Constructal flow of constructal thinking

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Abstract

The constructal law was first formulated at Duke University in 1996, and knowledge of it has since spread globally. Thousands of researchers have used the term "constructal", and many more are familiar with it. This dissemination and reception of constructal thinking can be interpreted as a point-to-area flow, originating from Duke University and reaching the entire world. We explore this flow through computer-aided textual analysis, starting by identifying geographical centers of activity and revealing active communication channels between them. Furthermore, we explore how new branches of constructal thinking evolve and diverge in new directions. Overall, the point-to-area flow that we are able to quantify and visualize demonstrates that constructal thinking evolves to reach broader audiences with increasing ease. Thus, we observe a constructal point-to-area flow in the dissemination and reception of constructal thinking.

Keywords: geospatial analysis, geospatial discovery, constructal thinking.

1.Introduction

The term "constructal" was coined by Adrian Bejan in the mid 1990s (Bejan 1997). 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", and "constructal theory". All of these phrases are part of a larger body of constructal thinking that has kept growing over nearly three decades (Bejan 2000, 2016, 2020, Bejan & Errera 2016, Bejan & Lorente S 2013, Bejan & Merkx 2007, Bejan & Zane 2012). We call this larger body of thought "constructal thinking".

The overall growth of constructal thinking is quantifiable through Google Books Ngrams, for example (2019 English corpus, Michel et al 2011). The Google

Books data demonstrate that book authors have been using the term “constructal” with increasing frequency. (The frequency is rising over time, both in absolute numbers and relative for “constructal” compared to all other words.)

The present article goes beyond quantifying absolute or relative growth. Our main interest is to explore how constructal thinking has spread geographically. In particular, we ask how constructal thinking has spread from Duke University to the rest of the world, connecting an increasing number of researchers. Has this network of researchers evolved such that information that flows through it spreads both faster and further?

Our present article answers this question in the affirmative based on five key insights:

1) Presently, constructal thinking takes place all over the world, on all continents.
2) While the term “constructal” was coined at Duke University, constructal thinking outside the university has grown much faster.
3) The growth of constructal thinking outside Duke University has led to the appearance many highly active centers where constructal thinking takes place.
4) Some of these centers are interconnected by highly active channels of communication.
5) Not all centers are equally interconnected. Instead, constructal thinking is becoming an increasingly diverse scientific culture with multiple, partly independent cultural groups.

Together, these insights substantiate that the network of researchers who use the term “constructal” has evolved such that new ideas that flow though the network can reach active researchers more quickly and in a broader range of geographical and cultural settings. Thus, the network facilitates constructal thinking to flows faster and further.

Insights similar to ours have been reported in a previous study performed in 2016 (Razera et al. 2018). This earlier work considered 885 records from the Web of Science database. The records, ranging in date from 1996 to 2016, were represented as a graph with vertices for each author and edges for co-authorships. The researchers thus studied constructal thinking as a social network. The analysis of the properties of this network led to conclusions similar to ours. Thus, our work replicates these earlier findings independently and with a larger and more recent dataset, and perhaps thought an analysis geared slightly more towards geospatial analysis.

Our final suggestion—that constructal thinking can be seen as a constructal flow of ideas—has also been anticipated, namely by Errera (2018), who argued that constructal thinking is leading to a paradigm shift in Thomas Kuhn’s sense—and this would suggest that constructal thinking is evolving and flowing, as we also reconfirm.

2.Materials and Methods

To study how constructal thinking has spread around the world, we begin by collecting 6,785 publications (predominantly articles, conference presentations,

and academic books). This corpus is generated through an advanced search for the term “constructal” in the Scopus database (2023). All documents are considered that contain the term “constructal” in their full text or metadata.

After collecting the data, we proceed by geocoding the author affiliations of each article as well as the textual content taken from each abstract. For the latter purpose, we have employed a self-developed method of geographic information retrieval published elsewhere (Baciu 2020). After removing all records that have no geocodable material, we are left with 6,619 documents.

To study geographical distributions, we employ Geospatial Discovery for Text (GDT), an interactive interface that we previously developed for other research (Baciu, Kajarekar 2023). This interface is designed to help us identify hotspots of research activity and discover and visualize active channels of communication between them.

In our GDT-visual, we draw each publication as a gradient line on the map. The line starts white in the location 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 collected from the article’s abstract. Overall, most of our geographical datapoints come from affiliations, while only comparatively few come from the content of the abstracts.

3.Results and Discussion

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

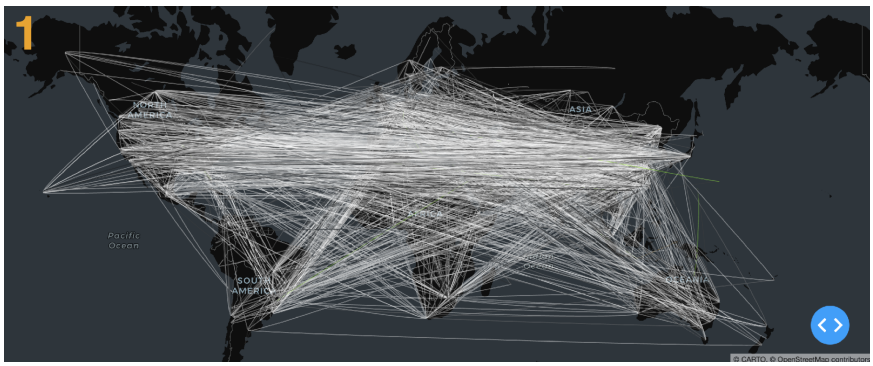

Figure 1. Constructal thinking has spread all over the world, including Australia, Asia, South America, and Sub-Saharan Africa. The visual speaks for itself.

In **Figure 1,** we show that constructal thinking takes place all over the world. Evidently, there is high activity both in the Global North and South. In our previous research we have studied what everyone calls "the Chicago School". This previous study has collected more than 100,000 volumes of books and periodicals that have mentioned any kind of "Chicago School" since 1850 (Baciu 2017, 2019). Compared to the Chicago School, our present study shows that constructal thinking has spread more broadly, in particular to the Global South.

In the introduction, we have mentioned that our insights independently replicate the results of a study about constructal thinking performed by in 2016, by Razera et al.. Like us, Razera and his collaborators have found that constructal thinking has spread all over the world (Razera et al. 2018, p. 107, 109). The main difference that we observe, is that constructal thinking was not found in Oceania in the 2016-study, whereas today it is widely present there.

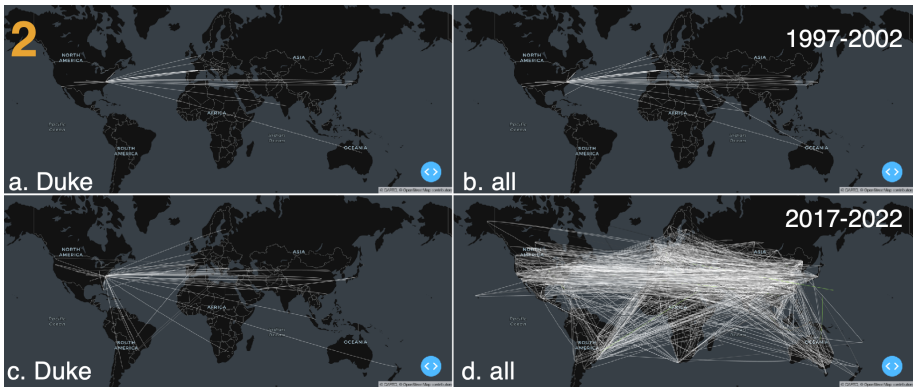

Figure 2. Constructal thinking has initially started at Duke University, but research activity outside the university has grown much faster.

In **Figure 2,** we show that constructal thinking has started at Duke, but it has grown much faster outside the university. In the illustration, we show this effect by comparing research in the years 1997-2002 and 2017-2022. In 1997-2002, most constructal thinking was affiliated with Duke (Fig. 2a, b). In 2017-2022, Duke has become slightly more active, but activity that is unaffiliated with Duke has taken the upper hand (Fig. 2c, d), exceeding activity at Duke by two orders of magnitude.

Thus, the initial impulse for constructal thinking can be said to have clearly come from Duke. However, the rest of the world has become much like a soundbox that reverberates and resounds with constructal ideas, giving substantial volume to them.

In 2016, Razera et al. observed this phenomenon as well, and they also quantified it in multiple alternative ways that support the same conclusion (Razera et al. 2018, p. 108). Our present evaluation reconfirms their earlier observations.

The same type of phenomenon is also found with regard to cultural change in other bodies of thought. A good example is the Chicago School (Baciu 2018). Initially, the term Chicago School had close ties to the city. Over time however, it has spread over the world with Chicago Schools having appeared in new contexts. Suddenly, authors mentioned schools of thought such as the "Chicago School of the West" which was associated with a group of researchers at UCLA. In parallel, scholars in Europe became fascinated with the Chicago School and recounted its history to Europeans (Baciu 2021). Compared to the Chicago School, constructal thinking has spread faster in the Global South. (We have observed its presence in the Global South already in our first insight.)

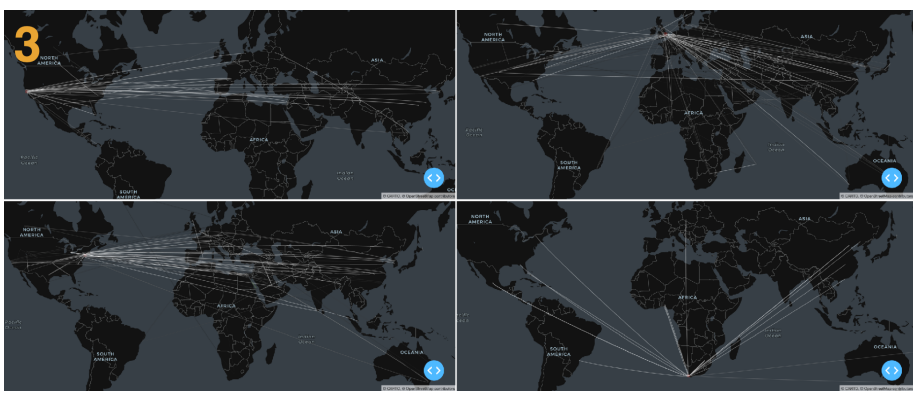

Figure 3. There are highly active centers of activity. The visual shows: top left San Francisco, bottom left New York, top right Cambridge, and bottom right Cape Town (50 km window around each). These are places where the data shows high activity, but they are not the four most active places.

In **Figure 3,** we visualize the existence of highly active centers of research. Places such as Durham, Paraná, Porto Alegre, Rio Grande, Bologna, Parma, Cambridge, Toulouse, Istanbul, Cape Town, and Beijing are highly active, whereas most of the globe is on average much less active. In the figure, we show that even outside the

most active centers of research, the same type of hierarchical organization is found, with centers of slightly lower activity such as the ones shown in the illustration.

This type of distribution is also known as a Pareto distribution, named after Vilfredo Pareto, who described it based on income data towards the end of the 20th century (Pareto 1896). Such a distribution is a general outcome of evolutionary processes, and it is found in many different types of data including city sizes, income, word frequencies, and scientific impact (Baciu 2018, 2020). In our earlier research, we found the same distribution among the various senses of the term “Chicago School”, for example (Baciu 2017, 2018, 2019,2020). Note that with such long-tailed distributions, calculating the average level of activity may make little sense, as the average may tend to approach zero (Taleb 2020).

Our present observation—of a disparity between highly active and less active centers of constructal thinking—is by no means unexpected. The illustrations of Razera et al. (2018, Fig. 3a,b p. 108) also clearly show a Pareto distribution when visualizing research activity among people who have published about the constructal law and countries where constructal thinking takes place. The observations that both Razera et al. and we have made thus substantiate that construal thinking is spreading just as one would expect.

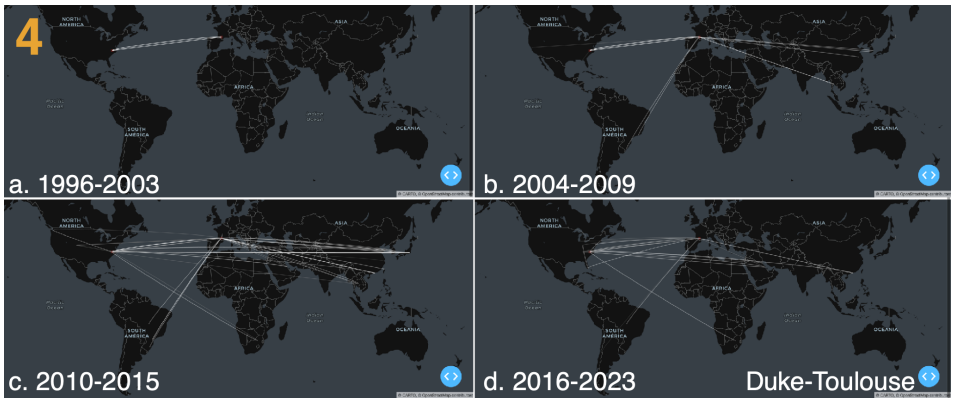

Figure 4. There are highly active paths of communication. The visualization shows Duke-Toulouse, which has stayed active since the 1990s and has reached a peak of activity in 2010-2015.

In **Figure 4,** we show that there exist highly active paths of communication. Places such as Durham and Toulouse have been strongly interconnected since 1996. We interpret this finding in the sense that these highly active paths of communication between highly active centers of constructal thinking facilitate ease of communication. Through these paths, new ideas can spread efficiently, reaching active thinkers with little effort (Bejan, Lorente 2012).

The existence of highly active paths of communication is commonly observed in many types of data. Trees have few large trunks and many small branches. Cars drive over few highly active highways into numerous less active byways. Airplanes connect highly active airports, while also providing access to many other, less active destinations (Bejan 2016).

With respect to constructal thinking, the presence of highly active paths of communication has already been observed by Razera et al. (2018). Thus, our observation is thus once again unsurprising and as expected.

Figure 5. There may be breakaway groups. For example, many publications are affiliated with Beijing but unaffiliated with either Duke or Toulouse.

In **Figure 5,** we show that centers of constructal thinking may evolve independent of one another. Focusing on Beijing, we show that research affiliated with Beijing connects this city very broadly to the rest of the world, yet it does not connect it in our dataset with either Durham or Toulouse, which are highly active centers of research, as already mentioned. Thus, the developments in Beijing may be interpreted as a branch of constructal thinking that is at least partly independent of other important branches.

Razera et al. (2018) and his collaborators made roughly the same observation. They observed the existence of multiple, independent clusters of constructal thinkers. Furthermore, the Chinese cluster was active but not connected to the other clusters in their dataset as well (ibid. Fig. 4, 5, p. 109).

To further substantiate our finding, we have mathematically explored the properties of the network of constructal thinkers. Specifically, we are representing the network as a square matrix. In this representation, each author has a row and a column, and each field of the matrix contains the total number of articles that any

two authors have co-authored. When we perform matrix decomposition on this matrix, we observe that the matrix has multiple eigenvectors with eigenvalues greater than 1. Each of these eigenvectors is as an independent dimension of the matrix, which we interpret as an independent cultural dimension of the network.

Thus, constructal thinking is a culture with multiple diverse dimensions. Each dimension grows at its its own average rate. In our matrix analysis, this growth rate is estimated as the eigenvalue of the eigenvector.

Must cultures have such diverse cultural dimensions. The previous study of Chicago Schools also revealed the existence of hundreds of independent Chicago Schools, as well (Baciu 2018, 2019, 2020). Furthermore, similar branching processes are found in most types of data, at all scales. The universe has evolved from an equal-density universe into a universe with many branching super-galaxies and void spaces between them (Tully et al. 2014). Similarly, trees commonly grow many branches that stretch independently to catch the sunshine. Furthermore, ecosystems also host many species of animals that reproduce independently, which has inspired researchers to draw evolutionary trees with many branches when they discuss animal diversity. Last but not least, cultures diversify. In most cultures ideas are disseminated and received, and they evolve, diversify, and branch out in many new directions (Baciu 2018, 2020). Thus, the observation that constructal thinking also becomes increasingly diverse is no surprise.

To conclude this presentation of five key insights, we can say that all of them are as expected. We are obtaining evidence for things that one would generally expect

to see, anyway. We see patterns of growth that: 1) have already been observed by a previous study (Razor et al. 2018), 2) are commonly observed among bodies of thought that is disseminated and received in large groups of authors and audiences, 3) match up with commonly observed patterns of evolution and diversification in other fields of study. The fact that our insights seem so unsurprising makes them all the more trustworthy (Pinker 2018).

4.Outlook

Constructal thinking brings authors together, uniting them in an evolving network. As this network evolves, hierarchies with highly active centers of research and highly active paths of communication become increasingly apparent. These hierarchies facilitate the flow of new ideas, allowing them to reach authors easily and efficiently (Figures 3 and 4). At the same time, the shape of the network branches out to allow for an increasing amount of independence and freedom. Over time, new ideas reach researchers in a broader range of geographical and cultural settings (Figure 5).

This evolution towards both clearly pronounced hierarchies and increasing freedom is what the constructal law has been formulated to describe. According to the constructal law, systems evolve in ways that facilitate movement that reaches its destinations faster and further (Bejan 1997, 1998). This is also what we have observed in our present study of the constructal thinking. The network of constructal thinkers that we have studied has evolved in a way that lets ideas flow easily and efficiently and to an increasingly diverse range of geographies and cultural groups. Thus we can say that we are observing a constructal flow of constructal thinking.

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