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# CONSTRUCTAL NETWORK OF SCIENTIFIC PUBLICATIONS, CO-AUTHORSHIP AND CITATIONS

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**Abstract.** This paper presents a network analysis of the scientific publications, co-authorship and citations associated to the word "constructal" that appears in Journals between the years 1996 to 2016 using search engine recognized in the international academic community. The constructed networks consider the existing relationships between authors and the number of publications and citations in the studied range of years. The results show that constructal field has been growing and spreading. The papers have been published so far in all continents except Oceania. The subjects of the papers also cover diverse areas from Engineering, Thermodynamics and Mechanics to Physics, Biomedicine and Biophysics. The number of publications and citations is still in the exponential stage of the growth of the S-curve and it has reached the amount of 108 publications and approximately 2,300 citations in 2016. A characteristic exhibited by natural networks, hierarchy, also emerges from constructal network: few authors with large number of publications/citations, and many authors with small number of publications/citations.

***Key words:*** Constructal networks, Number of publications, Co-authorship, Citations.

## 1. INTRODUCTION

The Constructal law – "For a finite-size system to persist in time (to live), it must evolve freely in such a way that it provides easier access to the imposed (global) currents that flow through it" – has been stated by Prof. Adrian Bejan in 1996 [1]. Growing literature emerged supporting Constructal law and its validity by determining the shape and structure of natural and engineered flow systems [2–6]. Bejan [7–9] showed that this law of physics can also account for the phenomenon of evolution and proposed a new concept of life in Physics [10–13]: "life is movement that evolves freely, in both animate and inanimate spheres". All the flow systems animate and inanimate are alive; if the flow stops, they die. Was this message heard? How many researchers are taking into account Constructal theory in their researches and how they are connected among themselves? A possible answer to these questions can be found studying scientific collaboration [14–17] among researchers in the academy, which use or apply constructal theory in their works. According to Bejan [12] "we work with colleagues to create new things that facilitate movement for everybody; collaboration itself is movement, as well as another word for organization, a flow configuration with purpose and the freedom to change, which together mean life".

The main objective of this work is to build and analyze the constructal network based on the possible relationships between authors who published on constructal realm in journals, from 1996 to 2016, using a

digital search engine recognized in the academic community, namely Web of Science. This analysis makes possible to infer the importance of co-authoring Constructal network, how is it spreading around the world, the main researchers, where they live and the evolution of the constructal network in time.

## 2. CO-AUTHORING NETWORKS

In a co-authoring network all authors of the same work are connected to each other, each author is a vertex of the network and an edge exists if these authors are coauthor of a same work. According to Newman [17] the majority of authors have few coauthors however there are few authors that have hundreds, even thousands of coauthors. Each publication that is inserted in the network represents a group of coauthors connected together. Authors belonging to different groups connect these groups. This modeling is known as the Click Network.

A Network of Clicks is one in which its dynamics of formation and evolution involves the addition of mutually connected vertices. This set of connected vertices is called a click and the merging of clicks generates the Clicks Network. Pereira *et al.* [18] used a network of scientific journals in which each title is modeled as a click: words from the same title are connected and clicks link by overlapping the common word.

The structure of a social network can be modeled by a graph $G = (V, E)$, where $V$ is a non-empty set of objects called vertices and finite and $E$ is a set of unordered pairs of $V$, called edges. The topological characterization of the network and the comparison between communities can be done through statistical indices, which depend only on information contained in the two sets cited above. The social network presented here, contains authors who have published on constructal field from 1996 to 2016. With them, it was possible to build the constructal network and see how this network has evolved in time. It was also possible to identify the main contributors, how they are connected to their collaborators and where they are located over the globe.

## 3. METHODOLOGY

The data were obtained in the published works on the constructal field from the year 1996 to 2016. Four steps were established to investigate the constructal networks:

*Step* 01 – Establish the main digital search engines that would be used. Web of Science was selected as the digital search engine.

*Step* 02 – Determine the keywords for search in digital search engines. Constructal was the keyword to determine the scientific works and its corresponding authors which were selected to be included in the constructal network.

*Step* 03 – Establish criteria for exclusion and inclusion of papers that will be used for the construction of co-authoring networks. The authors of the constructal network were selected if they publish at least seven works. If they met this requirement their main collaborators were also included in the contructal network, even they have published only a few works.

*Step* 04 – Build the co-authoring constructal network. In this stage, 885 journal publications were selected from the database Web of Science [19] to build the co-authoring constructal network, using the authors of each article selected in the previous stage reaching the total amount of 842 authors. The data corresponding to the name of the authors were modeled as a click network. The authors are the nodes of the constructal network and two authors are connected, if they are co-authors of the same work. Figure 1 shows a more simplified network which was elaborated with the criterion of highlighting the authors with seven or more publications, and their main working partners that have more than three publications. The size of the circles is according to the Degree of each author (see Table 1), i. e. the number of edges that are adjacent to the node. A significative measure of node importance in a network based on a node's connections is named eigenvector centrality. Table 1 presents the eigenvector centrality of some actives authors working on the Constructal network. It is also important to notice that the research groups shown in Fig. 1 have different gradient colors, which represent the strength of the connections with the main author of the research group (e.g. in the main group the strongest colors are from the closest connections with Bejan). This collaboration network takes into account only the networking among the authors not taking into account the number of journal publications or citations. The network was generated graphically using the Gephi 0.9.1 software [20].

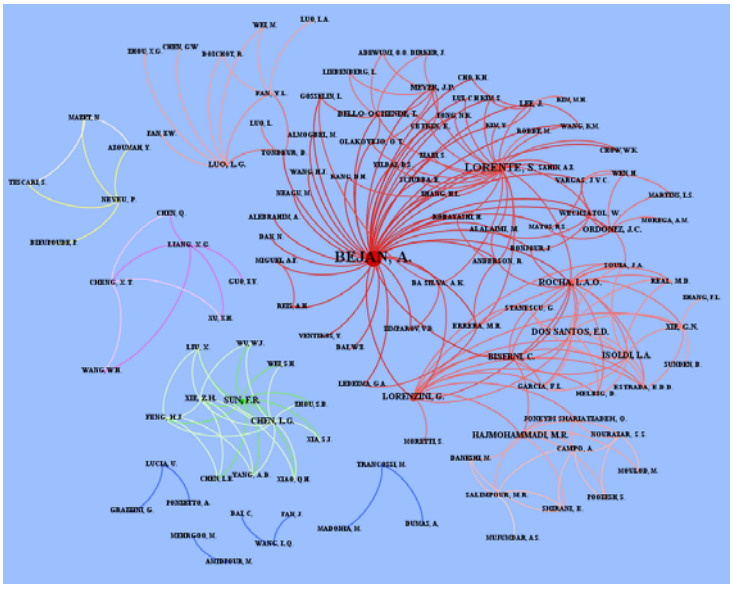


Fig. 1 – Co-authoring Constructal network.

*Table 1*
Degree and Eingenvector Centrality of the authors

| Autors | Degree | Autors | Eingenvector Centrality |
|---|---|---|---|
| Bejan, A. | 45 | Bejan, A. | 1,0000 |
| Lorente, S. | 26 | Lorente, S. | 0,6942 |
| Lorenzini, G. | 15 | Rocha, L.A.O | 0,5416 |
| Rocha, L.A.O. | 15 | Lorenzini, G. | 0,4678 |
| Sun, F.R. | 11 | Biserni, C. | 0,3930 |
| Dos Santos, E.D. | 11 | Dos Santos, E.D. | 0,3343 |
| Isoldi, L.A. | 11 | Isoldi, L.A. | 0,3343 |
| Chen, L.G. | 10 | Anderson, R. | 0,3044 |
| Biserni, C. | 10 | Bello-Ochende, T. | 0,2965 |
| Hajmohammadi, M.R. | 10 | Meyer, J.P. | 0,2807 |

## 4. METHODOLOGY

Figure 1 has shown that the constructal network is spreading and growing. Many research groups are embracing the constructal law and applying it to their works. This observation is corroborated by Fig. 2a that presents the evolution of number of publications which are related to constructal field. This number has increased from the first journal paper published in 1996 to around the rate of 10 publications per year from 1997 to 2003, and it continued to rise until reached the rate 100 publications per year in 2013–2016. This growing can also be noticed when it is observed the number of citations in the literature. Figure 2a also shows that the rate of number of citations per year has increased from 10 citations per year in 1997 to 100 citations per year in 2004, and reached 1,000 citations per year around 2010. The rate of the number of citations continued increasing steadily until reaching around 2,300 citations in 2016.

An important question that emerges, when it is investigated the number of publications and citations, is the role of the Prof. Bejan's in these indicators. Figure 2b indicates that as time passes, in spite the enormous production and number of citations (approximately 330 in 2016) of Prof. Bejan, the percentage of works produced by him in the constructal field has diminished from 100 % of all constructal paper journals published in the range 1996–2000 to around only 10% in 2016. In the other side, Prof. Bejan's citations have also decreased from 100 % in the range 1996–2003 to 30 % of all citations in the constructal domain in 2016.

The total number of authors that are publishing in the Constructal domain is spreading and growing. This evidence is shown in Fig. 2c, which also presents another characteristic of the constructal network which is also observed in natural networks: hierarchy. This figure clearly elucidates that hierarchy also rules

this network presenting a few researchers with a larger amount of journal publications and many authors with small number of publications.

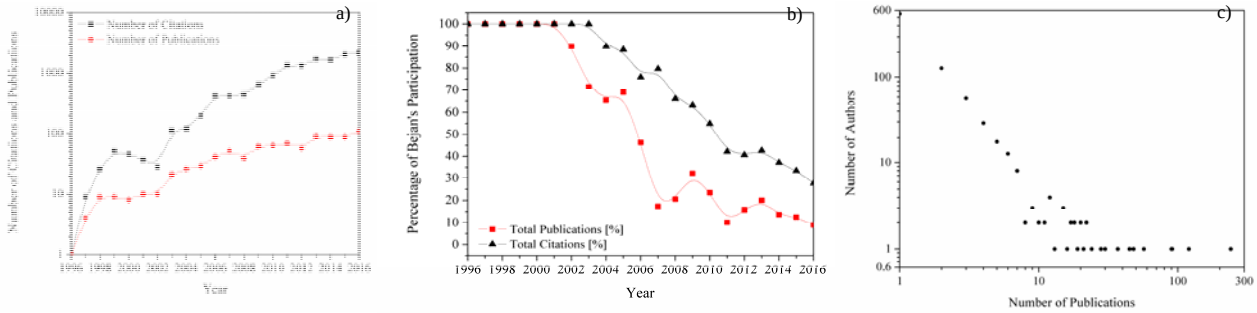


Fig. 2 – a) Total number of publications and citations where the word "constructal" appears in the text; b) percentage of Prof. Bejan's participation in the total number of publications and citations; c) number of authors as function of the Number of Publications.

Another interesting finding is the participation of some actives researchers in the constructal field. Figure 3a shows the percentage of these authors in the total number of publications in the period 1996 – 2016. This figure indicates the names of 19 actives researchers where each one is responsible for at least 2% of of all the publications. It is also important to know the countries where live most of the active authors in the constructal field. Figure 3b shows that they are distributed on 14 countries around the globe corroborating the information of Fig. 2b that constructal theory has been adopted and spreaded around the world. Constructal theory has emerged while Prof. Bejan was solving a thermal engineering problem [1]. This fact could suggest to someone that Constructal theory has been embraced only for researchers that work on this area. Figure 3c elucidates that this is not true. Constructal law has been used in several areas of knowledge: from Engineering/Thermodynamics to Materials Science, Biomedice, and Biophysics, among others [2–13].

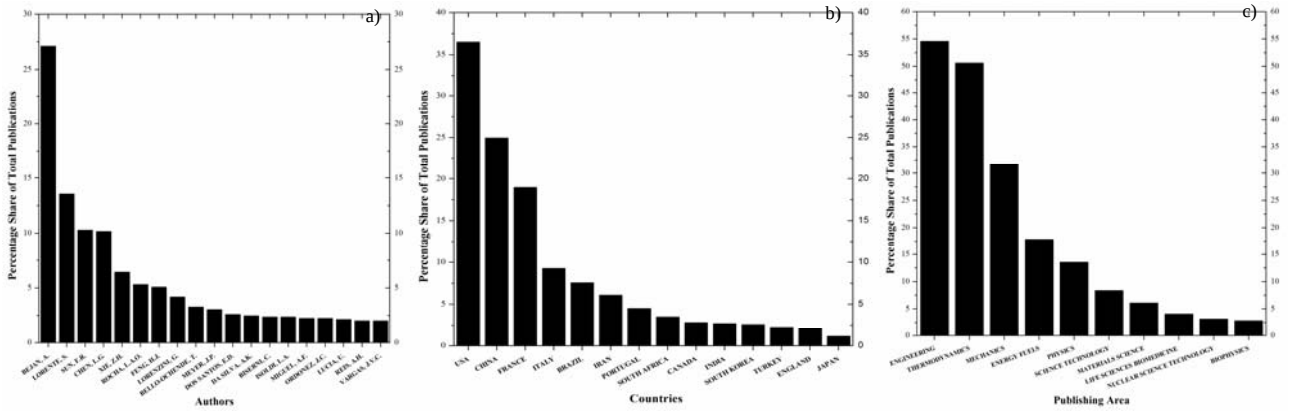


Fig. 3 – a) Percentage of participation of some actives authors in the total number of publications; b) percentage of the participation of author's nationality in the total number of publications in the constructal field; c) percentage of participation of knowledge areas as function of the total number of publications.

Another way to see the Co-authoring Constructal Network is shown in Fig. 4. This figure was built by selecting the authors with more than 11 published works (authorship + co-authorship) and their main research partners. These authors have their name highlighted on the network. The lines of partnership aim to show the strength of connection between the authors, so that each color represents a certain amount of collaborated works. The size of the circles, representing each author, highlights the amount of published works. These aspects are described in the caption presented at the top of the collaboration network. The purpose of this network is to highlight the main research groups and their main collaborators, showing the strength of connection that each group has. In addition, one can visualize the main connections between different research groups and which authors are responsible for expanding the Constructal theory for new researchers.

It is also interesting to know how the international connection among the authors of the Constructal Network works. Figure 5 shows the geographical distribution of some actives authors of the Constructal network and their international cooperation with the colleagues in the area. The size of the circles represents the number of journal papers published as described in the caption of the figure. The criterion for the elaboration of this map was to insert all authors with more than 11 published works (authorship + co-authorship), and to show the international connections among them. This figure also makes possible to see the emergence of the main development sites and propagation paths of the Constructal theory around the world and how it is going with the flow.

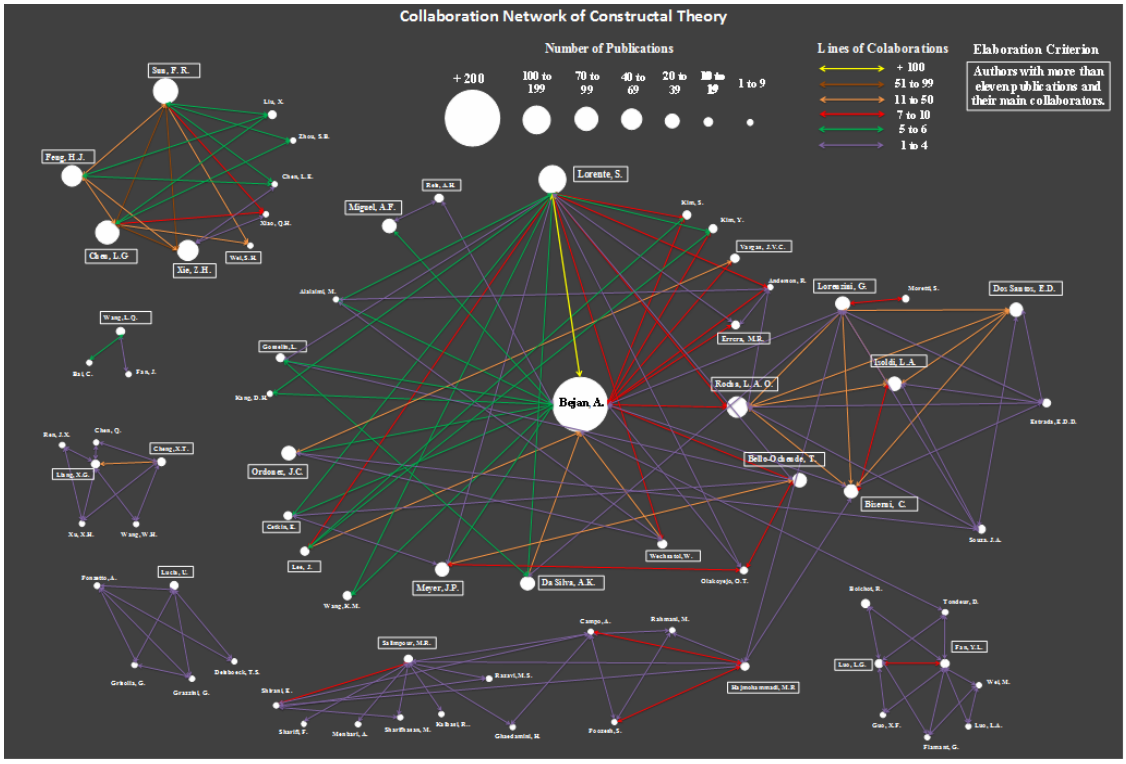


Fig. 4 – Co-authoring Constructal Network.

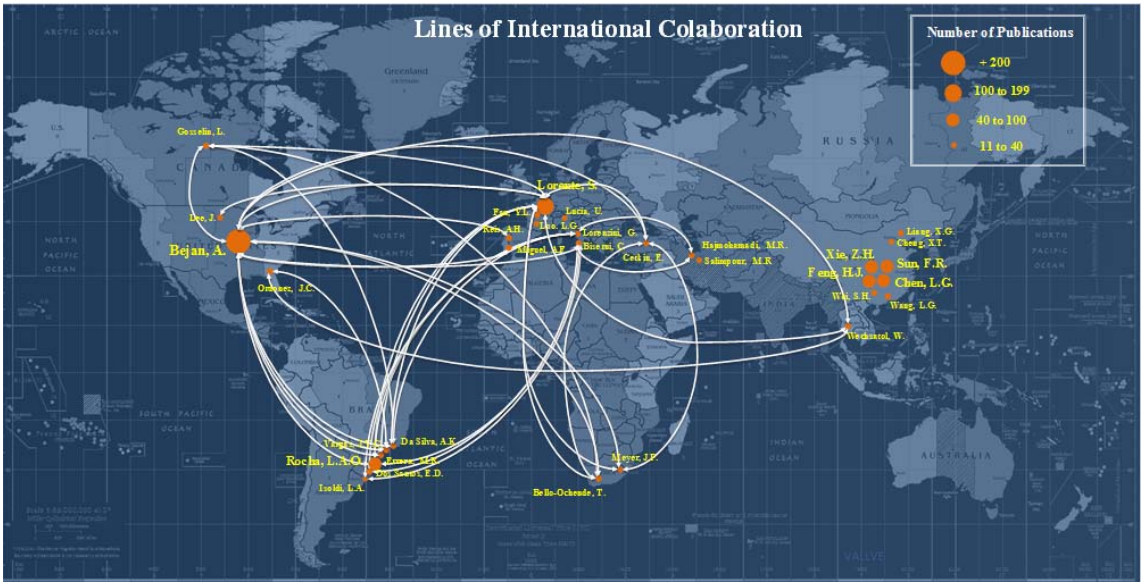


Fig. 5 – Lines of International Collaboration.

## 5. CONCLUSIONS

This paper presented a collaboration network connecting the researchers that have been publishing in the Constructal domain called Co-authoring Constructal Network. The used database was Web of Science; 885 papers journals and 842 authors/coauthors were collected from 1996 to 2016. The authors of the constructal network were selected if they have published at least seven works in this domain. The results indicated that this network is spreading and growing steadily. The results also showed that 90% of the journal papers published in 2016 in the Constructal field were published without Prof. Bejan as a coauthor indicating that the field is already well established, i.e. there are many constructal research groups working independently. It also showed that researchers that have been publishing in the Constructal realm are located all around the world and they have connections among them, i.e. most of them collaborate with each other. The constructal network presented a characteristic that is also noticed in natural networks – hierarchy – a few authors publishing larger number of paper journals and many authors with small amount of publications. Future works can explore the behavior of the constructal network using other databases as Scopus and Google Scholar.

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