, biodiesel and biogas), and additional details are reported in Graciano et al. [3]. As a result, the first law of thermodynamics states that:

$$\frac{dT_{cyl}}{dt} = \frac{(\dot{Q}_w - \dot{W}_p)}{m_{gm}c_{v,gm}};\ \frac{dp_{cyl}}{dt} = \frac{R_{gm}\left(\dot{Q}_{comb} + \dot{Q}_w - p_{cyl}\frac{dV_{cyl}}{dt} - \frac{p_{cyl}}{R_{gm}}\frac{c_{v,gm}dV_{cyl}}{dt}\right)}{V_{cyl}c_{v,gm}} \tag{5}$$

$$\dot{Q}_{comb} = m_f\frac{Q_{comb}}{\Delta t_{comb}};\ \Delta t_{comb} = \frac{60\,\Delta\psi}{2\pi N};\ r_c = \frac{V(\theta = \Delta\psi)}{V_c} \tag{6}$$

in which $Q_{comb} = \bar{Q}_{comb}/M_f = (\bar{h}_P - \bar{h}_R)/M_f$– heat of combustion on a mass basis, that

depends on $\overline{h}_P$, $\overline{h}_R$, at T_{cyl}, and $\lambda = AFR_r/AFR_{st}$, the molar based specific enthalpy of products, reactants, and excessive air ratio, respectively, where AFR_{st}, AFR_r – air to fuel ratios, stoichiometric and real; $\Delta\psi$ – fuel injection angle; r_c – cut-off ratio, and V_c – dead volume.
The entropy generation rate in the compression and expansion strokes are calculated with Eq. (4) by making $\dot{S}_{flow} = 0$, and in the combustion:

$$\left(\frac{dS_{cyl}}{dt}\right) \cong m_{gm}\frac{s_P - s_R}{\Delta t_{comb}} \tag{7}$$

The CI-ICE variables for the cycle are calculated as follows: $E_i = W_i = \oint p_{cyl}dV$; $p_{m,i} = \frac{W_i}{V_d}$; $p_{m,fr} = \left(C_1 + \frac{48N}{1000} + 0.4\bar{S}_p^2\right)K_2$; $p_{m,ef} = p_{m,i} - p_{m,fr}$; $\eta_{ef} = \frac{W_{ef}}{Q_{comb}}$; $E_{ef} = W_{ef} = p_{m,ef}V_d - W_{fi}$; $S_{gen} = \oint \dot{S}_{gen}d\theta$; $E_D = T_0 S_{gen}$; $\eta_{II} = \frac{E_{ef}}{E_i + E_D}$; $y_D = \frac{E_D}{E_i + E_D}$.
Additionally, E_i, E_{ef}, and E_D are the indicated, effective and destroyed exergy, respectively, $W_{fi} = m_{f,adm}(p_{m,comb} - p_0)/\rho_{gas}$ – fuel pumping work, and K_2 an adjustment parameter [3], and $p_{m,comb} = \frac{1}{\Delta\psi}\int_{2\pi}^{2\pi+\Delta\psi} p_{cyl}d\theta$.

3. Results

The 1[st] law model was validated for the Lintec 4LD 2500 engine and MWM 229.6 [3]. Only the Lintec 4LD 2500 engine was considered in this study, with: $CR = (V_d + V_c)/V_c = 16$ (compression ratio), ROD/CS = 3.45 (conrod-crank ratio), $B = P_d/2CS = 0.85$ (bore-stroke ratio), ROD = 0.207 m, P_d = 0.102 m, 6 cylinders,
C_d = 0.9, $V_c = 6.537 \times 10^{-5} m^3$, and r_c = 4.5. Figures 1a and 1b show the impact of the cut-off and bore-stroke ratios on CI-ICE performance, respectively.

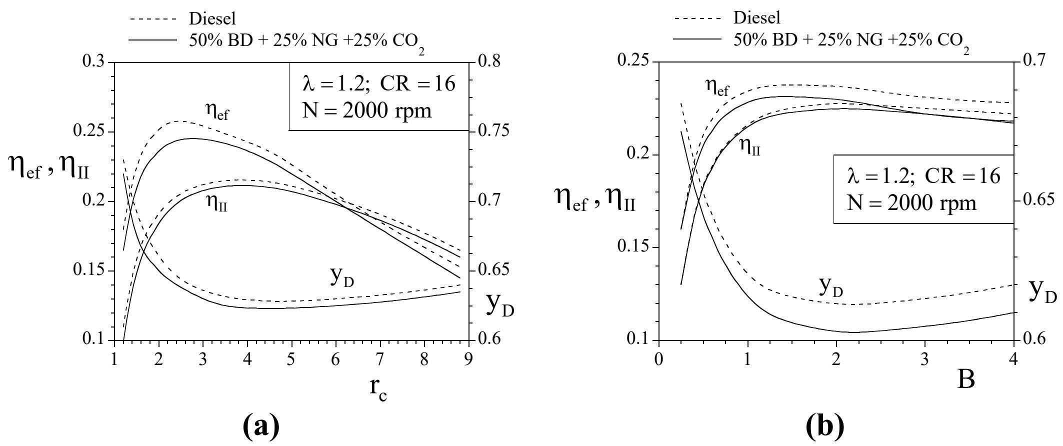

Figure 1. The CI-ICE optimization for: (**a**) Cut-off ratio; (**b**) Bore-stroke ratio.

4. Discussion and Conclusions

As r_c is reduced, pressure increases, and W_{fi} as well, thus 1st and 2nd law efficiencies decrease and exergy destruction increases, which happens also for high r_c, now due to low pressure. Consequently, there must be an optimal r_c for maximum efficiencies and minimum exergy destruction. Indeed, $r_{c,opt} \sim 2.4$ for $\eta_{ef,max} \sim 0.26$, but $r_{c,opt} \sim 4$ (agrees with the Lintec 4LD 2500 design) for $\eta_{II,max} \sim 0.21$ and $y_{D,min} \sim 0.63$, as shown in Fig. 2a. A similar shift in the optima location happens for $B_{opt} \sim 2$, according to Fig. 2b. In conclusion, constructal law has revealed the true optimal CI-ICE morphology.

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Constructal Law Conference (CLC 2023)
Freedom, Design an Evolution
Turin (Italy), 21 – 22 September

Canon Collaborative

Christine Bizzell[1]

Keywords: human, freedom, life, design, well-being, nature

Introduction

The experience of freedom varies greatly from one individual to the next, as "life is a private movie" [1] – and there are two things humans can do to enhance life – "improve the script, and enjoy the show." We feel this intuitively and can also deepen our understanding through the physics of life as movement and the continuous evolution of this movement [2]. Freedom to move and change is essential to a happy life, which varies greatly depending on an individual's circumstances and geography. As life is movement [2], freedom to move in our unique and desired direction is critical to human well-being and flourishing.

The concept of freedom for the human experience is understood broadly in terms of a lackof coercive constraint in the areas of personal and economic autonomy [3]. To truly be empowered as designers and producers of our own private movie of life, a more objectiveunderstanding of freedom would be helpful 1) to support an individual's ability to confidently scan the horizon for opportunity and 2) to discern the most optimal path forward in our private movie and movement called life given present constraints.

The Constructal Law teaches us that the 'how' is one, and the 'what' are the many – and in this case, the number of whats matches the number of human beings on the planet [1-2]. We are each unique and wondrous creations, and not unique in the sense that we each must be free to adapt the design of life to facilitate our movement toward our distinct and original picture of a beautiful life. The perception of beauty in life is in the eyes of the individual [4].

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Humans were created by the same flows that generate life all around us and "we are a part of nature; its oneness includes everything, even us" [2]. The urge to have more freedom – to move and freely make "feel good" changes to the configuration of our lives to promote ease is natural [1] and ever-changing [4]. As humans, we are empowered as designers of our lives, and directors of our own movies, by and through the Constructal Law governing the evolution of everything.

Human Freedom

Humans are flow systems, similar to but more complex than airflow through mudcracks [2]. The Constructal Law teaches us that every living system, including humans, requires freedom to evolve to achieve greater access to the currents flowing through them and through their immediate environment (the niche). From the Constructal Law, we learn that freedom is good for design and makes natural organization possible [1]. "In human society today, freedom of thought and movement goes hand in hand with access to power(watts), space, and wealth" [5]. However, cultural constraints abound and are everywhere in social organization [1] and can prevent this natural, self-organization from happening [2].

Constraints and resistance are unavoidable, naturally. Life design evolves in one direction in time: to become less imperfect over time and to minimize the negative effects of friction (personal stress) and other resistances that inhibit an individual's ability to move – to flow through life with greater ease. Unfortunately, human lives are impacted by bad ideas – rigid, unnatural, outdated, and unevolved designs, which make it "harder for human beings to thrive" [2]. The tendency to evolve to flow more easily occurs naturally – as the human mind has an instinctive urge to recognize and understand what it needs to retrieve (fuel) in order to move more easily [4] – best-utilizing energy available for movement and overcoming obstacles. [2].

Most individuals determine the best design for their lives through trial and error – with various levels of personal freedom in adapting the design of their work and life to facilitate progress toward goals and vision for the future. However, with greater knowledge of the distinctive currents moving within, humans are empowered to effect design changes to enhance our movement. Individuals can also build recognition of design that *does not* welcome our freedom or enhance our movement – growing cognizance of where there is no flow will support in navigating pathways and opportunities for design change. All forms of resistance become data for humans to effect design changes to life to enhance personal flow and freedom.

Interconnected Living Systems

Humans are part of a larger system "as big as the globe" [1] and none of us operate in isolation – we are flow systems within flow systems and are shaped by and connected to the world around us in a global tapestry of flow [2]. Our immediate environments (the niche) contain magnificent diversity and hierarchy, which "are necessary features of this natural flow design" [1], which is evolving to flow more easily as a whole [2]. Therefore, symbiosis and collaboration support the flourishing of the whole of humanity and the systems we find ourselves within.

Symbiosis and collaboration come from the selfish urge to survive and move more easily–"we collaborate in order to flow together in ways that serve us better individually" [1]. For humans, this occurs in the forming of relationships and communities – connecting our movement with other like-minded humans that can support us in moving further faster, and with greater ease. Every human is meant to design and redesign life to move with progressively fewer losses [1].

All flow systems are destined to remain imperfect, yet the design should adapt to facilitate movement as a whole [1]. According to the Constructal Law, the few large and many small currents must flow together, with resistance (stress) being balanced or uniformly distributed across the whole. This uniform distribution of stress gives each part a maximum chance at survival [2] – minimizing friction for more individuals and enhancing the flow of the whole organization. In the case of a human organizational system, these are partnerships, teams, communities, and organizations made up of individual [human] flow systems. Individuals must be as free and autonomous as possible within the larger flow system, with the balance of stress across all movements.

Humans empowered as designers of life

"Knowledge is the human capacity to effect design change that is useful to humans" and better-utilizing language advance these adaptations, therefore facilitating and enhancing our individual movement on the landscape of life [1]. "Every aspect of the flow of humanity rests on communication" – for organizing and for the transfer of knowledge. Building an understanding of the natural currents of energy that move through humans at the individual level, combined with effective use of language associated with these currents of energy, empowers each as designers of the system(s) and organization through which they are carried – our various roles in life.

The natural currents of energy moving within an individual are highly unique and cannot beduplicated or replicated. In addition, these natural currents are continuously morphing and evolving as they move on the landscape of life as they encounter resistance in the form of personal stress. As with any living system, the 'riddle' of design is solved by first illuminating what flows [2].

With a greater understanding of the specific and natural currents of energy that flow through us at the individual level, we can more swiftly adapt the design of life to promote personal freedom, movement toward the future, and ease or positive well-being. "New configurations and rhythms emerge so that they offer greater access to what flows" through us at the individual level and in our varied organizational systems [1] – and because "flows morph to increase flow access for the whole, the whole becomes the winner" [2].

Conclusion

The Gallup Organization's psychometric survey "CliftonStrengths" identifies an individual's natural and recurring patterns of thinking, feeling, and behaving. This survey sequences 34 possible currents of "strength" or energy according to their prevalence within an individual's natural modes of operating – with layman's language associated with each current. For most individuals, the first 10 strengths are highly active and dynamically visible within their various environments. These currents of energy manifest as "strength" when they are keenly recognized, consciously engaged, and productively utilized to moveus in our desired direction. Gallup research also shows us that these natural strengths are connected to individual well-being [6].

At Canon Collaborative, the Constructal Law empowers individuals, partnerships, and organizations as designers of the system(s) through which illuminated human strengths are carried – designers of their lives. With greater knowledge of these natural currents of strength, combined with effective use of their language, individuals can be empowered to dynamically design access to their unique and natural human strength and flourishing, finding their symbiotic partners and collaborating within their niche to find greater flow andgreater ease in life.

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Constructal Evolution of Networks of Exergy Flows

Mauro Reini[a*], Casisi Melchiorre[b], Michele Capobianco[a], Emanuele Nadalon[a]

Extended Abstract

The Constructal Principles

The Constructal Principle was formulated by Bejan as a fundamental Physical Principle, with the same generality as the First and Second Laws of Thermodynamics [1]. Then, it has been shown that it can be considered an extension of the Maximum Entropy Production Principle [2] and has been used in the literature to explain the shape and structure of many flowing systems [3]. The constructive principle states that the shape of that structure must evolve in the direction that allows for higher flow through the domain, and in many cases, the result is a tree-shaped structure [3].
Very few papers in the literature deal with discrete network systems, even if the general validity of the Constructal Principle is not limited to continuous media. In the paper, a special class of discrete system is considered, made up of a network of exergy fluxes, whose nodes are the exergy conversion processes, where the exergy destruction takes place, whilst the arcs represent the exergy flows exchanged among the nodes, or with the outside (see figure 1). The network takes its primary exergy resources (F_{Tji}) from the outside environment and produces some kind of product (P_i) for the outside or its own growth.

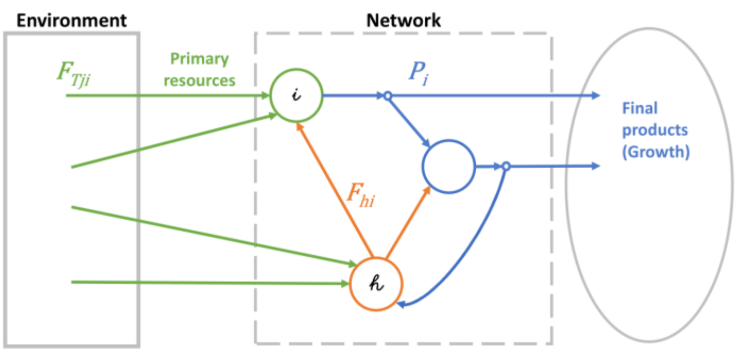

Figure 1. Scheme of an Exergy Flow Networks.

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This network may represent a power plant, a metabolic network, an industrial sector, etc. The aim of the paper is to infer the consequences of the Constructal Principle for this kind of systems. Exergy is chosen because it allows a consistent evaluation of the *thermodynamic effort* for producing, at the same time, mechanical, thermal, and material flows [4]. Without losing generality, the Fuel / Product paradigm can be introduced for the flows definitions, so that each flow in the network could be identified as a local (or global) resource required by the process inside a node, or as a local product, consumed elsewhere by other nodes, or outside the network. The Fuel / Product paradigm is the basis of applying the Exergy Cost Theory [5, 6], allowing the specific exergy consumption (k) and the unit exergy cost (k*) to be obtained for each product.
The matrix structure of the Exergy Cost Theory easily allows obtaining the unit exergy costs in terms of only one primary exergy resource (F_{Tji}) through the following equation 1:

$$k_{ji}^{*} \triangleq \frac{F_{Tji}}{P_i} \tag{1}$$

Two types of flows may be identified in this kind of networks:

- the flows of energy and materials that *feed* the process inside each node,
- the flows of energy and materials that make up the *hardware* of each node and support it in order to exist and persist (in the engineering language, the fixed capital for owning, maintaining, and operating a system).

An energy conversion model has to be introduced in each node, to link the efficiency of the process (the resistance to flow, represented by the specific exergy consumption (k)) with the resource investment in its hardware.
The Constructal Principle states: "*For a finite-size flow system to persist in time (to survive) its configuration must evolve in such a way that it provides an easier access to the currents that flow through it*". In the paper, the boundary conditions are identified which allow the arising of some structures, different from the tree-shaped ones, during the evolution of networks of exergy flows, as prescribed by the Constructal Principle. It can be easily inferred that the exergy of the product flow of the network (P_i) has to increase, like the water flowing in a river basin, the air flowing in the pulmonary ducts, or the heat extracted by a cooling system of a computer CPU. By means of simple mathematical derivation, the following equation 2 is obtained:

$$\partial k_{ji}^{*} < \frac{\partial F_{Tji} k_{ji}^{*}}{F_{Tji}} = \frac{\partial F_{Tji}}{P_i} \tag{2}$$

If $F_{Tji} > 0$,
it means that the availability of the resource considered is increasing in time, so that the cost of the product, in terms of that particular resource, may also increase on condition

that the previous limit is respected.
If $\partial F_{Tji} \leq 0$,
it means that the resource is declining. It is worth noting that this condition is typical of resource exploitation after, or around, the Hubbert peak [7]! In addition, it may be regarded as quite a common condition in nature, where evolution has led to a very complete exploitation of available resources. In this case, the k^* has to decrease, to respect the prescription of the Constructal Principle. In other words, when a specific resource is declining, the unit exergy cost reduction of the product of the network, in terms of that resource, is the driver of network evolution.
When a process is able of obtaining a product homogeneous with one of its direct (or indirect) fuels inside the network, the evolution toward the unit exergy cost reduction of that product may reach a point, in which the cost is lower than that of the fuel. At this point, the Constructal Principle (the further reduction of the unit exergy cost) can be invoked for the creation of a new arc, connecting the product and a fuel of the component in hand. In this way a recycle is appeared inside the network.
Finally, the paper outlines how the Constructal Principle, applied to the network of exergy flows, allows us to infer that no residues and sub-products may be indefinitely accumulated in the environment. On the contrary, they have to be generally converted into some kind of product by different production processes. This occurs not because it is convenient, or because it is a moral duty, but because this allows the system to evolve consistently with the physical principles and avoid extinction. It can be easily noted how this conclusion strongly supports the paradigm of the *Circular Economy*.

Keywords: Constructal Principle, exergy, energy networks, exergy cost reduction.

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Evolution of a cross flow heat exchanger for electricvehicle thermal management

Erdal Cetkin[a*], Sinan Gocmen[b]

Abstract

The pollution associated with fossil fuels in transportation is approximately 1/4th of the entire global emissions. There are many studies to integrate renewable sources with distinct applications and electric vehicles are the main choice for transportation applications. Thereare some drawbacks on the adaptation of electric vehicles related with their charging time,range (stored energy) and lifetime of battery cells. The charging speed and lifetime are affected greatly from the battery temperature. Therefore, thermal management system is essential for battery electric vehicles to enhance lifetime with increased charging speed. There are many distinct thermal management strategies such as air, cold plate, immersion,phase change material, heat pipe and their hybrids. Here we consider the evolution of a cross flow heat exchanger which is being used to condition air circulated inside a battery pack. The design evolution is in agreement with Constructal law as it is subjected to constraints from the industrial perspective such as ease of manufacturing, cost and suitability with other components in the thermal management system as well the volume and area constraints. Distinct serpentine and parallel channel heat exchangers are considered but a specific serpentine design is considered to be the best performing design due to its ease of manufacturability, homogenous coolant distribution, ease of application,even though it corresponds greater pressure drop and less temperature uniformity in comparison to a competing parallel channel counterpart.

Keywords: Thermal Management, Electric Vehicles, Parallel Channel, Serpentine.

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1. Introduction

Deceleration of climate change and pollution associated with fossil fuel emissions requires them to be minimized. Transportation is responsible for 1/4th of the global emissions [1] and the use of renewable energy sources in transportation could be enabled with electric vehicles. There is an optimal temperature range for the maximization of battery lifetime (15-35°) [2]. The literature focuses on thedevelopment of distinct state-of-art battery thermal management systems such as air, cold plate, immersion, phase change material, heat pipe and their hybrids [3]. The heat exchanger design evolution is in agreement with Constructal law as it issubjected to constraints from the industrial perspective such as ease ofmanufacturing, cost and suitability with other components to uncover best possibledesign for the given time.

2. Materials and Methods

Table 1 documents the material properties of liquid coolant, length scales of heat exchangers, and boundary conditions. The coolant is selected as the 1.5 times the required cooling rate of the designated battery pack under 1C discharge rate. The flow is laminar with the maximum Reynolds number of 632. The simulations werecarried out by ANSYS Fluent [4]. The conservation of mass and momentum equations were solved with steady-state fashion, and convergence criteria for eachparameters are 1e-8.

Table 1. Material properties, dimensions and boundary conditions.

Material Properties (Water-Ethylene Glycol)	Value
Viscosity (Pa.s)	0.00315
Thermal conductivity (W/m.K)	0.419
Specific heat (J/kg.K)	3494
Density (kg/m^{-3})	1065
Dimensions	
Pipe thickness (mm)	1
Diameter of serpentine (mm)	5
Diameter of distributor/collector channel (mm)	8
Distance between parallel channels (mm)	20
Boundary Conditions	
Coolant inlet mass flow (kg/s)	0.05
Coolant outlet pressure (gauge) (Pa)	0

3. Results

Figure 1a and 1b show the location of one serpentine and how four of these serpentines are located, respectively. Figure 1c shows that the maximum pressure difference of approximately 30 kPa is experienced with almost identical velocity. Figure 1e, 1f and 1g document how the pressure and velocity distribution is affected when parallel channels receive/discharge coolant from one port attached to the main distributor and collector channels with variable port diameter to create similar flow resistances along the flow paths. This solution decreases the maximum pressure difference 30 and 2 times in comparison to serpentine.

4. Discussion and Conclusions

The results show that serpentine design yields the maximum pressure drop with almost identical coolant distribution to each of four serpentine. Parallel channel heatexchangers decrease the pressure drop greatly (more than 10 folds) with flow non- uniformity. However, the cost of manufacturing and possible welding problems limit the use of parallel channel heat exchangers. Overall, even the optimized parallel channel heat exchangers are superior from the thermo-fluidic performance due to manufacturing simplicity and cost serpentine designs are still timely.

5. Acknowledgement

This work is fulfilled within the framework of the HELIOS project which has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No.963646.

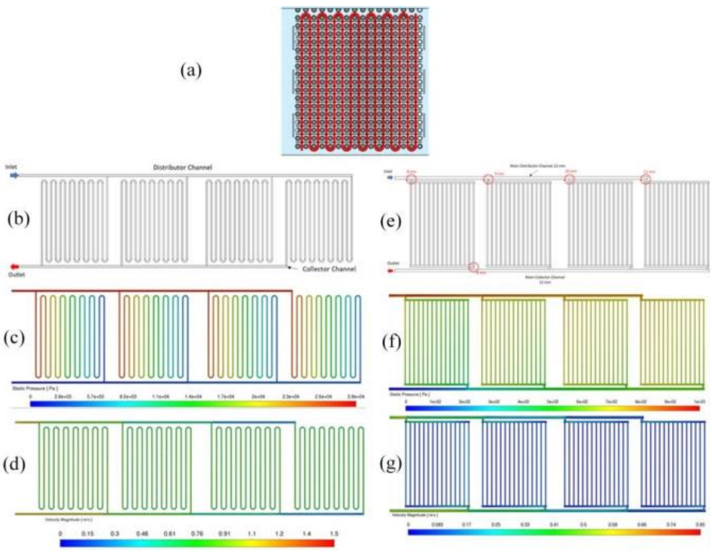

Figure 1. (a) Cooling pipe location (b) "design, (c) pressure distribution and (d) velocityfield of serpentine. Parallel cooling channel with auxiliary distributor channels (e) design, (f) Pressure distribution and (f) velocity field

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Analysis and Generalization of Multi-Branching Radial Flow Structures

Miguel R. Clemente[a*], Miguel R. Oliveira Panão[a]

Abstract

This study reexamines and generalizes the design of tree-shaped flow networks within disc-shaped bodies, assessing the evolutionary direction towards maximum freedom-to-morph of the geometric features with the flow architecture thermal and hydraulic performance. Primarily employed for thermal management, the design of such trees is centered on uniform distribution of points around the disk perimeter and minimizing flow resistance at each bifurcation. How- ever, balancing fluid and thermal performance while minimizing both simultaneously remains a challenge. The authors suggest that a generalized geometry definition using a multi-branching approach and hydraulic diameter setting is a way to overcome the challenge toward building constructal design tools in thermofluid engineering.

Keywords: Constructal Design, Svelteness, Disc-shaped heat exchangers, Thermal performance, Fluid performance.

1. Introduction

Over the last two decades, one of the highlights in constructal design literature has been the study of tree-shaped flow networks in disc-shaped bodies or disc-point structures. The design proposed equally distributes several points in a disc periphery, using Y-shaped bifurcations. The principal design method minimizes the flow resistance at every bifurcation, whether hydrodynamic or of thermal origin. Shortcut strategies employed in past research considered minimizing the flow path length [3, 5] or assuming a bifurcation angle of 75º [5], with structures with minimal length perform similarly to fully optimized structures [3]. Furthermore, these shortcut strategies effectively obtain all the geometry features, and the lower computational effort compensates for their slightly lower performance [5]. This work revisits the geometry definition of multi-branching architecture and proposes a generalization in its constructal design approach and hydraulic diameter setting.

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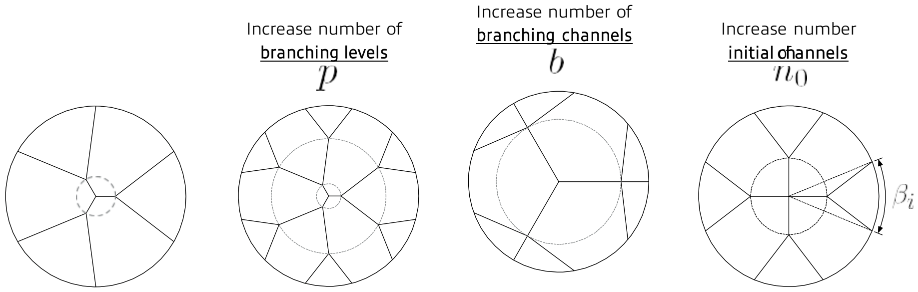


Figure 1. Ways to expand the number of points

2. Methods

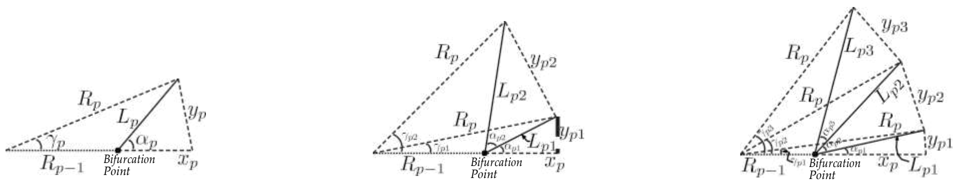
A disk with evenly distributed points connected to the center through identical chan- nels can expand the number of endpoints by increasing branching levels, the number of branches at the splitting point, or the initial channels from the center, as illustrated in Fig.1.

The branching process, represented by a triangular system (Fig. 2), is independent of disk radius changes and governed by the branching number. Increasing the branching number produces a pairing effect, where the triangular system for an even number of branches corresponds to the subsequent odd number. Solving the triangular system reveals the relationships between dimensions.

The concept of Svelteness, introduced by Lorente and Bejan [2], is a key parameter in the Constructal theory to measure the significance of flow configuration. It is a global geometric property that relates overall performance to flow survivability, indicating the evolutionary direction of a configuration. Svelteness is defined as the ratio between an external length scale and an internal length scale. Clemente and Panao [1] proposed a method to distinguish the external length scale in configurations with or without ramifi- cations, considering the square root of the configuration area.

In the absence of branching, the external length scale is equal to the radius, as previously considered by Wechsatol et al. [7]. However, this condition is now deemed valid solely for the initial channel. Once branching occurs, the external length scale consists of two parts: the radius of the initial channel and the square root of the area occupied by branching channels. The branching angles define disk sections known as "containers." Each branching level contributes a number of containers determined by the branching level length with an arc length. The configuration area is the sum of the occupied container areas. With the goal of minimizing fluid resistance, an objective function g is derived from the geometry impact on fluid resistance, and subject to constrained minimization using an interior point algorithm. To evaluate the performance of the flow system, a measure(ζ) is established to compare fluid and thermal resistance.

Figure 2. Triangles system for three pairs of branching number



(a) $b = 2$ and $b = 3$ **(b)** $b = 4$ and $b = 5$ **(c)** $b = 6$ and $b = 7$

3. Results

To assess the generalization, the derived relations are applied to the scenario of circular channels in a Hagen-Poiseuille flow. It is observed that as the branching level progressively increases, there is a repetition in the objective function. This implies that at any level *p*, the objective function solely depends on the angles. Consequently, once a specific angle is obtained for a given *b* and n_0, its value remains unchanged regardless of whether the number of branching levels (*p*) is increased or not. This characteristic reflects a memory effect inherent to the geometry, enabling the continuous increase in branching levels without significantly impacting computation time. This finding justifies the similar results obtained in [4], despite differences in the configuration of initial channels. On the other hand, in [6] this result wasn't observed, which may be attributed to the differences in the minimization method employed for calculating the angles. However, the lack of sufficient details on their minimization algorithm precludes a conclusive verification.
The results highlight the coherence between the Svelteness as a relevant parameter expressing the evolutionary direction of the flow configuration toward better thermal and hydraulic performance (higher ζ), as depicted in Fig. 3. However, the flow configuration with the best performance does not coincide with the maximum Sv. Fig. 4 depicts the effect of complexity (different branching levels *p*) and the freedom-to-morph (n_0) in the flow architecture thermal and hydraulic performance. The performance map highlights that trifurcations perform worse than bifurcations and simultaneously leverage some degreeof complexity and freedom-to-morph to direct the flow configuration toward increased performance.

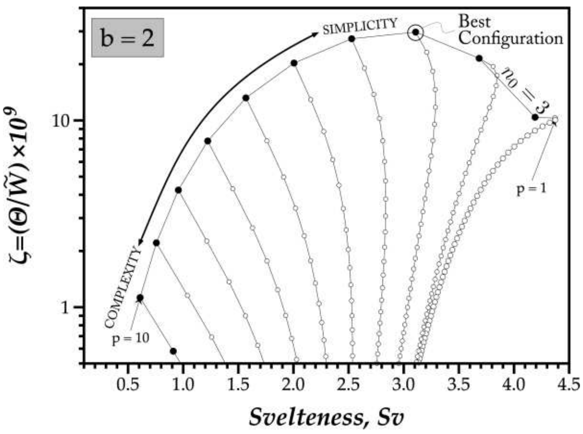


Figure 3. Relation between the evolution of flow configuration (Sv) and its performance (ζ) for branching channels *b* = 2.

4. Discussion and Conclusions

This work generalizes the method to generate the multi-branching geometry of radial tree-shaped flow networks in disc-shaped bodies. The flow architecture highlights the challenges in minimizing fluid and thermal performance and aims to improve their design. The first insight of the method is the presence of a memory effect in the geometry, pro- ducing different results from those presented by Wechsatol et al. [6] and eliminating the problem of considering computation time as a limiting factor for generating the design.

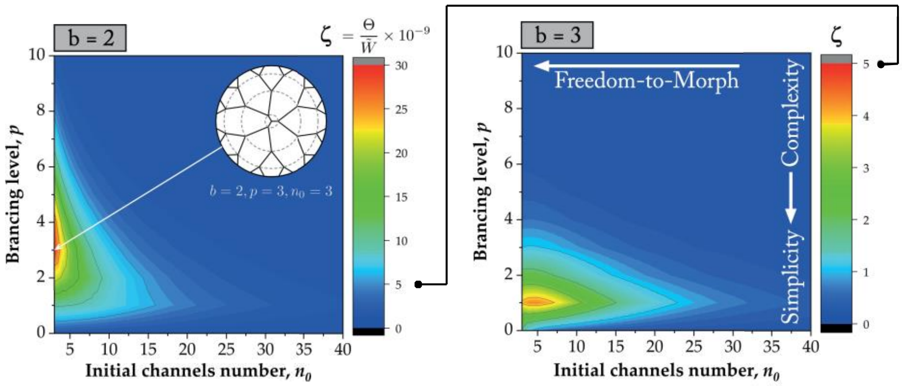


Figure 4. Effect of branching levels (p) and freedom-to-morph (n_0) in the thermal and hydraulicperformance (ζ) for both branching channels $b = 2, 3$.

For a given branching number (b) and an initial number of channels (n_0), increasing the structure complexity (higher branching level p) and minimizing the total branch length (objective function) uncovers the optimum and unaltered angle of each level throughout the architecture.

The Svelteness based on the configuration area allows differentiating the various possible configurations within the method. Together with a measure of the flow architecture thermal and hydraulic performance (ζ), the evolutionary direction point to the maximum freedom-to-morph (low n_0) and some degree of complexity (low p).

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Constructal Law Conference (CLC 2023)
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Drawing You Outside

Christine Forni[1]

Keywords: Drawing You Outside Integrates Constructal Law

Abstract

In my art practice, I have developed community art projects and individually rendered work reliant upon the principles of Constructal Law. In the first category, *Drawing You Outside,* an outdoor community-oriented drawing project integrating Constructal Law asa foundational element in both process and artworks.

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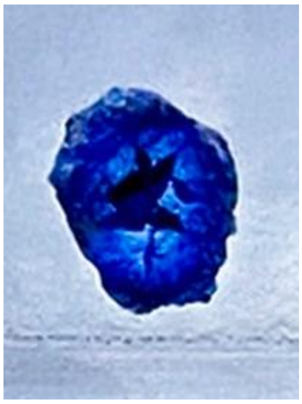
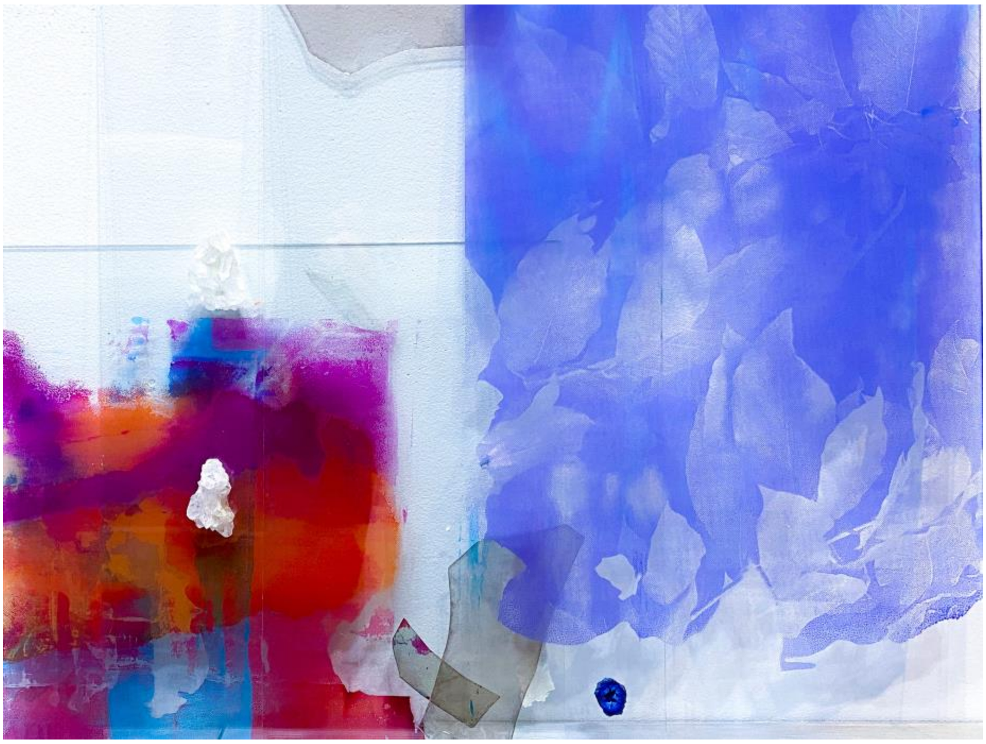
(Page 1 top: left to right) Constructal Law examples in my work. Acrylic ink painted onto a slice of mica by blowing hot air onto the surface of the mineral while the ultramarine blue ink dried. During the Pandemic I gathered unresolved pieces from current and previous works made during artist residences at Muséum National d'Historie Naturelle, and École du Breuil d'Horticulture in Paris, France. The materials were porcelain, vitreous enamel, paint skins and minerals. (Bottom: left to right) "Fragments," artwork referencing enlarged specimens, exhibition at the Hyde Park Art Center, Chicago. A piece of high fired porcelain dipped onto a leaf creating a small fossil like specimen showing Constructal Law flow systems.

In my studio practice, I research biological materiality structures through amicro lens to create visual imprints on enlarges slides creating sculptural painting.





(Page 2 top left to right) Constructal Law examples in my artwork. Photographic research I captured for Drawing You Outside, my photograph silkscreened onto glass of fallen leaves on a Chicago city park path. The growth of a collected quartz specimen and a azurite druzy mineral mounted to glass. (bottom) Paintings showing illusion of depth in real time by utilizing the painting techniques foreground, middle ground and background. Ink made using iron oxide filtered from wading ponds above an abandoned coal mine at the Evergreen Conservancy in Pennsylvania.

Being a visual artist, environmental activist, and creator of, Drawing You Outside, a project bringing communities outdoors to draw and connect to nature. I make charcoal sticks from fallen branches and inks using iron oxide filtered from coal mine sludge.

(Page 3 top left to right) Settling ponds at Evergreen Wetland Conservancy located above an abandoned coal mine in Indianna, Pennsylvania. (Bottom left) Iron Oxide pigment dried on stick and stones collected on edges of settling ponds filtering the water at Evergreen Conservancy. (Bottom middle) Glass mulling station used to grind, mix and suspend pigment into a medium for etching. Constructal Law happening in the lower right. (Bottom right) The bottom of the glass muller when lifted from the ink creating treelike forms.

I examine links between human behavior and the natural world. My work focuses on environmental compassion through poetic connections of habitat, anthropology, memory and Constructal Law. During my residency at the Comparative Anatomy Gallery in Paris I made porcelain botanical sculptures resembling bones while studying naturalists' collections of plant fossils and bone specimens. I was struck by the realization that all life has souls, intertwined together, carrying a memory of the past forward. I have exhibited at venues such as Ueno Royal Japanese Art Museum, DeCordova Sculpture Museum, Mexico's Museo Franz Mayer to Turin's Museo di Scienze Naturali.





Drawing You Outside is a way for participants to connect to nature, a way to slow down by creating a new way of seeing and being in nature and changing their visual routine. This process begins by collecting fallen trees branches on paths in City, State and National Parks. Following description Cennino Cennini, Il Libro dell'Arte (c.1400) "Take some slipsof willow dry and smooth cut them into pieces as long as the palm of the hand or little finger. Thus laying them in bundles, bind each with copper wire. Take a new pipkin and fillit with them; put on an earthen cover, so no air can not enter."[1] I use Cennini's treatise as a guide to create a modern version of making charcoal drawing sticks. In this way my life's work is a living testimony to carrying memory forward as I interpret the works of both thetreatise of Renaissance era philosophy and contemporary physicists theory to evolve its intellectual substructure and connecting it to our environment. "Change is key. Change makes an impression. Change revs up the creative mind. The imagined "next" may turn out to be a mirage, yet to imagine "change" is always healthy because it nurtures hope." [2]

[1] Cennino Cennini. *Il Libro dell'Arte, Chap. 33.— In what manner good and fine charcoal crayons may bemade*. (c.1400)

[2] Adrian Bejan, *Time and Beauty: Why time flies and beauty never dies,* Slowing Time, page 151, 2022

Constructal Law Conference (CLC 2023)
Freedom, Design and Evolution
Turin (Italy), 21 – 22 September

To Emerge or Not To Emerge, Reductive Freedom creates Life, Being and Death

Bert G. J. Frederiks* [1]

Abstract

This article explains *strong emergence* in reductionist terms. Two laws predict the structure of reality from general relativity to consciousness. The freedom law predicts how and when new beings, existences, life, and even new matter, will emerge and where reducibility ends. The law of life, or Bejan's constructal law, predicts how this life will evolve or die. If this being persists then it is either dead in the sense of being 'bricked,' or it is alive in the sense that it persists in its design while being a process. These laws are applied to brain and consciousness, and to the unification of quantum mechanics and general relativity—to universal life, and to the life of the universe.

Keywords: Emergence, Reductive freedom, Life, Consciousness, Unification, Causality.

1. Introduction

The Latin "natura" denotes the continual birth (or emergence) of what *is*. In defin-ing reductive freedom I shall explain the emergence of, for example, matter and consciousness. Following Bejan *life* is defined as *a flow-system of finite size that persists in time in its existence*.[2] The flow-system is *alive* because it flows *and*

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because it *persists*; 'inside' it *has* an *(intra)being* or *intraverse*, and as a whole it *is* an *existence*; it is also part of another being called its *extraverse*; this is not a part/whole structure and it is not a descriptive structure; it is a *predictive* descrip- tion of reality. Special about biological life is that it *delves* energy. Many other lifeforms are *dissipative* systems.[1] When and (probably) only when *reductive freedom* arises, life *causes* new natural systems or *beings* to come into existence, i.e. to *emerge*. Their *death* may fixate these beings even more. For instance, new atoms come into existence in stars; they are rather 'dead' or 'bricked' at lower temperatures; but not completely dead, since chemical reactions are still possible. What dies biologically dissolves, but its DNA may have passed on to new life.

2. Reductive Freedom, Life & Death

Take a look at Figure 1. With the eye of a reductionist one would think to see that the smallest (grey) particles ultimately are causative for the behaviour of the whole. Yet there often arises a structure in which these smallest particles are sub- dued, just like with parts of a mechanism; if you turn one gear in a clock then all gears and molecules and quarks are forced to turn with it. This mechanism or persistence makes its parts or particles unfree. They are subdued to the extra-verse that will control and determine them. This is top-down causation. The extraverse as a whole, becomes free of being completely determined by its parts. The extraverse depends on this reduct- ive freedom but is not determined by it.

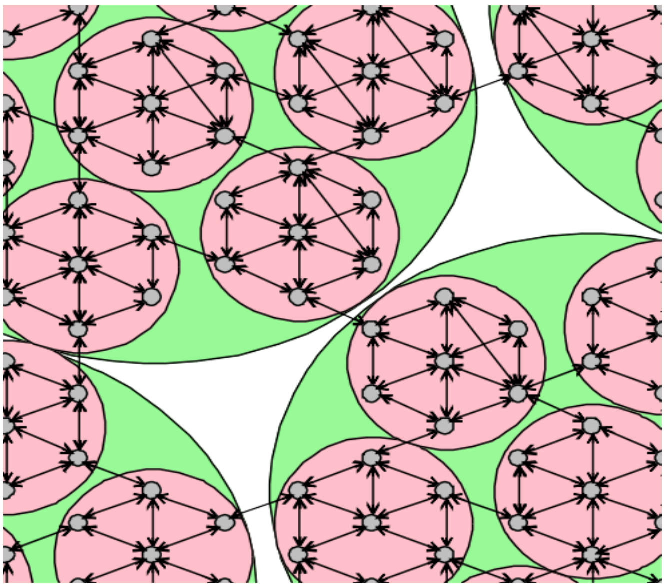

Figure 1: Freedom created by smaller particles (the grey circles) forming 'mechanisms' (pink circles) that accept input from outside and that provide output to the outside. The 'mechanisms' (pink circles) form 'new' or 'free' extraversal "matter." Green circles represent a next (extraversal) level.

When and how this being persists in its existence, i.e. stays alive, is predicted by the law of life, which is a rephrasing of Bejan's constructal law: For a finite exist- ence to persist (in time), thus to live, it must evolve freely in such a way that it can handle what it encounters more easily. Since persistent structures are stable they are quite common for the simple reason that they tend to remain.

If the reductive freedom of an existence is absolute then its inside is 'absent,' un- knowable and not causative; then we experience the existence to be a "particle" or "matter." Less absolute freedom will also create a somewhat independent being. So reductive freedom is abundant and fundamental. Because of non-linearities ex- isting everywhere, life usually implies that a given freedom is limited through feed-back loops. Input into freedom-giving entities often implies modulating thesefeedback loops.

3. Summary and Examples

Reductive freedom causes a new and *living* being or extraverse to emerge. This may die in a flash. The ones to stay alive will do so by following the constructal law or the law of life. The freedom law predicts the birth of a new being. The law of life predicts how and if this being will stay alive or die.

A micro-controller provides functions – i.e. possibilities or freedom – with which the software – and its human programmer – can do what they want.
A biological cell provides *freedom* to DNA to do its thing. This DNA can *evolve* phylogenetically – and somewhat ontogenetically.

Your thoughts and perceptions *live* in your brain without having knowledge of brains or neurons.[3] Your consciousness consists of thoughts and perceptions,and *not*, or only indirectly, of neural activation patterns. This *content* is *causative because of* reductive freedom created in the neural network. Our *consciousness* is a small *hierarchy* of beings of which we do not fully know its intraverses. Just *be-low* the top we have a *pre-consciousness* which we experience as *intuition* and, to- gether with instincts, as *feeling*.[3]

Our relativistic universe probably emerged from reductive freedoms in the quantum mechanical realm. I am not a physicist so I cannot claim more than some 'fantastic' insights; I explain how higher mass in our world is smaller in size inthe quantum realm; how this creates quantum-gravity, relativistic gravity, and general relativity; I explain the holographic principle regarding black holes; I ex- plain electromagnetism as a modulation in this mass; and how all this repeatedly leads to a "big bang," making the universe into a huge living 'thing'.[4]

4. Discussion and Conclusions

A 'new' being is not *fully* determined by its parts. It is determined recursively in the emerging extraverse. The extraverse is *made to be* causational. The 'new,' be- ing is a construction with *possibilities* that are, more or less strictly, taken care of by its intraverse, and the intraverse of the intraverse, etcetera, but *only as* possibil- ities or freedom. So *this* freedom is *designed*, *created* or *determined* in the intra- verse. This may give rise to again new, living beings or extraverses, and so on, ad infinitum. Reality – and consciousness – is a tree of life and death.

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Constructal Law Conference (CLC 2023)
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Use of the Constructal Law to Prove the Maximum Work "Principle" Defining Plasticity, Contact Friction and Continuum Media Flow Using a Variational Optimization Framework. Application to Extrusion Power Estimation

Adinel Gavrus[a*]

Abstract

This scientific work proposes a fundamental use of the Constructal Theory developed by Prof. Adrian BEJAN to prove on a mathematical point of view the "Principle" of Maximum Work (PMW) applied by the theory of material plasticity and tribology. The Constructal Law complete the thermodynamics principles and postulate in a quantitative manner the natural tendency of any finite size system to evolve towards an optimal space-time configuration, minimizing the losses and the entropy generation simultaneously to maximization of global entropy. In this sense, regarding a continuum media plastic flow, among all possible and admissible states undergoing specified boundary conditions and loadings, the real one minimizes the sum of the bulk deformation dissipated power, surface's friction dissipated power and all other losses. Together with the Virtual Powers Principle (VPP) it can be prove the PMW "Principle" as a theorem/consequence of the Constructal Law. After a short theoretical backgrounds accompanied by consequences concerning the convexity and the normality rule law of bulk rheological and contact interface's tribological potentials, will be recalled the Upper and Lower Bounds Theorems. Application concerning analytical estimation of forward extrusion power will be developed to proof the estimation of the average forming power P using the formula $P \approx (\tilde{P}+\tilde{\tilde{P}})/2$ where $\tilde{P}$ represents the Upper Bound Power estimation and $\tilde{\tilde{P}}$ the Lower Bound Power.

Keywords: Constructal Law, Variational Optimization, Maximum Work Principle, Plasticity

1. Introduction

During the past decades, Prof. Adrian BEJAN (Duke University, USA) has developed fundamental scientific researches concerning application of thermodynamics theory to define and optimize complex finite systems time evolution and design based on the called Constructal Law [1-2]. So starting from natural needs of any finite system time flow to minimizes resistance and losses, this law postulate than: *"for a finite-size system to persists in time (to live or to be able to survive), it must evolve in such a way that it provides easier access to the imposed (global) currents that flow through it"* as to facilitate access as much as possible under the constraints flows or which cross them minimizing the corresponding losses [1]. It has also observed that all natural system search to optimize the imperfections distributions to facilitate the time system flow and to minimize local resistances or required process evolution powers. In a mathematical point of view the Constructual

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Law can be seen as a resolution of a general variational optimisation problem under predefined physical constraints. Using recent author's scientific works [3-5], the Maximum Work Principle (MWP) [6] used in plasticity can be proof as a direct consequence of a general variational optimization problem searching to minimize during the flow the sum of all dissipated and losses powers. Moreover is also proof that the MWP can be apply to flow of any type of continuous media: metals, polymers, fluid, mushy state, proving also an equivalent form concerning contact friction stress work. Furthermore, it can be prove the convexity properties and normal rule properties of both plastic and friction potential. Analytical computations of material flow power concerning plane compression and cylindrical crushing [3-5] shown the feasibility of the proposed minimization problem. A new validation will be make here concerning estimation of extrusion process power.

2. Theoretical Framework

According to the theory of continuum media mechanics, for all material plastic flow defined by a body volume Ω, the dynamic mechanical equilibrium can be write from the Virtual Powers Principle (VPP) regarded as an equivalent form of the Newton's fundamental law by:

$$\int_{\Omega}[\sigma]:\left[\dot{\varepsilon}^*\right]dV+\int_{\partial\Omega}-\vec{\tau}\cdot\Delta\vec{v}^*\,dS=\int_{\partial\Omega'}\vec{T}\cdot\vec{v}^d\,dS'+\int_{\partial\Omega''}\vec{T}^d\cdot\vec{v}^*\,dS''+\int_{\Omega}\rho\vec{f}\cdot\vec{v}^*\,dV-\int_{\Omega}\rho\frac{d\vec{v}^*}{dt}\cdot v^*\,dV \quad (1)$$

The VPP is valid for any admissible virtual velocities field $\vec{v}^*$ undergoing corresponding boundary conditions, in particular for the real one $\vec{v}$, taking into account the Cauchy stress tensor $[\sigma]$, the virtual strain rate $[\dot{\varepsilon}^*]$= $\left\{[\nabla(\vec{v}^*)]+[\nabla(\vec{v}^*)]^T\right\}/2$, the friction stress vector $\vec{\tau}$ acting on the contact interfaces or velocities discontinuities surface $\partial\Omega$, a specific loading $\vec{T}$, an imposed velocities $\vec{v}^d$ on the border part $\partial\Omega'$, a specific imposed loads $\vec{T}^d$ on $\partial\Omega''$, a mass forces $\vec{f}$ and density ρ.

2.1 Theorem of « Maximal Work Principle »

Using the Constructal Law, for a deformable material evolution, it can postulate that the plastic flow takes place such that it minimizes the sum of the dissipated bulk plastic deformation power, of the friction power at the contact surfaces or interfaces' velocities discontinuities and of the imposed loads power regarded as losses. So the real values of all kinematic and mechanical variables (velocities, stresses, strains, strain rates) are those which minimize the total dissipated and losses power. As it shown by author in the recent research works [3-5] it is conclude that the real plastic flow state is obtain by minimizing the functional defining virtual dissipated/losses power:

$$P_d=Min\left(P^*_d\right)\,with\,P^*_d=\int_{\Omega}\left[\sigma^*\right]:\left[\dot{\varepsilon}^*\right]dV+\int_{\partial\Omega}-\vec{\tau}^*\cdot\Delta\vec{v}^*\,dS+\int_{\partial\Omega''}-\vec{T}^d\cdot\vec{v}^*\,dS'' \quad (2)$$

Using the loadings and kinematics boundary conditions it is obtain a variational minimization problem under specified constraints where all other virtual flow states require:

$$\int_{\Omega}[\sigma]:[\dot{\varepsilon}]dV+\int_{\partial\Omega}-\vec{\tau}\cdot\Delta\vec{v}\,dS+\int_{\partial\Omega''}-\vec{T}^d\cdot\vec{v}\,dS''\le\int_{\Omega}\left[\sigma^*\right]:\left[\dot{\varepsilon}^*\right]dV+\int_{\partial\Omega}-\vec{\tau}^*\cdot\Delta\vec{v}^*\,dS+\int_{\partial\Omega''}-\vec{T}^d\cdot\vec{v}^*\,dS'' \quad (3)$$

Neglecting mass and inertial forces, using VPP principle and all computations detailed in [3-5] can be write the following inequalities:

$$\left(\left[\sigma^*\right]-[\sigma]\right):\left[\dot{\varepsilon}^*\right]\ge 0,\forall\left[\sigma^*\right],\Phi_p\left(\left[\sigma^*\right]\right)-\sigma_0=0\,;-\left(\vec{\tau}^*-\vec{\tau}\right)\cdot\Delta\vec{v}^*\ge 0,\forall\vec{\tau}^*,\Psi_f\left(\vec{\tau}^*\right)-\tau_f=0\,.$$

In the opposite sense, for the real plastic flow characterized by the velocity field v, the strain rate tensor $[\dot{\varepsilon}]$ and the Cauchy stress tensor $[\sigma]$, any other state of the admissible stresses must also verify $\left([\sigma]-\left[\sigma^*\right]\right):[\dot{\varepsilon}]\ge 0,\forall\left[\sigma^*\right],\Phi_p\left(\left[\sigma^*\right]\right)-\sigma_0=0\,;-\left(\vec{\tau}-\vec{\tau}^*\right)\cdot\Delta\vec{v}\ge 0,\forall\vec{\tau}^*,\Psi_f\left(\vec{\tau}^*\right)-\tau_f=0\,.$

Starting from the above two relationships, it is possible to prove mathematically the convex shape of the potential functions defining both the plastic $\Phi_p\left(\left[\sigma^*\right]\right)$ and friction $\Psi_f\left(\vec{\tau}^*\right)$ criteria. Subsequently it is also prove the known property of normal rule i.e: $\left[\dot{\varepsilon}\right]=\lambda_p\partial\Phi_p/\partial\left[\sigma\right],\lambda_p\geq 0$ and $\Delta\vec{v}=-\lambda_f\partial\Psi_f/\partial\vec{\tau},\lambda_f\geq 0$. Based on the plastic and friction criteria convexity, the two above inequalities can be extended to the virtual stress and friction shear respecting $\Phi_p\left(\left[\sigma^*\right]\right)-\sigma_0\leq 0$ and $\Psi_f\left(\vec{\tau}^*\right)-\tau_f\leq 0$. It is then possible to conclude that for any state of virtual stresses $\left(\left[\sigma\right]-\left[\sigma^*\right]\right):\left[\dot{\varepsilon}\right]\geq 0,\forall\left[\sigma^*\right],\Phi_p\left(\left[\sigma^*\right]\right)-\sigma_0\leq 0;-\left(\vec{\tau}-\vec{\tau}^*\right)\cdot\Delta\vec{v}\geq 0,\forall\vec{\tau}^*,\Psi_f\left(\vec{\tau}^*\right)-\tau_f\leq 0$.

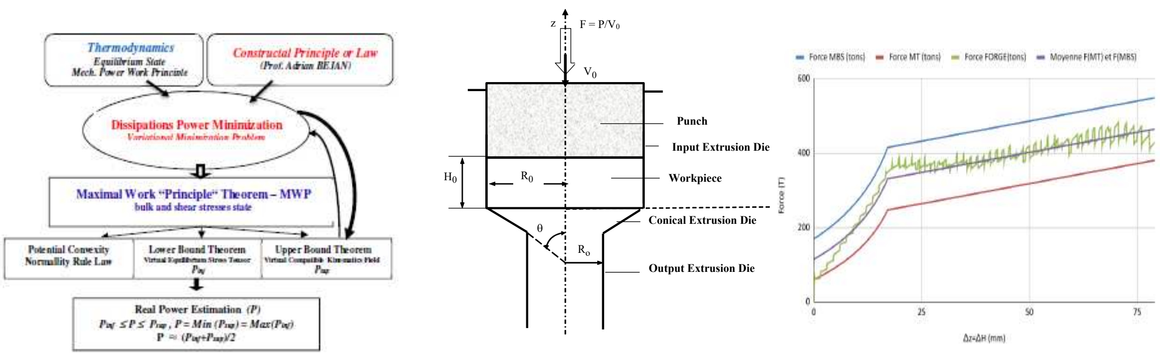
The first inequality define MWP [3-6] and it is prove here that it can be obtain as consequence of Constructal Law and VPP. The second inequality reflects in similar form the friction stress state.

2.2 Practical Consequences Synthesis and Results Concerning Forward Extrusion Process

Starting from Constructual Law, VPP and MWP it is also possible to prove the Lower and Upper Bounds Theorems (Fig. 1a) [6]. To valid the variational minimization principle of dissipations expressed by the optimization problem (2) it is propose to apply all these results to an axis-symmetric forward extrusion process at ambient temperature, considering isothermal conditions and quasi-static flow of a consistent rigid-plastic ($\sigma_0=cte$) incompressible continuum media (Fig. 1b). Using Upper and Lower Bound Powers [6] the Power P can be estimate by $P\approx(\tilde{P}+\tilde{\tilde{P}})/2$ where:

$$\tilde{P}=P_{\sup}=2\sigma_0V_0\pi R_0^2\left[\left(1+\frac{\bar{m}}{\sqrt{3}tg\theta}\right)\ln\left(\frac{R_0}{R_z}\right)+\frac{1}{\sqrt{3}}\left(\frac{\theta}{\sin^2\theta}-ctg\,\theta\right)+\frac{\bar{m}}{\sqrt{3}}\left(\frac{L_c^i}{R_0}+\frac{L_c^o}{R_i}\right)\right] \tag{4}$$

$$\tilde{\tilde{P}}=P_{\inf}=2\sigma_0V_0\pi R_0^2\left[\left(\cos^2\theta+\frac{\bar{m}}{\sqrt{3}tg\theta}\right)\ln\left(\frac{R_0}{R_z}\right)+\frac{\bar{m}}{\sqrt{3}}\left(\frac{L_c^i}{R_0}+\frac{L_c^o}{R_i}\right)\right] \tag{5}$$



a) b) c)

Figure 1. a) Flowchart of Variational Minimization Problem concerning the dissipated power P starting from the Constructual Law, the MWP proof and corresponding consequences

b) Axi-symmetric forward extrusion design, **c)** Comparison of Analytical Loads (Force *F*) - Punch Displacement (Δz) variation and FEM values F_{num} (Forge2®): MBS - Upper Bound Limit F_{sup}, MT - Lower Bound Limit F_{inf}, Mean $F = (F_{sup} + F_{inf})/2$ ($R_0 = 40$ mm, $H_0/2R_0 = 1$, $R_0/R_0 = 0{,}6375$, $\theta = \pi/6$ radians, $V_0/H_0 = 0{,}0625 s^{-1}$)

Here θ represents the conical die angle expressed in radians and $R_z = \max\left(R_o, R_0\sqrt[3]{1-3\Delta z t g\theta / R_0}\right)$ where R_o is the initial specimen radius (whit initial height H_o) and Δz is the punch displacement. A reference equivalent stress σ_0 supposed to be constant is defined from the real material rheological law using plastic energy equivalence ($\sigma_0 = 300\sqrt{3}\, MPa$) with an average estimation of the plastic strain $\bar{\varepsilon}_m = 2\ln\left(R_0 / R_i\right) = \ln(S_0 / S_i)$ (here 0,9) supposing a plastic Tresca friction law with a factor $\bar{m}$ estimated from the Coulomb coefficient by $\bar{m} \approx \mu\sqrt{3}$ (here $\bar{m} = 0{,}1$).

3. Discussion and Conclusions

Figure 2c shows that analytical estimation of required extrusion load evolution *F*, using the proposed mean power value obtained from the relationships (4) and (5), regarded as consequence of Constructual Law, is very close to the numerical one with an estimation error less than 1%-5%.

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Experimental characterization of steady state refrigerationof square plates with different channel shapes

J.F. Guil-Pedrosa*, L.M. García-Gutiérrez, N. García-Hernando, A. Soria-Verdugo[1]

Abstract

The performance of aluminum flat plate cooling systems is experimentally and numerically evaluated for a laminar steady-state refrigeration. An experimental facility allows to control and measure fundamental parameters for the cooling process, which can also be introduced as boundary conditions in a numerical simulation in COMSOL Multiphysics. The comparison of both experimental and numerical results showed good agreement in the distribution and maximum temperature.

Keywords: Cooling plate, Channel shape, Heat transfer, Laminar flow.

1. Introduction

Flat metal plates with an inner channel along which a liquid coolant circulates are used in various engineering applications as the basis of cooling systems, such as electronic devices, PV cells or electric batteries [1]. The shape drawn by the channel across the plate directly affects the cooling capacity and the pressure drop associated with the circulation of the coolant [2]. According to the Constructal law, the use of configurations found in nature architectures allows to improve traditional systems by minimizing pressure drop and maximizing heat transfer.

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In this work, the steady-state cooling performance of aluminum flat plates with an inner channel of circular cross section through which cold water circulates in laminar regime is evaluated experimentally and compared with numerical simulations. Novel configurations with shapes inspired by the outline of flowers arecompared with traditional configurations to quantify the improvement of the cooling capacity for the new configurations. An experimental facility was designed and optimized to characterize the cooling capacity of the plates.

2. Materials and Methods

Five different channel shapes proposed in a previous work [3] for the flat plate cooling systems were tested: two traditional configurations called square and fork due to their shapes and three novel configurations based on flower contours. The flat plates were 3D printed in aluminum with an external square shape of 15 cm side and 1 cm thickness. The cooling water circulates through its inner circular channel of 6 mm diameter in the middle plane of the thickness. The channel length of 439 mm and the position of the inlet and outlet remain the same in all configurations, so the fluid volume is kept constant. A top view of the middle plane of the thickness is presented in Fig. 1 for the different channel shapes.

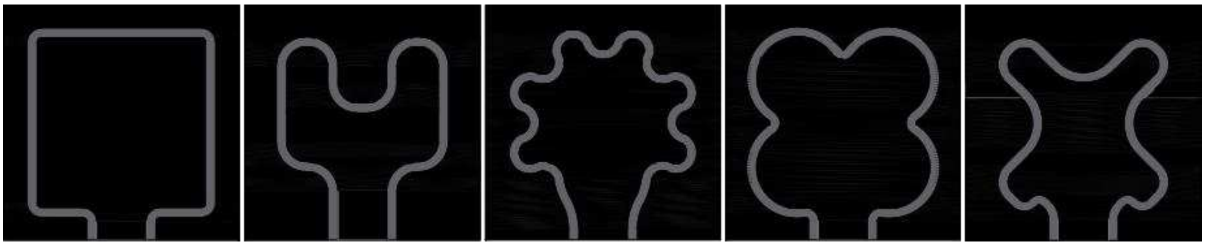

Figure 1. Top view of the cooling systems midplane, with the different channel shapescolored in gray and the solid aluminum in black.

The experimental facility already proposed for the transient refrigeration of the plates [4] was updated for the steady-state cooling. The facility allows to control the ambient temperature, the temperature of the fluid at the inlet of the plate, the flow rate of cooling water, and the heat flux input by means of a flat electrical resistance in direct contact with the bottom surface of the plate. An infrared camera measures the temperature distribution of the upper surface of the plate, considered representative of the whole thickness due to the high Biot number. The vertical walls of the cooling system are isolated. The cooling water mass flow rate was fixedto achieve a Reynolds number of 1250 and its temperature at the inlet wasestablished at 23 ºC. The heating power input was set at 200 W.

COMSOL Multiphysics was the software employed for the numerical simulations. The incompressible laminar flow was simulated without any turbulence model. The boundary conditions were only the non-slip condition at the walls, the experimentally measured mass flow rate at the inlet of the channel and a pressure condition at the outlet. The heat transfer simulation needed the temperature condition at the inlet of the duct, the inward heat flux from the resistance and the ambient temperature for the external natural convection on the upper surface of theplate, which were all measured experimentally.

3. Results

Figure 2 shows the upper surface temperature distribution of the cooling systems for the experiments (above) measured by the camera, and the simulations (below).

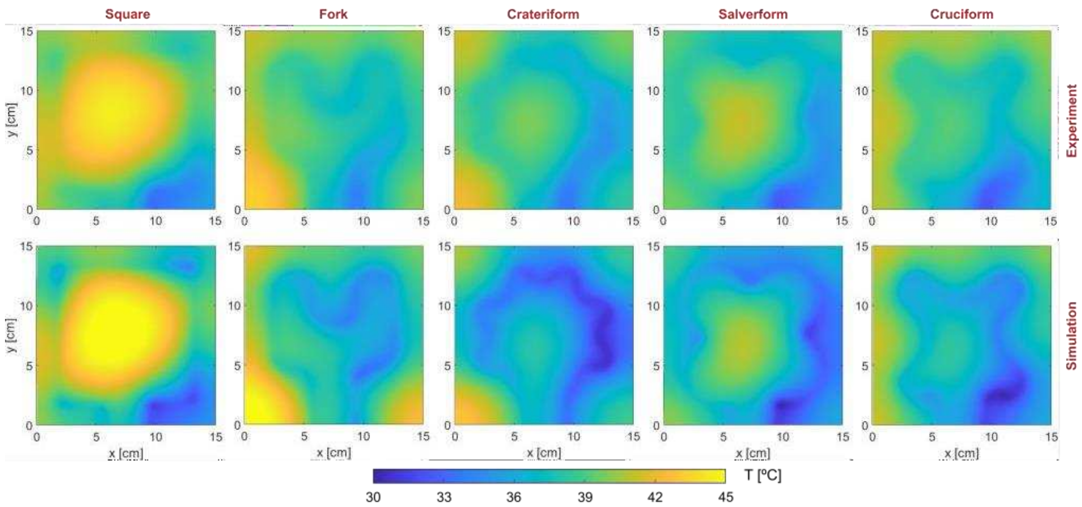

Figure 2. Experimental and numerical upper surface temperature distributions.

The similarities between the temperature distributions for each channel shape are conspicuous. The hot spots are located in the same positions, which coincide with the furthest points of the cooling channel near the channel outlet, as predicted by [3]. The highest maximum temperature, both in the experimental and numerical results, correspond to the square-shaped configuration with a value of 44.5 and 46.1 ºC, respectively. However, the largest discrepancy in the maximum temperature manifests in the fork-shaped configuration with a difference of only
2.6 ºC. The fluid temperature at the outlet is very similar in every configuration dueto the great contribution of the heat dissipation to the cooling water compared to the natural convection on the upper surface. The results show that all novelconfigurations exhibit a better cooling performance than the traditional ones.

4. Conclusions

The cooling performance of aluminum flat plates for steady-state with a heat inputof 200 W and laminar flow with a Reynolds number of 1250 was evaluated experimentally and numerically. The numerical results show good agreement withthe experiments. The novel configurations presented better performance in terms of distribution and maximum temperature than the traditional configurations in both experiments and simulations.

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Constructal Network of Maritime Transportation

Umit Gunes [1], Ismail Ekmekci [2]

Abstract

Global transportation has significant impacts on the world's lives and economies. Transporting freight from point A to point B can take many alternate forms, with each alternative having its own opportunities and challenges. Transportation studies require optimization, but optimization alone is insufficient as each optimization has its own optimal point only for a certain time. Due to the dynamic nature of transportation models, decision makers should also consider the time factor. Constructal law provides a way for people to be able to simplify international transportation, with one result from Constructal law involving "a few large and many small" [1] modes of transport for any route, similar to the configuration of a river delta. In aviation, this is referred to as the hub and spokes model. In this paper, we investigate these few large and many small (i.e., hub and spokes) modes of transportation for routes involving maritime transportation, using annual data from the Maritime Traffic webpage [2] to show how compatible current routes are with Constructal law.

Keywords: Constructal law, marine transportation, air transportation, road transportation, hierarchy, economics of scale.

Extended Abstract

Constructal Law explains all movement on the globe through the principles of physics, because every flow encounters new paths during its movement, and flow friction on each path determines each movement's direction and future. This phenomenon also happens in transportation on the globe. In the formation of transportation networks, this friction means cost per unit load. Transportation networks, just like flow branches, are realized using the network most suitable for that time period.

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2 Istanbul Commerce university, Department of Industrial Engineering.

Some of the results from constructal law involve the few large and many small, the economics of scale, the bigger being more efficient, and hierarchies, and the background of these results is simply physics. The same amount of fluid flowing from 2 smaller pipes to 1 large pipe experiences a pressure drop of 50% less laminar flow and 28% less turbulent flow (see Figure 1). All transportation (movement) on the globe depends on this simple principle known as Constructal law.

Figure 1. Fluid flow in two small diameter pipes and one large diameter pipe.

Materials and Methods

This study use 4 different datasets, as well as Marine Traffic [2], Airflow [3], Shipping Lanes and Flight Paths Map [4], and Roads of the World [5] as visualizations for explaining transportation (movement) on the globe.

Results

Figure 2 shows the Marine Traffic Density map [2], which is pivotal in illustrating global maritime flow by highlighting busy shipping lanes and potential congestion zones. Its significance lies in how it ensures maritime safety, facilitates efficient routing, and aids environmental conservation.

Figure 3 shows the Air Traffic Density map [3], which plays a crucial role in visualizing the intricacies of global flight patterns by pinpointing areas of aerial congestion and potential risks. Its importance is paramount for ensuring air safety, optimizing routing, and aiding airspace management.

Figure 4 shows the combined Air and Marine Traffic Density map [4], which provides a comprehensive visualization of the global movement above and below the skies and across the seas. This integrated tool is essential in understanding the pulse of international commerce, travel, and logistics. Its synthesis allows authorities and industries to identify potential choke points, optimize routes, and ensure the safety of both aerial and maritime corridors. Merging these maps equips stakeholders with a holistic view and fosters enhanced coordination, as well as efficient resource allocation and safer global transit networks.

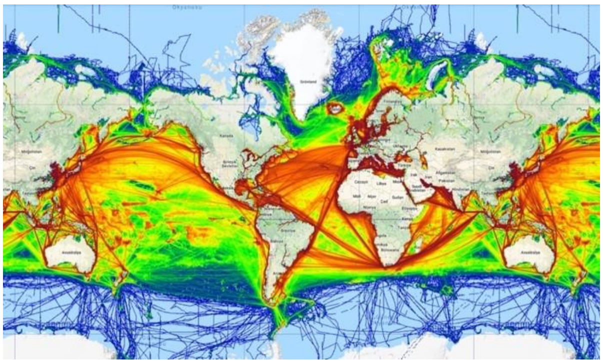

Figure 2. Marine traffic density map [2].

Figure 3. Air traffic density map [3].

Figure 4. Shipping lanes and flight paths map [4].

Figure 5 shows the World's Roads map [5] which presents a detailed tapestry of the vast network of highways, roads, and paths that crisscross the globe. This essential tool underscores the incredible infrastructural feats humans have achieved, as well as the interconnectedness of regions, countries, and continents. The map's importance is manifold, as it is offering insights for urban planning, transportation logistics, and infrastructure development.

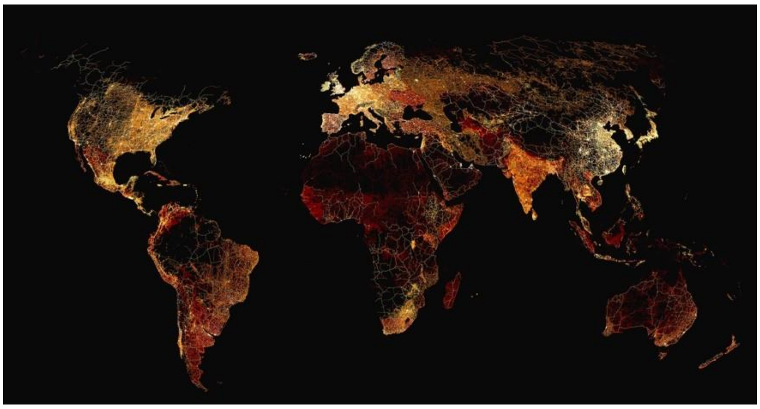

Figure 5. The entire World's Roads map [5].

Figure 6 shows the comparison between energy use per capita and GDP per capita [6], which offerscritical insight into a country's efficiency at converting energy into economic output. This relationship is vital for understanding how sustainable and efficient a country's growth model is. Higher GDP with lower energy use indicates an economy that is effectively leveraging its resources, promoting sustainability, and reducing its carbon footprint. Conversely, high energy consumption with lower GDP might signal inefficiencies or over-reliance on energy-intensive industries.

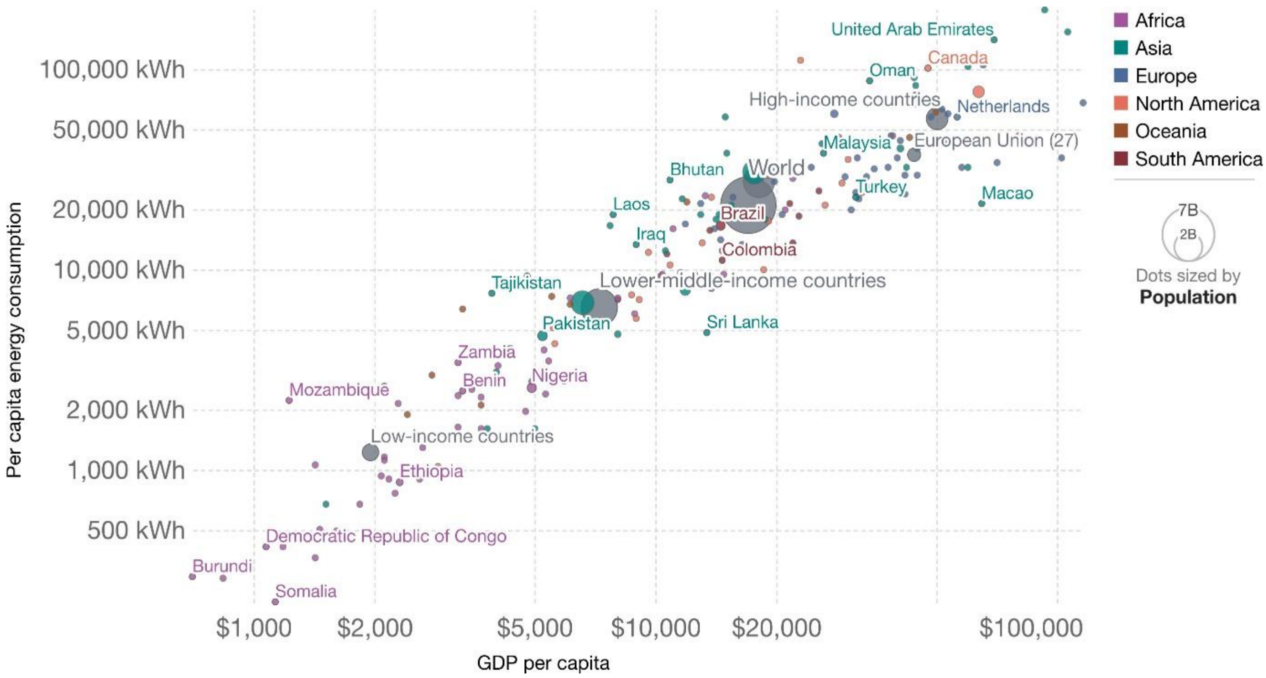

Figure 6. Energy use per capita vs. GDP per capita in 2021 [6].

Discussion and Conclusions

Constructal law explains the structure of air, land, and sea transport as the largest parts of movement on the globe and gives us the opportunity to make predictions for the future. This structure of transport is also closely related to energy use per capita and GDP per capita, because economies develop in attractive places with more movement, thus allowing these regions to become more attractive.

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A Constructal History of Ephesos

Phillip Johnson [1]

Abstract

While the constructal law was initially developed as a theory to explain physical transport processes, it has shown promise to inform complex phenomena such as socio-economic or politico-cultural shifts. While these topics can be studied in a somewhat isolated fashion, circumstances grant the benefit of seeing all such processes comprehensively. One such circumstance is the city of Ephesos in Asia Minor. This paper will give a brief history of the city before drawing attention to particular processes and events which shaped the city and its trajectory while analyzing them according to constructal theory. Physical aspects of this analysis will focus on the Meander river, the harbor at Ephesos and its silting with time. Economic analysis will inspect commerce on the water-based highways and the linkage of the city with various empires. Cultural reflections will observe temples dedicated to Artemis, Hadrian, and St. John the Apostle and the role that various religions played in the city's life as pilgrimage destination. Finally, the cutting off of flow from all layers observed played a role in the demise of the city – a phenomenon which is also explained via the constructal law. This work will demonstrate that many such flows are interconnected with feedback-like behavior, yet still retaining constructal features.

Keywords: constructal law, river formation, economics, commerce, history

1. Introduction

The scientific field of the constructal theory has evolved from thermal-fluid systems to other transport systems, biological systems, and even socio-economic systems. Such broad applicability allows for the analysis of historical narratives which encompass all of these factors. This paper will present a three-tiered evolutionary history of the ancient city of Ephesos which is informed by the Constructal Law. The analysis is categorized under the heading of physical, socio-economic, and religio-cultural forms of flow. Brought together and synthesized, a high level narrative can be crafted which explains the ancient city from its birth to its decay.

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2. Physical Theory

The subterranean flow of the earth has pushed the landmass of western Anatolia into the regions, creating the ridges of Turkey with the Cappadocian plateau. Due to the elevation difference between the mountains and sea level, there is a geopotential gradient, which drives water (precipitation or subterranean sources) towards the sea. The paths taken by these various currents have varied in history. The constructal law tells us that the system will continue to evolve such that that configuration of these rivers has morphed to increase flow axis. These reconfigurations are due to various geological and meteorological causes.

Rivers also shape their river bed. They further move silt and sediment. For example, both Meander rivers silted up their gulfs. This led to changing locations of the nearby settlements. Human residence also had an impact as deforestation, ploughing, and goat grazing all contributed further to erosion/accumulation.

3. Socio-Economic Theory

Fertile lands along the hydrological pathways of rivers and seas have been historical been vital location for human residence. These locations have provided the facilitation of human transportation and the shipping of goods via such waterways. Most important were the cities at the adjoint between a river network and the coast of the sea. At these locations, transmission from the inter-regions to the outer world of the sea were connected and linked broader nodes of travel and trade. These pathways are multi-layered in this capacity: with the constant flow of people and goods comes socioeconomic flow. This leads to the gatherings of human communities and the nascent idea of the city, which has a larger concentration than agrarian communities, villages or towns.

Further, the constructal law says that in order for this city to thrive it must reconfigure itself to continually increase its flow access. This occurs through urban growth. The city can publicly or privately build more residences, marketplaces, and infrastructure to facilitate intracity travel. As it evolves in its configuration to increase flow access, a feedback loop is created whereby the increase of socioeconomic flow allows for the evolution reconfiguration and the evolution of configuration allows for more flow.
These considerations can also be applied in the reverse order: any physical changes to the water pathways which result in a loss of flow to the city will lead to its diminishment with time. We have both examples occurring in this geographical region. Firstly, the Little Meander silted up the harbor and cut off trade access to the sea. At numerous occasions the citizens sought to retain or increase flow access by dredging up the silt and maintain harbor access. Despite these efforts, the city ultimately became an inland city and today sits seven kilometers away from the coastline. This loss of access to the sea played a significant role in the city's demise, among other factors (see below).

4. Politico-Cultural

There is an interrelationship between the wealthy and the political actors and a tandem desire to continually restructure the polity and the increased wealth of the state actors. This can be seen by simplest observation of the creation of marketplaces and roads, which are flow pathways towards commerce. Empires from the Achaemenids to the Romans build roads between cities to facilitate flow between them. Both intracity and intercity roads facilitate flow. Ephesos was connected to other cities throughout antiquity.

The polity also generated monuments for holy sites to bolster the attraction of pilgrims or (today) tourists. This was done historically through Artemis, Mary, St. John, etc. The generation of monuments serves as a dynamic attractor. Conclusively, the feedback loop described the terms of the growth of a city: through commerce the city can increase its building projects and new facilities net increased commerce.

5. Civilizational Flow

The cultural legacy is transmitted through the ages and has a bearing even on the current nature of the site. The city of Ephesus is one of the most popular tourist locations in Turkey today. Historical artifacts, to use the language of construct a theory, are flow fossils. Interestingly enough, fossil configurations still transmit a message. Although fossil messages must be bolstered by other artifacts, either textual or archaeological, fossil configurations still transmit information into the ideas of living persons. There is therefore a sustained flow of information and concepts which draws the attraction of persons as pilgrims and patronage Ironically, the city of Ephesus is both dead and alive. It is no longer flowing as a city. There are no inhabitants, there is no river. There is only, physically speaking, a flow fossil. Yet there are still flows of people and goods, not because of physical flow, but because of informational flow. On a conceptual level, Ephesos is alive as long as there are people for whom the idea of Ephesos is alive and flowing. Only with the cessation of the civilizational ideas will the city be lost forever.

Static Optimization is Not Constructal Law

Lage, José L.[a*], Junqueira, Silvio L.M.[b]

Abstract

The genesis of Constructal Law has been the observation of discrete processes in which a series of geometric modification are sequentially implemented to facilitate the flow taking place in a system, resulting in intermediary optimized configurations. The time evolution of these intermediary configurations -called by us *dynamic optimization*- reveals morphing geometries increasingly similar to those of existing natural (and artificial) systems. Optimizing in constructal is not an end, but a means; it is how the system evolves toward survival. Finding any intermediary optimal configuration -called by us *static optimization*- reveals a time-shot of the evolution movie, and this is not Constructal Law. Static optimization predates Constructal Law, and it ignores evolution or the temporal component of the constructal process. Constructal Law is about dynamic optimization, continuous morphing, now realizable with advanced smart materials and manufacturing processes.

Keywords: constructal, evolution, dynamic optimization.

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1. Introduction

In the second edition of Advanced Engineering Thermodynamics [1], chapter 13 (p. 704) begins with three questions about: (1) observing the geometry of natural flow systems, (2) the increased complexity in time of natural structures, and (3) a physics principle for predicting geometric form. A little over one-hundred pages later, the Constructal Law is spelled out (p. 807) as: "For a finite-size open systemto persist in time (to live), it must evolve in such a way that it provides easier access to the imposed (global) currents that flow through it."

This law statement is a crafted proclamation with several specifics, orcharacteristics that bound the meaning and applicability of the Constructal Law.These specifics are: the "finite-size open system" – meaning, a macroscopic (i.e.,not a differential, or microscopic) system through which an entity (e.g., mass or heat) flows; the "persist in time" – referring to a dynamic (as opposed to static)system, one in which time varying changes are observable; and "provides easieraccess to … flow" – indicating a specific type of time varying change, or evolution, i.e., one to facilitate the flow. Hence, a closed system, or a system though which nothing flows, would automatically by unrelated to the Constructal Law. A system whose time evolution is to hinder the flow, would also not fit. All these specificsseem very straightforward, including the one about temporal modification: a system that does not allow changes in time would not be suitable for the Constructal Law.

Notwithstanding, the temporal specification has been ignored by a very large number of Constructal Law studies focusing on optimizing flow systems. These are studies with a clear objective: to find the optimal, the single best state configuration. Classical examples include finding the optimum geometry for maximum heat transfer, or for minimum pressure-drop (or increasing flow rate). Noticeable is the static characterization of the objective, i.e., to find a single, a static, or time-invariant state. This objective is not new in engineering, and, more importantly, it departs from the temporal specification of the Constructal Law.

2. Static Optimization is not Constructal

The paragraph following the Constructal Law statement [1] is striking: "This law has two parts. The first recognizes … to construct paths of ***optimal*** access
… " (emphasis added by current authors). Interestingly, optimization is presented as a key component of Constructal Law, found in the original design principle [1]:"All these features - purpose, …, optimization, construction- can be seen in the living and nonliving systems optimized … ." This is not the first time the words "optimal", or "optimum", or "optimization" are seen in relation to Constructal.

In fact, the genesis of the Constructal Law is said to have been the result ofa "… geometric ***optimization*** method for cooling electronic systems." [1], p. 807. This optimization refers to the placing of electronic boards inside a channel, via thermo-fluids analysis. The determined geometric optimum, be it the distance between boards or the location where the electronic should be placed is unique, i.e., it does not vary or change in time. This optimum is called here "*static optimum*", the result of a static optimization; it is not time-dependent, and the system does notevolve in time before or after reaching it. There can not be further improvement(s) in the access of what flows, no time-varying changes in the system to be observed. There is no evolution – finding the optimum ends the process of facilitating the access to what flows. Inasmuch the idea of Constructal might have evolved from the said study, clearly the study itself lacks the most important component of the Constuctal Law, specifically the time evolution component.

What seems unclear is the role the process of optimizing a system has in the Constructal Law. Particularly because several original studies of Constructal Law

[1] are based on optimization. If, by definition, an optimum state is a final state for a system seeking to facilitate access to what flows, then the evolution of the system can no longer proceed unless the pursue of facilitating access is no longer satisfied (this would be an evolution toward a less efficient flow system – or a "devolution").

One way or another, the two specifics of Contructal Law, namely the facilitating access and the continuous evolution, would no longer be concurrently present.

Hence, studies in which a static optimum state is found for a certain flow system can not claim to follow the Constructal Law. Two observations help consolidate this view, namely:

1. the pursue of a single, optimal configuration in flow systems is an engineering activity that predates the idea of Constructal; static optimization is not new; hence Construcal Law would not be new either;

2. if a system with a certain, single geometric optimum configuration indeed falls under the Constructal Law, then the only surviving specifics of the law would be the observation of natural geometries and the law itself; the temporal characteristic of the law, or the key component of Constructal Law, would be lost and the Law would cease to exist.

What seems contradictory is the realization of optimum systems being destined to disappear. According to the Constructal law, surviving systems must continuously evolve to survive. If an optimum state is found, there can be no longer be any further improvement – the system already provides optimum access; hence, this system will eventually disappear. To reconcile optimization and Constructal Law one can see static optimizations as intermediary configurations. Now, the time evolution of these intermediary configurations -called *dynamic optimization*- reveals morphing geometries evolving toward survival. Finding any intermediary optimal configuration reveals a time-shot of the evolution movie. Constructal Law is about dynamic optimization, continuous morphing, now realizable with advancedsmart materials and manufacturing processes.

3. References

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Convection Heat Transfer from a HorizontalCircular Cylinder in an Adiabatic Tank – Application to Thermal Energy Storage

Shigeo Kimura[a*], Yoichi Utanohara[a], Michael Vynnycky[b]

Abstract

Convection heat transfer from a horizontal cylinder placed in an adiabatic circular domain was studied numerically as well as experimentally. The transient heat transfer process went through three different stages characterized by their distinctive heat transfer mechanisms. The conduction from the heated cylinder set in at a very early stage, and then steady convection from the cylinder quickly replaced the early conduction, with no influence being exerted by the outer adiabatic boundary in both cases. As the convection became weak due to diminishing temperature difference between the cylinder and surrounding fluid,there was eventually a stage in which the heat transfer from the cylinder was only compensated by downward conduction via the horizontal boundary between the upper hot and lower cold fluid bodies, coinciding with the complete termination of convection. The time-history of the heat transfer process described above, which is a simple model for the efficiency of the heat exchanger in a thermal energy storage tank, was presented in terms of nondimensional parameters such as the Rayleigh number, the inner to outer diameter ratio, and the dimensionless diffusion time.

Keywords: Natural convection, Heat transfer, Circular cylinder, Energy storage.

1. Introduction

Natural convection heat transfer from a heated circular cylinder that is horizontally positioned is one of the classical problems. Early works attribute to authors such asSparrow & Lee [1], and Merkin & Pop [2]. Raithby & Hollands [3] were the first to introduce an outer boundary having a different temperature to that of the inner; this implies flow in a horizontal annulus. This work was further extended to a Stefanproblem by Nandi & Yadida [4], and to the problem of a superconducting cable by Zhu et al. [5]. When the outer boundary is replaced by an adiabatic wall, the evolution of natural convection heat transfer is important for designing thermal energy storage systems, which is the main theme of this paper.

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2. Problem statement and Methods for Analysis

The geometric and thermal conditions of the problem are schematically shown in Figure 1. The heat transfer evolution after the inner cylinder temperature is suddenly raised is monitored numerically and experimentally. It should be noted that the innercylinder is a simplified model of a heat exchanger placed in a water tank.

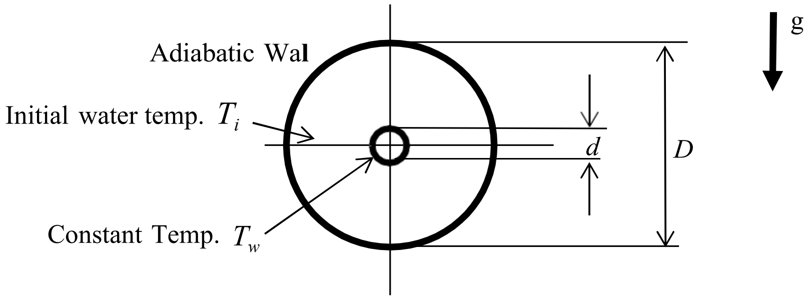

Figure 1. The schematic of the geometry and thermal conditions

3. Results

Transient numerical experiments were carried out for three different inner to outer diameter aspect ratios (3, 5 and 8). The Rayleigh number, Ra , was varied from 103 to 106 in numerical simulations, and up to 4×10^8 *in experiments. The results indicate that there are three distinct heat transfer regimes: initial conduction, steady convection and termination of convection, as shown in Figure 2 for* D/d *= 5 and*

Ra = 10^6 . From a$_s$ practical point of view, the duratio$_s$n of the period of steady convection is of most relevance, because the heat exchanger is supposed to functionefficiently only during that time. The steady convection lasts until the fluid surrounding the cylinder remains sufficiently cold so that the temperature difference produces a convection driving force. By calculating the thermal energy necessary to raise the temperature of the space above the inner cylinder, the following proportionalities are found: $t\,\alpha/(D^2 - d^2)$: $Ra^{-1/4}$ in laminar convection, and $t\,\alpha/(D^2 - d^2)$: $Ra^{-1/3}$ in turbulent convection. The numerical and experimental results are shown graphically in **Figure 3.**

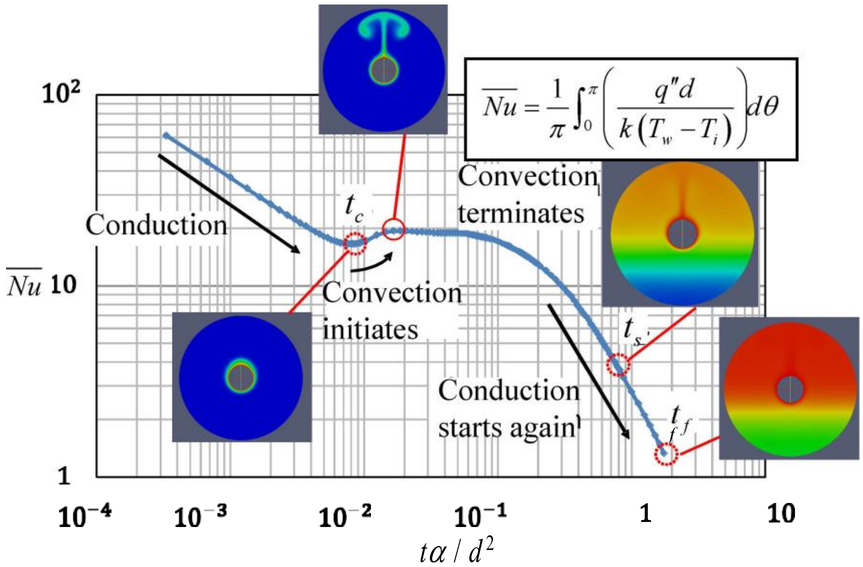

Figure 2. The time-history of the average Nusselt numbers, $\overline{Nu}$, and temperature fields as a function of nondimensional diffusion time

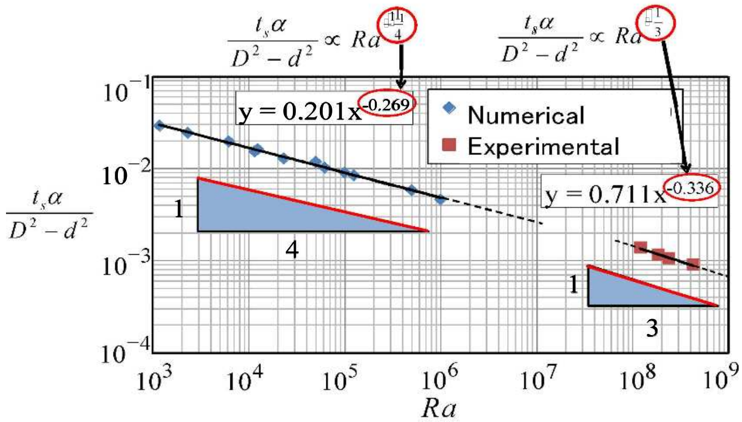

Figure 3. The dimensionless time, t_S , at which convection essentially terminates,plotted as a function of the Rayleigh number based on the inner cylinder diameter.

4. Discussion and Conclusions

With applications of thermal energy storage in mind, the time-history of heat transfer rates from a heated cylinder in a circular domain has been studied based on numerical simulation and real physical experiments. The results were analysed via a scaling law and presented in terms of relevant nondimensional parameters. It was found that the period in which convection is the primary heat transfer mechanism becomes shorter as the Rayleigh number becomes larger. The scaling law suggests that the nondimensional period is correlated with $P\alpha^{-1/4}$ in laminar flow and $P\alpha^{-1/3}$ in turbulent flow. These proportionalities have been proved numerically and experimentally. The present results will help in the design of a thermal energy storage system having a horizontal heat exchanger.

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Constructal Law Conference (CLC 2023)
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Constructal Theory of Flapping Wing Unmanned Aerial Vehicles

Rebecca Edelman[1]

Abstract

This paper reviews recent progress on unmanned aerial vehicles (UAVs) through the lens of constructal theory. Emphasis is placed on using constructal theory in order to understand the relationship between different degrees of freedom within these complex dynamic systems. Size scale, one of the most significant factors in the design of any UAV, is analyzed in terms of its relationship to velocity as well as energy consumption. Specifically, constructal theory is used to predict the minimum size at which any UAV will need to be tethered in order to support its energy requirements.

Keywords: Unmanned Aerial Vehicles, Constructal Law, Energy Efficiency, Micro UAV

1. Unmanned Aerial Vehicles

Constructal law accounts for all features of design in nature, including the direction of evolution of animals that fly. Constructal theory states: "for a finite-size flow system to persist in time (to live) it must evolve such that it provides greater access to the currents that flow through it" [4]. A flying animals' ability to live is dependent on their ability for efficient flight: an animal that can sustain itself in flight for a greater distance will be able to more easily evade predators and capture prey. All animals have in their own way evolved in a direction towards more efficient flying capabilities. Constructal law explains the occurrenceof the natural evolution that led to the birds seen today.

The evolution of the aerial industry can be understood through the lens of constructal law in a similar vein. This paper will specifically focus on unmanned aerial vehicles (UAVs), for which the global market is rapidly expanding due to the many cases in which UAVs are determined to be superior to manned aerial vehicles. The significant fact that there is no pilot onboard leads to the preferred use of UAVs over that of manned aerial vehicles in cases in which the work can be categorized as either dull, dirty, or dangerous. Work such as tedious data collection doesn't require a human onboard. UAVs can also be used in environments thatare undesirable for humans, such as combat zones or areas with toxic chemical plumes.

Furthermore, UAVs can be much smaller and therefore cheaper as well as have fewer safety regulations and life support requirements than their manned counterparts: manned aerial vehicles must minimize rapid acceleration or bumpy trajectories; however, these factors do not affect a UAV control system and are not considered as heavily in the design process [18].

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2. Classifications of UAVs

Until recently, there were two primary types of UAVs: fixed-wing UAVs and multirotor UAVs. However, there are a few unfortunate tradeoffs in these designs. While multirotor drones can hover and are somewhat maneuverable, they have far shorter flight times due to increased energy usage and are much louder because of the high rotor speeds. Similarly, although fixed-wing drones have longer flight times, they cannot hover, have low maneuverability, and require high forward flight speeds in order to stay in the air. Flapping-wing UAVs, or ornithopters, are far more efficient in terms of aerodynamic performance, have increased maneuverability, and are able to hover if desired [4]. When birds flap their wings, a portion of the lift force is generated passively due to the flexible nature of their wings interacting naturally with the aerodynamics of the air. Multirotor drones get rid of all passive propulsion, leading to the use of far more energy. Similarly, traditional aircrafts such as airplanes use their wings only for the generation of lift, while relying on the engine for thrust. Flying animals use their wings for both thrust and lift, which again reduces energy consumption and takes advantage of air currents [7]. Since ornithopters can fly at lower speeds, they are far more maneuverable and can be designed to hover [1]. This summary is supported by **Figure 1**, below

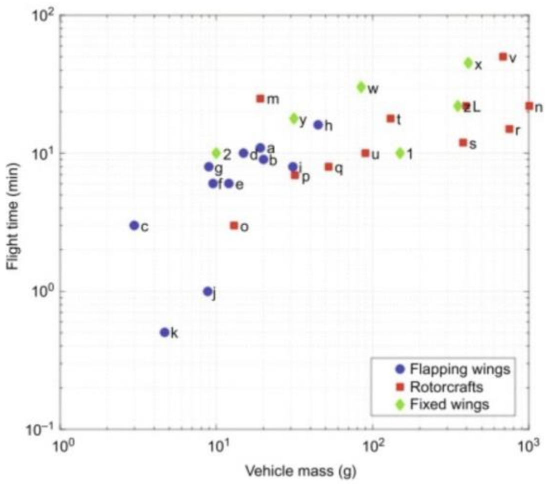

Figure 1. Plot of flight time vs. vehicle mass of the following micro UAVs: a: Nano hummingbird, b:DelFly Explorer, c: Delfly Micro, d: H2 Bird, e: MicroBat, f: Bionic Bird, g: Avitron V2.0, h: 36-cm Ornithopter, i: 28-cm Ornithopter, j: 15-cm Ornithopter, k: 10-cm Ornithopter, L: Parrot Bebop drone, m: PD-100 Black Hornet PRS, n: DJI Phantom 2, o: Seiko-Epson uFR-II, p: Ladybird V2, q: Mini X6, r: 350. QX2, s: AR. Drone 2.0, t: QR Y100, u: QR W100S, v: eBee, w: Black widow, x: Wasp III, y: Univ. Florida MAV, z: H301S, 1: Diamond 600 EP, 2: EPFL MC2 [20]

In the design of a UAV, one of the first considerations is size. UAVs can weigh anywhere from less than 1 lb to over 10,000 lbs, and this range is only increasing with developing technology [10]. The size of the UAV is extremely relevant in its design, as it determines the cruising speed of the vehicle. While it is intuitively understood that larger vehicles have higher cruising speeds, constructal theory can be used to find the clearer quantitative relationship that the speed, V, is proportional to the mass, M, raised to the power of ⅙ [3]. In this paper, the vehicles of interest will be micro UAVs: those that weigh less than 1kg.

3. Tethered vs. Untethered Micro UAVs

Micro UAVs can be divided into two categories: tethered and untethered. Tethered micro UAVs must be wired to a ground power supply in order to fly, as they are so small that they cannot support the weight of the battery. There are a small number of micro UAVs that existnear this boundary, tabulated in Table 1.

Table 1. Summary of Existing Micro UAVs

Name	Developer	Weight (g)	Horizontal Flight Speed (m/s)	Tethered
DelFly Micro [9]	University of Delft, Netherlands	3.07	5	N
RoboBee [14]	Harvard	.08	2	Y
Golden Snitch [11]	Tamkang University	8	-	N
Black Hornet Nano [13]	Prox Dynamics AS	16	10	N
Hummingbird [12]	Purdue	12	-	Y
Soft Actuator Insect-like robot [6]	MIT	0.665	Hover Only	Y
PBP drones [2]	Technical University of Delft	14	-	N
Mesicopter [5]	Stanford	3	Hover Only	Y
Unnamed [17]	Harvard	3.22	-	N
Micro glider	Harvard	2	0.0007	N
Nano Hummingbird[5]	Aerovironment	19	5	N
Robofly [8]	University of Washington	0.19	~Hover Only	Y
Piccolissimo [19]	University of Pennsylvani a	2.5	-	N
Microbat [15]	Caltech	12.5	-	N

In order to better understand micro UAV design, discerning where this boundary lies is essential. In other words, what is the minimum size at which a UAV can exist before it must be tethered? The flight of a UAV can be divided into two components: horizontal flight and the initial vertical flight that takes a vehicle to the height at which it can cruise. Although the vehicles being studied are on the order of insects, in order to be a successful aerial vehicle it must be airborne at a scale useful for humans: a minimum of about 5 meters, or lifted above the rooftops. A successful UAV must first use its energy to lift itself to this minimum height before then using the remainder of its energy to move at this height for some period of time. Therefore, the transition from tethered to untethered lies at the point at which a vehicle can lift itself to the required altitude, with no extra energy for horizontal propulsion. As smaller vehicles are analyzed, the mass of the body and components of the flying object becomes negligible in comparison to that of the battery. Therefore, the key to identifying this transitionpoint lies in the answer to the question of how much energy is needed for a battery to lift itself to the required altitude; in other words:

$$E = MgH \quad (1)$$

$$\frac{E}{Mg} = H \quad (2)$$

Where E is the energy stored in the battery, M is the mass of the battery, and H is the height lifted. Therefore, whether or not an aerial vehicle must be tethered to the ground is dependent primarily on the energy density of the battery used. So the minimum size of an untethered aerial vehicle will continue to decrease as increasingly efficient batteries are developed.

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A Constructal Perspective on Time-Evolution of Online Social Network Structures

Raymond Lennon[1]

Abstract

Social network theory is the study of structured connection between individuals and how information is disseminated across groups. To predict the complex growth and evolution of highly-connected social networks, modelling assumptions are required including the definition of each individual's motivations and behavioral trends. In the following paper, the constructal theory of evolutionary design is applied to studying the natural propagation of social network structures – particularly as they present in online social media platforms. Via application of the constructal theory of logistic spreading and maximization of access, predictions are drawn about how a user's network – and the engagement with within that network - evolves over time. A Monte-Carlo-style simulation is proposed to gain insights in the time-evolving behavior of these systems, including thegrowth and stagnation of individual user profiles. Theories are compared and validated against real- world social media metrics to illustrate the efficacy of constructal theory in this domain

Keywords: Social network, evolution, connectedness, digital access, interaction modelling

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1. Theoretical Background & Modelling Assumptions

Two individuals, either on a digital forum or the 'real world', can be considered either familiar or unfamiliar. The degree to which the two individuals associate may be scored either by their frequency of real-world interaction or by the degree of mutual engagement in each other's online presence. This framework is well-represented by a sparse weighted undirected graph where each node (N_{ii}) is a user, and the degree of familiarity between users is the edge weight (F_{iiii}). Users withoutany familiarity can either be considered to be disconnected or have a familiarity of zero – a useful alternative for the construction of adjacency matrix representations as seen later.

Individuals do not evenly divide their attention online between their connections; literature studies report that users – regardless of their network size - primarily engage with only a small subset of their friends (the size of which scales logarithmically with network size) – and that even within this subset, a small number of cross connections dominate the interactions (following an inverse exponential distribution).

Additionally, it is supposed that no users exit the social network, although this is not entirely reflective of actual social media platforms that enable account deletion.

2. Network Evolution

Within a social media site, a user can gain connections a number of ways:

1. Algorithmic: The social media server suggests user accounts to reach out to (based on similar interests, geographic proximity, demographics, etc.)

2. Directly: Either the user extends a personal invitation to another user or vice-versa. This isrepresentative of, for example, searching for an acquaintance's username.

3. Via Mutuals: Two users are connected – or recommended to connect – based on the number of mutual connections that they share. This is a dominant form of connection- forming, and distinguishable from the second case because it is 'undirected' (is not initiatedby either user).

Of principal concern is the third form of growth/ spreading. It is further assumed that the likelihood of choosing to accept a mutual connection is a function of the number and familiarity of shared connections. With this framework, analysis of the network time-evolution can begin. Moving forward, the "user" referenced is assumed to be an individual new to a particular social media platform (e.g. online connections), but with a preexisting network of real-world connections. The time evolution begins when a user creates their account on a social network platform. The entry of this user into the platform is defined by the initial time t_0.

For convenience, a sorted adjacency matrix T ("true") is presented. Every entry in the matrix t_{iiii} represents the degree of familiarity between members i and j of the network, meaning that the matrix is symmetrical about its diagonal. Because only a single friend group is considered, it is assumed that two individuals with low familiarity to the user will have a similarly low familiarity with each other. Such an adjacency matrix is presented in Figure 1. An extension of this model mayuse a more holistically accurate social network approximation, such as a gaussian random partitiongraph[1]. In Figure 2, a simulated adjacency matrix for an online environment, note that familiarity correlates with network density; two users that are highly familiar are more likely to connect with each other online. The user of interest's connections can be considered to lie in the topmost row of the matrix.

The user of interest, considered to occupy the upper-leftmost element of the matrix, initially has a challenge increasing the size of their network. This can be spurred by reaching out to their close friends, but the initial growth phase is slow regardless.

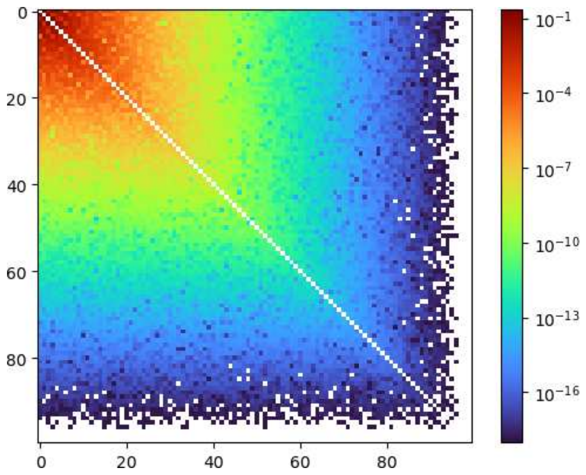

Figure 1: Possible real-world adjacency matrixfor population subset. Note logarithmic color scale, diagonal symmetry.

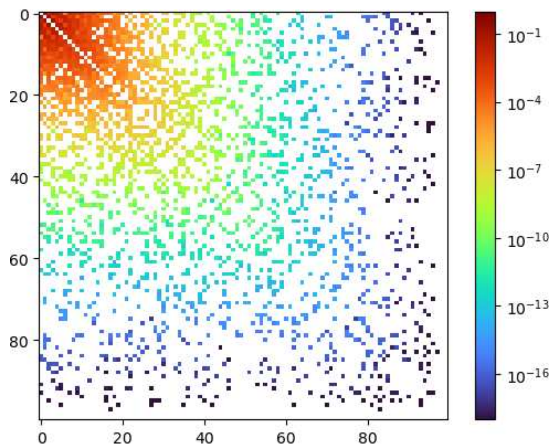

Figure 2: Corresponding fully developed online adjacency matrix. Observe higher density in topmost left corner corresponding to high-familiarity.

Once a critical number of connections is achieved, the growth rate of the network becomes self- sustaining, as incoming high-familiarity connections continue to introduce their own highly connected networks. Here, the 'spreading' of connection across the network is at its fastest (intermediate growth).

Eventually, enough of the user's real-world network has been represented digitally that growth begins to slow down. Although connections certainly still exist with many shared friends, they lack sufficient familiarity to want to connect. At this point, mutual connection growth stagnatesand the number of connections in the user's network achieves a quasi-static equilibrium.

3. Agreement with Experimental Literature & Final Remarks

More work remains to mathematically and computationally demonstrate the three-phase spreading phenomenon that constructal theory predicts.[2] The described theoretical framework, however, which is backed up by literature data and sociological trends, is indicative that such an S-curve spreading evolution is plausible. Network evolution data is not easily found for this type ofevolution – the best readily available data charts the network scale of online dating sites, which areanalogous but not exactly the same as regular social networks – still, the trend of an individual network's size demonstrates diminishing returns, as shown in Figure 3. [3] Other constructal trends emerge when looking at broad social trends – for instance, the proportion of connections that a user engages with actively within their network decreases with network size, which indicates a 'diminishing returns' aspect of online engagement (Figure 4).[4][5] All of these trends support the hypothesis that evolution within a time-evolving social network is consistent with the constructal theory of simultaneously increasing access (an expression of familiarity) while also experiencing diminishing returns for high numbers of connections.

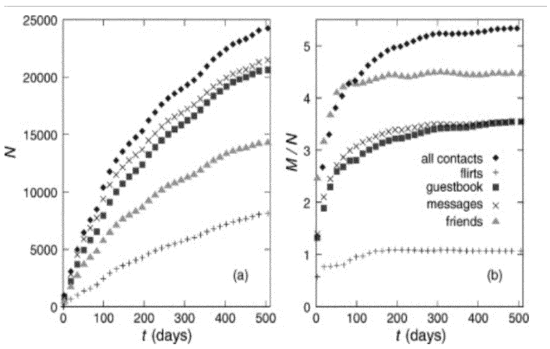

Figure 4: Collective & individual network size as a function of time, from Holme et. al

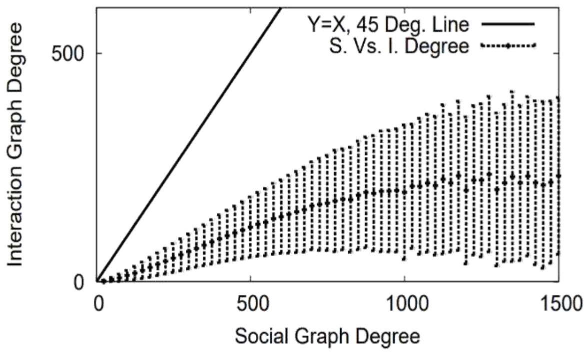

Figure 5: Logarithmic profile of engagen as a function of network size (45° represents engagement with entire netw (Wilson et. al)

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Morphing capillary networks for passive water pumping

Xuewei Zhang, Sylvie Lorente[1]

Keywords: capillary flow, network growth

Extended Abstract

Capillary flows characterize the movements of liquid under a driving force generated at the interfacebetween liquid and gas in confined space. Such flows find applications in civil engineering [1], microfluidics [2], or aeronautics [3]. But examples can also be found in nature where plants root branchto maximize their water uptake, as in hydrotropism [4,5]. In this work, we propose to predict how capillary networks grow by connecting more and more branches to water sources in order to increasethe water uptake, in a deterministic fashion. We show that morphing happens by generating tree- shaped structures whose geometrical features evolve as the number of connected sources increases. By allowing the network to choose its branching among randomly distributed sources, each step of growth corresponds to a maximum flow rate. Our theoretical approach allows the evolutionary network to morph entirely its structure and to extract the highest amount of fluid possible for constant volume. The structure of the network always maintains enough capillary strength to overcome global friction losses. We develop an in-house numerical tool inspired by works describing blood flow circulation in the human body. Keeping the initial features of the latter approach, we write a completely different algorithm dedicated to capillary flows in which the network grows by letting new channels spring out to connect to new water sources for higher flow rates, while morphing its configuration for minimum global flow resistances.
The constructal development of the capillary network is based on the following assumptions: 1). The network consists of cylindrical tubes with radius r, and length l. 2)

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gravity is neglected since the Bond number, Bo, is always below 1. 3) The flow inside the network is in steady state and laminar flow. 4)

There is no intersection between channels and the length of one channel has to be greater than its diameter, $l > 2r$. 5) The radius relation between the mother channel with its two daughter channels follows the Hess-Murray's law [6–9] as

$$r_m^{\gamma} = r_{d1}^{\gamma} + r_{d2}^{\gamma} \tag{1}$$

where m stands for the mother channel, $d1$, $d2$ corresponds to the two daughter channels, and theexponent γ equals 3 for laminar flow.
For the dendritic capillary network, from any inlet to the network outlet, the balance betweenpressure and friction losses can be expressed as

$$\frac{2\sigma cos\theta}{r_{outlet}} = \frac{8\mu}{\pi} \sum_{i} Q_i \frac{l_i}{r_i^4} \tag{2}$$

where σ is the surface tension, θ is the contact angle (θ = 0° in accord with [10]), Q is the volumetric flow rate, and μ is the dynamic viscosity.The driving force in every channel has to be strong enough to overcome the friction losses due to the flow rate in the channel that leads to the maximum flow rate at the outlet, which requires the difference between the capillary pressure in a channel i and the friction losses upstream the outlet cross-section of the same duct. We call the difference Capillary Strength (CS) and express CS as where CS must not be negative throughout the network.

$$CS_i = \frac{2\sigma cos\theta}{r_i} - \frac{8\mu}{\pi} \sum_{0=1}^{i} Q_{max,0} \frac{l_0}{r_i^4} \tag{3}$$

The domain where the network resides grows as the network grows. For a 2D circular configuration,the radius of the domain, R_i, increase as more inlets are connected to the network

$$\pi R_i^2 = \left(\frac{i}{N}\right) \pi R_N^2 \tag{4}$$

where i is the current inlet number and N is the total inlet number. R_N is the final radius of the domain which is 5 cm here. With each inlet added to the network, the increment of the network volume is $\delta V = V/N$, where V is the final volume of the network, $1cm^3$.
The generation of the network starts with placing the outlet at the perimeter of the domain (Figure 1). The first inlet is randomly placed within the domain with a radius, $R_\$$, and connect to the outlet while the total volume of the network (contains one channel for now) is δV, as in Figure 1(a). Thensecond inlet is randomly place in the domain with a radius, R_2. Inlet 2 is temporally connected to the midpoint of the first channel and split the first channel into two channels (green dotted lines in Figure 1b). The connection providing the highest flow rate forms the final configuration (black linesin Figure 1b). As more inlets are connected to the network, the newly placed inlet will temporally connect to the 20 channels that are closest to it. The generation continues until there are N inlets in the network.

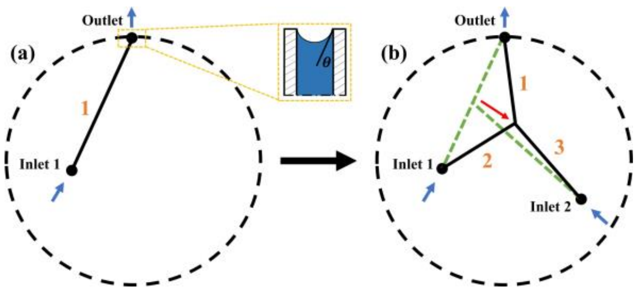

Figure 1 Illustration of the network generation.

The capillary networks with 500 inlets generated in 2D plane and 3D sphere are presented in Figure2 as an example. The channels in the networks are color-coded based on the corresponding capillarypressure and flow rate.

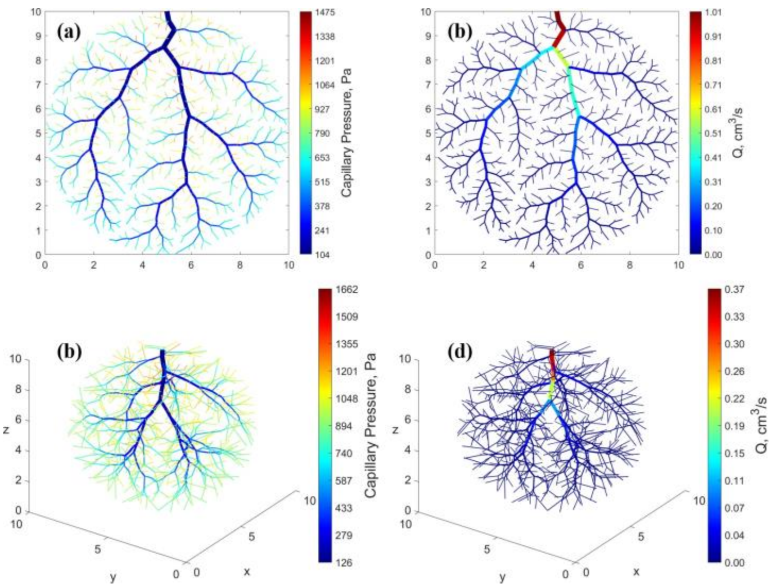

Figure 2 Examples of capillary network with N = 500 inlets. The capillary pressure ((a) and (c))and flow rate ((b) and (d)) distribution are shown at the end of the generation.

The capillary networks are generated with 10, 50, 100, and 500 inlets. Each network is generated more than 15 times since the inlets are randomly placed. The average maximum flow rate and bifurcation angle (β) of the capillary networks are present in Table 1. Capillary networks generated within a plane allow higher flow rates than networks generated within a three-dimensional domain,for the same network volume whilst the average bifurcation angle remains around 71°, which is in agreement with the documented angle of constructal design of T- and Y-shaped constructions [11].
In addition, the results suggest that capillary networks generated within a plane allow higher flowrates than networks generated within a three-dimensional domain, for the same network volume.

Table 1 Average flow rate and bifurcation angle of the capillary network

	2D				3D			
N	10	50	100	500	10	50	100	500
Q, cm^3/s	1.7150	1.3208	1.2088	1.0366	1.3342	0.6733	0.5476	0.3639
β, °	72	72	71	71	71	71	71	72

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What Hath Bejan Wrought?

Terry Bristol[1]

Abstract

My aim here is to understand the basis of Bejan's powerful Constructal insight. To begin I briefly review several of his most impressive accomplishments, two in particular, (1) his account of the Arrow of Time in terms of the evolution of the organizational design of reality, and (2) his recasting of the Euler-Lagrange Principle of Least Action in terms of a Principle of Design Optimization. Based on a clue from Bejan, I explore his fundamental 'embrace of the finite', rejecting infinitesimals as 'unreal'. There are two historical traditions that reason oppositely about the finite and infinitesimals. The Analytic tradition reasons in terms of completed infinitesimals and infinities. The Synthetic tradition reasons in terms of incomplete infinitesimals and infinities, everything is finite, 'as small or large as you like' but always finite. Contrasting their two approaches to the quadrature of the circle, the Analytic tradition imagines it can finally reduce the circle to linear constructions, at the limit, accepting the completion of an infinity of steps. The Synthetic tradition, exemplified by Archimedes, approaches the question differently, both inscribing and circumscribing, and finding the proper Proposition at the intersection. The Ancient Greeks had a 'horror of infinitesimals' because such reasoning lead to erasing the essential difference between lines and curves. The embrace of the finite, somewhat unexpectedly, entails these conceptual opposites. The broad reality of conceptual opposites are the components for Bejan's optimization. Tracing the Synthetic tradition, I suggest that Bejan sounds like Pythagoras, who inspired Plato and laid the foundations of the Golden Age of Greek philosophy and geometry with his theory of proportions, harmonic ratios, the representation of reality in terms of the One and the Many. More recently, the Synthetic tradition arose again in Europe, 1650-1850. I point out connections between Bejan, Leibniz and Lazare Carnot on the early articulation of engineering thermodynamics. Finally, I argue that the "bigger tent" needed to house the Constructal Principle is engineering, not 'Physics'. I connect Bejan to the modern philosophy of engineering. Bejan's Constructal insight both illuminates and is further illuminated by the work of Petroski, Vincenti and others.

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In the mid-1990s Adrian Bejan had an insight, and an intellectual dam broke. Bejan continues to reflect upon just what was so special, and so powerful, about what he brought to the surface. How is his insight to be understood and properly represented in the milieu of 20^{th} and 21^{st} century thought?

Bejan's honest exploration, with serial reports of his advancing understanding, is particularly attractive. He openly struggles with key issues. He reflects, that in hindsight he really didn't know, didn't fully understand, what he had found.

The aim of this essay is to join with Bejan [1] to try to understand the core, the fundamental nature of his powerful insight.

In Part One, I briefly celebrate a few of, what are to me, his most important accomplishments. In Part Two, based on Bejan's own suggestions, I undertake a broader philosophical and historical search for clues as to the nature of his Constructal Principle[2]. In Part Three, I offer some revisionist thoughts. In Part Four, I suggest an action agenda to place Bejan at the head of the emerging philosophy of engineering and engineering worldview, making him a prime candidate for a Nobel Prize; perhaps several.

PART ONE: What happened when the dam broke?

I want to acknowledge and celebrate Bejan's discoveries, however, to comply with the publisher's space restrictions I will focus explicitly on only four.

First, Bejan [1] explains the Arrow of Time in terms of the evolutionary design process, and the recursively developing Organization of reality. I must emphasize the magnitude of this achievement. The question of the Arrow of Time has been central to all philosophical and scientific inquiry from the beginning of recorded history. While explaining the basis of the Arrow of Time, he brilliantly critiques the still dominant, so-called Entropic Arrow of Time along with its mechanistic formulation of thermodynamics.

Second, he explains that all change is an evolving design action that, by its very nature, continually morphs toward a better design [1]; more on this later. Change, newly understood as a natural, spontaneous evolving, irreversible design process, doesn't need any external mechanical 'causes'. These insights come along with a brilliant critique of the Darwinian 'mechanism' of evolution, which, notably, doesn't have any inherent net direction.

[2] Bejan and I both agree that what has called the 'Constructal Law' is a First Principle. I prefer to refer to his insight as the 'Constructal Principle'. My full reasons will become clear by the end of this essay.

Third, Bejan newly understands [1] that the spontaneous design process incorporates, or embodies, an inherent freedom. Yet, this freedom also has a direction, evolving toward greater freedom. Pythagoras, 2500 years ago, may be the last person to have properly understood this. Bejan tells us that it was only after twenty years of reflection that he fully recognized and understood that freedom was an essential characteristic of evolving design action.

Fourth, Bejan [1] critiques the original Euler-Lagrange Principle of Least Action properly reinterpreting the issues in terms of a more general Design Optimization Principle. Thousands have struggled over two centuries of confused disputes over this deep issue. Once again, I emphasize, what Bejan has done here is huge, and seriously underappreciated.

PART TWO: What was the basis of Bejan's insight?

Despite the enormous literature developing Bejan's accomplishments, there is one question, at least for me, that remains open. What was the basis of Bejan's insight? I want to praise Bejan for sharing his struggles to understand and to properly represent his core insight. Bejan fully appreciates that he has an intellectual 'tiger by the tail'.
Without reviewing his attempts to identify just what it was that he saw that set him off, I will focus on one characteristic that he mentions early on, repeats several times over the years and lately points us to. That is, the importance of his embrace of the finite. He reflects: "Object and finite size are old concepts in human thought, much older than the mirage of the infinitesimal size. I stressed this observation in the very last paragraph of my 2000 book."[3] "Most of this work (i.e. constructal law) could have been done two centuries ago, before thermodynamics. It is a mystery that this was not done then."[4]

Investigating Bejan's insight, I argue that, actually, much of it was developed two centuries ago. Indeed, important aspects were recognized more than two millennia ago.[5] These historical and philosophical connections are my own guesses, certainly incorporating my own biases. So, before I proceed, it may be of value to briefly review my own intellectual trajectory leading to thermodynamics and to this conference.

I started my undergraduate degree at University of California at Berkeley intending to major in Astronomy. That morphed into mathematics and astrophysics, plus interest in chemistry and biology. Each of these options seemed to be too narrowing. Then I discovered and graduated in philosophy of science, embracing the study of all the sciences. In graduate school at the University of London, I recognized that the dominant philosophy of science was unable to make sense of science, both what it is and how it works. Furthermore, I didn't see myself in scientific reality with its deterministic laws. Inside the scientific description of reality there were no people, and, in particular, no

[3] Freedom and Evolution, page 190.
[4] Shape and Structure, page 313
[5] None of these historical connections should, in any way, be taken to detract from Bejan's brilliance, hard work and accomplishments. On the contrary, these connections place Adrian Bejan in the company of the rare great contributors to humanity's understanding of the nature of reality and our meaningful role in it.

inquirers Scientific knowledge would be pointless. I realized that the scientific worldview is not 'self-referentially coherent', meaning that it can't account for itself, can't account for itself as part of reality. In the supposed scientific reality, scientific theory can't make sense of how it was discovered. My early mentors and colleagues were all prominent rebels in the philosophy of science, and had similar concerns: Karl Popper [2], Thomas Kuhn [3], Paul Feyerabend [4] and Imre Lakatos [5].

My PhD research [6] focused on determining the limits of science, guessing that it might be possible to understand science as a special case within some more general theory.[6] One obvious limitation of the scientific worldview was its inability to account for, or make sense of, irreversibility. It was this that led me to make a closer examination of thermodynamics.

One of my recent mentors is Peter Atkins, at Oxford University, who has written a dozen books on thermodynamics, including one of the most popular textbooks in *Physical Chemistry*. In an early book, *The Second Law* [7], Atkins noted: "Carnot and Boltzmann epitomize thermodynamics. Carnot traveled toward thermodynamics from the engine, then the symbol of industrial society. Boltzmann traveled to thermodynamics from the atom, the symbol of emerging scientific fundamentalism." Then Atkins surprised me by claiming: "Thermodynamics still has both aspects." I had been taught that Carnot and caloric were mere historical footnotes, that the Clausius-Boltzmann-Gibbs version offered the correct history and modern formulation. It took me literally three years to convince myself that Atkins was correct, that there are two histories and two current versions of thermodynamics.[7]

Donald Cardwell (Manchester) [8] had a further realization:
"Almost traditionally, it seems, accounts of the development of the concepts of work and energy have tended to describe them within the classical framework of Newtonian mechanics. … I would like to suggest that this may be to take too narrow a view of the case. It is to project backwards our present specialist arrangement of scientific knowledge, our present divisions between the sciences, and to assume that past development was strictly guided by these divisions. And this is to make questionable historical and sociological assumptions."

Emphasizing that the two versions were not compatible, Atkins speculated that they might be complementary. I explored whether one might be a special case of the other. My working hypothesis for the last few decades has been that Carnot's engineering thermodynamics is conceptually more comprehensive, subsuming and superseding all possible classically scientific formulations of thermodynamics. That's enough of my background and my perspective bias.

[6] I published the essence of my PhD research is a semi-popular book: *Give Space My Love – An Intellectual Odyssey with Dr. Stephen Hawking*

[7] In discussing Atkins's contention with my colleague, Robert Ulanowicz, he concurred, recollecting that when getting his PhD in Chemical Engineering at Johns Hopkins, at his PhD orals he, of course, received the obligatory thermodynamics question. He said that if he had answered with anything having to do with particles bouncing around, he would have been out on the street the next day looking for a job selling real estate. The Johns Hopkins program clearly favored engineering thermodynamics.

Two Historical Traditions – the Analytic and the Synthetic

To probe Bejan's clue that 'embrace of the finite' was a fundamental aspect of his Constructal insight, we need to understand his notion of the finite. He tells us that it is to be contrasted with infinitesimals.[8]

The best way I know of to distinguish these is by reference to two historic traditions that reason oppositely about the finite, infinitesimals, and infinities. The Analytic tradition reasons in terms of completed infinitesimals and infinities. The Synthetic tradition reasons about infinitesimals and infinities as incomplete, allowing whatever you are talking about to be 'as small, or large, as you like', but always finite.

To illustrate, there was an ancient problem of determining the area of a circle, referred to as quadrature. A standard approach was to place a polygon, say a square, inside a circle, touching the inner edges of the circle. The area of the square is a very rough first estimate of the area of the circle. Next one increases the number of sides of the polygon, to a pentagon, hexagon, and so forth. As you increase the number of sides, the area of the polygon more closely approaches the shape and area of the circle. Now, if you imagine that you can complete this process, allowing the polygon to have an infinite number of sides then you succeed in expressing the area of a circle in terms of a linear construction. At the limit you imagine that you have reduced the circle, and in more general applications the area under any continuous curve, to reasonings in terms of linear constructions. The Analytic tradition reasoned that the sum or integral of the inscribed polygon with a completed infinity of number of sides, where the length of the outer sides of the final polygon are infinitesimals, allowed one to express the area of the circle in terms of lines. This sort of limit argument is central to Analytic Calculus.

The Synthetic tradition insists that infinitesimals and infinities are to be thought of as incomplete, so you can't have a polygon with an infinite number of infinitesimal sides. A common expression is that an infinite series has no final step, is never complete. The series of inscribed polygons can 'get as close as you like' but never reaches equivalence with the circle.

For the Analytic tradition the area of the circle, or the area under any continuous curve, can be expressed in terms of the language of lines. In effect, the reasoning adopted by the Analytic tradition <u>erases the conceptual difference</u> between lines and curves. As an undergrad I characterized the analytic limit argument as 'jumping over the asymptote'. For the Synthetic tradition lines and curves are essentially different, by their very nature. Indeed, the mathematics of lines and the mathematics of curves are conceptually

[8] Bejan, from *Freedom and Evolution*, page 223: "The "fundamental" is the truth that lies as "foundation" (means bottom). The secret–the brick–is of finite size not infinitesimal. The difference between finite size and infinitesimal is like the difference between black and white, night and day, dead and alive, and pregnant and not pregnant. The infinitesimal does not have freedom, flow, organization, and evolution. The finite size does." "The fundamental is the building block. The brick is macroscopic, not infinitesimal."

different, and you can't legitimately express, or reduce, one to the other.

Bejan emphasizes that infinitesimals are not real, implicitly criticizing the Analytic tradition. What is perhaps most important to recognize is that when you embrace the finiteness of realities, you get an unexpected bonus: the reality of opposites. Finite realities, forms and all motions/changes are composed of opposites. Leibniz [9] introduced the concept of an 'action' to express this new dualistic concept of change. There was an explosion of articles around Leibniz's time concerned with understanding the 'composition of motion'. My research suggests that it was Christiaan Huygens [10] and Jean le Rond d'Alembert [11] who first began to appreciate the duality in forms and motion. Johann Bernoulli provoked the dialogue with his question about the 'path of swiftest descent', which, it turns out has two irreducible opposite components. The curve cannot be expressed as an analytic (Eulerian condition) function. Huygens first emphasized the cycloidal character of this and various other 'optimizing' curves. Notably even Galileo had two component forces in his treatment of the bending beam. Looking back further in history, seeing the world in terms of pairs of opposites was foundational to Greeks physics.

Opposites are co-defined, like local and non-local, so that, by their very nature, one cannot be reduced to the other. For me at least, this wide-spread definitional duality is still not well-understood.[9]

What I want to suggest here is that the embrace of the incompleteness of reasoning about infinitesimals and infinities leads to the finiteness of realities with the somewhat unexpected entailment of an essential duality in the composition of all forms and motions/changes. In the Synthetic tradition, as Bejan realizes, in his 'science of forms'[10] there is a sort of dynamic cooperative tension between two opposite types of components in all real forms and motions/changes.

Awareness of the difference between the Analytic and Synthetic approaches reaches far back in history. That lines and curves are incommensurable opposites is often traced back to Archimedes. In his A *History of Greek Mathematics*, Sir Thomas Heath remarks that Ancient Greek geometers had a "horror of infinitesimals".

Archimedes was the genius of Greek Geometry but both historians and his contemporaries were unclear how he worked, how he reasoned, until recently. In 1905, a now famous manuscript of Archimedes was discovered. In a letter to a friend, now entitled *The Method*, he explains. He refers to the analytic and the synthetic, heuristic themes that go back to Pappus. He 'confesses' that he uses analytic methods and constructions to make an initial guess at a geometric proposition. But he makes clear that he would never trust the analytic formulation until he had translated it into

[9] That 'opposites are co-defined' is a rather bold, unsupported assertion on my part. A proper account involves an appreciation of the history and Synthetic nature of Projective (Perspective) Geometry. Duality is a fundamental feature of Projective Geometry, where, for instance, points and lines are co-defined. Per hypothesis, all dynamic conjugate variables, all complementary dynamic variables, are co-defined. See Lazare Carnot's 1803 essay "Geometry of Position" [12], or more recently the work of Felix Klein [13] and Hermann Grassmann [14].

[10] Worth noting is that the mature Leibniz tells us his whole philosophy can be understood as a 'science of form.'

Synthetic terms and produced a Geometric Proof.

What's happening here? Geometric proofs are about optimal forms. To help see this, Archimedes always approached a question in two opposite ways, such as inscribing and circumscribing a circle with polygons. At the intersection of these opposite asymptotic approaches, he finds the optimal Synthetic Geometric expression of the Proposition.[11] It strikes me that Archimedes's synthetic geometry of optimal forms is what his close follower Galileo was referring to when he suggested that 'the language of universe is written in triangles, circles and other geometric figures'; optimal geometric forms.[12]

After learning all the Euclidean-like proofs in middle school, I expect that we were all rather surprised, as was I, when we were made aware that there aren't any such perfect Euclidean lines or perfect Euclidean circles in nature. These are Analytic idealizations. But what then is the more general geometry in terms of which these are idealizations?

One of Bejan's most interesting observations is that many people have <u>empirically discovered and described</u> properties like scaling, hierarchies, power laws, complexity and so forth in nature. But Bejan sees that in some crucial sense they don't <u>understand</u> these properties. He distinguishes their simple empirical 'descriptions' from his 'theory' perspective way of understanding these properties. I imagine we are seeing here Archimedes's distinction between analytic descriptions and synthetic geometric understandings. The descriptions that people arrive at empirically are Analytic, tacitly incorporating infinitesimal analysis. Using his Constructal insight, what Bejan gives us are synthetic geometric expressions, properly understanding these realities as dynamic finite optimals. This guess offers an interesting way to think about the fundamental issue of the relation between science (analytics) and engineering (synthetics).[13]

One other illustration shows how the embrace of the finite leads to the time-dependent aspect of motion/change. The foundational straight-line motion in Newton's First Law is a series of infinitesimal linear steps. Each infinitesimal step is instantaneous, static it itself, does not involve any finite duration or finite length. Each infinitesimal is a sort of spatial and temporal 'nothing'. In Zeno's Arrow Paradox [18], the sum, or analytic integral, of these infinitesimals instants is still timeless and point-like, again a sort of spatial-temporal nothing. What I want to emphasize here is that each infinitesimal lacks Bejan's finite duration and finite length. In his contrasting of the finite and the infinitesimal Bejan emphasizes that infinitesimals are not 'real', not what we observe in nature.

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[11] Heath [15,16] notes that the Analytic tradition is concerned with deductive proofs of Theorems, where the Synthetic tradition is concerned with constructive geometric proofs of Propositions.

[12] Pushing my luck in offering unsubstantiated guesses, what I describe as Archimedes' Geometric proofs, looks rather like Isaac Newton's method of fluxions [17]. Newton's modern analytic commentators miss that the whole of the *Principia* is written in terms of Synthetic geometric arguments and proofs.

[13] There was a question and a suggestion, after my talk in Turin. The thought was that I needed to allow for a more 'reasonable', 'practical' place for 'analytic science', that I had relegated to be subsumed and superseded by engineering inquiry and knowledge. I agree and accept the point. 'Science', understood as analytic descriptions (Theorems), either tacitly or explicitly based on infinitesimals, has a role in helping us, as with Archimedes, to make initial guesses at synthetic geometric Propositions. I am now inclined to suggest that these first analytic steps are <u>perhaps essential</u>. Yet we lack any understanding of why.

I have been struggling with how to express what is missing in Newton's straight-line idealization. It seemed to me that there are at least two ways. Recalling the theme that real finite change involves the duality of lines and curves Newton's straight-line idealization lacks the irreducible curvilinear component. Newton comes up with an entirely separate theory of gravity to handle curvature. The other way to express what is missing considers that the finite step, no longer an infinitesimal instant, involves a finite duration. Real finite change/motion is <u>composed</u> of two opposite components and is time-dependent.

Bejan realizes that design action is a composition of continuously balancing, optimizing opposites. Without opposites as foundational components of reality, Bejan's optimization would not make sense. All design action is finite, in both spatial and temporal terms, having two optimizing components.[14]

Bejan emphasizes that the optimals are not static over time, not 'patterns'. They are dynamic designs evolving toward better designs, by their very nature. Please notice that 'optimality' is an engineering design concept, not science. All forms and all motion/changes now appear to have an inherent design aspect that naturally, by the very nature of design itself, develops the design.

Then Bejan just blew me away. Bejan: "All locomotion is a rhythm, because all creatures on Earth locomote in the presence of gravity. … The rhythm is the one-two that comes from balancing better and better the time spent on the vertical (to lift the body) and the time spent on the horizontal (to push the body forward)."[15] Perhaps because I am a bit slow, it took me a few days after reading this and his brilliant application to understanding all sorts of animal locomotion, on the ground, in the air, in water, to recognize that the path of locomotion could be represented as a cyclic, up-and-down, sinusoidal wave. Compare this wave-propagation with Newton's differential, infinitesimal straight-line representation of mechanical motion.[16]

As an aside, Bejan's treatment of optimization suggests another alternative line of inquiry toward understanding his core Constructal insight. It has to do with 'couples' and 'coupling'. Coincidentally, I have only recently been introduced to couples (see Petroski's recent book, *Force*). Curiously, I also recently read Capecchi's *History of Virtual Work Laws* where he passingly points out that you will find a treatment of couples in every engineering textbook, and yet never in any physics textbook. If true, why might this be? Couples involve 'opposite' forces. For Bejan couples and coupling were essential from the beginning: "I quoted Rudolf Clausius because … to account for coupled thermomechanical behavior he had to formulate a second principle, the second law, in addition to the conservation of energy. With his new principle came the concept of entropy, which was completely foreign to science."[17] Then Bejan casually points to the alternative Constructal, engineering thermodynamics treatment: "Today the new

[14] Bejan, in Shape and Structure, page 3, "Natural macroscopic structure is not only spatial but also temporal."
[15] Freedom and Evolution, page 180
[16] To fully appreciate this requires that one grasps the meta-paradigm shift from a reductionist ontology of infinitesimals to the ontology of finite entities with internal energy; see below.
[17] The Physics of Life, page 240.

principle [to account for coupled thermomechanical behavior] is the construction of geometric form, and the new concept is objective, or purpose." Right here we see that 'entropy' is not to be a fundamental concept in engineering thermodynamics. Per hypothesis, couples are about engines, and finite engines are incomprehensible to non-dualistic analytic physics.

The notion of the composition of essential opposites (viz. couples) went underground due to the dominance of Analytic Calculus. Bejan sees what happened: "Instead, modern physics embarked on a course tailored to the principle of infinitesimal local effects. Constructal theory is a jolt the other way, a means to rationalize macroscopic features, objective, and behavior (i.e. evolutionary design)."[18]

On an appreciative note, essential opposites re-emerged, re-surfaced, albeit enigmatically for analytic science, in the foundations of quantum theory. In a recent article, "Quantum Theory only makes sense in Lazare Carnot's participatory engineering thermodynamics, a development of Leibniz's dynamics",[21] I develop the connection.

Before leaving this theme, I offer, that in my opinion, the best treatment of the finite and infinitesimals relation is found in Lazare Carnot's *Treatise on Metaphysical Principles of the Infinitesimal Analysis* [22]. He speaks of 'as small as you like … but always finite'. In the essay, Carnot presents a supportive but critical understanding of Lagrange's Analytic version of the Principle of Least Action and the Calculus of Variations: both are 'useful' in a limited sense, but infinitesimals are not representative of what we observe in reality. Lazare Carnot is, of course, the father of Sadi Carnot [23] the latter known as author of the first essay in what came to be called thermodynamics.

To summarize so far, in attempting to discern the core of Bejan's Constructal insight, I pursued his finiteness clue from finite realities to duality, and to an understanding of optimality as a coupled, continually balancing time-dependent trade-off between the opposites. Constructal 'flow', as 'motion/change', is time-dependent, distinguishing it from the differential infinitesimal motion of classical Newtonian mechanics. Natural, spontaneous finite evolving design action is conceptually more comprehensive, subsuming and superseding the concept of mechanical motion by infinitesimal steps.

There is an analogy here, and perhaps more than that, with what de Broglie pointed out in quantum theory, that all phenomena have both an irreducible particle component and a complementary irreducible wave component.[19]

Economist Kenneth Arrow speaks of the periodic surfacing, 'like an underground river' in history, of ideas associated with the Synthetic tradition (cited in Warsh [24] *Knowledge and the Wealth of Nations*).[20]

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[18] Freedom and Evolution, page 190.

[19] Besides the complementarity in quantum theory of position and momentum, each concept to be understood in a new post-mechanical way, there is the complementarity of energy and time. This latter awaits a new Constructal understanding. See Lazare Carnot's [29] well-known 'principle of engineering practice'.

[20] Arrow's 'underground river bursting to the surface, attracting startled attention, then disappearing again' was about a presentation in 1929 by Allyn Young: "Increasing Returns and Economic Progress." "It was a vigorous dissent from the

The most powerful and well-developed surfacing since ancient times was in the period 1675-1850 in Europe. The prominent initial contributors included Galileo, Huygens, Newton, Leibniz, the Bernoullis, d'Alembert, then later Maupertuis, Lazare Carnot, Gaspard Monge, Navier, Coriolis, Poncelet and eventually Poincare and Duhem. All these contributors explicitly claimed intellectual ancestry from Archimedes. I see them all as working in the Synthetic tradition, leading to engineering thermodynamics.

Princeton historian Charles Gillispie, who rediscovered Lazare Carnot for the English-speaking community, characterizes the 1675-1850 period as an intellectual transition from "the Science of Mechanics to the Science of Machines (Engines)." This transition corresponds to a shift from Analytic to Synthetic. Kuhnian paradigm shifts were imagined to be *within* science, from current science to more advanced science, from one analytic description to a more advanced analytic description. Per hypothesis, Gillispie's transition is from Analytic to Synthetic and is from analytic mechanics to 'engineering mechanics' (viz. engineering thermodynamics). As such the transition is better represented as a 'meta-paradigm shift', not *within* the framework defined by the presupposition of classical mechanics, but *from* classical mechanics to a conceptually more comprehensive engineering framework.

Despite the meta-shift, the advocates of the Analytic, the science of mechanics, didn't just go away. Indeed, the Analytic tradition associated with Euler, Lagrange and Hamilton was foundational for the subsequent advances of classical science, modern mathematical physics (viz. prior to quantum theory).

The best representation of the meta-shift was put forth by Leibniz [26] as a fundamental shift from Statics to Dynamics. Leibniz introduced the term 'Dynamics' into the study of nature. Statics was characterized in terms of infinitesimals and differential mechanical 'contact causality', A–>B. The cause of the change in motion of B comes from an 'external' cause. Dynamics on the other hand is Holistic, A<–>B, when A hits B, B hits A just as hard.[21] Bejan has recognized that the Constructal Principle leads to, or entails, a Holistic perspective, a Systemic Framework [27]. "The bigger idea is the oneness of system and environment."[22] Motion/change no longer requires an external mechanical cause (force) but is spontaneous and eternal. Energy, understood in a new dualistic sense, in terms of living force, is conserved.

There is a different ontology in the holistic framework. It is composed of finite entities with their own internal energy. Imagine a world of people walking around and doing things. Their motion is not being caused by external causal impacts. The new ontology is not the micro-billiard-ball world of the mechanistic reductionist. Leibniz's revelation was that reality was composed of spontaneously active finite entities. He came to understand them in terms of engines; for him reality is 'engines all the way down'. Justin

conventional wisdom of the day. He spoke of qualitative change, disequilibrium, increasing complexity, "cumulative causation" – all code words for processes not yet fully understood. Returning to Harvard he boarded a ship and died of influenza in the epidemic in 1929, at the age of 53."

[21] Bejan's reference to Sancho Panza captures the idea: "Sancho was right: the windmills hit his master just as hard as he hit them." *Physics of Life*, p. 233

[22] *Time and Beauty*, page 166

Smith [28] reviews Leibniz's shift in his book: *Divine Machines: Leibniz and the Sciences of Life*. Leibniz's meta-shift to Dynamics unifies traditional 'physics' and 'biology' in a new way. To appreciate Bejan's characterization of the finite motion/change as the rhythm of animal locomotion one must recognize that he has shifted to this new ontology.

Beyond Leibniz, in a next generation work, in 1803, Lazare Carnot [29] published *Fundamental Principles of Equilibrium and Motion*. Carnot who studied under d'Alembert mentions that he sees his work as completing what Leibniz 'vaguely' initiated. Carnot proposes a more general engineering worldview to supersede all possible scientific worldviews. His 'engineering mechanics' is the first formulation of engineering thermodynamics. Carnot critically emphasizes that are no engineers in 'rational mechanics' reality (scientific reality). In Carnot's engineering reality we are all participant engineers in a world of participant engineering; agents in a world of agency.[23] Carnot isn't just offering a different 'analytic description' of reality. To establish his thesis, he goes on to offer a specific challenge. He points out that there is a principle of engineering practice, that everyone knows, that, "we always lose in time or velocity what we gain in power (strength)." Carnot reports that he has carefully examined all the 'rational mechanics' and none of them are able to account for, or even make sense of, this simple well-known principle.

Drawing out the implications, based on this principle, engineers have options. They can accomplish a task, for instance, using pullies, faster or slower. Engineering actions are, consequently, time-dependent, path-dependent. Whatever action the engineer undertakes requires a choice, for a reason, for a purpose.[24] Engineers, as Carnot characterizes them, have a necessary freedom, albeit constrained (see Florman's *Existential Pleasures of Engineering* [30]).

Carnot distinguishes what I take to be the Analytic and Synthetic traditions: "There are two ways of looking at mechanics and its principles. The first is to consider it as the *theory of forces*, that is to say, of the [external] causes that impart motions. The second is to consider it [holistically] as the *theory of motions* themselves. In the first case, the reasoning is based on whatever causes, which impress or tend to impart motion to the bodies, to which they are supposed to be applied. In the second case, we look at the movement as already imprinted, acquired and residing in the bodies; and one seeks only the laws according to which these acquired motions propagate, are modified or destroyed in each circumstance. Each of these two ways of considering mechanics has its advantages and disadvantages. … The first [Analytic] method, therefore, offers much more ease; so, it is, as I have observed above, almost generally followed. Nevertheless, I have adopted the second [Synthetic] approach here, … to reduce everything to the theory of the communication of motions."

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[23] Based on the introductory section of Sadi's essay, I have referred to this in the past as Carnot's Epiphany. It captures the sense in which the engineering worldview is self-referentially coherent.

[24] Although Bejan shies away from using the word 'intelligent', it seems clear to me that making a choice for a reason, with a purpose in mind, one would naturally refer to it as an intelligent choice. See my presentation on YouTube: "The Systems Engineering Worldview, The Technological Structures and Functions of Reality' [27]

Carnot goes on to emphasize that empirically discovering analytic descriptions is always the first step. He notes that "By following this [second] approach, we soon recognize, as I said above, the necessity of recourse to experience." Most of the contributors to the Synthetic tradition are explicit about 'learning from experience' as a first step. Poincare [31]is famous for this in more recent times.

I mention and emphasize that Lazare Carnot contribution, 'two centuries earlier', illuminates certain aspects of the nature of Bejan's Constructal Principle.

I can't resist one last deep dive into history and philosophy that sheds light on the Constructal Principle. Most of Ancient, and subsequent, western philosophy and mathematics appears to have been at least stimulated by Pythagoras (570-490 BCE). Pythagoras [32,33] was Plato's primary inspiration, and consequently, at the foundation of the Golden Age of Greek philosophy and geometry. Several features of Pythagoras's philosophy seem to me to resonate with Bejan's. The idea that realities are <u>finite ratios</u> is a core commitment of Pythagoras. It is worth emphasizing that 'ratios' don't appear naturally in any of the modern Analytic scientific theories (descriptions), at least until the notion of ratios of essential opposites reappears in quantum theory. Pythagoras introduces a theory of proportions, balances and the harmonic organization of the universe. Pythagoras even suggests the universe at the most fundamental level is based on a 'binary principle'; a couple, calling to mind the Eastern yin-yang. Speculatively, Pythagorean harmonics could be optimal ratios of opposites. One of the foundation images associated with Pythagoras and Plato is 'the One and the Many'. The Principle of the One unifies the diversity of the many both spatially and temporally.[25]

In his dialogue, *Timaeus*, Plato [34] has the gathering ask Timaeus a simple question: How did the universe come to be as it is? Notice that this is a generative cosmogonic question. He is not being asked how the universe is eternally, not about the uniformity, symmetry and space-time invariant laws of the dominant modern analytic reductionist cosmologies.

Timaeus gives four general answers that remind me of Bejan's developing worldview. First, he tells the gathering that he could only give a 'likely' answer about the specifics of the path. However, second, he adds, 'one thing is certain', that the universe always moves to the good. I imagine that this is what Bejan captures in his theme that design action always morphs to a better design. In my understanding the only other person to get this deep insight was Leibniz who argued that reality is always, continually the best of all possible worlds.[26]

Timaeus then talks about the Architekton (or Demiurge), the Master Craftsman[27] of the universe. Master Craftsman is what we understand today as the creative engineer. Asked about the plan from which the Architekton works. Timaeus is careful, in his third

[25] Leibniz says 'space' is the Organization of current relations and 'time' is the Organization of succession.
[26] I asked Bejan at the conference if he thought he might be a re-incarnation of Pythagoras. Pythagoras believed that all souls are immortal and that, after death, a soul is transferred into a new body (metempsychosis). Pythagoras claimed that he was able to remember his last four lives.
[27] See the entry on the *Timaeus* in the online Stanford Encyclopedia.

answer, telling them that it is not, by its very nature, a copyable plan. In other words, it is not such that you could use the plan to make an identical universe elsewhere at another time. My way of understanding this is that it is not a 'completable' plan, not a plan that could be expressed in Analytic terms, with a definable endpoint, with a completable goal at some 'eventual' (viz. Analytic) infinite time. Bejan emphasizes the characteristic of design flows, that by their very nature, do not have a pre-defined goal, they are free, even though they always morph to a better design. In other terms, the universe could not have been generated, or derived, from an 'axiomatizable' plan, from analytic scientific laws.[28]

As another aside, who else has recently embraced the finite? Max Planck is the only other person in modern history to have introduced a new type of finiteness principle. When confronted with two opposite theories of light, each accounting for an aspect of his black body phenomena, Planck 'somehow' resolved the opposition by introducing a new dynamic, finite 'quantum of action'. Planck was reportedly obsessed with the historical link to Leibniz's concept of an action.[29]

PART THREE: Problems of Interpretation

I have a concern with Bejan's representation of his Constructal insight as a 'Law', to be understood within an expanded conception of 'science' (Physics), rather than as engineering. Bejan and I agree that his Constructal Law is definitely a First Principle, relative to the framework defined by the presuppositions of a classical analytic science, of mathematical physics (viz. again prior to quantum theory).[30] You can't derive the Constructal Law from the established reductionist physics. What Bejan calls the Constructal 'Law' is not a 'law' in any established sense. His ability to 'predict' features of the structures and functions of reality is not a 'prediction' in the classical sense of a scientific prediction. Is there a better way to represent Constructal 'predictions'?

I have shared Bejan's pain in trying to understand how to represent his Constructal Principle. It is indirectly a question I have struggled with for several decades, for me it is inseparable from the question of how to understand the relation between science and engineering.

Bejan's 'Law' representation of the Constructal insight suggests that we consider 'expanding' our understanding of what we mean by 'science' by adding the Constructal

[28] Relating this to the Synthetic tradition, the open, potentially infinite coming to be of reality can have no final step or stage. Bejan: "We do not predict an end design, because end design does not exist we predict the direction of evolutionary change over time." *Freedom and Evolution*, p. 183

[29] Yourgrau and Mandelstam [35] highlight Planck's 'obsession' with the connection to Leibniz. But they dismiss it by giving an analytic interpretation of quantum theory, as quantum mechanics. Planck suggested that to better understand quantum theory we might benefit by studying Leibniz more carefully.

[30] I always exclude quantum theory from what I mean by 'science', because quantum theory is not a classical-type of theory (viz. not an analytic type) as Bohr, Heisenberg and Pauli all emphasized. I hope that Bejan has perhaps been stimulated by my recent publication where I argue that quantum theory can only be understood in terms of engineering thermodynamics. Indeed, I anticipate that the Constructal Principle will soon be able to improve our understanding of quantum theory, and make sense of quantum reality, in a new productive way.

Law, as a new First Principle. Bejan proposes that we think of 'Physics' in this new sense, as the "bigger tent". The word 'Physics' would have a new, for me enigmatic, meaning. There is an analogy here with what the American Pragmatists suggested. Pragmatists often represented their new practical perspective as a new expanded understanding of 'science'. Personally, I consider pragmatism as an early attempt at a philosophy of engineering and engineering worldview.

What Bejan and the pragmatists propose is not wrong if you recognize the change in the meaning of their term 'science'. But I think it is seriously misleading. As a consequence, the power and scope of the Constructal Principle remains underappreciated in most disciplines and as a unifier of all disciplines. I want to suggest that the 'bigger tent' is engineering where design, optimization, and improvement[31] are recognized to be natural characteristics of engineering practice.

The question as to the relation between science-engineering is the same question as the proper understanding of the relation between the Analytic and Synthetic representations of reality and knowledge. It is also the same question as the proper understanding the relation between the Clausius-Boltzmann-Gibbs mechanical formulation of thermodynamics and the Carnots' engineering thermodynamics.

I have adopted a new mantra to characterize the meta-paradigm shift from Statics to Dynamics, from Analytic to Synthetics: "You can't get here from there". The point being that there is no way to 'reason' from within the conceptual framework of classical science to the conceptual framework of engineering, from the Analytic to the Synthetic. It is a conceptually revolutionary step, a conceptually, logico-mathematically discontinuous meta-paradigm shift. I offer these thoughts to suggest another way to understand the Constructal Law as a 'First Principle'. Historically, in the 18th century the clear demonstrations of the limits of Analytics in terms of the question of the Path of Swiftest Descent, was not enough to lead the community to the more comprehensive Synthetic framework. One cannot 'reason' to a conceptually more comprehensive, superseding understanding even from a clear demonstration of the limits of your current, conceptually less comprehensive, 'mechanical' perspective.[32]

Like Bohr, Bejan doesn't want to 'leave anything behind', anything that has been successful. Bohr's later Correspondence Principle [37] required that any more advanced theory must be able to account for the successes of the prior theories. This gets messy in the meta-shift because 'science' (Physics), both in process and result, has been misrepresented. I think that all that Bejan wants is already captured in his evolutionary design process, since it is naturally, recursively enabling.

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[31] Engineering 'problem solving' is seeking to move from a current state of affairs to a future more desirable state of affairs. As one engineering colleague told me he teaches his students that engineers as problem solvers are 'novel value creators'.

[32] With the help of Elvis, his Bejan's colleague's Welsh corgi, Bejan leads us from the Euler-Lagrange version of 'Least Action' to the engineering path of the Design Principle of Optimization. Historically these higher-order Geometric solutions were investigated by Huygens, the Bernoullis, Leibniz, Newton and d'Alembert in terms of the Path of Swiftest Descent, the Catenary and other isoperimetric paths and structures. See Design in Nature, page 179ff.

Henry Petroski [38], Bejan's colleague at Duke, is the author of twenty-plus books in philosophy of engineering. On understanding the relation between science and engineering, Petroski argues that 'everything you thought of as 'science' is actually engineering' (see his *The Essential Engineer*).[33] Petroski's point is reinforced by noting that since there are no inquirers in the supposed scientific world, it is not self-referentially coherent. The supposed scientific knowledge and worldview can't account for itself, or even make sense of itself, as a component of scientific reality. As pragmatist John Dewey [39] argued, we need to move from 'the spectator representation of inquiry' to 'the participant engineering representation of inquiry'. All meaningful knowledge of the 'real' world can only be made sense of coherently, self-referentially, as engineering knowledge through the practices of exploratory engineering.

Stanford aeronautical engineer Walter Vincenti [40] laid down an epistemological challenge to the scientific account of knowledge. In his seminal book, *What Engineers Know and How They Know It*, he argues, "Modern engineers are seen as taking over their knowledge from scientists and, by some occasionally dramatic but probably intellectually uninteresting process, using this knowledge to fashion material artifacts. From this point of view, studying the epistemology of science should automatically subsume the knowledge content of engineering." However (!), he adds, "<u>Engineers know from experience that this view is untrue</u>."

Vincenti continues, "Engineering is not 'merely' applied science. Engineering knowledge is not derivative from science, but <u>an autonomous body of knowledge</u>. Aeroplanes are not designed by science, but by art – in spite of some pretense and humbug to the contrary. The creative, constructive knowledge of the engineer is the knowledge needed to implement that art."
Bejan sees that the knowledge associated with the Constructal Principle is not part of classical physics, but he still wants to call it 'Physics'. He argues, "The preceding chapters unveiled the physics basis for phenomena and concepts that traditionally are not acknowledged in physics: freedom to change, evolution, design, complexity, life, performance, economies of scale, diminishing returns, innovation, and social organization. <u>These concepts constitute a new body of knowledge</u>."[34] In this last sentence he comes temptingly close to Vincenti's thesis that engineering knowledge, the real knowledge of the world, is an autonomous body of <u>engineering knowledge</u> – not physics.

Vincenti is pointing out that you can't derive an aeroplane from science. A crucially important entailment from Vincenti's simple but profound thesis is that engineers are able to understand aeroplanes, and cellphones, indeed, all technologies in ways that scientists never can. Taking this one step further, engineers should be able to understand, particularly with the Constructal Principle, the technological structures, and

[33] See also Petroski's Washington Post newspaper article: "If you want to change the world, don't ask a scientist, ask an engineer."
[34] Freedom and Evolution, page 136

functions of reality in ways that are beyond scientific knowledge.[35]

Toward the end of *Time and Beauty*, Bejan fully endorses the Participant engineering thermodynamics evolutionary design perspective:
"Your life, every hour and every day, is a sequence of changes that you make—right versus wrong, up versus down, and so on, endlessly. You make decisions every moment you perceive a click. That's your freedom. Your life is the design, and you are the designer. You can choose to live one way or another, but you have to think about the change. Even the decision to think about every decision is a change, because previously you were not thinking about it. So, it's about you. Making changes that are not routine will be good for your life. Luck in life comes from freedom to have more choices, more turns at throwing the dice."[36]

What strikes me is how Bejan, starting with awareness of the importance of finiteness, along perhaps couples and coupling, through a series of increasingly profound reflections, marked along the way by the realization about freedom,[37] finds his way to a sophisticated philosophy, a philosophy of engineering with fundamental insights about the evolving design, the evolving organization, of engineering realism. I imagine there is more to come but what he 'hath wrought' so far is amazing.

PART FOUR: Action Agenda

Bejan's accomplishments, as I have noted, are already huge, but his recognition in minimal. I have suggested that Bejan's representation of the Constructal Law as Physics is misleading. Along those lines I prefer, as is evident from my above remarks, to refer to what he calls the 'Constructal Law' as the 'Constructal Principle'. Whatever it is that Bejan discovered it is not a 'Law' in any normal or traditional sense. To obtain his due recognition I suggest that we all move to represent the Constructal insight within the 'bigger tent' of engineering.

With Bejan leading the modern articulation of the philosophy of engineering and the engineering worldview there will be a new understanding of the Carnots' synthetic engineering thermodynamics and how it subsumes and supersedes the Clausius-Boltzmann-Gibbs mechanical (analytic) formulation. Following on the STEM movement, wider appreciation of the Constructal Principle will open the door to numerous novel cross-fertilizations in many disciplines.

Bejan is correct in claiming that the Constructal insight unifies all the academic and

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[35] Vincenti makes an interesting 'prediction' that might illuminate Bejan's use of 'prediction'. Vincenti, the aeronautical engineer, maintains that if we discover, in the future, a planet like the Earth, the same size with the same type of atmosphere, if there are life forms with exoskeletons that fly (viz. think locusts) he can predict their size. See also my video entry, footnote 21 above.

[36] Time and Beauty (p.186)

[37] Freedom and Evolution, p.223 "Freedom is the mother of all evolution and science. If you doubt that, think of it in the opposite direction, to the absurd: what kind of science would it that be where the choices made long ago are already the best, rigid forever? It would be useless, with no purpose and no future. It would be the opposite of the science [engineering] that attracts us, inspires us, and empowers us on earth."

practical disciplines. However, the proposal to understand the new unity under the name of Physics is unlikely to attract the disciplines in the humanities, let alone the broader engineering, practical policy and evaluation sectors. The proper understanding of engineering practice naturally incorporates the development and the evolution of value. Classical physics is notorious for claiming that values are nonsense, and that 'science' has discovered that life, the universe, and everything is meaningless. Of course, from their 'spectator' perspective they have not even been asking the questions, found naturally in the participant perspective, relevant to such broader issues.

Although traditionally the Nobel Prize has been awarded disproportionally to those who would identify themselves as theoretical scientists, that is changing. Nobel's *Will* is quite clear that the award is to be for practical, engineering advances and accomplishments. Bejan deserves a Nobel Prize, and with the proper understanding of the discipline-unifying breadth of engineering thermodynamics, perhaps several Nobel Prizes.

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Evolving Algorithms

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Abstract

Over the last 20 years, social media has become a dominant force in modern interactions. More and more people have started using the networking sites and alongside this, there has been a rise in content generation by “content creators.” This massive change of how human interaction is defined led to the rise of addiction, especially amongst teenagers. This paper explores how the TikTok algorithm has used the Constructal Law to provide access to a content creator’s videos, thus increasing the probability of addiction.

Keywords: Evolution, Addiction, Algorithm, Social Media, Constructal,

1. Introduction

Social Media is an unavoidable force in modern society. As of 2018, 2.9 billion people were confirmed to be monthly users of social media [1], and it is estimated that 4.7 billion will use it in 2023. But why is social media so much more pervasive in our lives than in previous points of recenthistory? What makes certain social media’s more used than others? And how has our addiction grown over time?

A crucial component of social media’s success is the increased access of communication between people and the facilitation of spreading ideas. Not only does it make access to information and friends easier, it is possible for people to enter a virtual world wherein there are no restrictions. With this increased access to information, oppressed people from all over the world, such as Arab women,are freed from regimes, as is evidenced by the reporting of higher levels of empowerment due to theease of engaging, sharing and

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reforming online [3]. As is described by Adrian Bejan and Sylvia Lorente's article *The Physics of Spreading Ideas*, tree shaped channels allow ideas to spread more easily, and the complexity of the design of these channels increases with time [4]. Therefore, this raises the crucial question of where on the S curve of the distribution of ideas does social media currently fall? Is the next form of social media going to have a significantly more pervasive hold onour lives or have we reached the point of diminishing returns?

2. Defining the Success of a Social Media

All social media platforms are motivated by profit, and much of this profit comes from advertising and data collection. As is described by Metcalfe's Law or the "network effect", the value of a communications network is proportional to the square of the number of connected users in the system [5]. It is important to note, however, that this is a general law and does not differentiate between the success of different social media networks due to differences in their structure. To increase profits by increasing data collection time, companies are incentivised to keep users on the application for as long as possible. This can be reframed as social media aiming to provide the mostamount of content to a viewer without them losing interest. To do so, many companies turn to using addictive mechanisms, either by making viral success appear attainable or by providing the most engaging content, to increase retention rates.

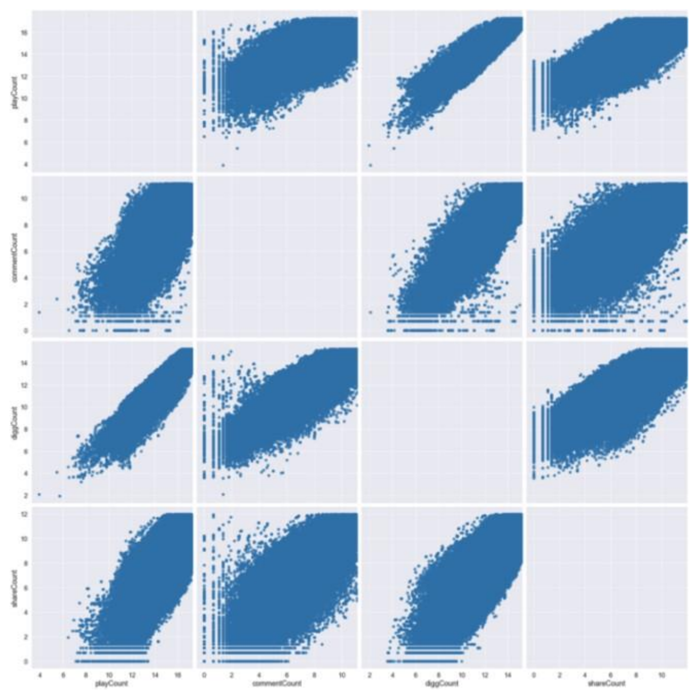

Figure 1: Correlations between number of video plays ('playCount'), number of comments ('commentCount'), number of likes ('diggCount'), and number of shares ('shareCount'). Each variable iscrucial for defining the amount of video engagement on TikTok

3.The Main Players

The first recognised social media is MySpace, it had a community of 115 million users [6]. It was then quickly surpassed by Facebook, which has cemented its place as the most popular social mediafor the last 12 years. Facebook's monthly users currently stands at 2.9 billion [7], however, there isa new player in the game, TikTok. In 2020, during the Covid-19 lockdowns, TikTok was the most downloaded app and twice as many videos were uploaded during this tme than during previous months [8].

MySpace and Facebook are similar sites wherein you curate your own profile with elements of yourown identity such as favourite movies, music, and TV shows. However, whilst MySpace grew mostly through small indie bands advertising their gigs and connecting with groups of fans, Facebook was created as an intimate site for college students to talk to (and about) their peers [9]. On the other hand, TikTok is a site in which people consume and create minute long videos using interesting filters and cuts.

4.Addictive Mechanisms on Social Media

Congruent with the increase in users of social media, social media addiction and polarisation has also increased. This addiction is so pervasive that Facebook addicted people have similar neural reactions as those who are addicted to cocaine or gambling addicts [10]. In fact, perhaps counterintuitively, along with increased connectivity [11], as social media use increases, there is a more pervasive feeling of social isolation amongst users [12]. To increase the time spent on the app,the algorithm characterises what videos the user is most likely to enjoy based off the content of thevideos they have previously interacted with. Using the analogy of the flow of a fluid system, the algorithm aims to provide a path which has the least resistance to a viewer. The algorithm then feedsthe user more, similar content, however, since humans are more likely to engage in material which evokes awe, anger or anxiety over other emotions [13], this material is usually more extreme than previous content to further entice attention to the videos. Thus, users frequently get pigeonholed in extreme niches.

Interestingly, to keep individuals addicted, TikTok does not follow a simple ease of access flow system model, instead it uses variable rewards. In evolution, ancient humans were driven to meet their needs by releasing dopamine to inspire these humans to get out of their state of depravation. Insocial media, the beep of a notification releases a flood of dopamine, causing one to check their phone. However, the notification is not always rewarding, which increases the dopamine released when the desire for an interesting message is satiated [14]. Similarly, TikTok does not always queuethe video that will be the most engaging to the viewer next but has a fluctuation of rewards [15].

TikTok mimics the trend of fostering addiction by trying to increase one's social connection to people, and by using online popularity to seek others' approval and support. A study on addiction to YouTube, another video creating and sharing social network, showed that whilst engaging in content was addictive, there was a higher coefficient of indication linked to content creation and addiction [16]. Thus, it can be assumed that on an application such as TikTok, where content creationis possible for anyone, and is in fact a crucial part of the use of the app, these will have a further increase in levels of addiction.

An interesting difference in TikTok from other video platforms is that it doesn't generate recommended videos based off people you follow [17], instead it includes videos that are similar tothose you have previously engaged with. TikTok determined engagement via watching time, likes, comments and shares. Additionally, it recommends content based of hashtags that are currently trending. To link like videos together, Bytedance, the parent company of TikTok, uses natural language processing of text components in and around the video and visual processing on the videoitself to identify trending elements. Due to this, it appears more attainable to go viral on TikTok than on other social medias. A type of gamble that makes stardom appear attainable and thus encourages users to post more.

5. Discussion and Conclusions

In conclusion, the constructal law is evident in addiction on Social Media platforms because the platform aims to create easier access of information to the individual. This follows the same arrangement as other, smaller scale communication structures: it spreads in a logistic curve. Secondly, there is the nodal connection between the different facets of the algorithm. When plotted this results in a blobby structure with dendrites. Finally, due to the capitalistic model of social media companies, they aim to increase engagement. Thus, to make a video go viral, content creators have determined that it is important to post at times when there are the most people on the platform. This allows a video to more likely be promoted by trending hashtags to a greater number of people. As can be seen in other examples of the constructal law, it is easier to move along paths with lots of other elements flowing in the same direction. Therefore, since social media is a flow system, the most successful algorithms follow the same laws to promote access to individuals as a waterway or a tree would.

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Evolutionary Aeroelastic Design of Aircraft

Pezhman Mardanpour[1]

Keywords: Design as Science, Evolution, Constructal Law, Airplanes and Helicopters, Air Transport Routes, Flow of Stresses

Abstract

The chief objective of this presentation is to stimulate and fast-forward the evolution of aircraft aeroelastic design. Our approach proceeds from the principle that better design provides better access for the flows that inhabit the system. The results reveal that when the stresses flow smoothly, the stability of the structure improves.

It was known in the literature that when aeroelastic instabilities occur, energy is pumped into the system. This fact is in accord with the first and second laws of thermodynamics that cover the conservation and direction of energy transfer. However, there was no clear explanation to discuss why this phenomenon occurs until the recent collaborative work of Mardanpour and Bejan [1-5]. They discovered that the strangulation in the architecture of energy flow (i.e., flow of stresses) is the main cause of this phenomenon.

State-of-the-art aeroelastic design and analysis methods are very well capable of capturing aeroelastic instabilities (i.e., divergence, flutter, etc.). However, they come short in explaining the reasons behind the occurrence of such instabilities. Our recent discovery explains "why" a certain design parameter (e.g., engine placement) influences the aeroelastic flight envelope of the aircraft. Our approach proceeds from the principle that better design provides better access for the flows that inhabit the system.

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In another preliminary work, we used the concept of the flow of stresses [6-11] to explain why swept flying wings achieve higher flutter speed compared to curved wings. The investigation ofthe aeroelastic instability through the lens of constructal law showed that the design of flying wing aircraft does not evolve toward a curved configuration because swept configurations better meet the aeroelastic requirements.

Furthermore, in my most recent collaborative work, we applied the same analogy and explained why inflected (curved) flying wing aircraft achieve higher flutter speed. Our results prove that the inflected configuration that provides easier access to the flow of stresses and has less stress strangulation is the most stable configuration.

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Architecture and the Constructal Law: A Powerful Toolfor Envisioning Sensory Architectural Experiences in aRapidly Changing Environment

Lazaros Mavromatidis[a*]

Abstract

There is a widely held belief that contemporary architectural creation is inexorably linkedto the need to reimagine forms, morphologies, and volumetric elements in order to take full advantage of the latest technological advancements. However, while current research endeavours tend to prioritise the technical aspects of architecture, it is equally importantto recognise the critical role that past spatial archetypes can play in shaping present and future design activity [1]. This necessitates a renewed focus on the integration of the intuitive and empirical knowledge and a more systematic approach to revisiting historical spatial archetypes, reinterpreting them in light of current design challenges and re-invent architectural imagination under the prism of climate change [2]. The constructal law can serve as a powerful tool for interpreting past sensory experiences and envisioning on the creation of future spaces, bridging the gap between history and architectural imagination. By recognising the universal tendency for flow systems to evolve towards increased efficiency of energy and matter distribution, architects can analyse past typologies and design new spaces that optimise these flows. This approach can be used to explore the evolution of sensory experiences in architecture throughout history. By analysing the wayin which the distribution of light, energy, sound, and air flow was optimised in past structures, architects can gain insights into the sensory experiences that were prioritised indifferent historical contexts. These insights can then be used to inform the design of new spaces that prioritise different sensory experiences, depending on the goals and cultural context of the project. Furthermore, the application of the constructal law enables the prediction and facilitation of more effective design for future spaces. By integrating this approach with historical and cultural analysis, architects can create buildings that are not only efficient and sustainable but also meaningful and culturally relevant.

Keywords: Sensory perception, Architectural design, Evolutionary dynamics, ConstructalLaw application, Adaptive environments, Climatic Constructal Heterotopia.

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1. Introduction

The 21st century seeks to identify core mythological archetypes that can address the pressing issue of "*climate change*". The resurgence of nature in architectural theory and practice transcends the traditional Vitruvian principles of durability, functionality, and beauty, embracing a contemporary ethos of equity, biodiversity,and prudent progress through the notion of eco-conception. Applying a heterotopological approach inspired by Foucault, a framework is proposed to viewclimate change as a spatial problem governed by thermodynamic laws, introducing the notion of "*climatic constructal heterotopias*", that are founded on four essential scientific principles [1]. The first principle acknowledges the inherent variability of climate within these thermodynamic spaces. The second principle posits the existence of a hierarchised network of counter-climates and counter-spaces that overlap and interact. The third principle addresses the complexand multifaceted nature of these heterotopias, encompassing various systemic dimensions. Finally, the fourth principle recognizes that climatic heterotopiaspossess a constructal dimension and adhere to natural laws of thermodynamicsand Adrian Bejan's constructal law.

2. Materials and Methods

Architecture serves as a visual representation, comprehensible through human senses. It connects to spatial archetypes, enhancing spatial comprehension's clarity and compactness. Architectural conception encompasses three features. Firstly, thebuilding size is determined by scale choice, whether large or small. Secondly, the architectural image conveys a meaningful message through shapes, structures, aspect ratios, and their organization on the visual plane. Each component holds unique symbolic significance. Finally architectural volumetric is characterized by "*Svelteness*", a notion that is used to quantify through the relative thinness of building elements the architectural quality of the conceived volume [3]. This dimensionless number is employed to gauge the effectiveness of communicating architectural ideas and facilitate the flow of the conceptual process by sensorially quantifying the building elements employed to convey the message.

3. Results

The svelteness S_V of a "*climatic constructal heterotopia*" is calculated according to Bejan & Errera [3] as the ratio between the external length scale and the internal length scale. The external length scale represents the hypothetical compact volume of the shape, while the internal length scale refers to the volume resulting from the architectural creation process, which sculpts the hypothetical volume (refer to Figure 1).

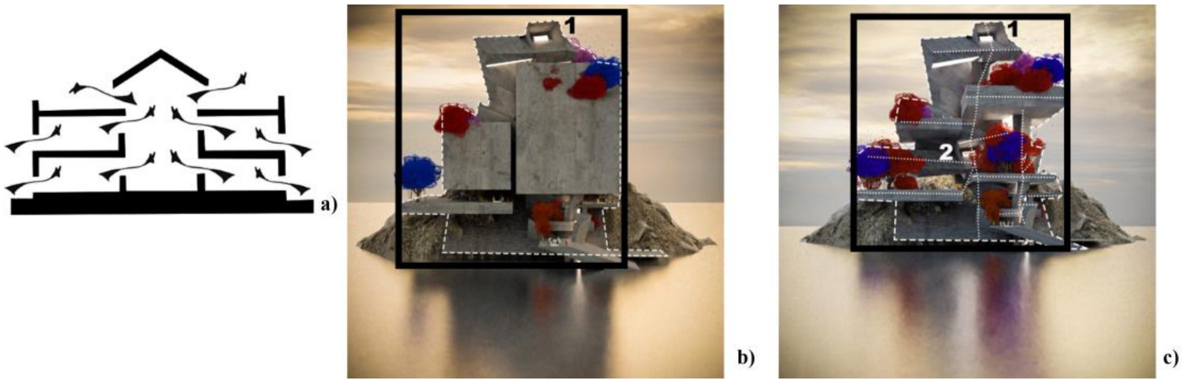

Figure 1. Evolution of Sveltness during the conception of an architectural volume that aims to facilitate natural ventilation : (a) a typical archetype scheme that enhances natural ventilation ; (b) volumetric conception: Variation N°1, S_V = 3.76 ; (c) volumetric conception based on a tree shaped development : Variation N°2, S_V = 6.82.
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In Figure 1, the svelteness property (Sv) of an architectural object, initially inspired by a classical archetype to enhance natural ventilation, evolves gradually into a complex volumetry during the conceptual phase. The svelteness increases as the volume is sculpted, combining void and volumetric elements, resulting in a decrease in the overall constructed volume. Consequently, the architectural object becomes more visually lighter, and more svelte. The svelteness of the architectural volume in Figure 1 was calculated using Bejan and Errera's equation [3], with the square root of the area of the black rectangle representing the external length scale (using the actual height and length of the building), and the square root of the area covered by the dashed white line representing the internal length scale.

4. Discussion and Conclusions

Architecture carries significant meaning, which is why it holds importance. It is a disciplined field, governed by precise rules and principles. Altering the definition of architecture solely to align with the narrative of eco-conception would diminish the rich spatial experiences offered by the built environment. Nature, with its inherent complexity and dynamic evolution, presents valuable processes that can be effectively integrated into architectural practice. Adhering to the constructal law, which establishes clear terms, rules, and principles, allows for a harmonious amalgamation of these natural concepts with the discipline of architecture.

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Shape and Structure in Electromagnetic Fields

Alexandru M. Morega[a*], Mihaela Morega[b]

Abstract

In the continuous media approach, the physics that describes the coexisting couplings and interactions between the electric and magnetic fields is modeled by Maxwell-Hertz's laws that predict how these propagating fields may source each other and rationalize electromagnetic radiation. This paper evidences how the constructal applies to a system of fluxes only. If ponderablematter occurs, it participates in this evolutionary process. It morphs together with the fluxes.

Keywords: Electromagnetic field; Evolution; Propagation; Interactions; Imponderable.

1. Introduction

The *Constructal Law* (CL) was introduced as a law of Physics in inanimate and animate, natural, and artificial (engineered) systems [1,2]: *For a finite-size flow system (not infinitesimal, one particle, or subparticle) to persist in time (to live), it must evolve withfreedom such that it provides easier and greater access to what flows*. CL forefronts thefreedom of reconfiguration as a condition of evolution, persistence, and survival. The"morphology" of the system must change or be changed (*e.g.*, for designed systems) sothat the work required by the flows is minimal, the heat produced is transferred as efficiently as possible, *etc*. General principles such as *equipartition* and *parsimony* can be observed in the resulting designs. Earth-size engines convert their heat input (originally from the sun) only partially into power and reject the difference as heat to theambient, the cold sky [2]. Heat transfer in space is an electromagnetic field (EMF). AsCL refers to *ponderable* (*material*) *flow* systems to which the macroscopic continuummedium concept applies, the present paper attempts to affirm the CL's validity for EMFin a unique, physically natural *imponderable* setting: a *vacuum* system.

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2. Physics

In a vacuum, the system's volume and boundary are *imponderable*. EMF existence is conveniently accepted by assuming the vacuum as a particular case of "extreme rarefaction" of matter in the limit r $\rightarrow$ 0. Thus, EMF may be seen as (*a state of*) *matter*. This hypothesis justifies the ponderomotive actions produced by the EMF at a distance by contiguity (continuous in space) in finite time (continuous on the time scale of the speed of light in a vacuum). Maxwell-Hertz laws [3] are used to describe them. The "materialized" vacuum system has electrical permittivity, e_0, and magnetic permeability, m_0, universal constants of physics. EMF has energy[1],$W_{em} = \oint_{\Sigma} \mathrm{S}\boldsymbol{n}_i dA$, S = E×H, momentum, $P_{em} = \int_{V_\Sigma} \mathrm{g}_{em} dv$, torque, $M_{em} = \int_{V_\Sigma} (\mathbf{r}\times\mathbf{g}_{em}) dv$, g_{em} = D×B = $\varepsilon\mu$(E×H) = c^{-2}S, $c = 1/\sqrt{\varepsilon_0\mu_0}$, parts of the energy balance: $-\delta W = \mathrm{d}E$ (W is work, E is energy). Heat may be produced in ponderable media (Joule effect, dielectric and magnetic heating).

How can CL be acknowledged and interpreted in a vacuum environment?

We admit the coupled electric field (EF) and magnetic field (MF) that densely (continuously) fills a vacuum space with no eigen or neighboring ponderable, movingmedia. From the perspective of classical electrodynamics, CL reads: To evolve (persistingin time and space). The flux-only imponderable systems must "morph" their couplings,which source and model each other. The EMF structure and its (wave) propagation pattern are determined by the EMF source type, e.g., the antenna (a material system). EMF (EF+MF) crosses the imponderable vacuum system, whose boundary "lets it pass" without perturbing it. Thus, the EF and MF generate each other, coupled in a "morphology" specific to the field source (antenna), which gives the dynamics of the resulting EMF wave that propagates (time and space evolution) at co. Hence, CL applies also to a system made of fluxes only. If ponderable matter occurs, it participates in this evolutionary process. It morphs together with the fluxes.

3. Results

EMF morphology (modes of propagation) is "drawn" by its source and the intrinsic EF-MF coupling. Figure 1 shows the EMF field for two excitation modes of a dipole(Hertz) antenna: in the *near-field* (NF) region, the electric field (EF) is connected to theantenna (the electric conduction current inside the antenna is connected with the displacement currents of the EF flux tubes); in the *far-field* (FF) region, the EF disconnects from the antenna and travels on, coupled to the MF.

[1] W_{em} – electromagnetic energy; S – Poynting vector; E – electric field strength; H – magnetic field strength; P_{em} – EM impulse; M_{em} – torque of EM impulse; r – radius; g_{em} – specific EM impulse; c – speed of light

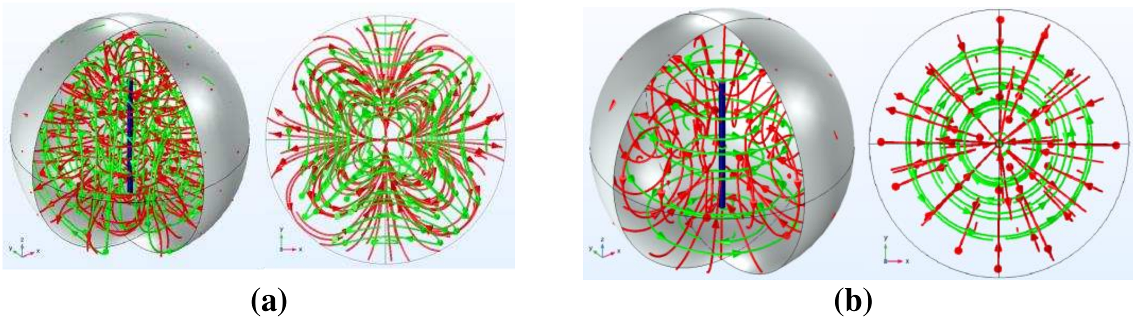

Figure 1. The electric (red) and magnetic (green) fields for the half wave dipole antenna, powered: (a) By its ends; (b) By the middle. The oscillator frequency is 74.98 MHz.

In the NF region, the EF is "connected" to the antenna, and the conductive current (insidethe antenna) is connected to the displacement current (outside). The EF is decoupled from the antenna in FF, and only displacement current persists. The MF surrounds the EF flux tubes. The two time-varying fields, EF and MF, may source each other and justify EMFradiation [1]. Other couplings and interactions may occur when a ponderable matter is present, blueprinting the structure and shape of the aggregate field-matter system [2].

4. Discussion and Conclusions

The EMF existence and mode of propagation (evolution) in a vacuum, imponderable system, hypothesized as a state of (extreme rarefaction of) matter, highlights a constructalmode of coupling – a path of minimal impedance for the EF and MF fluxes ("flows"). Forponderable systems, the EMF interaction with the matter is explained using photons (massless particles) rather than waves. EMF's physics extends then the CL to "flows" thatdetach from the source and evolve in space and time (in EMF, they propagate) in ponderable or imponderable systems. Their source constrains their structure and coupling mode. Their existence is limited by the presence of ponderable (dissipative) matter andthe distance to the field source.

So, what means "constructal shape and structure" in this context, especially in the FR? It may be suggested that it is the particular aspect (spectrum) of the coupled EF-MF stated by Faraday and Ampére (curl) laws – they describe EMF wave propagation as coupled EF and MF solenoidal fluxe that "source" each other.

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Geometrical Investigation of Forced Convective Flows over Staggered Arrangement of Cylinders Employing Constructal Design

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Abstract

The present work shows a numerical study of the geometrical investigation of a staggeredarrangement of four cylinders subjected to incompressible, laminar, unsteady, two- dimensional, and forced convective flows by means of Constructal Design. The purposes are the maximization of Nusselt number (Nu_D) and minimization of drag coefficient (C_D) in the arrangement. The problem has one area constraint (A_o) and three degrees of freedom:S_T/D (ratio between the transversal pitch of intermediate cylinders and their diameters), S_{L1}/D (ratio between the frontal longitudinal pitch of cylinders and their diameters), and S_{L2}/D (ratio between the rear longitudinal pitch of cylinders and their diameters). The configuration is investigated for three different Reynolds numbers (Re_D = 10, 40, and 150)and using air as working fluid (Pr = 0.71). The conservation equations of mass, momentum, and energy are solved with the finite volume method. Results showed that Reynolds number affected the design of the arrangement, especially the optimal longitudinal ratios that presented asymmetric configurations.

Keywords: Constructal Design, Geometric Investigation, Forced Convection, Staggered Cylinders, Computational Modelling.

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1. Introduction

One important aspect of the thermal project of heat exchangers is the investigationof strategies to augment the heat exchanger with the lowest possible forces for fluidmotion. Therefore, the use of different shapes for the cylinders as elliptical, squareor trapezoidal bodies and the use of fins or protrusions in the tubes to improve the thermal performance of one cylinder or arrangement of cylinders have been reported [1]. In the Constructal Design framework, important recommendations about the design of arranges of tubes have been reported following the ConstructalLaw principle [2 - 3]. Despite several contributions, few have been investigated about using different longitudinal pitches on staggered elementary arrangement of cylinders, which is investigated here.

2. Methodology

The present work considers laminar, unsteady, incompressible, and forced convective flows over an arrangement of cylinders defined in a staggered configuration, as illustrated in Fig. 1. The problem is modeled by the conservationequations of mass, momentum, and energy [4], which are numerically solved withthe finite volume method by means of the commercial code FLUENT [5].

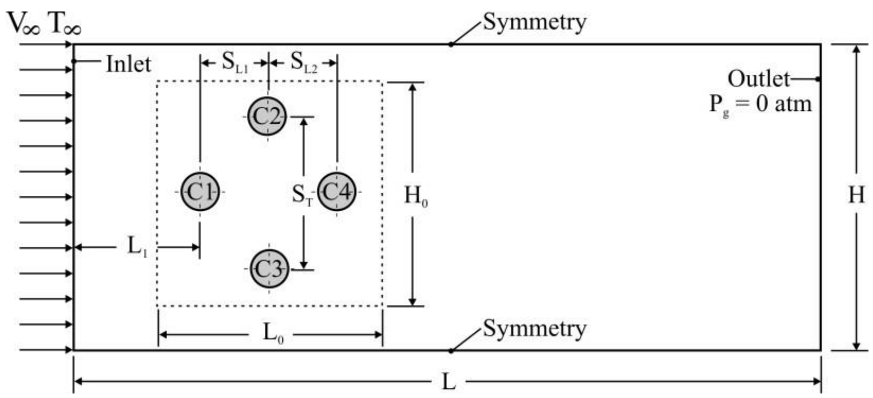

Figure 1. Computational domain of the staggered arrangement of cylinders subjected to forced convective flows.

The main purposes are to maximize and minimize, respectively, the spatial averaged Nusselt number (Nu_D) and the drag coefficient (C_D) in the arrangement of cylinders. For each cylinder, the Nu_D and C_D are given, respectively, by:

$$Nu_D = hD/k = \partial T^*/\partial n^*|_{n^*=0} \quad (1)$$

$$C_D = F_D/2\rho V_\infty^2 DW \quad (2)$$

For the geometrical investigation, it is considered an occupation area $A_0 = 6D \times 6D$and three degrees of freedom: S_T/D, S_{L2}/D, and S_{L1}/D. The exhaustive search is usedhere to investigate the influence of the Reynolds number over the three times minimized drag coefficient, $(C_D)_{3m}$, three times maximized Nusselt number, $(Nu_D)_{3m}$, and corresponding optimal degrees of freedom. The subscripts F and T denote the optimal ratios for the fluid dynamic and thermal purposes. All degrees of freedom were investigated step-by-step for optimization with an exhaustive search, totaling 288 simulations. Despite that, it is presented here only the effect ofthe Reynolds number over the optimal configurations.

3. Results and Discussion

Figure 2 illustrates the effect of Reynolds (Re_D) over the three times minimized drag coefficient, Fig. 2(a), and three times maximized Nusselt number, Fig. 2(b), and the corresponding optimal fluid dynamic and thermal configurations, and Fig. 2(c) shows the temperature fields for the optimal thermal configurations. For both purposes, asymmetrical longitudinal pitches conducted to the best performance. Thebest thermal arrangements were obtained for Re_D = 10 and 40 with intermediate cylinders near the rear and frontal cylinders, respectively. For Re_D = 150, the arrangement tends to be more symmetric than the configurations with Re_D = 10 and40, i.e., $(S_{L2}/D)_{2o,T} = 4.0$ and $(S_{L1}/D)_{3o,T} = 3.0$. Moreover, for Re_D = 150, the optimalarrangement intrudes more into the occupation area than the best configurations reached for the other Reynolds numbers.

4. Conclusions

In general, it was noticed that the staggered arrangement of cylinders is dependent on the operational conditions and the use of asymmetric pitches between frontal and intermediate cylinders, as well as, between the intermediate and rear cylinders can benefit the performance of heat exchange of the problem.

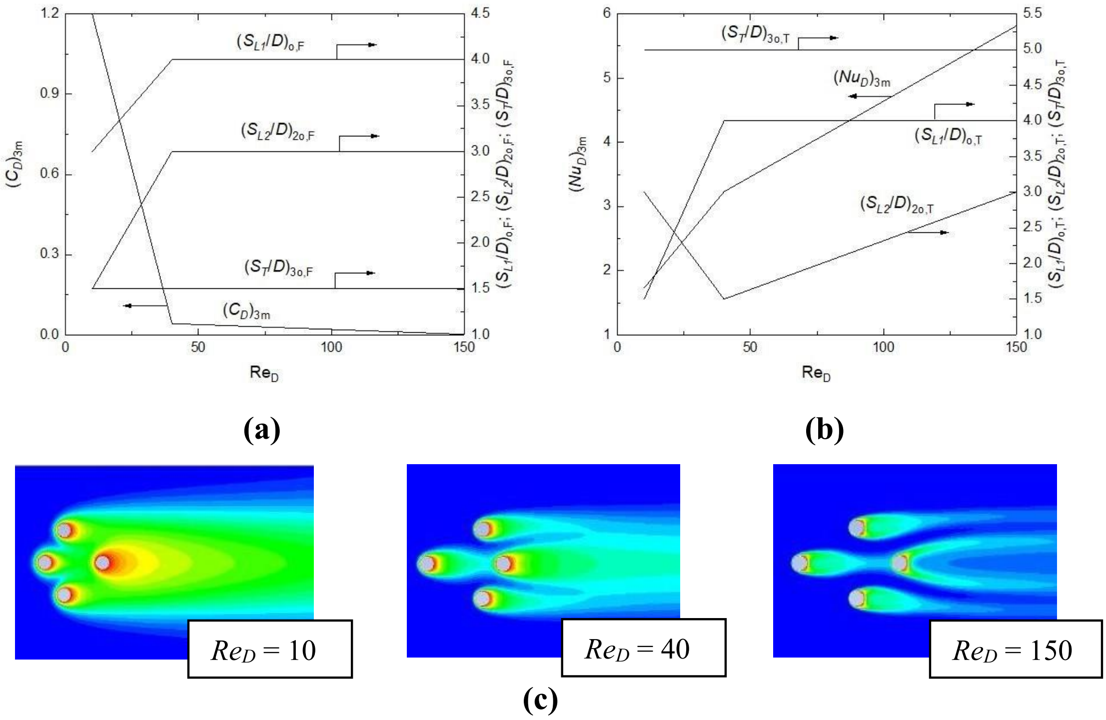

Figure 2. Effect of Re_D over: (**a**) $(C_D)_{3m}$ and corresponding optimal shapes; (**b**) $(Nu_D)_{3m}$ and corresponding optimal shapes; (c) temperatures for optimal thermal configurations.

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Constructal Law Conference (CLC 2023)
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Constructal Design of Multicopters

Juan C. Ordonez[a,b], Camilo Ordonez[a]

Abstract

Multicopters vehicles have important applications in agriculture, search and rescue, transportation, and in the general support of scientific missions. They are mechanically simple, and their control is a relatively mature technology. However, designers of these systems are faced with multiple options related to the number of propellers to use, their placement, and battery and motor sizing. Within the framework of constructal design, we investigate patterns which inform the placement and sizing of components as a function of system constraints. In particular, we explore how freedom of design impacts the multicopter agility and energy efficiency and, in this way, the emergence of geometrical features as the technology evolves. It is expected that the constructal patterns discussed here can enable novel future designs of multicopters at different scales.

Keywords: Constructal Theory; constructal design; robotics; multicopters; drones; flight agility.

1. Introduction

The use of constructal theory in connection to robot navigation was introduced by the authors in the CLC 2019 [1], by relying on the constructal theory of tree canopies and roots [2] to guide robot navigation across forest environments. Aerial images captured by a quadrotor were used along with the theory in [2] to predict ground level distribution of obstacles that a ground mobile robot would be likely to encounter while traversing the tree covered area. That work, [1], also demonstrated how path planning algorithms could be enhanced by being informed by constructal theory.

Constructal theory has been used to explain technological evolution patterns in the context of aerial vehicles. Bejan et al., [3], studied the proportionality between wing

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span and fuselage length, and between fuel load and body size. Similarly, for helicopters, [4] studied correlations between helicopter mass and propeller radius, and between the helicopter engine and its take-off mass. In general, it is possible to derive optimal ranges for the size and weights of components (or organs) that enable flight [5], as a result of trade-offs between increased efficiency and added weight of components that enable flight. This paper explores some implications of the constructal law and results of constructal theory to the design and control of multicopters.

2. Multi-Modal Locomotion - Walking, Running, and Flying

Although the majority of quadcopters are designed for flight, there have been designs that combine different modes of locomotion. A salient example is the Hybrid Terrestrial/Aerial Quadrotor - HyTAQ, [6], in which a cage-like structure enables the possibility of ground locomotion (rolling) in addition to flying. Reference [6] reports experiments in different surfaces and under different modes of locomotion and compares their power requirements (Fig. 1(a)). The natural transition among modes of locomotion has been documented for animals [7] and engineered systems. In Fig. 1 (b) small quadcopters are added to the velocity - body mass figure that Bejan and Marden [7] produced for animals. The body mass of the quadropters selected and their maximum speed places them in a cluster that is consistent with flying with air drag.

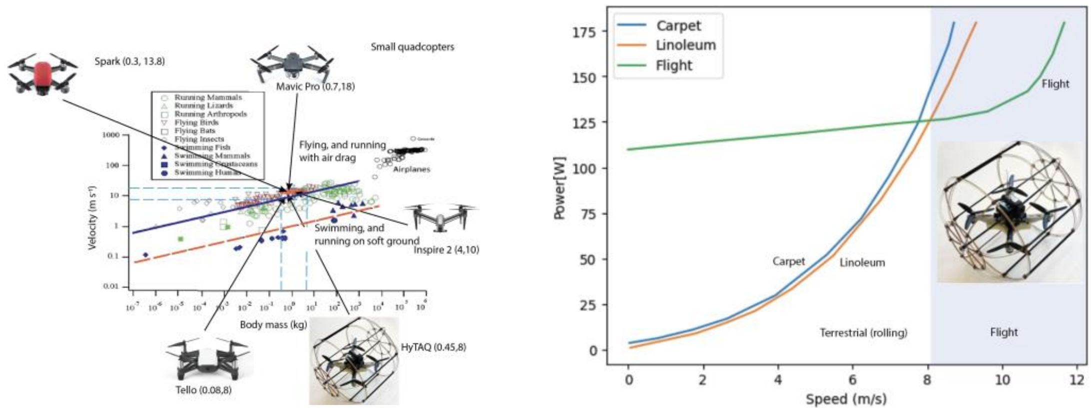

Fig. 1: (a) Experimental observation of an optimal transition between modes of locomotion for a hybrid terrestrial/Aerial quadrotor (after [6]). (b) Placement of small quadrotors among observations from [7] in regards to the constructal theory for scale effects in running, swimming and fly ing.

3. Constructal Patterns for Multicopter Design

Symmetry in multicopter design is important to simplify their control and actuation. Here we consider the Y and spoke patterns of Fig. 3 and study the influence of the geometry in the vehicle agility.

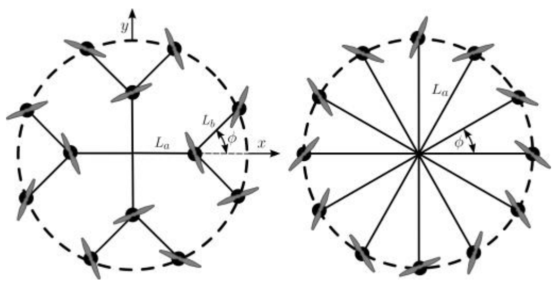

Fig. 3: Constructal quadcopters.

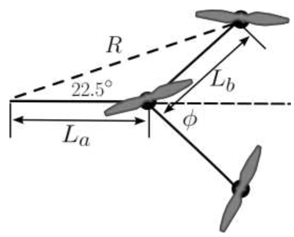

Fig. 4: Y constructal pattern

Assuming a multicopter with Nr = 12 and Y-patterns, a total of 4 Y-patterns would be required to maintain symmetry of the vehicle. If the total radius of the multicopter is R, it follows from the geometry of Fig. 4, that $\cos\phi = (R\cos\frac{\pi}{8} - L_a)/L_b$. In this preliminary study, we assume that the mass of the frame and mass of motors and propellers is located at each joint of the structure. Thus, for the Y pattern, the total mass of the vehicle becomes, $M = 4m_a + 8m_b$, where m_a and m_b are the point masses located at the joints of the primary and secondary branches of the pattern and are given by $m_a = m_m + \rho_f L_a$ and $m_b = m_m + \rho_f L_b$, where m_m is the mass of single propeller and motor, and ρ_f is the mass per unit length of the vehicle frame.

Under these assumptions, the moments of inertia about the x and y axis are then computed as follows: $I_{xx} = I_{yy} = 2m_a L_a^2 + 4m_b(L_b \sin\phi)^2 + 4m_b(L_a + L_b\cos\phi)^2$. The maximum moment about either the x, $\tau_{x,max}$, or y, $\tau_{y,max}$, axis is obtained when there is a maximum differential thrust. That is, when the propellers of one half (with respect to the axis of symmetry) of the multicopter are generating maximum thrust (i.e., operating at ω_{max}) and the propellers of the opposite side are at minimum thrust (0N): $\tau_{x,max} = \tau_{y,max} = 2k\omega_{max}^2 L_b \sin\phi + 2k\omega_{max}^2(L_a + L_b\cos\phi) + k\omega_{max}^2 L_a$ where a quadratic relationship, relating thrust and angular velocity, $T = k\omega^2$, has been used (see, for example, [9]). The maximum vertical acceleration of the platform is obtained when all propellers are operating at maximum thrust and is determined by $a_{max} = (12k\omega_{max}^2 - Mg)/M$. The maximum angular accelerations about the x and y axes are $\alpha_{x,max} = \tau_{x,max}/I_{xx}$, $\alpha_{y,max} = \tau_{y,max}/I_{yy}$. By varying the density of the frame between 0 and 1, we see from Fig. 5 that the optimal angle ϕ increases as the density of the material increases. Using the same density values, the normalized angular acceleration was computed for the spoke pattern and compared against the normalized acceleration obtained by the optimal Y-pattern for each density value. Fig. 6 shows the increased agility provided by the Y-Pattern.

4. Conclusions

This paper presents an attempt to locate small drones, including some with multiple modes of locomotion, within results of the constructal theory that unifies scale aspects of running, swimming and flying [7]. Additionally, the paper compared constructal Y-patterns against spoke-like designs and showed that the Y-patterns result in increased multicopter agility. Simulation results produced optimal geometries for Y-pattern designs. Future work will consider experimental verification of the designs.

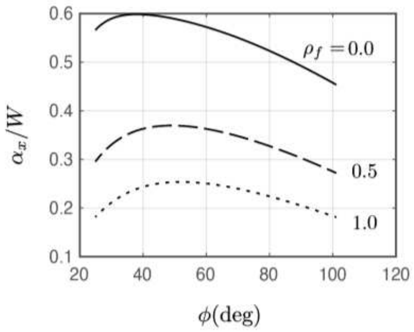

Fig. 5: Optimal branch angle for different frame densities.

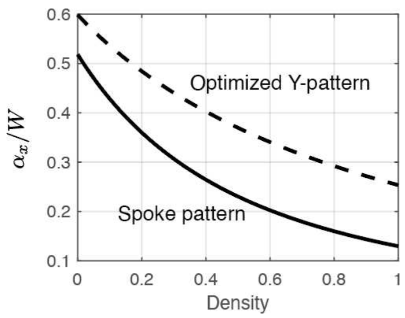

Fig. 6: Comparison of Patterns to Maximize Multicopter Agility.

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Analysis of entropy on the European market of energyand energy commodities prices

Papla, Daniel[a*], Siedlecki, Rafał[b], Ostasiewicz, Katarzyna[c]

Abstract

We analyze the problem of entropy in the moments of transition from a normal economic situation (2015-2019) to the Pandemic period (2020-2021) and the period of Russia's attackon Ukraine (2022-2023). The research in the article is based on the analysis of electricity, oil, coal, and gas prices in 27 countries of the European Union and Norway. The daily datacover the period from January 1, 2015, to March 30, 2023, and were analyzed in the form of two-dimensional sets of electricity price and commodity price. The work uses, among others, the James-Stein estimator. The results came out inconclusive.

Keywords: Entropy, Energy Price Prediction, Economic Crisis.

1. Introduction

The concept of entropy occurs primarily in thermodynamics but also the theory of probability, information, stochastic processes, and economics and finance [1, 2].In finance and economics, entropy often determines the measure of system order,which is a prerequisite for making effective forecasts [4]. Based on financial market

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theory the prices of financial assets during normal times follow a random walk [5].It means there is a high level of entropy of financial asset prices which can lead to severe mistakes made by financial analysts and economists, which can deepen the crisis. According to Bejan Constructal Law [3]: „For a finite-size flow systems to persist in time, it must evolve with freedom such it provides an easier access to its flows". The paper aims to analyze the degree of prediction of energy, oil, coal, andgas prices.

The following hypothesis was put forward in the article: In the period of economic slowdown and economic crises, the entropy of prices in the energy market decreases. In the article, we also analyze the problem of entropy in the moments oftransition from a normal economic situation (2015-2019) to the Pandemic period (2020-2021) and the period of Russia's attack on Ukraine (2022-2023).

In our research, we use methods that allow us to take into account the non-linear nature of the studied phenomena, and we also analyze current data, not only from the period of the COVID-19 pandemic but also from the current period, including,among others, armed conflict in Ukraine.

2. Materials and Methods

The research in the article is based on the analysis of electricity, oil, coal, and gas prices in 27 countries of the European Union and Norway (associated country). Thedaily data cover the period from January 1, 2015, to March 30, 2023, which were analyzed in the form of two-dimensional sets of the country's electricity price and commodity price. We used statistical analysis and estimation, e.g., entropy estimators by James-Stein, Jeffreys, or Laplace [7]. Packages Gretl and Statistica were used for statistical analysis, and entropy estimation, especially for rolling Our research confirms previous research [8, 9, 10] that during the crisis when governments support financial markets entropy decreased, and during stable times entropy is close to maximum and there could be big problems with short-term forecasts [6].

In the near future, on the one hand, a transition to green energy and a decrease in demand for oil, coal, and gas as a source of electricity is expected on the other hand, dynamic technological development significantly increases the electricity demand, which in turn will extend the transition time to green energy. This can cause another period of increased entropy and a decrease in predictability.

The methodology presented in the research should help in the analysis of the electricity and energy resources market.

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A noise reduction procedure: A Constructal approach

Yazdan Razi[a*], Kittinan Maliwan[b], Y. Ezunkpe[q] and F. Barez[c]

This paper reports an experimental procedure based on the Constructal Law to reduce noiselevel. The study investigates both the component level and the system level noise reduction. It is shown that at 100% load and at the second construct 3dB will be reduced.

Keywords: Constructal, Noise Reduction, Correlations, Second Construct

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1. Introduction

Reducing the noise levels in server designs have been one of the objectives of designers in IT systems[1]. In this paper, we try to lower the noise level by using a Constructal Approach. The Constructal Law states that: "For a finite size system to persist in time, it should evolve in a manner to provide an easier access to fluid going through it[2].In an Industrial Context, to persist in time means that a program which supports a system should not be eliminated. One of the reasons that we madeuse of Constructal Law, is its power to predict the design[2]. In some of past publications in the industrial contexts, such as the Refrigeration, Thermal Management in Microgravity, Stability analysis and finally Charger Thermal design were addressed[3-5]. Here, in this paper the Acoustic Aspects and Constructal Law will be investigated. The system under study is a 2RU server, and the noise generation will be mainly due to four cooling fans which are in the push mode. We made a distinction between Component level and System level acoustic designs. Our method in this paper is purely experimental. The paper is presented in five parts. In part one, the acoustic set up, the measuring system and the characteristicsof the acoustic chamber ill be explained. The experimental protocol will be explained in that section. Part 3 is devoted to noise reduction; in 3a the componentlevel noise reduction will be explained. While in section 3b, the system level noisereduction will be presented. In part 4, some curves to characterize the acoustic of the system will be presented and finally; in part 5 the conclusion and discussionswill be presented.

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2. Materials and Methods:

In this section we will focus on the experimental set up and the Data AcquisitionSystem that we used. We conducted all experiments in an anechoic acoustic chamber with 10 Microphone set-up, see Figure 1. The chamber's temperature is maintained at a constant temperature, and humidity. The microphones are connected to a DAS System provided by Nelson Company. A software is usedparticularly for the results of this system. The test results covers component and system levels which will be discussed in Section 3.

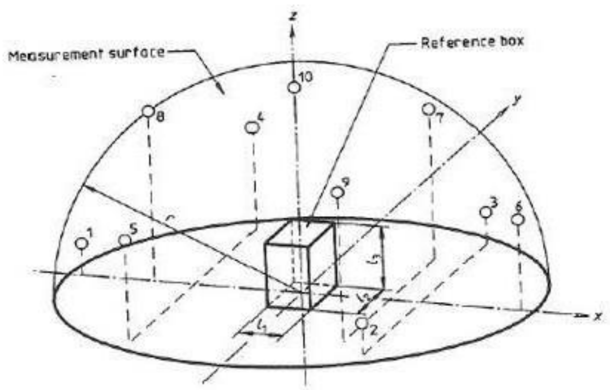

Figure 1. 10 Mics System

3. Results

Section 3 will be composed of two sections: 3a and 3b.3a: Component level In section 3a, our experimental protocol will be presented in two parts.

First, we will present the acoustic results of cooling fans. Then after establishing the base line, we will put foams on the fans. The places where the foam is applied is shown in Table 1.

Table 1. Component Level Solution.

The Load	Bare System	Foam Solution	Helmholtz
40%	72.6	72.3	72.1
50%	79	77.8	76
70%	86.5	86	86
100	97.7	96.4	96.2

In this section, we apply designing the baffle. We mean that we add a duct to the existing server (see figure 2).

Figure 2: The ducted server

In coming to this design, the first construct was adding the baffle. Then the second Construct was creating a section for each fan.
The results are presented in **Table 2**.

Table 2. System Level Solution

The Load	averaged Speed	First Construct	Second Construct
40%	4700 RPM	71.9	70.3
50%	5600 RPM	77.1	75.7
70%	8000 RPM	85.7	85.1
100%	11700 PM	95.1	94.6

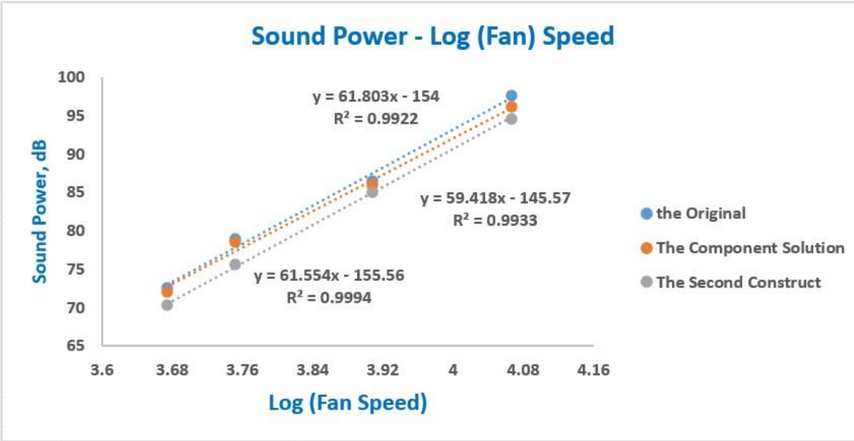

Figure 3

4. Discussion and Conclusions

In this paper we proposed a simple method to reduce the noise level in a 2 RU server. The speed of fans is changed from approximately 4000 RPM to 12000 RPM. Our strategy of noise level reduction was based on Constructal Law. We did that in two parts: Component level and System level. It was shown that at 100% load, we can reduce noise level by 4dB.

5. Acknowledgements

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The emergence of AI-assisted software development inthe light of the Constructal Law

Stephen Périn[a*]

Abstract

Conversational AI and Generative AI technologies have recently seen an acceleration in their development, and massive adoption, despite inherent risks and and unresolved issues, such as security, confidentiality, accuracy, or ethics, among others. Software developmentrepresents one of the many human activities impacted by the advent of AI. While it deliverssubstantial productivity and wellbeing enhancements for developers, it also poses a potential threat to traditional software development processes, possibly overhauling the entire development workflow. Nevertheless, developers are already embracing these imperfect and unsecure AI tools. This paper will consider the emergence of AI-assisted DevOps and the evolution of the underlying LLM technology, shifting from linear input- output prompting to the branching tree-of-thoughts approach through the lens of constructaltheory. Our aim to show how both phenomena are shape by the same fundamental principle.

Keywords: Chain of Thoughts, Constructal Law, Generative AI, Large Language Model,software development, Tree of Thoughts.

1. Context

Recent advancement in Generative AI (GAI) and Conversational AI (AI), driven by tech giants, catalyzed a rapid and massive wave of adoption of these technologies, specifically in textual and media content creation. According to

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OpenAI, their emblematic GAI/CAI service ChatGPT, reached100 million monthlyactive users merely two months after its public launch on November 30th, 2022 [1].The domain of software development and operations is among the extensivespectrum of human activities affected by the rise of GAI/CAI, which might potentially, overhaul or reshape traditional processes in software development.

2. The emergence of AI-assisted DevOps

3.1 A rapid embrace of an emerging yet imperfect technology

Despite inherent risks and unresolved concerns surrounding GAI/CAI, such as relevance, intellectual property rights, data confidentiality, energy footprint, hallucinations, or ethics, among others [2, 4], developers are increasingly adoptingAI tools to improve their efficiency, and wellbeing [5–8]. Among 90,000 software developers surveyed by StackOverFlow [6], "*70% are using or are planning to useAI tools in their development process this year* – despite 40.2% of the professionaldevelopers acknowledging the inherent mistrust in these tools. The next paragraphswill delve into the emerging phenomenon of AI assisted DevOps [9], and the evolution of Large Language Model (LLM) reasoning approaches [10–12].

4.1 Constructal patterns in LLMs reasoning approaches

The evolution of reasoning approaches as summarized in the recent publication by Google DeepMind and Princeton University [10] is a perfect illustration of a flow architecture evolving in time, according to the Constructal Law. In this case, the LLM reasoning flow started with a simple input/output prompting (IO) flow, similar to a Point-to-Point flow, then, with the Chain of Thoughts prompting (CoT)[11], appeared what can be view as several flow regimes, which expanded to a parallel-flow structure of the Self-Consistency with CoT (COT-SC), leading then to the Tree-of-Thoughts (ToT) [10], displaying typical branching in a tree-like flow structure of a One-to-Many or Point-to-Surface constructal pattern [13], similar to a well-known reasoning pattern in AI, known as backtracking. 4.1 LLM: an imperfect, yet beneficial, AI-assistant for software development

J.D Weisz and his co-authors provocatively asked, "*Perfection Not Required?*" in their research paper [2]. Their conclusion, intriguingly, is that an imperfect AI- assistant for software development is markedly better, for the professional, than none. As the researchers elaborate: "*counter to expectations, software engineers felta generative model that produced imperfect output – such as code with compilationor logical errors – would be a useful aid […]*". This finding aligns with the sentiment expressed in a recent survey of 90,000 developers, with 42% trusting theaccuracy of AI tools, and a further 31% remaining "*on the fence*" [6]. Notably, constructal theory does not advocates for perfectly optimized flow systems, but, instead, endorses the "*optimal distribution of imperfection*", which enhances the overall resilience and adaptability [13], as highlighted and explained by Professor Bejan: "*Perfection is the enemy of evolution*" [14] and "*the* *advantage of not beingprecise: more freedom to change*". The current imperfections of LLM may, paradoxically, contribute their adoption, as these allow developers to challenge their own understanding of the problem to be solved, and indeed, according to Kristen Nygaard, cocreator of Simula, "*to program is to understand*".

3. Conclusion

According to Professor Adrian Bejan, "*the evolution of the human & machine species is oriented in time from the naked man to the man with progressively morepowerful add-ons (artifacts, contrivances, devices, machines, science)*" [15]. Withthe development of LLMS, GAI/CAI and AI-assisted DevOps, we are presently observing the birth of a new "subspecies", the "*developer & AI*".

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Music distribution and solar powered futuristic scooters as strange bedfellows: Modernizing personal transportation—breaking free away from long term robust design inertia and socio-economico-cultural considerations, and prospects ahead based on exoskeleton (r)evolution, and wide global adoption of innovation in transportation based on constructal law.

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Abstract:

Wide adoption globally of radical improvements in energy use in transportation systems--whetherpersonal or industrial--may suffer solidly from design inertia and from long lasting socio-cultural anchors that are likely to impede on significant necessary progress ahead. The closest examplesthat we can rely on when inferring the size of the inertia to change we are facing ahead come of course from a thorough analysis of the reluctance to change in instances of similar and comparable magnitudes that we faced in the prior socio-technico-economic history of humankind.Our current world is much affected by several radical changes in transportation related scientific knowledge and theory, and technological practice, most of which have all seen dramatic opposition in their respective pre-adoption times. A cursory look at one's daily life in an advancedeconomy will show the general dependence on average on a 5-6 times oversized personal transportation device–the personal automobile--that utilizes still relatively ancient--by industrial revolution standards--technology, the Lenoir (1859)-Beau de Rochas (1862)-Otto four stroke internal combustion engine, and that is still manufactured using mostly Ford principles and is still owned and financed by users using mostly principles of law and social norms borrowed from property rights usage in real estate, as adapted for and augmented by the mobility of the automobile. Mobility, personal and of goods and services we use daily, is

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embedded in our lifestyles to an extent that we can barely recognize fully. In fact this is so much so that we can paraphrase Bejan as defining humankind as a species characterized substantially by its ability to better optimize over time energy use for improved mobility, and defining the practice of economics as physics through its core focus on the provision of financially efficient mobility from energy use and transformation. Meanwhile, unlike virtually fully global adoption of digital music distribution and other digital mobile entrepreneurial opportunities, and in spite of our amazing progress fighting deeply rooted inertia in other areas, transportation-as-a-service (TaaS) continues to fight to make inroads among the cultural adoption by youth.

In this paper we start with the conclusion that no radical change in renewable energy use for personal transportation globally will occur until the next generation solutions are adoptable by youth roughly in the same design evolution way in which the history of music distribution occurred. In short, the composition fallacy shall predict quite easily that a sixteen years old high school student will not purchase a Tesla in Solar City California (now, maybe South Texas) with the same likelihood that a sixteen years old in Hyderabad India will possibly make emerge a global app time-share rental solution for a much wider range of youth globally adopting an affordable and reliable TaaS solar power based mobility solution–metaphorically called here "solar scooter."

In the paper we show how we reach this conclusion highlighted above, and what it should tell us at the intersection of technology and business for the way ahead in renewable energy use in personal transportation systems. Similarly to Steve Jobs's "$-per-song" 1997 iPod introduction optimization indicator, we are introducing the term "affordability of personal generalized-distance-traveled"--APGDT--, and we argue that wide global adoption of renewable energy use plus exoskeleton-advances adopted in, and transferred from the military to civilian applications in transportation will evolve in such a way as to maximize this function as applied to an ever larger number of global beneficiaries over time. The above is but only a corollary of the application of the construcal law to transportation systems as affected by evolution of design in technologico- culturally man made systems. We compare existing proposed solutions to renewable energy usein personal transportation systems, from Tesla and Lightyear personal vehicles to car sharing models, city scooters, and multi-modal solutions, from the perspective of the likelihood of global maximal APGDT optimization to be reached faster, and with lower and decreasing overall environmental impacts, and we assess factors determining likelihood of comparative adoption and contribution to the global design progress of each solution, and a rough prediction on by when is such future state reachable in 50% or above of the world. At this preliminary stage in ourresearch we expect that Solar Stirling co-generation widely adopted including for non- transportation related consumer use, combined with digital sharing of TaaS solutions and exoskeleton applications may be the winner.

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Teaching Law of Motive Force and Constructal Law to Sophomore

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Abstract

As of relatively recent, two fundamental laws of Nature (Thermodynamics) has been discovered and documented: one is 'Constructal Law' by Adrian Bejan in 1996 and another is 'Law of Motive Force' by Achintya Kumar Pramanick (present author) in 2014. These two independent laws of nature have greatly enabled physical solutions of a numerous variety of practical as well as purely theoretical problems of interest. This way to find generalized methods is certainly the most practical and the surest, for he who seeks the method without having a definite problem in mind seeks in vain. As such present attempt has been devoted to make these laws amenable to the sophomore through archetypes. Law of Motive Force is exemplified analytically through the solution of classical generalized Pohlhausen's problem with Hartee's velocity profile following the tractate: that is the distribution of some finite amount of insulating material on one side of a flat plate when the other side is exposed to a laminar forced convection so as to minimize the heat transfer on the whole. On the other hand the Constructal Law is illustrated adopting scaling analysis through the power law growth of an arbitrary process and decay of another complementary process those are inherent in any physical phenomenon. A tacit connection between the Law of Motive Force and the Constructal Law is ensued. On the basis of foregoing analyses for the first time a new Thermodynamic Brain Model following heat engine notion in support of Marshmallow Test is presented where it is proposed that Amygdala behaves like heat source, Prefrontal Cortex mimics with the heat sink, and Pineal Gland as a heat engine where work production is tantamount to thought output. The inevitable neurological communication channel that exits between the Amygdala and the Prefrontal Cortex bypassing the Pineal gland is modeled in analogy with the thermodynamic Bypass Heat Leak as was put forward first time in open literature by Bejan.

Finally, it is argued that the suggested Thermodynamic Brain model will enable at least

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behaviorists to understand the involution and hence the evolution of large number of biological systems in turn.

Keywords: Law of Motive Force, Constructal Law, Thermodynamic Brain Model, Marshmallow Test, Involution and Evolution.

1. Introduction

The creativity sprouts out of emotional pain [1, 2]. Inventiveness demands free time [3]. Research requires curiosity, diligence, and aimful thinking [4]. The Latin '*mudo corde*' describes it better [5, 6]. Also a researcher has first much to do with the overcoming of one's own inferiority complex [7, 8]. True sādhanā [9] begins thereafter to enhance the consciousness [10].

With the age and experience in research come the twin dangers of dwindling into a philosopher of science while being enlarged into a dotard [11-13]. Eventually it is recognized that everything is related to each other and thus a unification is still possible however the diversified the antagonistic avenues may be [14].

For any physical principle there underlines a mental (psychological) principle [15, 16]. Thus it is instructive to find a psychological reasoning behind any discovery. As of recent two laws of nature has been discovered, namely, Constructal Law [17] and Law of Motive Force [18]. It is interesting to discover a psychological connection.

In this present endeavour, first the Law of Motive Force will be explicated. Then Constructal Law will be enunciated. Finally, Law of Motive Force will be exploited to provide a brain model for thought output in analogy with the heat engine [19]. Indeed it is true that no research is effective until and unless it becomes a textbook material that it is amenable to sophomore. To find generalized methods is certainly the most practical and the surest, for he who seeks the method without having a definite problem in mind seeks in vain.

2. Law of Motive Force

The word 'motive' has a psychological connotation. Until recently [18] the human understanding about motive was poor, vague and scanty. It is only a commonplace experience that nature evolves out of conflicts of two antagonistic attitudes: one favours the event and the other opposes it. The law of motive force has been phrased as [18]: ***"Every motive force is self-contradictory in its existence."*** Thus for two opposing tendencies of force-like quantities to conserve, we can write [18]

$$F_f + \hat{\lambda} F_b = C_a \tag{1}$$

where F_f is the 'forward motivation' (favoring agent) and F_b is the 'backward motivation' (antagonizing agent), $\hat{\lambda}$ is an accommodating factor [18], and C_a is an apparently constant which may fluctuate around a mean value [18]. In sum, in accordance with the law of motive force any two opposing tendencies are not unbounded (conserved).

3. Constructal Law

A generalized statement for the Constructal Law can be phrased as [17]:

"For a finite-size open system to persist in time (to live), it must evolve in such way that it provides easier access to the imposed (global) currents that flow through it."

One of the essential features of Constructal Law is the self-braking mechanism which can be represented by a functional form of the type [17]:

$$F = at^{n} + bt^{-m} \tag{2}$$

where the factors (a,b) and the exponents (m,n) are known constants, which are the features of the model that captures the phenomena. These four parametric constants are non-negative and the F is a function of time t. It is to be recognized that for the stationarity (optimality) the so called function F is locally constant. By means of Eq. (2) we actually realized a competition between the slower and the faster process. In Eq. (2), if we replace the time variable by spatial coordinate, it will be competition between a smaller and the larger element. The competition between time scales (slower and faster processes) are analogous to the spatial scales (smaller and larger). It is to be remarked here that the competition between space and time is also possible. In synopsis, one of the essential features of the constructal law is that nothing grows unbounded and thus Eq. (2) is analogous to Eq. (1).

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General Formalism for Structured Flows According to Constructal Law

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Abstract

Flows from point to line or to surface (and vice versa) that obey a set of constraints are necessarily structured (Constructal Law). We can observe this in natural systems, in man- made systems, in the economy and in society. Here we develop a formalism for general application in point to line and point to surface flows with constraints. We show that flow structuring occurs between successive branching levels and that it is possible to find a general structuring law of the respective flow tree according to the Constructal Law.

Keywords: Constructal Law, Flow trees, General formalism.

1. Introduction

"*For a finite-size flow system to persist in time (to live) it must evolve such that it provides greater and greater access to the currents that flow through it*" [1]. Withthis axiom, known as the Constructal Law, Adrian Bejan in 1996 inaugurated a new scientific discipline focused on the generation and evolution of structure in flows of matter and energy. In fact, the evolution of flow structures is a corollary of the Constructal Law and allows framing and understanding from a theoretical point of

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view the living and inanimate structures that we find in Nature, and the evolution of man-made systems in what we call technological evolution.
In this article we present a general variational formulation and a formalism for structured flows according to the Constructal Law.

2. Variational formulation of the Constructal Law

The requirement of "greater and greater access to the currents" is equivalent to requiring "increasing conductivity" or, alternatively, "decreasing resistance" to flow. In complex systems the evolutionary decrease in resistance to flow at each stage is always limited by the existence of constraints. In the presence of a given set of constraints, the Constructal Law implies that the flow architecture evolves toan optimum for which resistance is minimal. Thus, if R designates the total flow resistance, the Constructal Law can be expressed in a variational form as:

$$(dR)_X = 0\ ;\ (d^2R)_X > 0\ ;\ X = I, \Delta\phi, G \tag{1}$$

where I stands for current, and ϕ=P (pressure), T (temperature, V_E (electric potential), etc. and G for geometric constraints. This statement is very powerful in the sense that it allows unifying the principles of extreme entropy production rate that have been used "ad-hoc" in the study of complex systems for decades [2].
Living systems survive because they minimize the rate of entropy production by reserving useful energy (exergy) to carry out their vital functions. In fact, for that purpose, constant internal currents must be maintained to feed their basal metabolism. In this case the Constructal Law reads $(dR)_I$ = 0. The current I flows under the action of a potential difference $\Delta\phi$, such that $I = \Delta\phi/R$ and the exergy destruction rate is $\dot{E} = RI^2$. Therefore, minimizing the resistance faced by a constant current I leads to the minimization of exergy destruction. Living beings have developed flow structures with minimal resistance to ensure their goodperformance and survival.
On the other hand, many other natural systems survive because they keep their exergy destruction rate as high as possible in the context of constraints. In these cases, the potential drop is fixed, and the minimization of the total resistance $(dR)_{\Delta\phi}$ = 0 leads to maximum exergy destruction rate $\dot{E} = (\Delta\phi)^2/R$. Examples, among others, are the Earth's climate system [3], and the sea/beachface system [4].
In this way, Constructal Law unifies and makes sense of the “principles” ofMaximum Entropy Production rate (MEP) used as governing principle for most inanimate systems, and the Minimum Entropy Production rate (mEP) used in the study of living systems (see [2] for details).

3. General rules for flow trees with minimum resistance

Because of the Constructal Law, point to line flows and point to surface flows mustbe structured. Structure means branching so that the flow tree exhibits the least possible resistance in the context of imposed constraints. Let B_n be the number of branches of the tree at branching level *n* and let r_n be the resistance of each branch.

Thus, the resistance corresponding to branching level *n* is $R_n = r_n/B_n$ and the potential drop at that level is $\Delta\phi_n = R_n I$ where *I* is the constant current flowing inthe fluid tree with *N* branching levels. Thus, the flow tree constraints read: *I=constant*; $\Delta\phi = \sum_n^N \Delta\phi_n$ = *constant*. Finding the minimum resistance of the flow tree is equivalent to minimizing the functional in the r.h.s. of the equation:

$$(dR)_{I,\Delta\phi} = d\left(\sum_{n=1}^{N} {r_n}/{B_n} - \lambda_1 \sum_{n=1}^{N} {B_n\Delta\phi_n}/{Nr_n} - \lambda_2 \sum_{n=1}^{N} \Delta\phi_n\right) = 0 \quad (2)$$

where $\lambda_1$and λ_2 are constants (Lagrange multipliers). We find $\lambda_1 = NR_n/I$ which means the tree resistance R_n is the same at each level. On the other hand, $\lambda_2 = 1/I$ that indicates that $\Delta\phi_n$ is also identical at each branching level. As a result, the number of branching levels $N = RB_n/r_n$ depends on the ratio B_n/r_n, i.e. minimum resistance may be achieved through minimal branching level *N*, with (B_n = 2) andsmall r_n or with higher *N* and B_n but with the correspondent r_n. Here, the geometricconstraints play the decisive role. In pipe flows, resistance *R* depends on tube diameter *d* and length *l*. In a general form, with $B_n = x$, constant at every *n*, $R = \sum_{n=1}^{N} x^{-n} d_n^{-\alpha} l_n^{\beta}$, ($\alpha, \beta$ const.).The geometry of tubes is a geometric constraint to flow, and if a constraint exists $V = \sum_{n=1}^{N} x^n d_n^{\gamma} l_n^{\delta} = const.$, (γ, δ const.), minimization of total resistance with *x* variable yields $x^{-2n} d_n^{-(\alpha+\gamma)} l_n^{\beta-\delta} = \lambda$, or $R_n = \lambda V_n$ (if *V* stands for volume, total tube volume is constant at every level *n*),where λ is constant (Lagrange multiplier). Then, the following relation arises:

As an example of application of eq, 3 let us examine the case of laminar flow in atree of circular pipes for which $\beta = \delta = 1$, $\alpha = 4$ and $\gamma = 2$. In this case the total resistance to flow reads $R = \sum_{n=1}^{N} R_n = \sum_{n=1}^{N} \lambda^{\alpha/(\alpha+\gamma)} \left(x^{(\alpha-\gamma)/(\alpha+\gamma)}\right)^n l_n^{\beta}$, which increases with x. Minimum resistance occurs with $x = 2$ (bifurcating tree). Note that $x = 1$ must be excluded (point to point flow). Then, from eq. 3 we recover Murray'slaw of ratio of tube diameters in bifurcations, and because R_n is constant, from the previous equation for R we also obtain the law of ratio of tube lengths.

4. Conclusions

Structured flows are ubiquitous, which makes the Constructal Law a fundamental axiom for a wide range of sciences and technologies, from animate and inanimate natural systems to engineering. Here we briefly showed how general rules for building optimized flow trees can be defined based on the Constructal Law.

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Constructal Design of a Mineral Carbonation System for Post-Combustion Carbon Capture

Claudia Gasparovic[a*], George Stanescu[b], Marcelo Errera[a]

Abstract

This paper addresses the constructal design of a mineral carbonation porous bed reactor for capture of post-combustion CO_2. Analytical models allowed to obtain optimized parameters for the aspect ratio of the elemental volume, which is then packed in a hierarchical flow structure to minimize pressure losses (energy requirements). Results for the multi-scale design show that it is possible to associate geometric configurations with pressure drops for the carbon capture (CC) devices and to seek configurations that lead to lower energy expenditure. The findings can be applied for other types of fixed bed reactors.

Keywords: Carbon Capture, Greenhouse Gases, Constructal Design, Mineral Carbonation, CCS.[1]

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1. Introduction

Carbon capture and storage (CCS) has been recognized as a crucial path on achieving climate change mitigation goals. Mineral carbonation (MC) is among the safest and most promising alternatives for CCS, but technical challenges such as energy penalties need to be overcome in order to scale-up the technology [1]. This paper addresses the Constructal Design of a mineral carbonation (MC) reactor for CO_2 capture by identifying geometric degrees of freedom and using analytical models for *merit figures* aiming to increase flow access, i.e., minimize flow resistance [2] (represented here by the overall pressure drop (ΔP) in the reactor).

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2. Materials and Methods

The fixed bed reactor is a set of porous medium of rectangular section and fixed width, composed of packed semi-spherical porous pellets. An additional third (apparent) level of porosity (φ) is occupied by gas channels. Each elemental volume (e.v.) of fixed area $A_0 \sim H_0 L_0$, (Fig. 1) consists of a stack (thickness H_0) of one porous bed (of length L_0, thickness d_s and area A_s), and half $d_0/2$-wide feeding and collecting channels on top and on bottom, with the apparent porosity of the e.v. being $\varphi_0 = 1 - (A_s/A_0)$. Alternating feeding and collecting flow channels are inserted between porous beds to feed and collect a stream of $\dot{m}_0'/2$ (kg·s^{-1}·m^{-1}) humid exhaust gas containing CO_2, which in turn permeates the porous medium and reacts forming stable carbonates [3]. The degree of freedom (DoF) for the e.v. is written as the aspect ratio $\widetilde{H_0}/\widetilde{L_0}$, where $\widetilde{H_0} = H_0/(A_0)^{1/2}$ and $\widetilde{L_0} = L_0/(A_0)^{1/2}$.

The three components of the pressure drop in the elemental volume (ΔP_0) ($\Delta P_{\mathrm{L0,in}}$ and $\Delta P_{\mathrm{L0,out}}$ in the free channel L_0 direction and ΔP_s in the porous bed of overall permeability K) are estimated analytically by considering respectively Poiseuille flow and Darcy flow [2]. By making $\frac{\partial(\Delta P_0)}{\partial(\widetilde{H_0}/\widetilde{L_0})} = 0$ and substituting the optimum aspect ratio $\widetilde{H_0}/\widetilde{L_0}$, the minimum pressure drop is found (Eq. 1).

$$\Delta P_{0,m} \approx 3^{\frac{4}{3}} \frac{\dot{m}_0{}'\mu}{\rho} \frac{(1-\varphi_0)^{\frac{2}{3}}}{\varphi_0} \left(\frac{1}{K^2 A_0}\right)^{\frac{1}{3}} \tag{1}$$

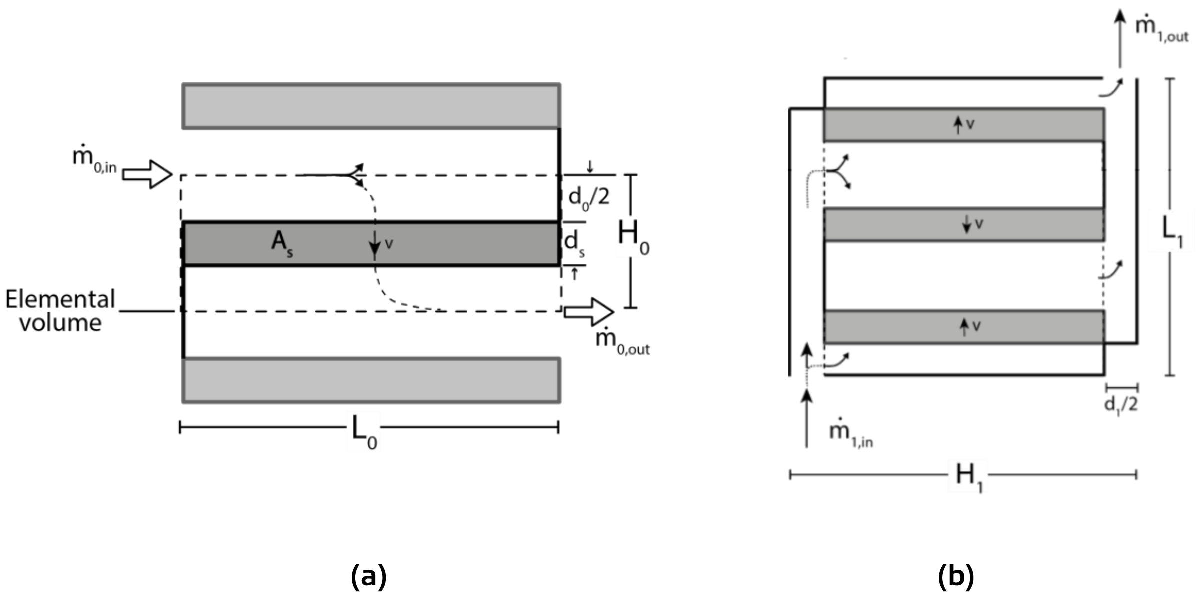


Figure 1. Carbon Capture system: **(a)** Elemental volume; **(b)** First Construct.

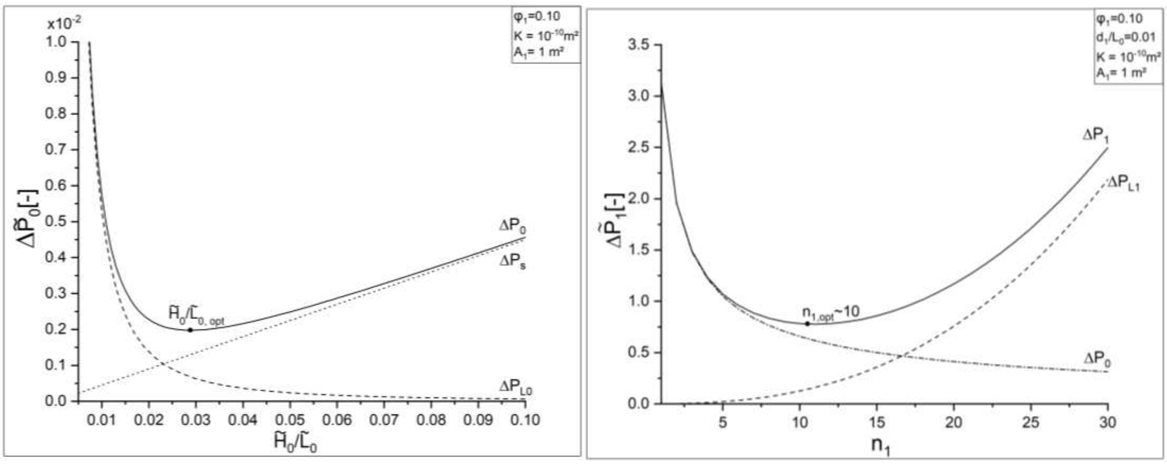
The same procedure is repeated for the First Construct (FC) of fixed area $A_1 = H_1 L_1 \sim L_0 L_1$ and apparent porosity $\varphi_1 \sim \varphi_0$, which is an assembly of n_1 elemental volumes connected by one feeding channel on one side and one collecting channel on the opposite side (Fig. 1). The twice minimized pressure drop for the FC is found by making $\frac{\partial(\Delta P_1)}{\partial n_1} = 0$, and after substituting $n_{1,\mathrm{opt}}$(Eq. 2).

$$\Delta P_{1,m,m} \approx \frac{2^4 3^{\frac{3}{5}}\, \dot{m}_1' \mu}{\rho \varphi_0{}^{\frac{6}{5}}} \left(\frac{\widetilde{d_1}}{\widetilde{L_0}}\right)^{-\frac{3}{5}} \left(\frac{1}{A_1^3 K^2}\right)^{\frac{1}{5}} (1-\varphi_1)^{\frac{2}{5}} \tag{2}$$

3. Results

Figure 2 shows how the pressure drop varies in the elemental volume and in the first construct with changes in the aspect ratio H_0/L_0 and n_1, respectively. Figure 2(a) shows that slender (longer than taller) elemental volumes will lead to lower pressure drops for all apparent porosity and that, as long as $\widetilde{L_0}/\widetilde{H}_{0,\mathrm{opt}}$ is used, pressure losses are of the same order of magnitude for a broad range of apparent porosity (φ) values.

Figure 3(b) shows that for each value of φ, there is an optimal number of elements in the first construct that leads to minimum pressure losses.



(a) **(b)**

Figure 2. Effect of aspect ratio H_0/L_0 and number of elements n_1 on dimensionless pressur in the elemental volume **(a)** and first construct **(b)**, respectively.

4. Discussion and Conclusions

Constructal Design has been employed to improve flow access of a fixed bed carbon capture system. Results show how the pressure drop (energy expenditure) varies with the geometric features of the device. The optimal geometry of the elemental system, and optimal number of elemental systems in the first assembly correspond to when the two terms of pressure losses are of the same order of magnitude (equidistribution of imperfections). The analysis presented comprehends a novel contribution to the Constructal Design of porous reactors since it is valid for any fixed-bed porous reactor, and it can be further extended to more complex cases.

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Sustainability assessment in built environment based onentropy generation

George Stanescu[a*], Marcelo Risso Errera[a]

Abstract

The irreversibility generation rate in any natural or technical system is a trusted quantitative indicator of its "inefficiency" or "imperfections". This is why the "entropy generation minimization" is one of the most used approaches for systems optimization. In complex situations, when multiple devices are participating together to maintain thermal comfort in built environments, the "total entropy generation" could indicate the magnitude of all losses due to the irreversible operation of real equipment and of losses due to the interactions with the environment, thus being able to constitute a prospect "sustainability index". This work addresses "total entropy generation" for "assessing" sustainability in the built environment seen as an ensemble of equipment (internal thermalcomfort). The "total entropy generation" is the sum of the entropy generation in each component of the ensemble consisting of an office space, together with an air conditioner and a power generator (internal combustion engine/TE) or PVs. We computed the entropygeneration per unit of emergy (labeled as "sustainability index") and compared for different configurations.

Keywords: Entropy generation, Sustainability assessment, Built environment, Constructal Theory

1. Introduction

The academy and state agencies alike seek metrics to assess what is and how much a given building or architecture design would be sustainable[1,2]. In this communication, we propose a prospect "sustainability index" for the use of residential or commercial built

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environments and its limitations. The rate of entropy generation could serve as an indicator of the level of sustainability of a system. The lower the rate of entropy generation in a system, the greater is its potential sustainability. We associate entropy generation with the major source of renewable and sustainable primary energy, the sun, by way of "emergy" [1] from photovoltaic panels. Constructal Theory [3] can provide a framework to evaluate how sustainability in the use of the built environment would evolve at a time when new infrastructure being built quickly on an unprecedented scale should coexist with the existing one. Would there be trade-off in the rate to replace theold *designs* by new ones (demolishing obsolete infrastructure)? Is there a metric that would be the main driver of the evolution of built environment?

2. Materials and Methods

The built environment's physical model as an example considered for studying the correlation between the emergy consumption and the associated entropygeneration, is represented by a daytime operation commercial office in Curitiba, Paraná, Brazil, located in a building with structure of reinforced concrete and a masonry envelope, which was comprehensively described by ref. [5].

The annual consumption of thermal and electrical energy to maintain the internal thermal comfort and the respective generation of entropy were estimated based on a mathematical model derived from the 1st and 2nd Law of Thermodynamics describing the operation of each component of the ensemble of heat pump and power generator (TE) or photovoltaic panels (PV). A heat pump operates according to a Carnot-type reverse cycle, while the power generator operates according to a Carnot-type direct cycle. All the components are considered irreversible, both internally and externally.

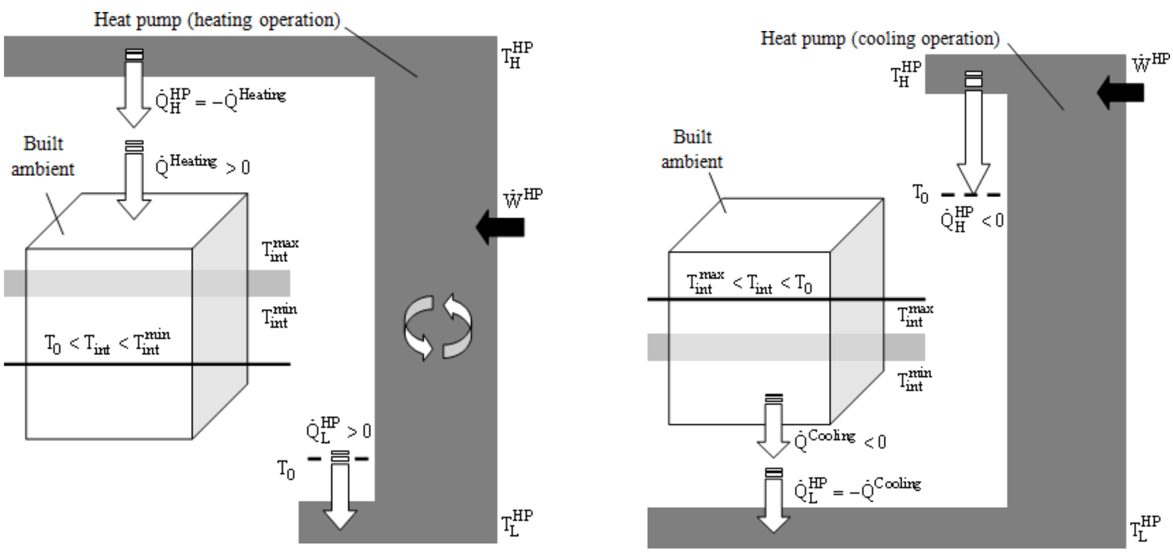

Figure 1. The ensemble of heat pump (HP) for maintaining the internal thermalcomfort in the considered commercial office (built ambient/BA.

3. Results

The numerical results presented in Fig. 2 are determined for two different configurations, BA&HP&TE and BA&HP&PV, when considering the following typical values for the HP's minimum and maximum operating temperatures, $T_L^{HP} = 253$ K$T^{TE} = 723$ K and $T_H^{HP} = 333$ K ,respectively, and of the thermal engine $T_L^{TE} = 723$ K $T_H^{TE} = 2400$ K also respectively, as well as the typical temperature of the TE's heating source, generation is considered according to published data for one conventional 40W mono-crystalline silicon, no cooling, with efficiency is 15% [6]. Thermal comfort achieved with temperatures between 18ºC-24ºC and relative humidity in the rangeof 60%–90%. To capture the effects of seasonal changes, numerical simulations were carried out based on the Climate Design Data 2009 ASHRAE Handbook for an 8,760 hours interval [5,7]. The emergy assessment is based on the solar transformity value, that takes 40kJ of sunlight to make 1 J of coal embodied energy [8].

4. Discussion and Conclusions

The gray shading in Fig.2 shows that all configurations using PVs require less emergy for their operation and generate less entropy. The proposed prospect "sustainability index" (seen right side of Fig. 2) compares different situations in which a given HP with the same COP receives electrical energy either from TE or PVs. When using PVs, the numerical values of $\Sigma_{index,1-2}$ are always greater than unity, which can support a metric to assess sustainability.

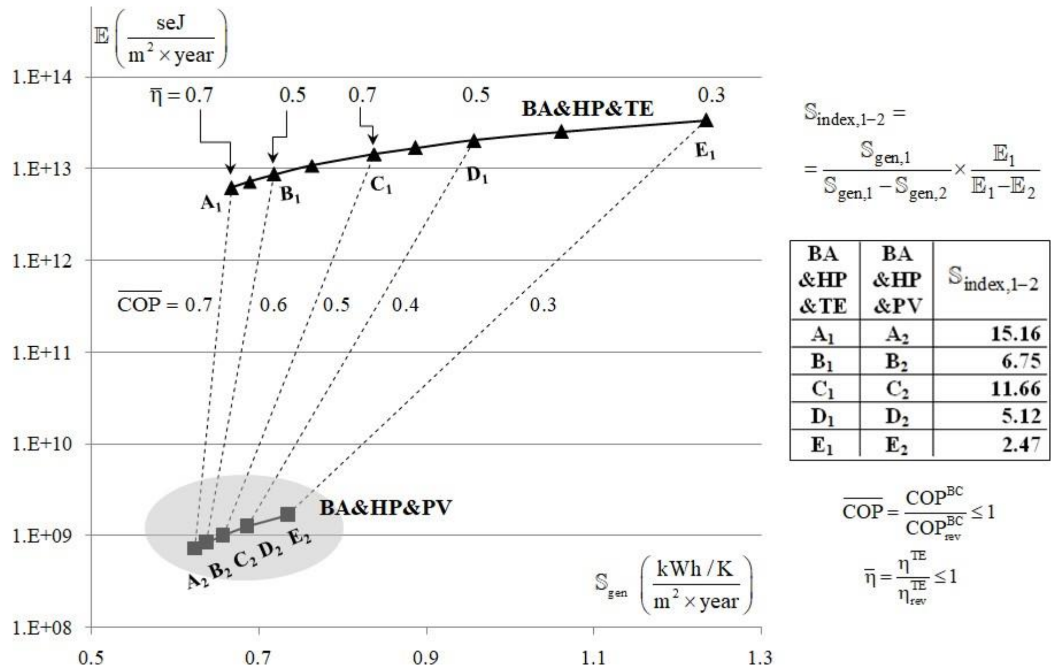

Figure 2. Emergy input versus entropy generation for the two consideredconfigurations, BA&HP&TE (▲) and BA&HP&PV (■).

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The intersection-of-asymptotes method applied to thestudy of skin temperature changes over time during running exercise

Giovanni Tanda[1]

Abstract

The intersection of asymptotes method is used to describe the skin temperature changes of human body during running exercise. Skin temperature variations are induced by the thermoregulatory mechanisms, which are affected by physiologicaland environmental factors. The purpose of this study is to link these factors in a compact and comprehensive way to provide an easy interpretative tool of this process.

Keywords: Intersection-of-asymptotes, Skin temperature, Running, Energy balance.

1. Introduction

The human body is subject to the laws of thermodynamics. At rest, a constant internal body temperature, of about 37°C, is maintained through a balance betweenthe metabolic heat production and the heat losses to the environment. As comparedto rest conditions, intense physical activity, such as running exercise, triggers muscular work, accompanied by an increased rate of metabolic heat production, and activates compensatory vasoregulation through a reduction of blood flow in theskin compartment (skin vasoconstriction) and an increasing demand of blood flowto active muscles. On the other hand, when the internal heat accumulation causes excessive core temperatures, blood must be redirected to the skin (skin vasodilation) to increase the heat transfer rate to the environment. The aim of this study is to provide a general interpretation of the skin temperature variations duringrunning exercise, under different intensity and environmental conditions. Thepresented approach is based on the method of intersecting the asymptotes, proposedby Bejan [1–4] as a possible criterion for the optimization of engineering systems.In this work, two different skin temperature changes over time (the asymptotes forthe "early" and "late" time periods of exercise), based on a simple lumped-parameter model, are outlined. From the balance of the two competing trends, the possible shape of the real skin temperature time-evolution, and the role played by the main variables upon which skin temperature depends, have been highlighted.

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2. Materials and methods

According to the two-node, lumped-parameter model, the temperatures of the core(T_{cr}) and the skin (T_{sk}) are introduced and two coupled heat balance equations, in transient conditions, can be derived separately for each compartment (see Tanda [5]for details).

Immediately after the onset of exercise (small t limit or early time period), the cutaneous vasoconstriction and the consequent delivery of blood to active musclesyield a reduction in the skin blood mass flow rate. The first asymptotic solution forthe skin temperature in the early period results to be

$$\frac{(T_{sk}-T_a)}{(T_{sk,0}-T_a)} = e^{-\frac{C^F}{\alpha\cdot m\cdot c_b}t} \tag{1}$$

where t is time, T_a is the ambient air temperature, $T_{sk,0}$ is the skin temperature at thestart of exercise, α is the relative mass of skin. m is the body mass, c_b is the body specific heat, and C' is the skin-to-ambient conductance. As the exercise progresses, the undissipated heat stored in the body leads to an increase in the coretemperature T_{cr}; to maintain the core temperature within a safe threshold limit, a vasodilator response (to carry excess heat out of the body through skin) is activated. During vasodilation, representative of the second part of the transient (large t limitor late time period), the rate of heat storage decreases, and the core temperature is likely to reach a quasi-steady platform. The following solution for T_{sk} is achieved where M_{net} is the net metabolic rate.

$$\frac{(Tsk-Ta)}{M_{net}/C^F} = 1 - e^{\frac{C^F}{\alpha\cdot m\cdot c_b}t} \tag{2}$$

Figure 1 schematically shows the typical trends of core and skin temperatures and the two asymptotic solutions for the skin temperature T_{sk} : the early-time limit (*I*), given by Eq.(1) and the late-time limit (*II*), given by Eq.(2).

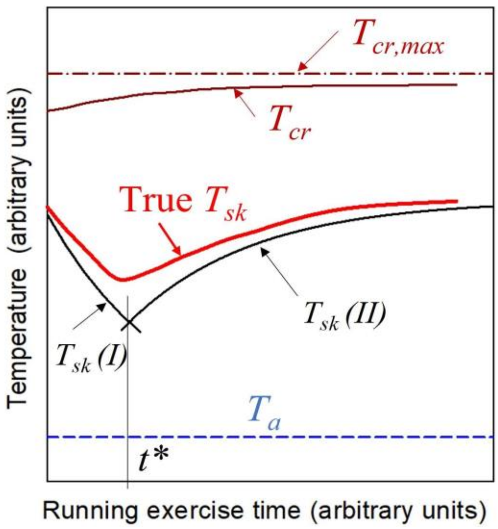

Figure 1. Typical skin and core temperature changes over time during running exercise. The asymptotic curves (*I* and *II*) for skin temperature, the exercise time to cutaneous vasodilation t^*, the maximum core temperature $T_{cr,max}$, and the ambient air temperature T_a are also indicated.

3. Results

The two competing asymptotes reflect the thermal responses of the skin during therunning exercise; their intersection identifies the most convenient time instant for the human body to switch the blood peripheral vasoconstriction to vasodilation in response to the exercise and their shape permits to infer the possible time-evolutionof skin temperature during exercise. Figure 2 shows how key parameters of the problem affect the two asymptotic solutions (left), and two representative skin temperature profiles with the respective asymptotic limits (right).

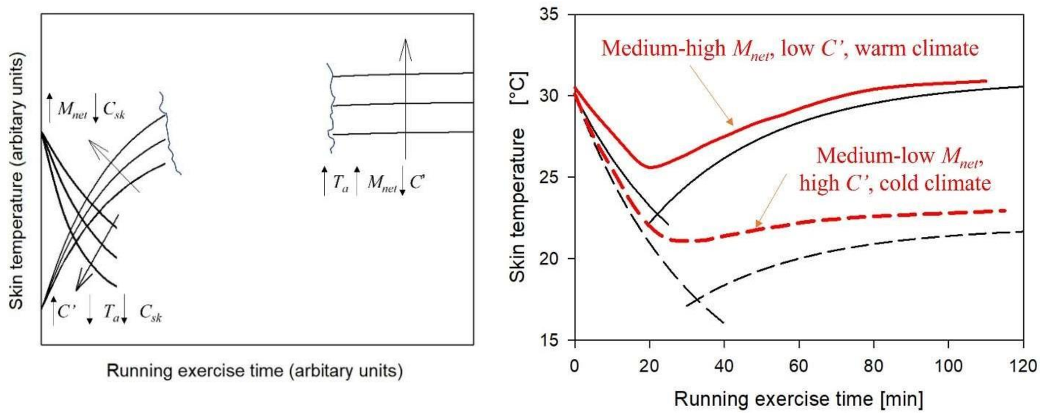

Figure 2. Effects of main physiological and environmental factors on the asymptotic curves(left) and on real skin temperature changes during exercise (right).

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From Thermodynamic Principles to Evolutionary Institutions: A New Frontier in Engineering

Alexander Tucker[1]

Abstract: Recent paradigm-shifting work has revealed that the thermodynamic feedbackprocesses which underlie physics, chemistry and biology have corresponding parallel processes in the socio-political, legal, and economic domains. This extended abstract aims to explore the challenges facing an emerging engineering discipline which integrates institutional design and governance within the framework of physics. It seeks to establish the means to engineer, evaluate and design institutions based on experimentally replicablesymmetries and to employ observable physical measures that can be iteratively optimised across tradespaces to tap into increasingly non-local potentials

Keywords: Thermodynamics, Evolution, Law, Economics, Engineering.

1. Introduction

The principal objective of this abstract is to explore the potential of integrating thermodynamic principles, particularly maximum entropy generation, into thedesign of for-profit corporations. Our analysis investigates the relationship between the concept of max-entropy thermodynamics and traditional shareholder value metrics and explores the outcomes and implications of physically-grounded measures of corporate performance on enhancing corporate adaptability, sustainable-growth, and long-term viability.

2. Methodology & Results

Our methodology centres on the application of systems engineering methods to the problem of institutional design and optimization within the framework of thermodynamics. This initial inquiry is structured as follows: (1) Identifying the corporate systems Form and Function, (2) Determination of Emergent Properties,
(3) Establishing Performance Indicators, and (4) Exploration of Optimizationprospects. The results of the preliminary analyses indicate that the practical application of physical principles, particularly maximum entropy generation, in the design and optimization of for-profit corporations, may offer distinct performance advantages when compared to previous methods.

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3.1 Form & Function

Traditional economic theory posits that corporations are legal entities established with the purpose of maximising profits for shareholders by providing goods and

services in the free market. Simultaneously, the thermodynamic perspective reveals that all living and non-living systems from simple systems like pouring milk into a cup of coffee to complex systems such as amoebas, primates and termite colonies, can be viewed as striving opportunistically to extract free energy from their environment at the greatest achievable rate given constraints. Theuniverse appears to exhibit a strong statistical preference for configurations of matter which efficiently capture and convert free energy into entropy [1]. Consequently, self-amplifying feedback loops that are subject to selection pressure favouring maximally dissipative states, result in the emergence of exceedingly complex behaviours such as: self-preservation, replication and growth [2]. The evolution of life, cognition and complexity is not a probabilistic fluke, but a natural consequence of the underlying laws governing our universe [1-4]. Darwinian evolution can be viewed as a special case of this underlying thermodynamic selection principle [5-7]. This underlying principle has been described at length elsewhere, and will be referred to generally as Maximum Entropy Generation (MEG) [2-7]. Extrapolating beyond single agents, self-organising social behaviour observed in colonies, superorganisms and tribes adhere to these same pressures, competing with other goal-directed agents for scarce resources [8]. Like all living and nonliving systems, for-profit corporations strive to opportunistically extract free energy from their environment at the highest achievable rate, therefore, the application of MEG principles to the analysis of corporations is a logical and natural progression.

3.2 Emergence

The pursuit MEG-optimization, within a market niche, selects for self-organising collectives wherein interactions among members exhibit emergent properties akin to collective-intelligence, thereby substantially augmenting the systems capacityto attain increasingly complex goals and, consequently, enhancing overall MEG-performance [9]. Suffice it to say, the emergent property of intelligence is likely the primary aim in designing corporations in accordance with physical principles. Systems engineering provides a structured and formalised framework for facilitating the emergence of higher level functions, such as collective intelligence, by providing systematic approaches to optimising various lower-level subsystems according to specific and measurable performance goals. Additionally,MEG provides an overarching framework to evaluate collective intelligence by quantifying the system's capacity to utilise available resources efficiently to extract energy from its environment. Optimising for MEG provides an integrative framework for corporate governance encompassing the multifaceted interconnections between the corporate system and its environment balancingefficient resource utilisation with an orientation towards transcending currentcapabilities and tapping into increasingly counter-intuitive potentials. As such, adopting MEG-based approach in corporate design and governance holds the potential to facilitate the emergence of higher levels of collective intelligence as measured by MEG-performance, by increasing operational efficiency, institutional adaptability and shifting decision-maker focus to longer time-horizons and broader environmental implications.

3.3 Performance Indicators

First however, we must consider the appropriate measures. However, bridging the gap between conventional methods of optimising for shareholder value and the novel approach of MEG poses a significant challenge. That said, from an information theoretic standpoint, currencies can be viewed as information about the allocation of goods and services in the economy. Consequently, maximising capital accumulation may already serve as a reasonable approximation for MEP. That said, while contemporary methods of maximising quarterly shareholder value generally leads to efficient resource allocation and productivity gains, criticsargue that it can result in rather narrow and myopic decision-making. As such, we may consider an orientation towards *lifetime*-MEG with an exponential or hyperbolic discount rate which balances short-term viability and adaptability with long-term growth, sustainability and innovation. Despite the absence of any standardised industry best practices for dealing with MEG-based performance indicators, using energy consumption or joules (J) as a measure offers a more stable and predictable measure of corporate performance, immune to the influences of inflation, interest rates, social behaviour, and governmental interventions, owing to its grounding in physical conservation laws. Thereby,corporations could explore the potential of such MEG-based measures, in quantifying and optimising performance and relative ranking, potentially leading to a scaled-down Kardashev-like measure for individual firms [10].

3.4 Optimization

As discussed above, corporations operate as self-reinforcing feedback loops which navigates the complex economic landscape and opportunistically allocates resources towards their own growth, replication, adaptation and survival. This complex emergent behaviour is traceable to sets of self-reinforcing feedback loopswhich follow precise invariances and symmetries, rendering them amenable to modelling, design, and optimization. Subsequently, control systems could be employed to monitor, analyse, and optimise these dynamic patterns of consumption, transformation and energetic flow throughout the company's operations. Enabling decision-makers to make data-driven predictions about the system's behaviour within standard operating conditions as well as reducing uncertainties and risks and anticipating future risks and opportunities. Optimising for MEG across the organisation lifetime implies increasingly efficient solutions to the notorious explore-exploit tradeoff between iteratively improving the efficiency, resource utilisation, and performance on known methods versus developing new adaptive methods that tap into new potentials. Achieving a balance between explore-exploit approaches in the pursuit of MEP implies employing adaptations that optimise efficient resource allocation and survivalwith long-term objectives like investment in research and development initiatives that may not yield immediate returns but are essential for long-term prosperity.

3. Conclusion

The objective of this study has been to explore the potential integration of thermodynamic principles, specifically MEG, into the design and optimization of for-profit corporations. We conclude that application of systems engineering methodologies provide a viable and practical methodology for the design and optimization of institutions within the framework of max-entropy thermodynamics. Through investigating the challenges and opportunities associated with integrating institutional design and governance within the framework of max-entropy thermodynamics, this initial feasibility study aimed to outline frameworks, methodologies, and strategies necessary to establish the foundation for an emerging discipline of thermodynamic institutional engineering.It is argued that adopting a thermodynamic perspective in institutional design and optimization offers distinct advantages compared to previous methods. Finally, we propose that maximising entropy generation over an organisation's lifetime serves as a potential pathway towards fostering long-term goal orientation, enhancing adaptability and ensuring sustainable growth.

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A Constructal law perspective of cancer's volume/area expansion ratio

Umberto Lucia[a], Giulia Grisolia[b], Debora Fino[c], Thomas S. Deisboeck[d]

Abstract

Constructal law is used to improve the analysis of the resonant heat transfer in cancer cells. The result highlights the fundamental role of the volume/area ratio and of its role in cancer growth and invasion. Cancer cells seek to increase their surface area to facilitate heat dissipation; as such this tumour expansion ratio declines as malignant cells start to migrate and the cancer expands spatially, both locally and, eventually, systemically. Consequently,we deduce that effective anti-cancer therapy should be based on the control of some ion transport phenomena in an effort to increase the volume/area ratio. This emphasizes restricting local and systemic spatial expansion of the tumour system and thus gives further credence to the superior role of novel anti-migratory and anti-invasive treatment strategies,over conventional anti-proliferative options only.

Keywords: Biophysics; Constructal law; Irreversibility; Cancer; Volume-area ratio in cellsystems

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1. Introduction

From a thermodynamic perspective, biological cells behave as thermodynamic engines that convert the inflow heat into work [1] by using two different cellular metabolic pathways [2]: the Krebs cycle, characteristic of normal cells, and the Warburg cycle, found in cancer cells. Consequently, any cell dissipates heat into its environment. Different metabolic processes have varying thermodynamic efficiencies [3]; as such, by the usual behaviour of open systems, the aforementioned metabolically different cycles are expected to present two distinct heat outflows through the cell membrane. In oncology, the fundamental Norton- Simon hypothesis was introduced: "Therapy results in a rate of regression in tumourvolume that is proportional to the rate of growth that would be expected for an unperturbed tumour of that size" [4]. This statement suggests tumour size has a fundamental role in cancer cells' behaviour, and, not surprisingly, 'volume' remains *the* interesting quantity clinically. Concerning the previous consideration that cells must dissipate heat, and that this heat flux is related to cell efficiency, we highlightthat the fundamental geometrical characteristic of heat transfer is the area of the cell's external surface. Thus, Constructal law can play a fundamental role in this analysis.

This paper will develop the analysis of geometrical characteristics of cancerstarting from some previous results [5] with regards to the role of heat transfer in cancer, also considering possible anticancer therapeutic strategies.

2. Materials, Methods and Results

The thermo-kinetic lumped model has been used to model this heat transfer [5] andholds to a characteristic time τ that can be defined [5]:

$$r = \frac{\rho c}{\alpha} \frac{V}{A} \tag{1}$$

where *r* is the cell mass density, *V* stands for the volume of the cell, *c* is the specificheat of the cell, α denotes the coefficient of convection, *A* stands for the surface area of the cell, which varies during the phases of the development of the cell itself.The cell can relatively abruptly change the ratio *V*/*A*. So, if we introduce the basis of the Constructal law, i.e., maximum heat flux, it follows:

$$Q = \alpha A \Delta T_0 e^{-t/c} \tag{2}$$

where ΔT_O is the temperature difference between the cell membrane external surfaceand the fluid around the cell. The thermal transient process ends in around $t = 3\tau$. We hypothesize that heat is maximum in relation to the cell surface area *A* and the characteristic time τ at the end of the transient interval:

$$\frac{dA}{A} \leq \frac{3}{2} \frac{dV}{V} \tag{3}$$

The resulting Equation (3) can be interpreted as follows: for normal, non-cancerouscells, in support of single cell growth, the relative variation of its surface area mustbe lower than the relative variation of its volume, i.e. volume expands more than surface area, else growth is impeded. This result agrees with the measurements of surface area-to-volume ratio developed in the analysis of cellular viscoelasticity ofred blood cells, which experimentally result in 1.50±0.12 [6]. Moreover, the relationship between morphology and phenotype has been recently investigated, showing that changes in cell shape precede and trigger some modifications in geneexpression and enzymatic function, but also in the tumour metabolome [3], suggesting cells undergo a phenotypic reversion [7].

3. Discussion and Conclusions

The dynamic equilibrium between cell proliferation and cell death, tissue morphogenesis, and differentiation is the control process of normal cell behaviour.When this balance is lost, transformation may occur and cancer can evolve - a combined effect of dysregulated morphogenesis and uncontrolled proliferation. The mechanisms that generate cancerous growth can be genetic and epigenetic but may also result from changes in the cell's environment and tissue organization. Many processes are related to nano-mechanical properties of the cell membrane and its structure. In this context, cell surface modifications may confer therapeutic potential. New drug carriers can be designed more efficiently for drug delivery barriers at every level of drug distribution, including systemic, tissue and cellular levels. Indeed, in cells all the biological processes convert molecular binding energy, chemical bond hydrolysis and electromagnetic gradients into mechanical work, which is often related to conformational changes and displacements. The study of ion transport phenomena in cancer pointed out [8] the regulatory role of ion channels and transporters impacting cell cycle phases of neoplastic progression,resistance to apoptosis and tumour cell invasion [8]. Cancer cells can store less chemical energy than non-cancerous cells due to their lower efficiency to metabolise energy [5]; over the same time interval, a cancer cell needs to dissipate more of this unused energy in form of heat into the environment. It follows that cancer cells must increase their external surface to optimize the convective thermal fluxes. As a biomechanical consequence, on the single cell level such surface extension is reflected in cell elongation, which in turn could trigger the onset of cellmotility. On a multicellular scale, such tumour invasion should damage adjacent tissue architecture and thus reduce mechanical confinement which, conceptually, facilitates further volumetric on-site growth, and fuels a vicious cycle. We stress that related biochemical phenomena occur: indeed, Na^+, K^+, and Cl^- ion fluxes are responsible for membrane voltage regulation, while Ca^{2+} and Mg^{2+} ion fluxes are responsible for protein folding, and Zn^{2+} being responsible for the control of HCO^{3-}formation. Each ion induces different heat effects, but all of them generate heat loss.All these processes occur contemporary during cancer growth and metastasis, and cancer growth is the result of the cells' energy management, and of the heat and mass transport through the tumor cells' membrane. Thus, cancer cells must strive todecrease their "volume/area ratio". This would explain the transition to the aforementioned migratory phenotype on the single cell level as well as angiogenesison the multicellular tumour level where the sprouting of vessels towards the tumour expands the exchange surface as much as it further reduces confinement and provides routes for cancer cell dissemination and eventually, metastasis – which canbe understood as a systemic tumour area optimization constrained by the 'host' organs specific carrying capacity. Intriguingly, highly metastatic kidney cancer cellshave been shown to exhibit increased cytoskeletal dynamic and deformation, whichhave been related to processes of vascular invasion. Consequently, novel concepts for anti-cancer therapy can be based on the control of some ion transport phenomenain an effort to target the tumour system's intrinsic 'volume/area' ratio decrease, i.e.,that it expands its surface area relatively more than its volumetric core. Specifically,this points towards favouring anti-migratory and anti-invasive therapeutic strategies as opposed to the conventional anti-proliferative modalities which would reduce thenumerator disproportionally and thus unintentionally create (re-)growth promotingconditions.

Finally, we note that our approach is not neglecting other metabolic levers that tumours can utilize. For instance, Equation (1) contains another fundamental thermophysical quantity, the convection coefficient α. Tumour cells can increase itto further raise heat transfer and this is related to blood flow and thus angiogenesis.In reality, all these factors work in parallel.

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Exploring 3PL outsourcing decisions on selected logistic performance: A Systematic Literature Review and Future Research

Anna Weerakoon Karunatilleke[1]

Abstract

Supply Chain Management is a network of facilities that produce raw materials, transform them into intermediate goods and then final products, and deliver these products to customers through a distribution system. When selecting a third-party logistics provider, the required speed, cost-effectiveness, and trustworthiness are important factors taken intoconsideration. A systematic literature review of state-of-the-art 107 publications on the relevant topic was done from the years 2016- 2023 to identify conceptual and empirical studies. The research findings are synthesized into categories of uncertain events, supply chain practices, and outcomes. The impact of emerging technology on various supply chain operations is examined in this research. Because it describes the pillar components for any supply chain change, the suggested work is valuable for both academics and practitioners. Practitioners can benefit from the knowledge of interventions and mechanisms to improvetheir supply chain performance. The scrutinized observation identifies several knowledge gaps where strategic use of 3PLs in the industry could be optimized and develops propositions for future research.

Keywords: Outsourcing, 3PL, Strategic Supply Chain, Logistics, Performance

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1. Introduction

Outsourcing components have increased progressively over the years (Thai et al., 2021). Logistics plays a major part in Supply Chain Management and has a direct impact on firm performance. In today's world, the majority of organizations outsource their logistical functions to third-party logistics providers (3PL parties). Companies outsource their logistical operations for a variety of reasons. They primarily strive to meet core business objectives while outsourcing non-core business activities.

When selecting a third-party logistics provider, the required speed, cost-effectiveness, and trustworthiness are important factors taken into consideration. Moreover, business companies must ensure that their outsourcing objectives and the service provider are in sync; this alignment is a critical task (Samgam and Shee, 2017), mainly in the risk management process and lack of collaboration between both parties (Langley and Infosys,2021, pp. 29–33). Complexity comes in the structure and risks companies run while searching for logistics operators (Sanchis-Pedregosa et al., 2018), which provide sophisticated logistics solutions on a regional or even global scale (Huang et al., 2019). This means that once a company selects logistics activities to be outsourced, it is important to determine the extent of logistics activities outsourced (Mageto et al., 2018).

In spite of the huge importance of the issue of supply chain performance, the literature is yet to link the disruptions from different sources with the existing practices and the outcomes. This paper aims to synthesize the fragmented knowledge of supply chain performance by addressing the key research question:

RQ: What are the different 3PL outsourcing decisions that affect logistical performance?

This is addressed by systematically reviewing the articles published in academic and practitioner journals during the past 8 years from 2016 to 2023. This paper begins by describing the method adopted in this literature review. Overall findings describe the state of development of the field and reveal what is known concerning the context, interventions, performance of supply networks, and the interrelationship between context and interventions and between interventions and outcomes. An investigation is made of the mechanisms that provide insight into the design of interventions for a specific context delivering specific desired outcomes. Based on the relationships between the different elements of the framework, a set of propositions is developed that will provide a basis for comprehensively operationalizing supply chain performance and building a testable model grounded in the literature.

2.0 A Systematic Review of Literature Methodology

A systematic literature review methodology (Tranfield et al., 2003) is used, in which there is a comprehensive search for relevant studies on a specific topic, which are then appraised and synthesized according to a pre-determined explicit method. The review strategy has a number of stages designed to provide a systematic and explicit method for comprehensive coverage of the research area investigated in this paper. The following steps were taken in this study:

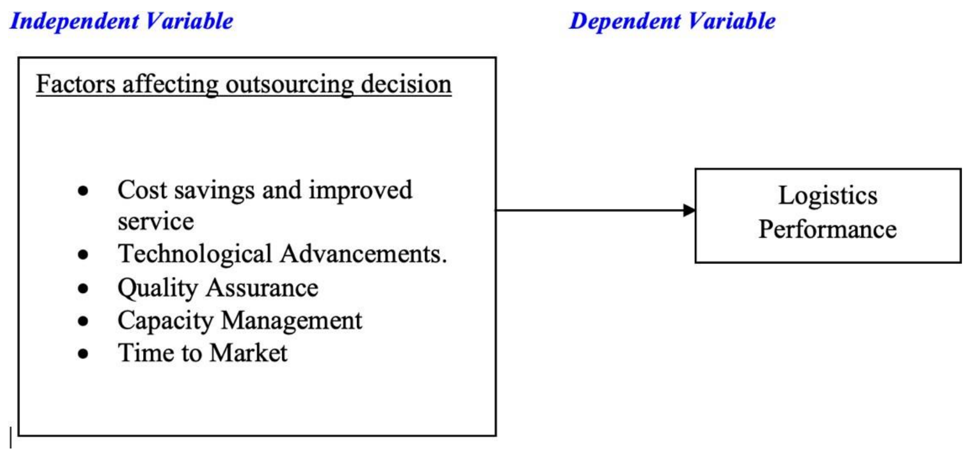
- Searching
- Screening
- Extraction and Synthesis
- Reporting.

3.0 Basic definitions of different constructs surrounding 3PL

Three waves of entrants have been disclosed when in-going the markets of TPL markets (Berglund et al., 1999).

1. "Traditional wave" when providing the logistical functions in the 1980's.
2. The second wave is basically about how the organization "FEDEX" does its logistical activities in the early 1990s.
3. The third wave is about how TPL has partly developed its technological, consultancy, and management systems.

The Figure 1.0 was formulated from the results of the systematic review methodology.
Figure 1.0: Conceptual Framework



4.0 Conclusion and Future Research

There are two contributions to this research. The first is identifying context-specific essential interventions and mechanisms and the second is relating them to generate desired outcomes. Although there have been several thousands of articles published, only a handful of them actually direct interventions to appropriate contexts.
Managing the supply chain is most challenging for any organization because of business practices, government regulations, technology capability, transportation infrastructure, etc. A literature review reveals a considerable spurt in research in the theory and practice of Supply Chain Management and 3PL. It is my hope that future research will pay more attention to generating much-needed conceptual and empirical work in the Supply Chain Management literature, thereby creating a body of literature that is more heavily influenced by a deeper analysis of the supply chain on a chain-wide or network basis

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Constructal Law Conference (CLC 2023)
Freedom, Design and Evolution
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Evolutionary design with freedom of fin channels

H. Almahmoud[a,b]

Abstract

In this article, a novel approach is presented where the focus is on freely varying the aspectratio of the fin shape to achieve a high-density heat transfer flow architecture. When the solid volume is specified, and the fluid flow rate is known, it is possible to anticipate fromtheory the flow configuration. The primary objective of this evolutionary design approachis to maximize heat transfer to the cold stream. One way to predict the optimal aspect ratio is by scale analysis of the physics that contemplates the heat currents through the fins. The theoretical findings are validated through numerical simulation which results in perfect match. This is a step towards complete evolutionary design that predicts all degrees of freedom.

Keywords: Evolutionary design; freedom; constructal; fins; extended services.

1. Freedom to change the configuration

Fins, also known as extended surfaces, play significant role on thermal performanceof various engineering applications. They serve as extended surfaces that enhance heat dissipation by increasing the surface area available for heat transfer. Efficient heat transfer in fins is crucial for maintaining optimal temperatures in electronic devices, power systems, and other heat-generating equipment. Recent publications in the field of heat transfer have shed light on the benefits derived from introducing multiple degrees of freedom to the flow configuration [1-4]. The aim of this paper is to introduce new theoretical findings and validate it by numerical simulations, building one brick towards predicting complete evolutionary design architecture.

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Consider a laminar and steady flow with temperature (T = 0) and speed U passing through set of parallel-plates fins that have high temperature base (T = ΔT), as shown in Fig. 1. The design is consistent of several elemental volumes, and for simplicity one elemental volume is being studied as highlighted in Fig. 1. For fixedfins and flow volume, the design has several degrees of freedom which we can represent in terms of aspect ratios. This work concentrates on deriving one degree of freedom, the fin shape viewed from the front (t/H).

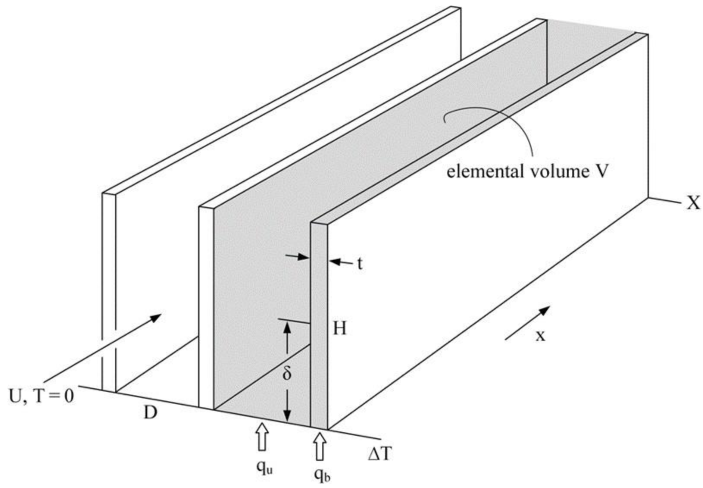

Figure 1 Flow channels of fins with heat transfer from the base.

2. Mathematical derivation of the optimal fin shape

The direction of the evolutionary design is guided by maximizing thermal contact between the base (ΔT) and the approaching cold stream. According to Bejan, the evolutionary design of the fin shape (t/H) that delivers maximum fin heat current (q_b) at fixed fin volume per unit flow length is given by [5, 6]:

$$\frac{t}{H} = 0.996 \left(\frac{h}{k}\right)^{1/2} \tag{1}$$

Where the fin conductivity (k) is also fixed, the heat transfer coefficient h is assumed constant and known, and the shape of the t × H cross section varied towardgreater heat transfer density in the fin volume. The base heat current [W/m] that corresponds to Eq. (1) is

$$q'_{\text{fin}} = 1.258\left(\frac{ht}{k}\right)^{1/2} \tag{2}$$

The validity of Eqs. (1, 2) can be tested in two ways, numerically (section 3) and interms of scale analysis. The fin profile t/H of Eq. (1) expresses a balance betweenthe resistance to fin conduction in the H direction $q'_{\text{cond}} \sim kt(\Delta T/\delta)$ and the resistance to convection at the fin surface $q'_{\text{conv}} \sim h\delta\Delta T$, transversal to the fin. Setting these two heat rates equal, we obtain

$$\frac{t^{1/2}}{\delta} = \left(\frac{h}{k}\right)^{1/2} \tag{3}$$

This result reveals the portion of the fin (δ) that truly functions as an extended surface of the base. When the balance between the two heat rates is reached, the finprofile is filled completely by heat flux lines that enter the fin from the base, and exit to the two sides, as convective heat flux. Therefore, the minimum working volume corresponds to H ~ δ, the base heat current per unit of fin volume is maximum, and Eq. (3) becomes the same as Eq. (1):

$$\frac{t}{H} = \left(\frac{h}{k}\right)^{1/2} \tag{7}$$

3. Results from numerical simulation

The second way to examine the theoretical analysis is by numerical simulation. we simulated our findings numerically using the finite element software COMSOL. The design consists of 2D rectangular fin with width t, height H, and constant temperature difference ΔT at the fin base as shown in the top right corner of Fig 2.

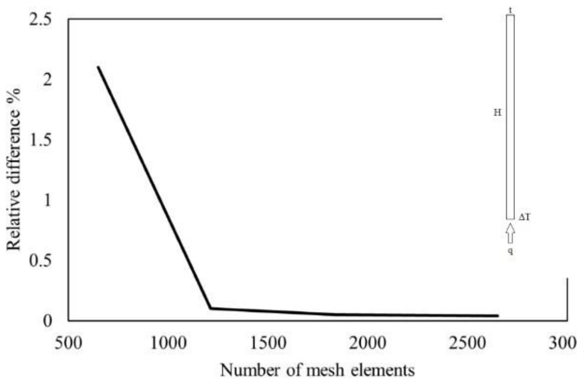

Figure 3 Numerical set up and accuracy test

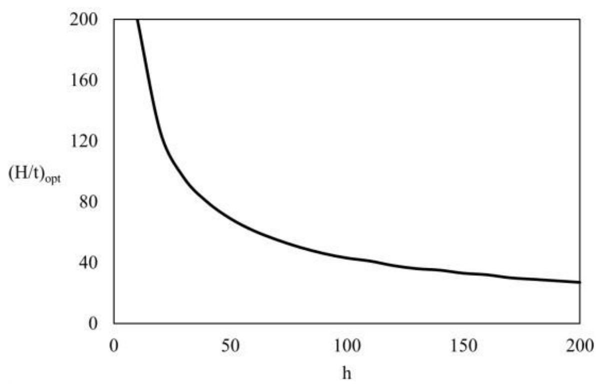

Figure 2 Optimal (H/t) ratios for range of h values

Additionally, this figure shows how the number of mesh elements plays the key role in the accuracy of the results. Starting with low elements number, we compare the result with coarser mech and calculate the result's relative difference % in an approach known as h-refinement. Therefore, the analysis was conducted at 1214 mesh elements where further increase in the elements would result in more computational effort with no sensible accuracy improvement.

The fin has two variables, the aspect ratio (H/t) and convection heat transfer coefficient h. For each h value there is an optimum $(H/t)_{opt}$ at which Eqs.1&2 are evaluated. Fig.3 presents the numerical results for the optimum aspect ratio for h values ranging from 10-200 W/(m2K).

Based on these $(H/t)_{opt}$ values, Fig.4 proves the validity of Eq.1 where the ratio stays constant at 1 for all h values. Next is examining Eq.2 through the same h and $(H/t)_{opt}$ values as shown in Fig.5. The CFD analysis showed exact match with the presented theoretical derivation. This work is the first step towards inclusive evolutionary design that studies all degrees of freedom to achieve higher heat dissipation while maintaining lower pressure drop.

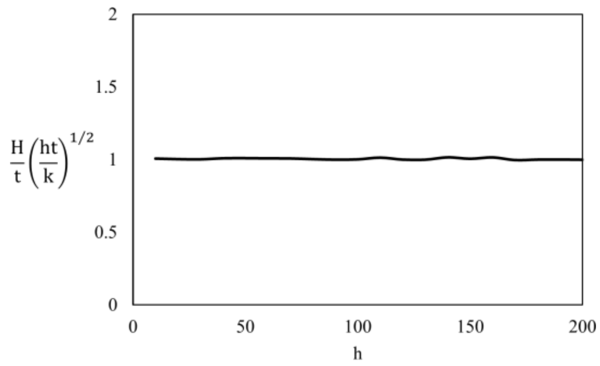

Figure 4 Numerical validation of Eq. 1.

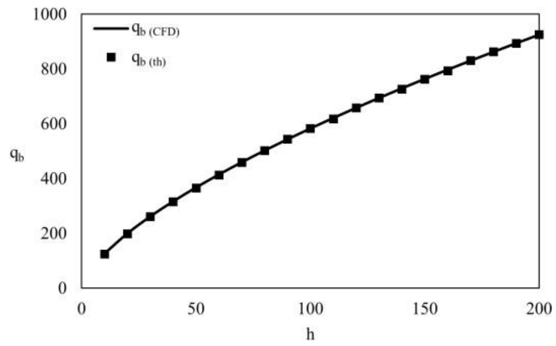

Figure 5 Numerical validation of Eq. 2.

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Thermal Performance Improvements in Heat Sinks by Using Constructal Law for Electronic Cooling Applications

Masoud Asadi[a], Mohamed M. Awad[b]

Abstract

Pin-fins are considered as the best elements for heat transfer improvement in heat exchanger devices. As one of the best method is to use geometric optimization of the topology of pin-fins (length, diameter and shape) based on the Entropy Generation Minimization (EGM) theory with the help of Constructal Law (CL). Such pin-fins are employed in a heat exchanger in a sensible thermal energy storage system so as to enhance the rate of heat transfer. First, the EGM method is used to obtain the optimal length of pin-fins, and then the CL is applied to get the optimal diameter and shape of pin-fins. Reliable CFD (computational fluid dynamics) simulations of various constructal pin-fin models are performed. The results showed that after optimization the net energy saving is increased by 24%.

Keywords: Pin-fin heat exchanger; Entropy generation; Constructal Law; Optimization; Computational Fluid Dynamics

1. Introduction

In this study, a new thermal energy storage system for pre-heating of internal combustion engines before running was designed. To have more efficient TESS, constructal theory coupled with Entropy Generation Minimization theory was applied. TESS works on the effect of absorption and rejection of heat during the solid-liquid phase change of PCM. This system was designed for a gasoline engine at 2° C temperature and 1 atm. A tube heat exchanger was used for storing thermal energy. Designing process was performed in two stages: (i) first, the length of tube was optimized by entropy minimization theory; (ii) then, the optimum configuration which causes to maximum heat transfer was found by helping constructal theory.

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2. Mathematical Model

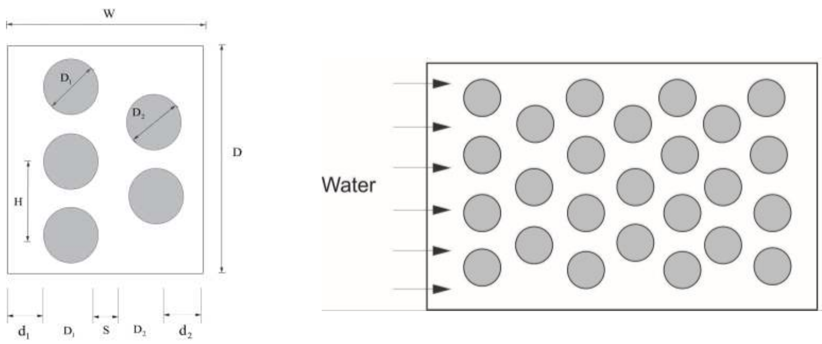


Fig. 1 (a) Two rows with unequal pin fins (b) structure of tube exchanger; view from above

Fig. 1 (a) and (b) show the case studied in this paper. The relationship between lost available work and entropy generation is as

$$\begin{cases} \dot{W}_{lost}=T.\dot{S}_{gen} \\ \dot{S}_{gen}=\dfrac{\partial S}{\partial t}-\dfrac{Q}{T}-\sum\limits_{in}\dot{m}S+\sum\limits_{out}\dot{m}S \end{cases} \tag{1}$$

The above equation states the Gouy-Stodola theory. Both heat transfer and friction factor can produce entropy. The entropy production owing to heat transfer can be calculated from

$$\dot{S}'''_{gen}dxdy=\frac{q_x+\dfrac{\partial q_x}{\partial x}dx}{T+\dfrac{\partial T}{\partial x}dx}dy+\frac{q_y+\dfrac{\partial q_y}{\partial y}dy}{T+\dfrac{\partial T}{\partial y}dy}dx-\frac{q_x}{T}dy-\frac{q_y}{T}dx+\left(s+\frac{\partial s}{\partial x}dx\right)\left(\upsilon_x+\frac{\partial \upsilon_x}{\partial x}dx\right)\left(\rho+\frac{\partial \rho}{\partial x}dx\right)dy$$
$$+\left(s+\frac{\partial s}{\partial y}dy\right)\left(\upsilon_y+\frac{\partial \upsilon_y}{\partial y}dy\right)\left(\rho+\frac{\partial \rho}{\partial y}dy\right)dx-s\upsilon_x\rho dy-s\upsilon_y\rho dx+\frac{\partial(\rho s)}{\partial t}dxdy \tag{2}$$

For the two-dimensional Cartesian system, the entropy production is

$$\dot{S}'''_{gen}=\frac{k}{T^2}\left[\left(\frac{\partial T}{\partial x}\right)^2+\left(\frac{\partial T}{\partial y}\right)^2\right]+\frac{\mu}{T}\left\{\left[2\left(\frac{\partial v_x}{\partial x}\right)^2+\left(\frac{\partial v_y}{\partial y}\right)^2\right]+\left(\frac{\partial v_x}{\partial x}+\frac{\partial v_y}{\partial y}\right)^2\right\} \tag{3}$$

and for friction factor from

$$\dot{S}_{gen} = \dot{m}\left(\int_{\rho_{out}}^{\rho_{in}} \frac{\nu}{T} dP \right)_{h=constant} \tag{4}$$

To analyze the entropy generation more efficiently the Bejan number was introduced recently. For Be=1 the heat transfer irreversibility dominates, when Be=0 the irreversibility is dominated by fluid friction effects, and Be=0.5 is the case in which the heat transfer and fluid friction entropy generation rates are equal.

3. Numerical approach

The configuration has four dimensions that can vary (S, D_1, D_2, H). Using the constraint the remained degree of freedom is three, $\frac{D_1}{D_2}, \frac{H}{D}$, and $\frac{S}{W}$. Here, the flow is assumed steady, laminar, incompressible, and two dimensional. All of the thermo-physical properties are assumed constant. The analysis of conservation equations for mass, momentum and energy can deliver the optimal configuration.

$$\frac{\delta \tilde{u}}{\delta \tilde{x}} + \frac{\delta \tilde{v}}{\delta \tilde{y}} = 0 \tag{5}$$

$$Re\left(\tilde{u}\frac{\delta \tilde{u}}{\delta \tilde{x}} + \tilde{v}\frac{\delta \tilde{v}}{\delta \tilde{y}}\right) = -\frac{\delta \tilde{p}}{\delta \tilde{x}} + \nabla^2 \tilde{u} \tag{6}$$

$$Re\left(\tilde{u}\frac{\delta \tilde{u}}{\delta \tilde{x}} + \tilde{v}\frac{\delta \tilde{v}}{\delta \tilde{y}}\right) = -\frac{\delta \tilde{p}}{\delta \tilde{y}} + \nabla^2 \tilde{u} \tag{7}$$

$$Re.Pr\left(\tilde{u}\frac{\delta \tilde{T}}{\delta \tilde{x}} + \tilde{v}\frac{\delta \tilde{T}}{\delta \tilde{y}}\right) = \nabla^2 \tilde{T} \tag{8}$$

$$(x, y) = \frac{(\tilde{x}, \tilde{y})}{L} \tag{9}$$

$$S = \frac{s}{L} \tag{10}$$

$$(u, v) = \frac{(\tilde{u}, \tilde{v})}{U_\infty} \tag{11}$$

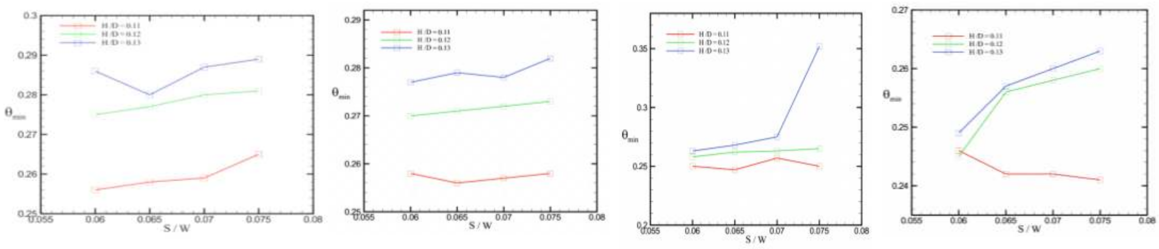
$$\tilde{T} = \frac{T - T_\infty}{T_w - T_\infty} \tag{12}$$

$$\tilde{p} = \frac{P}{\mu U_\infty / L} \tag{13}$$

Where Re and Pr are Reynolds and Prandtl numbers, respectively. T_∞, T_w and U_∞ are free-stream temperature, wall temperature, and free-stream velocity, respectively.
We are interested in the geometric configuration in which the global thermal resistance is minimized. The global thermal resistance can be measured from

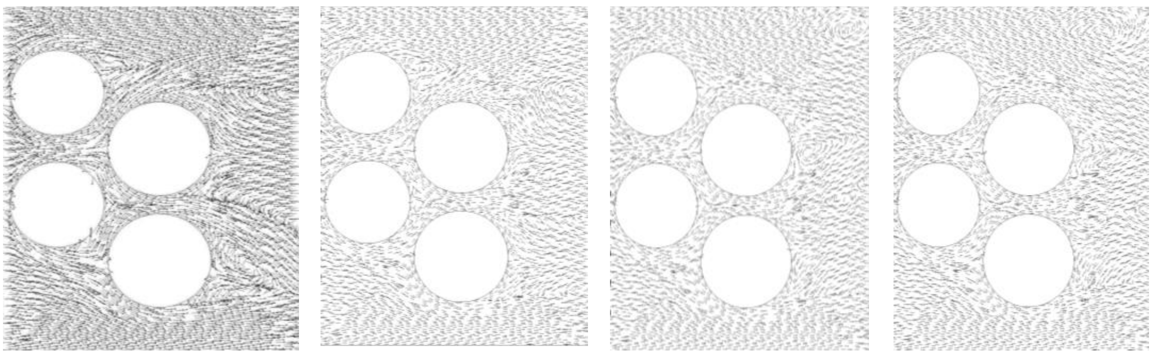
$$\theta_{max} = \frac{(T_w - T_\infty)}{q/L/k} \tag{14}$$

4. Results



(a) $\frac{D_1}{D_2} = 0.7$ (b) $\frac{D_1}{D_2} = 0.8$ (c) $\frac{D_1}{D_2} = 0.9$ (d) $\frac{D_1}{D_2} = 1.0$

Fig. 2 Global Thermal Resistace



(a) (b) (c) (d)

Fig.3 Stream functions forD_1/D_2 = 1.1, S/W = 0.06 and H/D = 0.12: (a) Re=10; (b) Re=50; (c) Re=100; (d)

The search for optimal pin fins was organized in three nested optimization loops. The pin-fin flow structure has three degrees of freedom which are designed as , $\frac{D_1}{D_2}$, $\frac{H}{D}$, and $\frac{S}{W}$. We started by fixing the tube ratio at 0.7. The degrees of freedom that remain are the streamwise ratio $\frac{S}{W}$, and spanwise ratio $\frac{H}{D}$. The non-dimensionalized flow length $\tilde{L}$ is set equal to 1.0, and the flow width is $\frac{\tilde{L}}{2}$. For the first run we fixed the tube diameter ratio at 0.7 and then the streamwise ratio was varied. It is possible to notice that there are appreciable differences among the global thermal resistance for three spanwise ratios, as shown in Fig. 2.

The procedure to reach the minimal overall thermal resistance was repeated: Fig.2 (b) to (d) show the function of the global thermal resistance for different $\frac{D_1}{D_2}$ values. For the ratio of $\frac{D_1}{D_2}$ = 0.8, there is similar trend as $\frac{D_1}{D_2}$ = 0.7. But for $\frac{D_1}{D_2}$ = 1.0, where the optimal configuration was placed, the constructal law shows different approaches.

The instability is amplified at higher Re, the frequency of wake area increases, and the distortion in the spanwise direction is intensified. At constant the spanwise and streamwise spacing but higher Reynolds numbers, the flow becomes turbulent before leaving the channel. With further increases in Re, the transition to the larger vortices starts successively, limiting the laminar range of longitudinal vortices and leading to fully turbulent flow further downstream without longitudinal vortices, Fig. 3 clearly shows this phenomenon.Conclusions

The estimation of entropy production is one of the best methods for the thermal performance optimization. In this study, some correlations to determine the entropy generation rate were proposed. In the first stage, the optimal length of tubes was found by the entropy generation minimization theory. Then, the constructal law was used to find the optimum configuration. The results indicate that using designed system by constructal law thermal energy can be stored 10.8% more than Gumus' system [1]. The effect of spanwise spacing on the Nusselt number showed that heat transfer rate is much more sensitive to spanwise spacing rather than streamwise spacing.

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Constructal Law Conference (CLC 2023)
Freedom, Design and Evolution
Turin (Italy), 21 – 22 September

Lines and curves and a homage to Leonardo

Dan C. Baciu[a,b]

Abstract

Leonardo da Vinci's drawing of a human figure placed in the center of both a circle and asquare continues to captivate the imagination of countless people. The idea for this arrangement dates back to Vitruvius, a Roman architect who stated that the human body can harmonize with straight-lined architecture as much as it does with round-shaped theaters, arches, or domes. Today, lines and curves have gained a much broader meaning.Lines stand for linear mathematics, while curves symbolize nonlinearity. This opens up a whole new range of perspectives. Lines can be used to describe creativity. Curves stand for play. Lines stand for evolution. Curves stand for revolution. Lines are used to represent vectors. Curves symbolize interplay between opposite forces and freedom to change direction. In this essay, I argue that when we look at the world that surrounds us today, we must almost necessarily look at it in two different ways that reveal two different perceptions: We see linearity and nonlinearity. Perhaps, if we were to translate this two-sided perception of the world back into Leonardo's graphical language, we would draw a human figure, as a symbol for ourselves, and we would place it in thecenter of both a square and a circle. We could let the straight lines of the squaresymbolize motion, creativity, and evolution, while the circle could stand in for freedom, revolution, and play. Like Leonardo's drawing, the constructal law, which is the topic of this conference, unites linear and nonlinear phenomena into one joint statement about the world that surrounds us.

Keywords: Art and Science, Leonardo da Vinci, Vitruvian Man, Creativity, Play.

The essay is available at https://doi.org/10.31219/osf.io/n862b and bit.ly/lines-curves

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Constructal Design of semi-elliptical blocks assembled into a horizontal channel subjected to flows with mixed convection heat transfer

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Abstract

This work investigates numerically the design of the heated semi-elliptical blocks assembled into a horizontal channel subjected to flows with mixed convection heat transfer. The main objective of the study is to maximize the heat transfer rate and minimize pressure drop in the system through the geometric variation of the blocks. To determine the constraints, degrees of freedom, and performance parameters, the Constructal Design method was used. The multiobjective assessment of the problem was carried out using the Technique for Order Preference by Similarity to the Ideal Solution method. The results indicated important gains in the thermal and fluid dynamic performances of nearly 40% and 703%, respectively, when the best and worst shapes were compared in the second optimization level. Also noteworthy is the importance of evaluating different arrangements of the blocks within the channel, and the difference in performance obtained was up to 40% for the thermal analysis and 12% for the fluid dynamic case. It is worth mentioning that, in the multiobjective viewpoint, the employed method above-cited correctly indicated the best configurations and the gain of performance in comparison with the pressure drop minimization and the heat transfer rate maximization.

Keywords: Elliptical Blocks, Constructal Design, Mixed Convection, Cooling.

1. Introduction

Heat transfer problems bring significant challenges since constant modernization and technological innovation require a continuous evolution of the means of dissipation and use of thermal energy [1]. Flows with heat transfer in channels containing heated obstacles inside constitutes an idealized basis for study regarding the convective cooling of electronic components [2]. This study investigates the heat transfer and the pressure

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drop of a system composed of a channel with semi-elliptical heated blocks mounted inside it. The system is subjected to the mixed convection mechanism under different flow conditions. The Design Construtal method [3], associated with the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method [4], allows the proposed system to be geometrically developed, helping to obtain the best thermal, fluid dynamic, and multiobjective performance configurations.

2. Mathematical and Numerical Modeling

The mass, momentum, and energy conservation equations are solved by the Finite Volume Method through the FLUENT® 2018 code and the buoyancy is resolved by the Boussinesq approximation [5]. Steady-state conditions, 2D domain, incompressible flow, and constant thermophysical properties are adopted. The buoyancy effect is considered transverse to the forced flow. The Reynolds and Prandtl numbers are fixed (Re_H = 50; Pr = 0.72), and the Richardson numbers are variable (Ri_H = 0.1; 10; 100). Different configurations are considered: arrangement 1: the two blocks are mounted on the lower wall of the channel; arrangement 2: the two blocks are mounted on the upper wall of the channel; arrangement 3: the blocks are mounted alternately on the channel walls, with the upstream block of the system being inserted into the lower wall of the channel. The degrees of freedom are defined through the ratios between the vertical and horizontal lengths of the semi-elliptical blocks (H_1/L_1 (block 1, upstream) and H_2/L_2 (block 2, downstream)), varying in the range of $0.1 \leq H_1/L_1; H_2/L_2 \leq 6.0$.

3. Results and Discussion

When evaluating different values of H_2/L_2 for fixed values of H_1/L_1, the geometries of H_2/L_2 presented the best thermal performances converged in an optimum geometric point which is the ratio of $(H_2/L_2)_{T,1o}$ = 6.0 for all arrangements studied. In all conditions of flow and arrangements studied, the lowest performance geometries were obtained for H_2/L_2 smaller than 1.0. In the first level of geometric optimization, in which the percentage difference in the thermal performance of the geometries once optimized ($(H_2/L_2)_{T,1o}$) was considered in relation to the geometries of lower performance ($(H_2/L_2)_{T,ws}$) as a function of H_1/L_1, approximate gains of up to 60% were observed for Ri_H = 0.1, and 66% for Ri_H = 10 and Ri_H = 100. In a second level of thermal optimization, where the aspect ratio H_1/L_1 is optimized once ($(H_1/L_1)_{T,1o}$) and the degree of freedom H_2/L_2 twice optimized ($(H_2/L_2)_{T,2o}$), the thermal performance gains of up to 38% were observed for Ri_H = 0.1, 41% for Ri_H = 10, and 29% for Ri_H = 100. The best performance was obtained with arrangement 3, with a gain of approximately 31% (Ri_H = 0.1), 36% (Ri_H = 10), and 40% (Ri_H = 100) when compared to arrangement 2.In the fluid-dynamic analysis, for all evaluated values of H_1/L_1, the worst results were obtained for $((H_2/L_2)_{F,ws})$ = 6.0, a situation in which the obstruction of the canal by block 2 was maximum. At a second level of optimization, the configuration optimized for arrangements 1 and 2 presented a superior performance of up to 635% concerning the fluid dynamic set, once optimized, with lower performance. For arrangement 3, the performance gain was approximately

703%. Furthermore, it was observed that inserting the blocks in the same wall of the channel is beneficial to the system in terms of fluid dynamic performance, given that, for all H_1/L_1 values evaluated, arrangements 1 and 2 presented better results in relation to the reduction of head loss in the system, presenting a superior performance of up to 12% concerning the arrangement 3.

Assuming that the thermal and fluid dynamic performances have the same relevance for the system, for arrangements 1 and 2, there is a region of multiobjective optimum displaced to the region where the devices present their combined ratios in the range of $2.0 \leq H_1/L_1$; $H_2/L_2 \leq 4.0$, since it was in this region that an increase in thermal performance was identified, accompanied by a practically constant pressure loss inside the channel, thus reaching the highest values of the multiobjective indicator. As for arrangement 3, the multiobjective optimum region was for the condition in which only one of the blocks presented a more significant insertion within the channel, i.e., $2.0 \leq H_1/L_1 \leq 4.0$ combined with values of $H_2/L_2 \leq 0.3$, highlighting asymmetric geometries for blocks 1 and 2.

4. Conclusions

This study showed the importance of the Constructal Design method for the evaluation of the proposed thermal and fluid dynamic problem. The obtained results are in accordance with the Constructal principle, showing that the geometric freedom is fundamental for systems to evolve their configurations in order to achieve the best performance. Moreover, the design is deterministic and non-random, since the most suitable sets for the studied performance indicators are justified through the physical phenomenology that involves the problem, providing greater access to the internal currents present in the system.

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Constructal Law Conference (CLC 2023)
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Impact of cars entropy flows in climate change

Angel Cuadras [a] and Victòria J. Ovejas[b]

Abstract

Climate change is an important research topic due to the catastrophic impact that may have in human societies. We evaluate the entropy flows generated by cars to estimate the most efficient car transport and its impact in the framework. We characterize the entropy flows, applying Gouy-Stodola theorem and constructal law. We find that environment entropy is higher than both combustion or energy transformation entropies.

Keywords: Entropy flow, cars, climate change, pollution.

1. Introduction

Climate change is an important research topic due to the catastrophic impact that may have in human societies. It is mainly due to greenhouse gases emissions such as CO_2 or CH_4. These gases are products of fossil fuel combustions used to provideenergy for buildings, transport and industry [1]. Several models to describe climatechange have been proposed, usually based on energy balance or temperature evolution. However, the path to future development is not well paved yet, so in thiscontribution we introduce a model based on constructal law. Classical thermodynamics usually considers the reversible path P_0 between two states S_1 and S_2 but other irreversible paths, such as P_1 or P_2 are possible (see figure 1).

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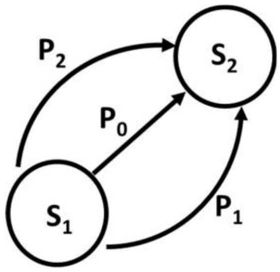

Figure 1- *Possible thermodynamic paths between states S_1 and S_2. P_0 stands for reversible path and P_1 and P_2 exemplify irreversible paths.*

According to constructal law, the chosen path will bethe one that allows the easiest flow. In fact, a simplebut effective study focused on convection flows in atmosphere due to changes in emissivity and albedo is based on constructal law [2]. In this contribution, we aim to evaluate the evolution of entropy flows involved in car operation in terms of constructal law and investigate its relationship with climate change .

2. Materials and Methods

The starting point are three cars of the same model (Volkswagen Golf), one operating with gasoline, the other with diesel and the last one fully-electric. We evaluate the entropy generation and entropy flows at the different stages required for car operation, as illustrated in figure 2 using well-known entropy equations of basic thermodynamics [3]. First, we compute the entropy flow being generated during combustion (S_{comb}), which is a consequence of (1) and it is inferred from standard tables [5]. It is generated *in situ* for gasoline and diesel cars and *ex situ* combustion electricity for EV cars. Second, the entropy flow due to generated energy and heat transfer to the environment S_{EC} inferred from Gouy-Stodola theorem. Third entropy related to CO_2, which can be divided between thermalisation and mixing with the air S_{therm_CO2} and its mixture S_{mix_CO2}.. Thermalisation refers to CO_2 transfer from the combustion chamber to the atmosphere, with a reference volume equivalent to that providing a CO_2 concentration of 420 ppm. Mixing entropy is related to CO_2 dissolution in air. Finally, emissivity entropy is related to the change in albedo because of CO_2 concentration and is calculated for an increase up to 425 ppm [6] whereas noise entropy is related to car's energy transformation into noise (considering 70 dB noisepressure for a combustion car and 50 dB for an electric car).
Combustion chemical equations for the three cars, which consider natural gas (pureCH_4) in combined cycle centrals for electricity generation, are:

$$CH_4 + 2(4O_2 + 15.08N_2) \rightarrow CO_2 + 2H_2O + 6O_2 + 30.16\,N_2$$
$$C_8H_{18(\mathrm{l})} + 12.5(O_{2(\mathrm{g})} + 3.76N_{2(\mathrm{g})}) \rightarrow 8CO_{2(\mathrm{g})} + 9H_2O_{(\mathrm{g})} + 47N_{2(\mathrm{g})} \qquad (1)$$
$$C_{12}H_{26} + 18.5(O_2 + 3{,}76N_2) \rightarrow 12CO_2 + 13H_2O + 69.56\,N_2$$

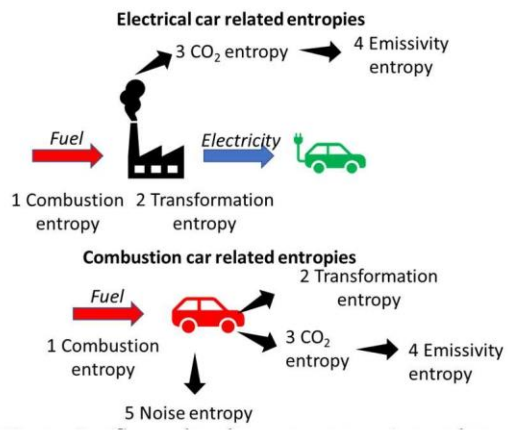

Figure 2 – Cars related entropy generation and entropy flows. Entropy is generated at combustion (1), transformation (2), CO_2 emission (3), CO_2 impact (4) and secondary entropy (5)

3. Results

We computed the entropy related toeach process and each car using manufacturer date related to fuel consumption. Results are listed in Table 1. The entropy flow increasesat each step. It is easily seen the lower impact of electric car with respect to combustion cars, and the relationship between energy, work, pollution and environment impact, each one related to a different entropy flow.

4. Discussion and Conclusions

Results show the success of the proposed methodology to evaluate the performanceof cars through different entropy flow paths. Constructal law optimises the compromise of energy, environment and social impact. It can quantify the energy efficiency of the system, the impact of pollution generation (CO_2 emissions), and the overall environment impact from the emissivity changes, which is related to theenergy balance of the Earth. In the future, social impact, i.e., from noise entropy for instance or ecosystem perturbations, along with the entropies related to fuel obtention should be studied.

Table 1. Fuel, energy, CO_2 emissions (provided by the manufacturer) and entropy related to each car and path for a 100 km distance. The fuel consumption is obtained from manufacturer. Total energy is obtained from fuel enthalpy. CO_2 emissions are obtained from stoichiometric equations and energy required. Entropies are described above.

	Gasoline	Diesel	Electric
Consumption (l)	5.10 l	3.8 l	-
Consumption (mols)	31.5	19	50
Total energy (MJ)	164.12	136.268	49.32
CO_2 emissions (kg)	12.1	10.9	2.2
S_{total} (kJ K^{-1})	3375	3005	709
Partial entropies			
S_{comb} (kJ K^{-1})	95	114	42
S_{EC} (kJ K^{-1})	387	283	153
$S_{therm\_CO_2}$ (kJ K^{-1})	86	79	14
$S_{mix\_CO_2}$ (kJ K^{-1})	0.82	0.78	0.04
S_{emi} (kJ K^{-1})	2802	2524	500
S_{noise} (mJ K^{-1})	5	5	0.5

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The Contribution of Constructal Law for the study of Complex systems

Claudia Gasparovic[a*], Marcelo Errera[b]

Abstract

In this paper, we address the way Constructal Law (CL) has been overlooked in complexity science. Concepts underpinning the CL and some of its applications to complex systems are reviewed to discuss a view of so-called complex systems "properties", such as evolution, self-organization and hierarchy, as flow configuration. To investigate this hypothesis, two questions are asked: i)Do any non-complex flow systems exhibit these properties? And ii) does CL facilitate the modelling of complex systems? As the evolution of configuration is described by Constructal Law, the emergence of certain evolutionary and adaptive behaviour no longer lacks a theoretical framework, and acknowledging this would make complexity more powerful as a discipline.

Keywords: Complexity, Complex systems, Modelling, Adaptive systems, Evolution,Constructal Law.

1. Introduction

Complex systems are pervasive in the natural world and are a mark of the human existence in the Anthropocene. Because of nontrivial emergent behaviour that prevents them from being fully predictable, complexity science usually employs

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models and tools such as fractals and self-reproducing computer models, which are descriptive, not predictive [1]. In order to *predict*, it is required a law and a theory based on that law [1]. The field of complex systems precisely seeks to uncover common laws for the emergent, self-organizing behavior seen in complex systemsacross disciplines [2]. The Constructal Law (CL) [3], which describes the emergence and evolution of configuration in nature, is one such principle. However, the "complexity" scientific community has been missing the opportunity to utilize CL as a first principle.
In this paper, by reviewing concepts underpinning the Constructal Law and examples of its applications to complex systems, we propose that some of so-calledcomplex systems "properties", such as self-organization, evolution, emergence andhierarchy [4,5], can be understood as the phenomenon of configuration in flow systems, as described by CL, and only the non-trivial, sometimes random, non- linear responses are exclusively complex systems properties.

2. Reframing complex systems with the Constructal Law

Inspired by Bejan (1997) [6], we ask: if self-organization is exclusive to complex systems, then what explains its emergence and evolution in a snowflake, channels in a cooking pot of rice or the free fall of a toilet paper [7]? The emergence of orderout of disorder has been a source of confusion in science [8], and an account of howsuch apparent entropy-defying self-organization takes place has been called the 'holy grail of complex systems' [4]. The Constructal Law clarifies the confusion by making visible a second time arrowin physics: that of how every flowing thing acquires architecture [9], which is calledevolution [10]. What is called "organization", then, is the configuration (design) ofa flow system that arranged itself to provide better access through the currents thatflow through it. It follows that the 'emergence' - considered the primary characteristic that distinguishes complex systems [11] - of configuration needs to be distinguished from the emergence of complex, non-linear behavior.

Another so-called complexity principle is hierarchy. Simon [12] argues that it is non-linearity that yields hierarchies, and they are the ones that have time to evolveamong possible complex forms. However, it will emerge in "non-complex" systemsas well, and Bejan [13] explains why: it is the natural flow architecture that connectsa point with a surface and a volume.

Important is that the principle behind the emergence of these properties in complex systems has nothing to do with non-linear or complex behavior, but with the evolution of flow systems as predicted by theories based on CL. These properties had been conflated because every complex system is a flow system. If this is true, then the use of CL ought to facilitate the modelling of complex systems, and indeed,several examples can be found in literature.

Reis and Bejan [9] proved that the constructal law provides a basis for understanding and predicting a highly complex flow structure such as the global circulation. Clausse *et al.* [14], used a simple and transparent convection/radiation model to anticipate the time-dependent response of the Earth climate to changes inthe albedo and greenhouse factors, using the constructal law to provide closure of the model equations. In economics, CL has been used to unify physics witheconomics to explain the hierarchical distribution of wealth on earth [15].

3. Concluding remarks

As Bejan and Errera [8] say, words have meaning, and the language of complexityneeds to be unambiguous. In this paper, we use words to help bridge the gap between Complexity Science and Constructal Theory, by elucidating a conflation between complex and flow system properties (organization, evolution, hierarchy). This reframing allows to no longer treat some predictable phenomena as unpredictable and to use predictive, not only descriptive tools to study complex systems, making complexity science more powerful as a discipline. It also providesanother route for investigation on what causes actual complex and non-linear behaviour in the interaction between flow systems, causing not only bottom-up, butcascading top-down effects. The discussion can also be extended to other propertiessuch as scaling and power laws, and self-organized criticality.

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Short peptide amyloids are likely a sequence pool foremergent proteins.

Witek Kwiatkowski.[a*], Jason Greenwald[a], Roland Riek[a]

Abstract

Our recent work has shown that amyloids can spontaneously form inside vesicles creating membrane enclosed complex structures of variable morphologies. This is possible becausefatty acids act as filters allowing passage of activated amino acids. By contrast, some aminoacids derived from the activated species become non-permeable and trapped in the vesicles.Similarly, extended nascent peptides are also trapped in the vesicles. It is hypothesized thatsuch preselected sequences become a sequence pool for the emergent proteins. During millions of years of evolution sequences in the current proteome diverged significantly from the original seed sequences. If this hypothesis is right, we should see the trace of thesesequences in the current proteome. Here we show that if we select all 6,7,8,9-mers in the proteome and calculate their amyloidogenicity there are more amyloidogenic sequences inthe current proteome than in the randomly created proteome of the same size. Moreover, there are more amyloidogenic sequences in archaea proteomes than in the larger primate proteomes suggesting that the evolution of the proteome is towards a smaller number of amyloidogenic sequences.

Keywords: protein, amyloid, origin of life

1. Introduction

Given the fact that a 100 amino acid protein has 20^{100} possible sequences it is evident that infinitesimally small part of sequence space is utilized by life. We have

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previously shown that amyloids can spontaneously form inside vesicles creating membrane enclosed complex structures with a certain degree of variability in morphology. This is possible because fatty acids act as filters allowing passage of activated amino acids. By contrast, some amino acids derived from the activated species become non-permeable and trapped in the vesicles. Similarly, extended nascent peptides are also trapped in the vesicles. [1]. This led us to propose a generalhypothesis that the seed sequences arose from short amyloid-forming peptides thatwere selected for in a prebiotic synthesis inside of vesicles. During billions of years of evolution sequences in the current proteome diverged significantly from the original seeds but if the hypothesis is right we should see the trace of the original selection in the current proteome. Therefore, we propose three testable hypotheses:

1. The number of amyloidogenic sequences in archaea is greater than the number of amyloidogenic sequences in primates.
2. The number of amyloidogenic sequences in the proteome is greater than inthe random generated proteome of the same size and composition.
3. The sequences that occur more often than expected are more amyloidogenic than those that have populations close to their expected values

2. Materials and Methods

We used the Universal Protein Resource (UNIPROT) to construct an Uniref50 database (UniProt Reference Clusters where clusters are based on 50% similarity, as of May 2020 it contained ~40M sequences and ~12G amino acids). From these, we constructed 3 additional databases:

1. Uni500K is a random selection of 500K sequences from Uniref50
2. Uniref50_primates is a subset of Uniref50 with taxonomy of primates (~148k sequences)
3. Uniref50_archaea is a subset of Uniref50 with taxonomy of archaea (~1.3 M sequences)

Each database was subsequently segmented into 6, 7, 8, 9-mer short sequences. As described in [2] for each database, the total occurrence of each amino acid AA_i is used to calculate the relative frequency of each amino acid fAA_i.

$$f_{AA_i} = \frac{total\ count\ of\ AA_i}{total\ count\ of\ AA}$$

This value is then used to calculate the expected population of each n-mer sequence found in the database E_p $(n\text{–}mer)$

$$E_p(n\text{-}mer) = \left(\prod_{i=1}^{n} f_{AA_i}\right) \times \ (total\ number\ of\ n\text{-}mers)$$

and then using the population of each n-mer $P(n\text{–}mer)$ the deviation of this population from the expected population $\delta Ep(n\text{–}mer)$ is calculated.

$$\delta E_{p:7}(n\text{-}mer) = \frac{P(n\text{-}mer_7) - E_p(n\text{-}mer_7)}{E_p(n\text{-}mer_7)}$$

Finally, for each *n-mer* the amyloidogenicity was calculated using Amyloid Propensity Prediction Neural Network software (APPNN) [3] and from that the percentage of amyloidogenic sequences in each database was calculated as follows:

$$\%\ Amyloidogenic = \frac{\sum n - mers_{APPNNN0.0}}{\sum n - mers} \times 100$$

3. Results

Table 1. Percentage of amyloidogenic sequences for each database. Database-R denotes the randomly generated proteome of the same size. * The number of 8- and 9-mers is too large to calculate the amyloidogenicity for each sequence in the entire Uniref50 database

n-mers	Percentage of Amyloidogenic SequencesUniref50 proteome:					
	entire, 500K	entire-R, 500K-R	primates	archaea	primates-R	archaea-R
6	17.86, 17.86	16.10, 16.13	15.70	19.68	13.33	17.95
7	23.20, 23.20	21.41, 21.46	20.49	25.32	18.02	23.75
8	-------*, 27.93	-------*, 26.18	24.81	30.30	22.27	28.82
9	-------*, 32.47	-------*, 30.67	28.90	34.96	26.32	33.56

As is evident from the table archaea proteins are significantly more amyloidogenicthan primate proteins and all proteomes are significantly more amyloidogenic thantheir corresponding random versions

Table 2. Percentage of amyloidogenic sequences for sequences below (-) and above (+) expected population.

n-mers	database	$\delta E_p(n\text{-}mer_j)$	% Amyloidogenic
6	UniRef50	-	13.93
		+	21.28
	UniRef50-R	-	16.05
		+	16.18
7	UniRef50	-	19.76
		+	25.38
	UniRef50-R	-	21.05
		+	21.68

Sequences that appear in the proteome with lower than expected frequency have lower amyloidogenicity (lower than random!) than those that appear at higher thanexpected frequency. Sequences from a randomly generated proteome do not displaya correlation between amyloidogenicity and their deviation from expected population. In conclusion, it is likely that the initial pool of protein sequences arosefrom an amyloid origin.

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Geometrical Investigation of Forced Convective Flows over Staggered Arrangement of Cylinders Employing Constructal Design

Ana Del Aghenese[a], Claudia Naldi[b], Hektor Borges[a], Gabriel Scursone[a], Luiz Rocha[a], Liércio Isoldi[a], João Prolo Filho[a], Cesare Biserni[b], Elizaldo dos Santos[a]*

Abstract

The present work shows a numerical study of the geometrical investigation of a staggeredarrangement of four cylinders subjected to incompressible, laminar, unsteady, two- dimensional, and forced convective flows by means of Constructal Design. The purposes are the maximization of Nusselt number (Nu_D) and minimization of drag coefficient (C_D) in the arrangement. The problem has one area constraint (A_0) and three degrees of freedom:S_T/D (ratio between the transversal pitch of intermediate cylinders and their diameters), S_{L1}/D (ratio between the frontal longitudinal pitch of cylinders and their diameters), and S_{L2}/D (ratio between the rear longitudinal pitch of cylinders and their diameters). The configuration is investigated for three different Reynolds numbers (Re_D = 10, 40, and 150) and using air as working fluid (Pr = 0.71). The conservation equations of mass, momentum,and energy are solved with the finite volume method. Results showed that Reynolds number affected the design of the arrangement, especially the optimal longitudinal ratios that presented asymmetric configurations.

Keywords: Constructal Design, Geometric Investigation, Forced Convection, Staggered Cylinders, Computational Modelling.

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1. Introduction

One important aspect of the thermal project of heat exchangers is the investigationof strategies to augment the heat exchanger with the lowest possible forces for fluidmotion. Therefore, the use of different shapes for the cylinders as elliptical, squareor trapezoidal bodies and the use of fins or protrusions in the tubes to improve the thermal performance of one cylinder or arrangement of cylinders have been reported [1]. In the Constructal Design framework, important recommendations about the design of arranges of tubes have been reported following the ConstructalLaw principle [2 - 3]. Despite several contributions, few have been investigated about using different longitudinal pitches on staggered elementary arrangement of cylinders, which is investigated here.

2. Methodology

The present work considers laminar, unsteady, incompressible, and forced convective flows over an arrangement of cylinders defined in a staggered configuration, as illustrated in Fig. 1. The problem is modeled by the conservationequations of mass, momentum, and energy [4], which are numerically solved withthe finite volume method by means of the commercial code FLUENT [5].

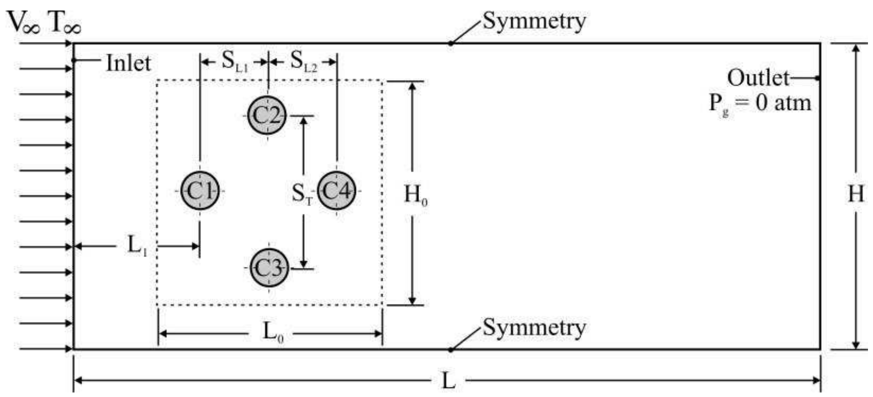

Figure 1. Computational domain of the staggered arrangement of cylinders subjected to forced convective flows.

The main purposes are to maximize and minimize, respectively, the spatial averaged Nusselt number (Nu_D) and the drag coefficient (C_D) in the arrangement of cylinders.

For each cylinder, the Nu_D and C_D are given, respectively, by:

$$Nu_D = hD/k = \partial T^*/\partial n^*|_{n^*=0} \quad (1)$$

$$C_D = F_D/2\rho V_\infty^2 DW \quad (2)$$

For the geometrical investigation, it is considered an occupation area A_0 = 6D × 6$D$and three degrees of freedom: S_T/D, S_{L2}/D, and S_{L1}/D. The exhaustive search is usedhere to investigate the influence of the Reynolds number over the three times minimized drag coefficient, $(C_D)_{3m}$, three times maximized Nusselt number, $(Nu_D)_{3m}$, and corresponding optimal degrees of freedom. The subscripts F and T denote the optimal ratios for the fluid dynamic and thermal purposes. All degrees of freedom were investigated step-by-step for optimization with an exhaustive search, totaling 288 simulations. Despite that, it is presented here only the effect ofthe Reynolds number over the optimal configurations.

3. Results and Discussion

Figure 2 illustrates the effect of Reynolds (Re_D) over the three times minimized drag coefficient, Fig. 2(a), and three times maximized Nusselt number, Fig. 2(b), and the corresponding optimal fluid dynamic and thermal configurations, and Fig. 2(c) shows the temperature fields for the optimal thermal configurations. For both purposes, asymmetrical longitudinal pitches conducted to the best performance. Thebest thermal arrangements were obtained for Re_D = 10 and 40 with intermediate cylinders near the rear and frontal cylinders, respectively. For Re_D = 150, the arrangement tends to be more symmetric than the configurations with Re_D = 10 and40, i.e., $(S_{L2}/D)_{2o,T}$ = 4.0 and $(S_{L1}/D)_{3o,T}$ = 3.0. Moreover, for Re_D = 150, the optimalarrangement intrudes more into the occupation area than the best configurations reached for the other Reynolds numbers.

4. Conclusions

In general, it was noticed that the staggered arrangement of cylinders is dependent on the operational conditions and the use of asymmetric pitches between frontal and intermediate cylinders, as well as, between the intermediate and rear cylinders can benefit the performance of heat exchange of the problem.

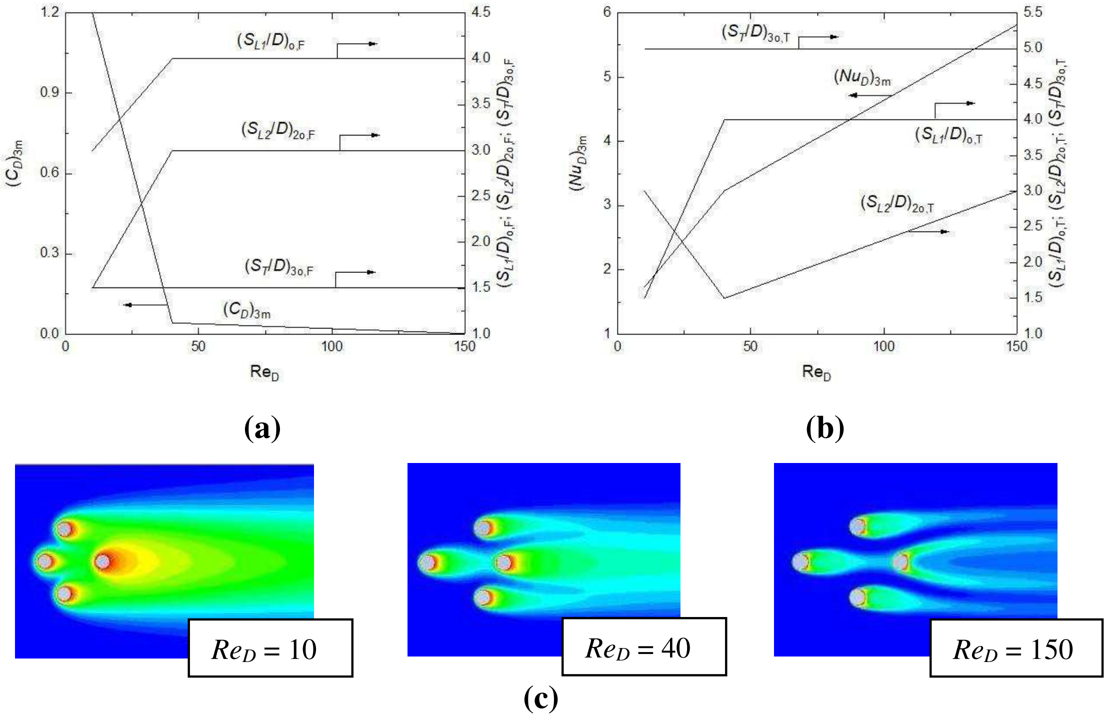

Figure 2. Effect of Re_D over: (a) $(C_D)_{3m}$ and corresponding optimal shapes; (b) $(Nu_D)_{3m}$ and corresponding optimal shapes; (c) temperatures for optimal thermal configurations.

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Constructal Law Conference (CLC 2023)
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Heterogeneous degradation in Li-ion batteries

Victoria J. Ovejas[a*], Angel Cuadras[a]

Abstract

Li-ion batteries are crucial for the forthcoming energy transition. They are complex systems that show heterogeneous current distribution patterns and degradation. The development of valid methods to determine their internal state as well as for performance optimization and life cycle extension are vital for battery full deployment. We study the entropy productionin the cells in the presence of temperature gradients. We observe that entropy is produced faster in the regions with larger temperatures which are generally associated with faster degradation patterns.

Keywords: Li-ion, Battery, Entropy production, Degradation, Modelling.

1. Introduction

Batteries are complex systems, composed of different materials and assembled in different geometries. Li-ion batteries performance decreases over time as cells degrade. In cylindrical cells, internal sheets are rolled together to form the jelly roll.Temperature gradients in the range of 2-6 ºC form in the radial direction of the jellyroll during operation [1]. Current distribution in the cells depends on rate, temperature and porosity/tortuosity and has been found to be heterogeneous as wellas material degradation [2]. We aim to study the current distribution in the cell due to the presence of temperature gradients in terms of constructal law to determine the entropy production on each region. From the results, we aim to understand the relationship between entropy production and heterogeneous degradation.

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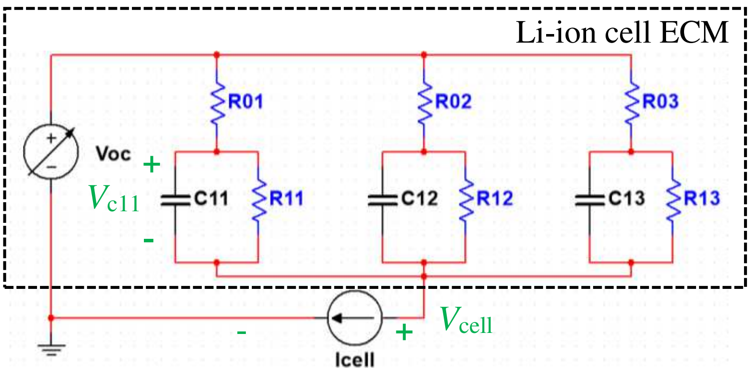
2. Materials and Methods

Data of 3 Ah cylindrical NCA Li-ion cells (Samsung IN21700-30T) have been obtained from a public dataset [3]. Cell voltage (V_{cell}) at 1C is obtained from the dataset and ps-OCV (V_{OC}) has been calculated from V_{cell} curves at a rate of C/20.

We have accounted for a 5 ºC temperature gradient in the radial direction of the jellyroll, which has been divided in 3 sections with different temperatures (Figure 1). Asimple Equivalent Circuit Model (ECM) has been employed. The different regionsin the jelly roll have been simulated by parallelizing 3 ECMs (Figure 2).

Subsection 1 Surface T_1 = 25 ºC	Subsection 2Central T_2 = 27.5 ºC	Subsection 3Core T_3 = 30 ºC

Figure 1. Jelly roll divided in three subsections, each one at a different temperature.



The voltage in the capacitors (1) and the current flowing on each branch (2) are simulated with Matlab.

Figure 2. ECM of the cell in which every branch represents a jelly roll subsection.

$$\frac{dV_{c1x}}{dt} = \left[\frac{y}{R_{0x}} - V_{c1x} \cdot \left(\frac{1}{R_{0x}} + \frac{1}{R_{1x}} \right) \right] \cdot \frac{1}{C_{1x}} \tag{1}$$

$$I_x = \frac{y - V_{1x}}{R_{0x}} \tag{2}$$

Where η is the overvoltage in the cell under polarization $\eta = V_{oc} - V_{cell}$. Resistances at T_1, T_2 and T_3 have been obtained from Arrhenius equation. Ohmicresistance (R_{ox}) variation with temperature (3-18 %) is considered as negligible compared to charge-transfer resistance R_{1x} (400-2700 %) [4] (Table 1). C_{1x} has been calculated from the relaxation voltage of the cell and the time constant of the branch.The entropy production rate is calculated from η, current and temperature T_x (3).

$$\frac{diS_x}{dt} = \frac{\eta \cdot I_x}{T_x} = \frac{\eta \cdot (\eta - V_{c1x})}{R_{0x} \cdot T_x} \tag{3}$$

Table 1. Resistances and capacitances of each branch.

Branch x	Temperature	Rox + R1x	Rox	R1x	C1x
1	25 ºC	21.06 μΩ	12 μΩ	9.06 μΩ	53 kF
2	27.5 ºC	19.62 μΩ	12 μΩ	7.62 μΩ	63 kF
3	30 ºC	18.31 μΩ	12 μΩ	6.31 μΩ	76 kF

3. Results

For a given overvoltage, the current distributes in the available geometry accordingto the opposition that finds on each branch (Figure 4), according to the constructal law. The largest current is found at subsection 3, which is the region with the largesttemperature and the lowest resistance (Table 1). The effect of current is found to bedominant for the entropy production as regions with larger currents produce entropyat a faster pace even if they are at higher temperatures (Table 2).

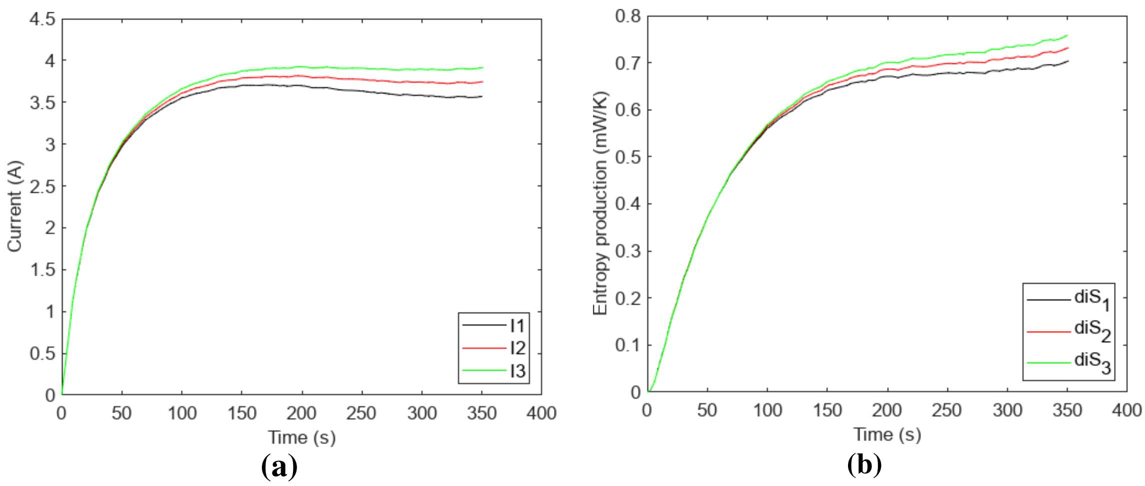


Figure 4. Results obtained at SoC = 100 % at a discharge rate of 1C. (**a**) Current flowingthrough the circuit branches; (**b**) Irreversible entropy production on each branch.

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Table 2. Entropy production rate (di$S$/dt) in the subsections after 350 s of discharge

Branch x	Temperature	di$S$/dt (mW/K)
1	25 ºC	0.704
2	27.5 ºC	0.732
3	30 ºC	0.759

4. Discussion and Conclusions

In general, it is found that the inner part of the jelly roll suffers larger degradation than central or outer parts [5]. Larger pressures and temperatures are commonly associated with this effect. We have found that larger currents facilitate the flow oflarger currents that produce irreversible entropy at a larger pace, as expected from constructal law. Further studies should be carried out to quantify the relationship between entropy production and degradation. The constructal law could be useful in battery design to minimize or homogenize the entropy production.

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Designing with freedom for the world. Motivating for Innovation in Defense Acquisition, and predicting execution of our mutual commitment for peace with better (military) systems design and implementation with the power of the Progress Principle and the constructal law.

Adrian S. Petrescu[1]

Abstract:

History of science and technology for innovation, particularly in relationship with advancement ofmilitary systems, is ripe with countless examples of use cases of the constructal law, and of course of adoption of advances in the military technology field to the civilian domain.

The United States had several semi-contemporary examples of radical advances in military systems, most which have secured the United States' and its allies' and partners' leadership in the world for peace in the past almost 80 years. Multiple flows have contributed over time to thissuccess. Surprising connections for their times become perfectly understandable when addressed retroactively with a fitted validated theoretical model in mind.

In this paper we start by identifying a sufficient number of training cases (representing an *approximately complete* set, see Dunn, WN, 1997) for our model of past evolution of military systems—as generalized definition-wise—and then using the built set and the constructal law of flows to inductively make likely predictions for what may need to be designed and implemented inresponse to ultra-authoritarian regimes bringing challenges to the freedom of thought driving and securing nations in the world. We make recommendations that are so far validated by several existing pertinent critical analyses of our (United States, allies and partners) acquisition needs fornow and into the future. Based on these, and on cases drawn from design inertia from our immediate past (several decades), we incorporate trans-, cross-, and inter-disciplinary work from economics of science and technology for innovation, organizational design and psychology and more to suggest necessary improvements in the DoD's approach to innovating for medium and long term securing of global peace and freedom.

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Advances in temperature control by direct injection of liquid water in positive displacement air compressors

George Stanescu[a*], Ene Barbu[b], Valeriu Vilag[b], JeniVilag[b], AlexandruHank[b]

Abstract

Temperature control through liquid water injection has been considered in recent decades to develop isothermal air compression. A great deal of interest was also devoted recently to evaluating such technology with a view to developing more efficient Isothermal Compressed-Air Energy Storage and Gas-Liquid Energy Storage systems. This study evaluates the effectiveness of such a temperature control method for air compression in positive displacement equipment. The presented approach considers the possibility of enhancing the thermal interaction between the liquid water drops and the moist air being compressed by "handling" the thermodynamic equilibrium between them during the compression process. In order to take advantage of the high value of the enthalpy of vaporization of water, it is assumed here that the liquid water that gradually enters the internal volume of the equipment presents itself in thermodynamic states along the saturation line, where it tends to vaporize removing energy from the gas phase. The Constructal Theory is used to evaluate the feasibility and effectiveness of such a temperature control method in reciprocating compressors and reciprocating internal combustion engines. In order to predict how such equipment could evolve technologicallyto operate with the lowest possible energy consumption, the maximum amount of liquid water injected into the internal volume of a reciprocating compressor is considered to make the compression process as close as possible to an isothermal process. The predictions made in this work corroborate well with already published experimental data.

Keywords: Evaporative cooling, Positive displacement equipment, Constructal Law.

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1. Introduction

To optimize power equipment, different technologies have been considered in recent decades to develop the isothermal process of air compression by temperature control through the injection of liquid water [1]. More recently, a great deal of interest has also been dedicated to such technologies with a view to the development of more efficient energy storage systems, such as the Isothermal Compressed-Air Energy Storage (i-CAES) [2] and the Gas-Liquid Energy Storage(GLES) [3]. The Constructal Theory is used here to predict how the reciprocating compressors and reciprocating internal combustion engines (ICEs) could evolve technologically to operate with the lowest possible energy consumption. Themaximum amount of liquid water that theoretically can vaporize inside the internal volume of a reciprocating compressor is considered, in order to carry out the compression process as close as possible to an isothermal process.

2. Materials and Methods

The approach presented in this study considers the possibility of enhancing the thermal interaction through the "handling" of the thermodynamic equilibrium between the various components of the system whose pressure increases and whose temperature also tends to increase during compression. It is assumed here that the liquid water that gradually enters the internal volume of the equipment presents itself in thermodynamic states along the saturation line, where it can easily vaporize by removing energy from the gas phase of the system. The states along the saturation line are reached in a pumping system that allows the liquid water pressure to increase slightly above the instantaneous pressure of moist air, followed by a slight expansion to pressures equal to those in the internal volume of the compressor. At the end of the expansion process, the water, initially in the liquid phase, separates into saturated liquid to be conducted to the internal volumeof the compressor and saturated steam that is released. As liquid water injection is controlled so that compressed moist air does not become saturated, continuously injected liquid water can vaporize, “triggering” a redistribution of internal energy between system components. The mathematical model employed to simulate the wet air compression process is derived from the equations of mass and energy conservation and the second law of thermodynamics.

3. Results

Numerical results obtained on the effectiveness of temperature control by liquid water direct injection into positive displacement equipment of the type of reciprocating compressors are shown in Fig. 1, where graphs indicate the variationof dimensionless temperature and pressure of the compressed gas, either when the proposed temperature control method was employed ($\varepsilon > 0$) or not ($\varepsilon = 0$) [4].

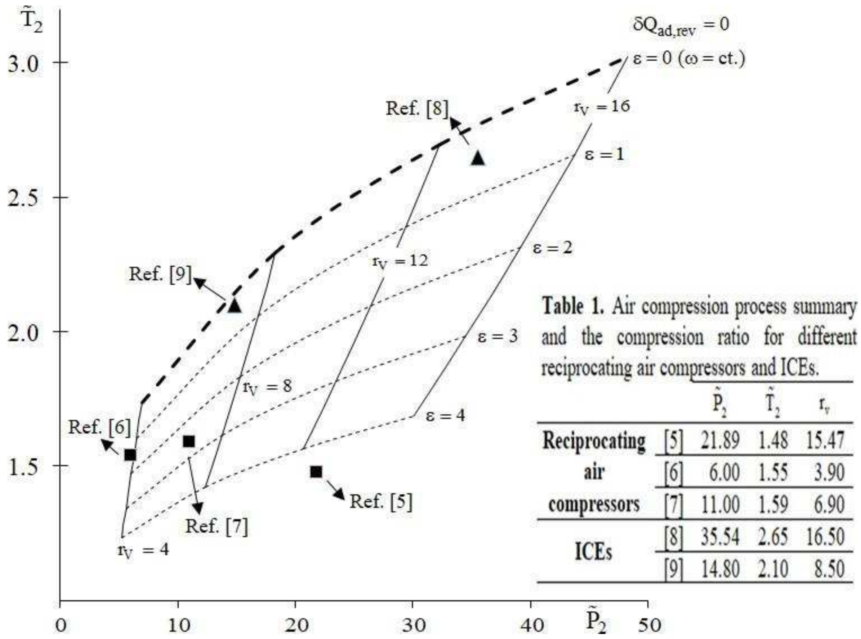

Table 1. Air compression process summary and the compression ratio for different reciprocating air compressors and ICEs.

		$\tilde{P}_2$	$\tilde{T}_2$	r_v
Reciprocating air compressors	[5]	21.89	1.48	15.47
	[6]	6.00	1.55	3.90
	[7]	11.00	1.59	6.90
ICEs	[8]	35.54	2.65	16.50
	[9]	14.80	2.10	8.50

Figure 1. Theoretical results on the effectiveness of temperature control by direct injection of liquid water and experimental data of "in-service" air compressors (■) and ICEs (▲) (r_v and ε are the rate of compression and relative humidity).

Predictions on the possible evolution of thermal control in reciprocating compressors with a view to reducing energy consumption, outlined based on the results obtained according to the Constructal Theory, corroborate well with already published experimental data in Table 1 [5-9].

4. Discussion and Conclusions

Providing a “globally easier flow configuration”, the Constructal approach presented here can be useful both for designing new equipment and for improving the performance of existing ones. Since numerical results suggest that it would be theoretically possible to achieve compression ratios of up to 30 in a single compression stage without exceeding the maximum temperature of 180ºC, this study sheds some light on possible new approaches for optimizing this type of equipment. To ensure the veracity of the obtained results, entropy generation is also being evaluated.

5. Acknowledgements

This study has been accomplished through the "NUCLEU" Programme within the National Research Development and Innovation Plan 2022-2027, implemented with the support of the Romanian Ministry of Research, Innovation, and Digitization, project no. PN23.12.09.01

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Environmental, Social and Governance in the Shipping Industry: From the Perspective of EU and Turkey

Huriye Dilbeste Tomur[a]

Abstract

The environmental awareness has an increasing role which encourages the companies to take their decisions regarding the maintenance of sustainability. The expansion, rationalization and standardization of the Environmental, Social and Governance (ESG principles) is emerging in the business world and the companies tend to adopt these criteria.As the maritime sector is one of the widest part of transportation, the adoption of ESG Principles has to be covered in order to reduce the shipping industry's potential drawbackson the environment. This paper aims to discuss the ESG principles and impact of each pillaron the shipping industry by comparing the legal arrangements in the European Union (EU)and Turkey. It will provide some insights on the correspondence of the legal arrangementswith the ESG principles under the legal systems of EU and Turkey.

Keywords: ESG Principles, European Union, shipping, sustainability, Turkey

1. Introduction

Today shipping industry enables to hauling goods over $14 trillion by controlling 80% of global trade [1]. In 2021 international shipping accounted for approximately2% of global energy-related CO_2 emissions [2]. While measures approved by the International Maritime Organization are likely to curb the rise of emissions over the

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2020s, greater policy ambition is needed to steer the maritime shipping sector ontothe pathway in the Net Zero Emissions by 2050 Scenario, which entails an almost 15% reduction in emissions from 2021 to 2030. In that sense, the supportive policies and collaboration among the countries will be critical for a sustainable environment.

Materials and Methods

This paper aims to discuss the implementation of ESG principles through the reporting mechanism and the role of ESG rating agencies. It will provide some insights on the correspondence of the legal arrangements with the ESG principles from the perspective of EU and Turkey.

2. Discussion and Conclusions

From the perspective of shipping industry each of ESG pillars have to be evaluated specifically to reveal the issues in maritime transport [3]. First of all, the environment term is related to the management practices of maritime operations. Secondly, the social term aims to set safety measures to minimize maritime accidents and better working conditions for the crew on-board. Also, it desires to raising awareness through the shipping seminars for all players in the sector as wellas the gender discrimination by focusing on the under representation of women in crew list. Thirdly, the governance pillar sets rules, practices and procedures for the maritime transport operations. Combating corruption especially in ports is considered under the governance pillar. The codes of ethics or anti-corruption rulesand laws under both national and international level are closely related to corporategovernance. There are some obstacles to imply ESG principles in the shipping industry. First ofall, ESG indicators deemed as non-financial by itself even they have financial consequences. It is expected that the better ESG performance will be positively affect the shipping finance porfolio [3]. However, the proof of this expectation andits impacts on the industry may not obvious. Secondly, ESG principles are measured by various ESG ratings firms which makes it complicated to find accuracy among the results [4]. Some providers make additional claims such as transparency and commitment to ESG as well as a company's environmental or social impact. It can be stated that the results might be differ depending on the ESGrating agency. Thirdly, the compliance of ESG principles have some burdens for the shipping companies. The risk of poor performance in the marketplace against awell-established set of metrics and adverse shareholder reaction might be forced thecompanies to comply with ESG principles even it increases the operational costs [5]. Therefore, the companies has to be compensated the costs to gain a competitiveadvantage in the marketplace for the long term. In other words, both the short and long term goals have to be balanced [6].

The initial steps taken by Turkey include most notably the ratification of the Paris Agreement on climate change. Borsa Istanbul's corporate governance index, sustainability index and its sustainability guide for companies are taken into consideration by the investors. Also, a draft guideline on *Green Debt Instruments and Green Lease Certificates* based on Green Bond Principles of the International Capital

Markets Association was published for public consultation on November 2021. Turkish Ministry of Treasury and Finance announced the preparation of *Sustainable Finance Framework Document* has been completed on November 2021.

The EU's Corporate Sustainability Reporting Directive will be enter into force in 2024. The companies will gradually take the necessary steps to comply with ESG principles during this time period. Also the new regulations - such as the inclusionof shipping in the EU's Emission Trading Scheme (ETS), as well as IMO's EEXI and CII ratings - are pushing shipping industry to consider sustainability [7]. The International Sustainability Standards Board (ISSB) is the agency charged with themandate to develop standards for ESG frameworks. However, a customized industry-specific format will be highly beneficial.

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The Constructal Mindset of Innovation

Author: Kalason Patrick[1]

Abstract: Innovation is the result of a process that involves the interaction of 6 cognitive forms which, by interacting, ultimately make it possible to structure the heuristic at this barycenter commonly called "discovery". Heuristics should not be confused with increment because discovery involves a sometimes radical paradigm shift.

Keywords: Cogitodynamics 1, Forms of intelligence 2, Iinnovation process 3, *Trikãla* of learning 4, Constructal trifunctionality 5.

1. Introduction: *It's Mozart that we assassinate*

Barely 6 years old in those blessed post-war years when copying and pasting was not a virtual operation on the screen, I undertook to make a world map with glue and strips of paper. But before gluing the continents that I had spread out on the kitchen table, I had the intuition to try to put them together as if they were a puzzle. To my amazement, everything fits together. Proud of my discovery I wanted to share it with my father who peremptorily cut my enthusiasm by quoting Genesis in which it is written that God had created the seas and the lands in one day and that I therefore did not have to exercise my curiosity to find out how.

Trikãla: Trikãla designates the triangular figure allowing in communication to map the transactional forms taken within it. The term "Kãla", means in Sanskrit "that which is permanent [trifunctional substance] in things that change". Wink: name not very far from that of its inventor... the author of this article.

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Many years later, during my time at university, this same curiosity sometimes invited me to share my vision on how to solve certain school problems that were in my opinion ill-posed. I found it natural since it was a Master-Research! For any sign of interest, an email from one of my professors reached me asking me to stick to the norm: "*Keep it simple and humble! Are you the only one who has it all figured out? And probably much more than those whose profession is research [my professors]? It's time for you to get there!* ". I got there by publishing at the end of the second year three books in a famous collection "Epistemology and Philosophy of Science", directed by the philosopher Angèle Kremer-Marietti, each of them providing innovative solutions to certain academic problems that arose. This was made possible with the contribution of a phenomenological law governing all forms of communication: the Constructal Law of Cogito-Dynamics.. What about teacher-discoverers? But there are thanks to Professor Stefan Bratosin for skillfully defending my princeps doctoral thesis.

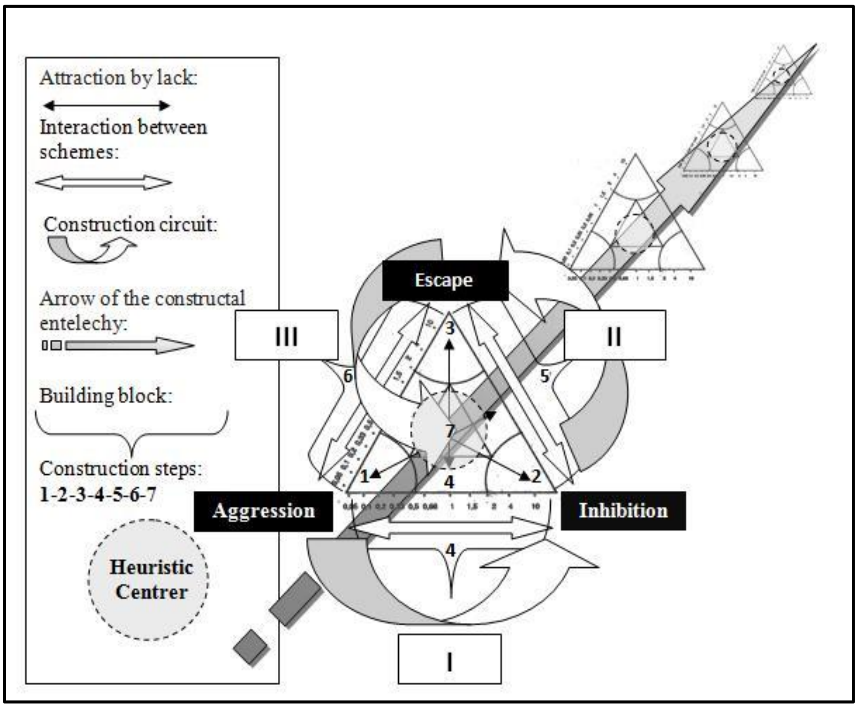
I really like this formula, which has become proverbial, taken from the title of Gilbert Cesbron's book "*C'est Mozart qu'on Assassine*" which is used to say that unjustified postures risk blocking the chances that a person to reach their full potential at best their capacity for innovation.

It must be believed that education would have favored only logical and hypothetical deductive thought to train its elites. Only, was it said, this hypothetical-deductive approach would make it possible to guarantee the observation of proven scientific facts, unlike an approach which would be inductive and which would consist in inducing the benefit of the treatment from the observation of an effect without this having been anticipated and specifically sought.

In reality, elitist cloning always finds its limits while having been useful for the stability of systems for a certain time before the imperatives of evolution pass through other means so that innovation and the cognitive processes that generate it do not turn everything upside down.

Understanding the processes of learning towards innovation means offering the possibility of stimulating evolution. As a contribution to this, constructal cogito-dynamics can be of great help, in particular by identifying and grasping how forms of intelligence affect performance. Because it must be recognized that the good old hypothetical-deductive methods, although useful, did not only do well for the heuristic prospects of higher education. Other complementary routes are possible.

2. Materials and Methods: *Since white symbolizes light, perhaps "bright thoughts" may well result from the cognitive play of their colorings in motion.*



- The use of the Trikãlian Constructal model inherent in all communications: It is made up of 7 spaces, each being defined by the greater or lesser interest that each has in *aggressiveness*, *inhibition* or (and) *escape* (the 3 summits of triangulation) or their interactions (the 3 sides of the triangulation resulting from the meeting of two summits and each distant from its opposite summit). See metrological figure on the next page.

- The use of the typology of cognitive forms [at the right places inside the Trikãla on the next page]: Whether it is a thesis director, a researcher or an engineer, the quality of their productions will be ensured over the long term insofar as they know how to draw inspiration from critical doubt. The creative state of mind of innovation involves the use in constructal synergy of the following cognitive forms, some of which are almost ignored by the education system.

- Analogical thinking
- Normative thinking (Haptonomic)
- Logical thinking
- Inductive thinking
- Deductive thinking
- Conductive thinking
- Invention – Heuristic thinking

3. Result: *It's heuristic*

Responding favourably to the requirements of each of these parameters, whether in engineering sciences (Adrian Bejan), or Cogitodynamics in communication sciences (Patrick Kalason), Constructal theory (endogenous of all developments) is eminently valuable and reliable beyond all reasoned doubts. Only the trikãlien coherence makes it possible to map the power of the interactions generating evolutions by the fact of the synergistic complementarity within the innovation.

CONSTRUCTAL TRIKĀLA OF COGNITIVE FORMS AT THE SERVICE OF INNOVATION

Constructal Trikāla of the forms of thoughts in Cogitodynamics generating innovations by interactions.

Heuristic & Constructal thought

"To congress"

Logical thought

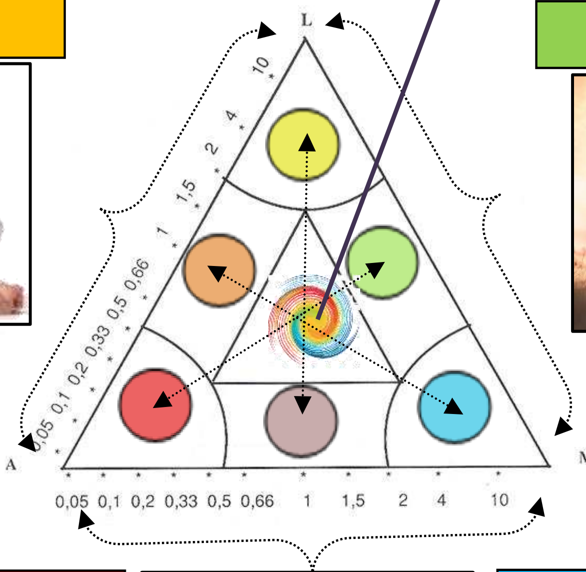
"To know"

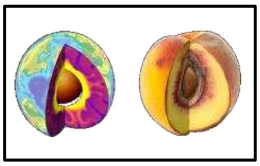
Deductive thought

"To undertake"

Inductive thought

"To apprehend"





Analogical thought

"To match"

Haptonomic thought

"To design"

Cf. // Constructal pedagogical abacus for skills evaluation.

Conductive thought

"To arrange"

Aptonomy: ability to perceive without seeing. To glimpse.

N.B. Due to the lack of proper *haptonomic thought* stimulation (in blue), *conductive* and *inductive thoughts* cannot be expressed. This makes *innovation* impossible because green needs yellow with blue and brown needs red with blue. Without the *haptonomic* (blue), *innovation* is rendered impossible: only the didactic (orange) remains!

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Constructal pedagogical abacus for skills evaluation

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Abstract The problem of being able to have a simple and intelligent tool allowing the evaluation, by the student, of the skills acquired, can be solved by taking inspiration from this innovative track of research and discovery which is based on the trifunctional Constructal System communications, in this case, applied to pedagogy.

Keywords: Evaluation 1, Skills 2, Constructal Abacus 3, Trikãla 4, Colorimetry 5

1. Introduction: *Mirrors are scary*.

Asserting themselves as science, the disciplines dealing with Information and Communication have this tendency to prefer the questions to the answers. For these reasons they give priority to satisfaction questionnaires which necessarily open the door to unconscious influence peddling on the conclusions whose underlying object is the protection of the academies, their professors and the doctrines, supposed to represent them.

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Trikãla: Trikãla designates the triangular figure making it possible to map the transactional forms taken within it. The term "Kãla", means in Sanskrit "*that which is permanent* [trifunctional substance] *in things that change*". Wink: name not very far from that of its inventor... the author of this article.

Without the discovery of oxygen and its action on combustion by Lavoisier (1775), without the 7 periods of the elements observed to date, constituting the lines of the periodic table of the elements brought to light by Mendeleïev (1869), chemistry would continue to be called "alchemy": this occult omniscience in vogue in the Middle Ages which claimed to be able to change lead into gold and postulated that a fluid called phlogiston (from the Greek φλόξ phlóx, flame) was present in combustible bodies.

If the hard sciences have largely extracted themselves from these esoteric visions, it is not the same for the flexible sciences, the human sciences, with a few exceptions, which experience great difficulty in designating the origin of the facts, preferring "*the quest for meaning in a crossed regard on the field of possibilities*"… (A bit of epistemology would save us from strabismus, wouldn't it? In these disciplines, phlogiston is a resistant virus).

When in 1980 I discovered the permanence of the three root behaviors inherent in any form of communication, namely "*Aggression - Inhibition - Escape*", which determine their styles and at the barycenter the evolution of forms by optimization [*// Design in Nature. A. Bejan*], it seemed natural to me to link the discovery of the trifunctional system of cogito-dynamics (metrological and synergistic) to the concept of Constructality thus named by Adrian Bejan ten years later: *Constructal Theory*. From then on, the Constructal Law will apply to the hard sciences as well as to the soft sciences, thus forming a coherent whole: the beauty of an "ontological" whole which belongs both to the order of essence and to the that of existence [*// Time and Beauty: Why Time Files and Beauty Never Die. A. Bejan.*].

As a professor, I have been surprised several times to note the conceptual timidity, inversely proportional to the initial enthusiasm which animated them, with which the academic institutions of the Human Sciences tried to approach the subject concerning the evaluation of performance of their teaching.

Pedagogical theories are numerous. Without denying the interest they bring to the richness of the debate, it must be recognized that none is able to propose better than tedious questionnaires with self-gratifying aims, likely to validate their institutional hypotheses [the famous inner flame]. Always the embedded presence of our phlogiston!

By asking the question of evaluation from “to have” and not from what pedagogy “is”, a metrological approach to the evaluation of teaching must be made possible and therefore ultimately mappable. In this, the Constructal Methodology, considering the trifunctional systemic nature of all communications in cogito-dynamics, of which pedagogy is a part, should not escape the beneficial lighting of the Constructal Law, just as it has been in many discoveries made for the benefit of previous areas of research. The way to follow is therefore to situate the evaluation not on the charisma of the teacher, not on the qualities of the students, or even on the accessibility or not at the level of complexity of the resources taught, but, of course, on this concrete purpose of all lessons which is the acquisition of skills by the student. Therefore, the nature of these skills must be clearly defined in the syllabus by precisely describing the objective of lessons.

2. Materials and Methods: Epistemology and stages in the construction of the Constructal Abacus breaks the useless complications.

The colorimetric construction of the Constructal Abacus for the benefit of the evaluation of the skills acquired by the student, attributed by himself, that is to say without involving either the academy or the teacher, requires the implementation synergy of the following themes:

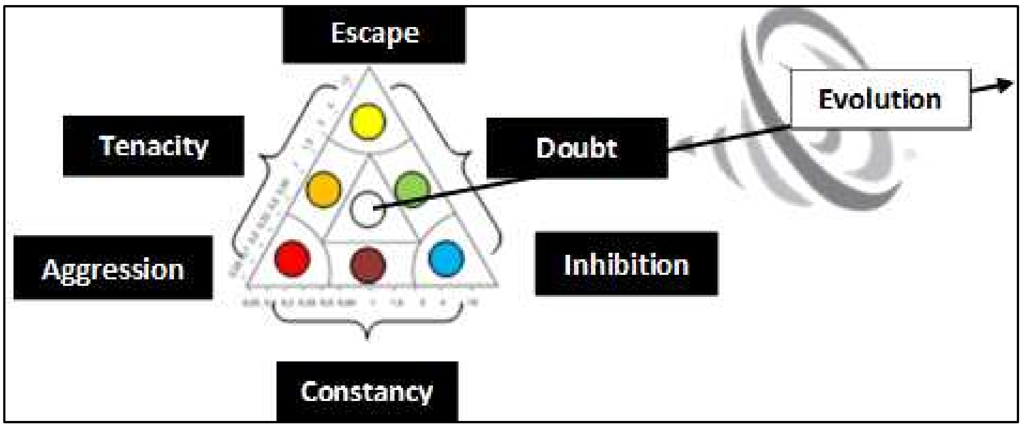
- *The use of the Trikãlian Constructal Model inherent in all communications*:

It is made up of 7 spaces, each being defined by the greater or lesser interest that each has in *aggressiveness*, *inhibition* or (and) *escape* (the 3 summits of triangulation) or their interactions (the 3 sides of the triangulation resulting from the meeting of two summits and each distant from its opposite summit). See metrological Trikãla figure below. (Cf. Kalason Patrick. *Title of the article*: "Constructal Interdisciplinary Concomitance of the Dynamic Variations of the Living to Cogito-dynamics". *Journal* PROCEEDINGS CONSTRUCTAL LAW & SECOND LAW CONFERENCE, 15-16 MAY 2017, BUCHAREST, ROMANIA. Vol., page 371- page 391. 2017).

- *The use of colorimetry (primary and secondary colors):*

The colors are distributed on the source Trikãla according to the following symbolism: red assigned to aggression, blue to inhibition, yellow to escape, green to doubt, brown to constancy, orange to tenacity, white (which is not a color but the sum of all) constitutes its Constructal Barycenter: the optimized shape. These colorimetric references have proven useful in understanding complex communication phenomena. In this way, our reader will always be able to find his way easily in this article because of the homothety inherent in the Constructal System of communications.

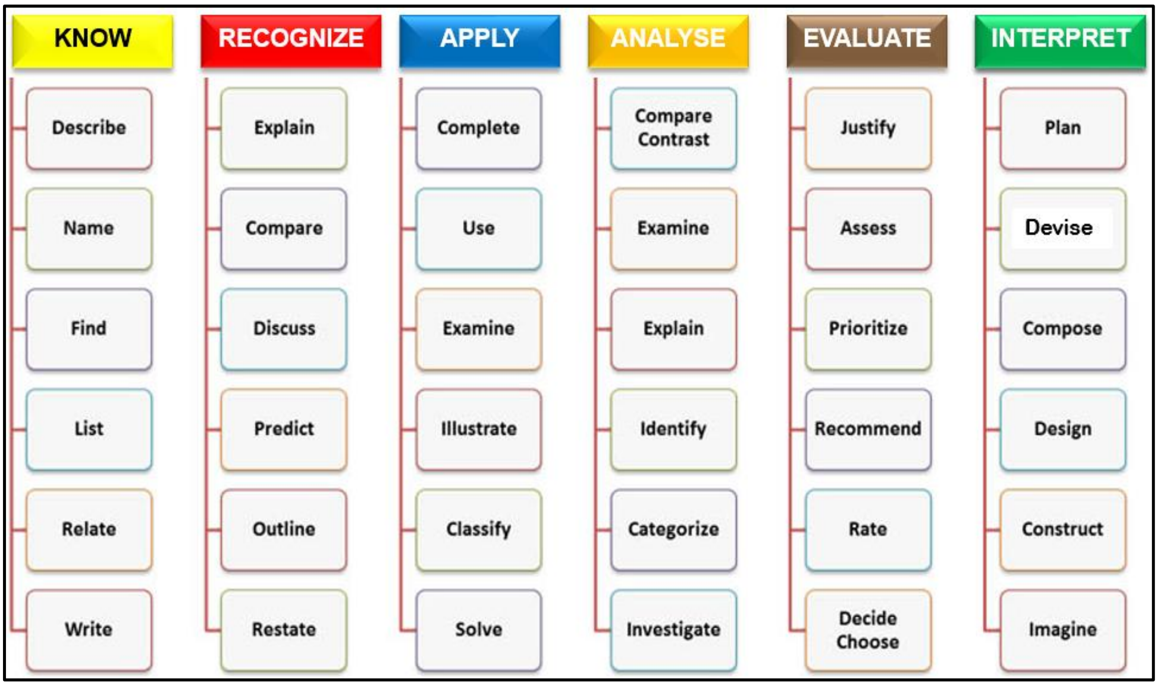
- *The use of Blum's 7 skills taxonomy (revisited) - Kalason:*



In 1956, Benjamin Bloom and his collaborators published a framework for categorizing educational objectives. This framework has been applied by generations of teachers from kindergarten through high school and by university professors as a teaching methods. This taxonomic framework initially consisted of six main categories of skills: knowledge, understanding, application, analysis, evaluation, the sixth [synthesis] of which epistemologically needed to be replaced constructively by "interpretation" (2017).

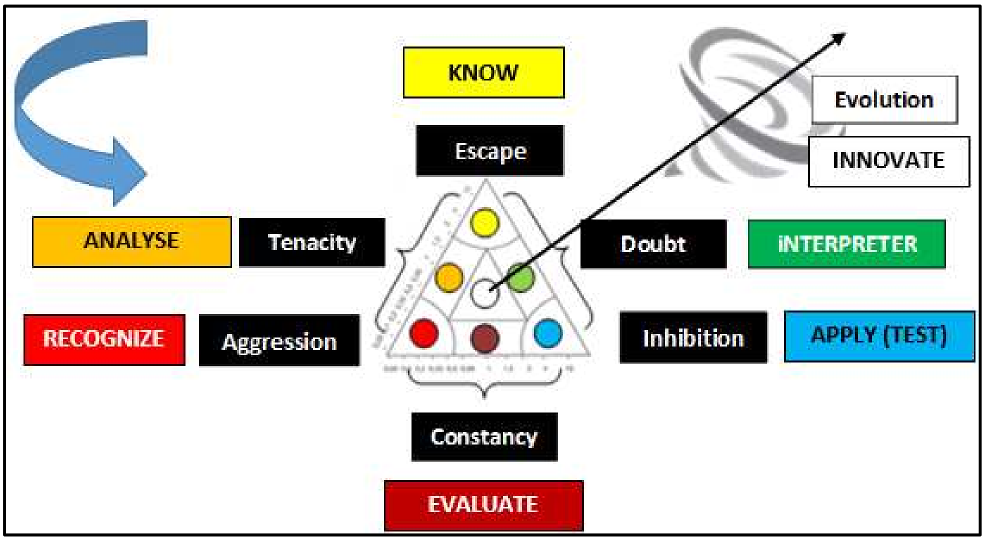
Would it be a question of deducing from this bewilderment that traditional teaching would fear the “doubt” nevertheless essential to the change of paradigm to open on heuristics?

Thus innovation naturally becomes the heuristic effect emanating from the synergistic movement between "primary" (see yellow, red, blue) and "secondary" skills and this at the barycentre of the Trikãla of cogito-dynamics: the 7th skill which is "innovation", that of the builder, that of the engineer.



This directory above can be converted Constructaly by the figure of the Trikãla below, which give birth to the heuristic, as a consequence of the synergy between the 6 skills (primary and secondary).

Let's be almost sure that when discoveries from different horizons converge, that we are faced with certainty.



- The use of the pedagogical pathway and its steps towards innovation:

Seven in number, the steps that ultimately allow access to the culture of innovation, are as follows, in a chronological order (the colorimetry in use makes it possible to identify the Constructal Nature of the positioning of each step within Trikãla).

I - Sensitization

II - Avoidance of possible pitfalls

III - Attempt

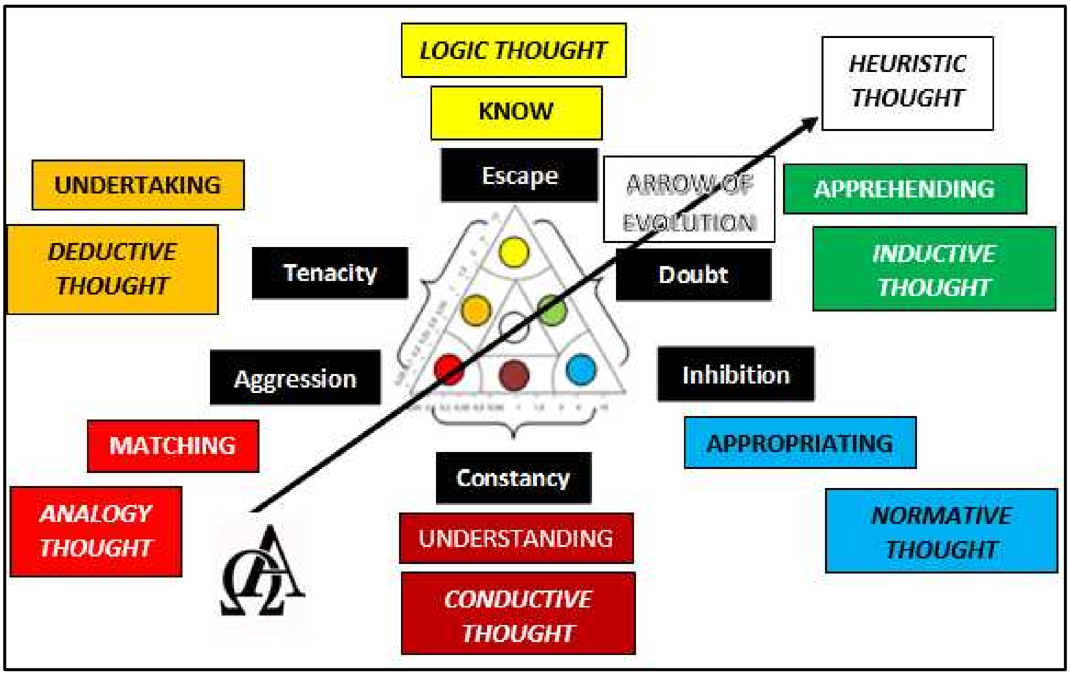
IV - knowledge

V - Application in simple

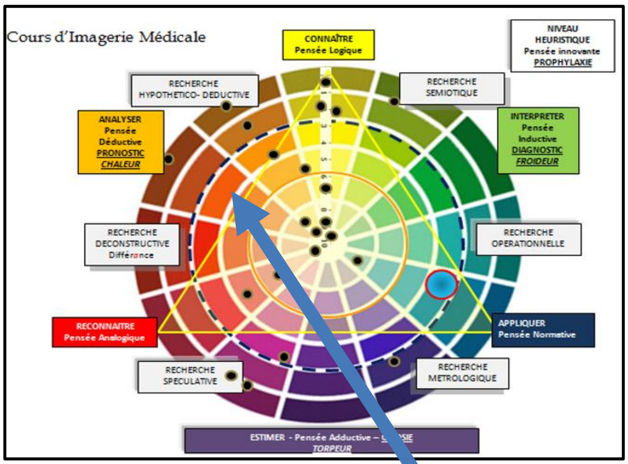
VI - Application in complex situations

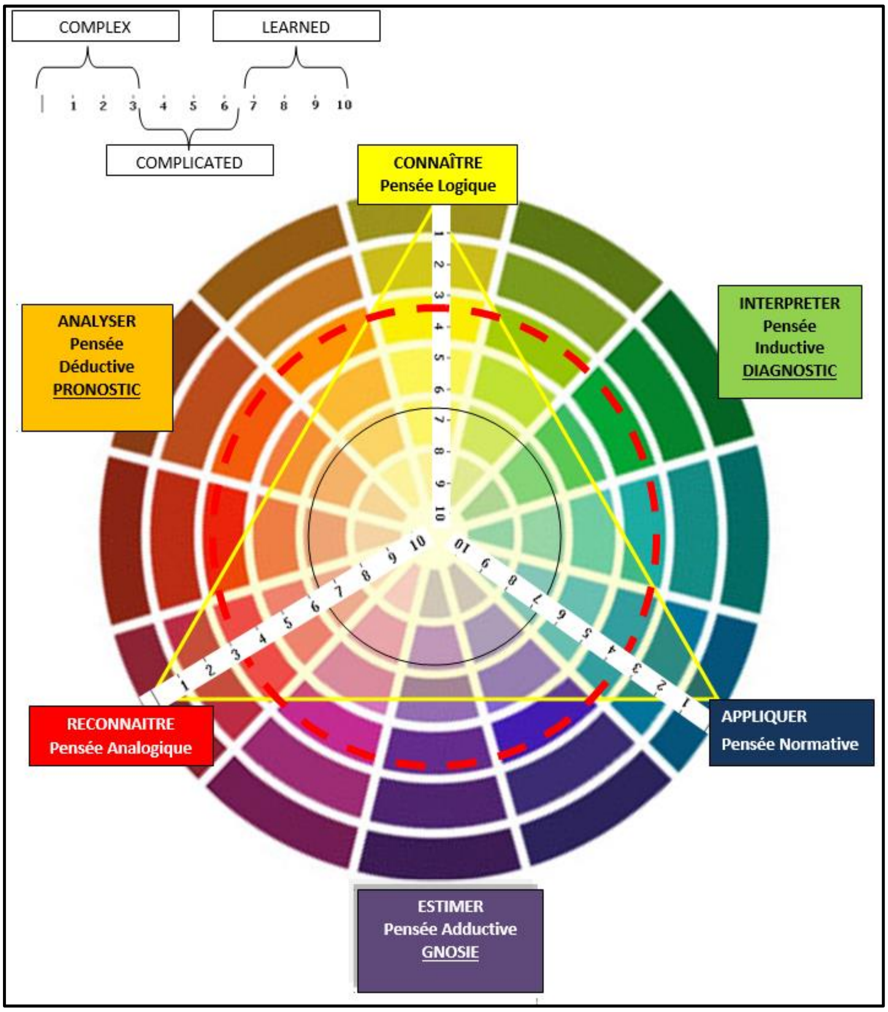
VII - Heuristic insight

- The use of the typology of forms of learning [below in bold capitals], *linked by homotheties to the typology of cognitive forms* [below in bold italics]*:*



3. Results: *In fine*. By including inside a chromatic circle the Constructal Trikãla of parametric skills we obtain this configuration on which a student can easily locate himself, by a single point, which he considers to be the center of gravity of the skills that he thinks he has or not acquired. The further the point is from the center of the [white] circle (value 10), the greater the learning difficulty was.





Here, the cloud from a "medical imagery" teaching session, shows a dark coloing of the balance point of the all evaluations.

This coloring suggests that the teaching was essentially based on the theoretical analysis of complex cases without sufficiently involving the students in the concrete practices. The educational path was therefore not respected (phase I, II, III, V).

5. Discussion and Conclusions.

The richness of the analysis make it possible, through the simplicity of the abacus, to offer an opening towards its computerization and should make the tool easily exploitable by the academies with genuine expertise whenever possible.