BioTRIZ: Subsidies for Projects in Biomimicry and Design

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Abstract
Biomimicry combines multiple perspectives from the biological sciences to generate creative productions through emulations of nature. In this sense, the integration of tools of such field in the design area is valuable and it would, ultimately, stimulate the transformation of the production cycles so that they can resemble the rich systems of the biosphere. Therefore, the present work aims to investigate the relevance of the applications of biomimicry tools in design, and, more specifically, the use of the BioTRIZ matrix, through a literature review. Therefore, the descriptor 'BioTRIZ' was used in international databases. On the Web of Science, 6 publications were obtained in the period from 2008 to 2020. 8 works were found in Scopus between 2008 and 2020. In Google Scholar, a search for Brazilian contributions was conducted in the same period of the aforementioned repositories, totaling 4 publications. The prevalence of BioTRIZ in projects in design, architecture and technology was evidenced. In addition, it was noted that the principles of innovation derived from biological systems tend to provide more numerous and creative contributions in terms of generating alternatives. It is also worth mentioning that BioTRIZ is more adaptable to ecological and sustainable practices compared to the TRIZ tool. Furthermore, when adopting aspects of biomimicry in their repertoire, professionals integrate natural knowledge that demonstrate potential to propagate innovative projects based on the conservation of biodiversity and that can also stimulate quality of life. It is suggested to analyze and experiment with the BioTRIZ tool in new project contexts.

Keywords: Biomimicry, BioTRIZ, Design, Sustainability, Bioinspiration

Introduction

Biomimicry integrates knowledge from the biological sciences to generate innovations in various fields. For Benyus (1997), it corresponds to the emulation of nature and considers the biosphere as a model, measure and mentor for technologies aimed at the elaboration of products, systems and processes, also enabling the improvement of pre-existing creations. Notably in design, resources from biomimicry have been applied to establish analogies and abstractions of forms, processes, behaviors and ecosystems in many projects for our society.

In fact, in the creative domain, it is essential to implement tools and methods that assist in materializing results and proposing solutions to the challenges faced in projects, expanding the scenarios of abstraction, immersion and experimentation. In this sense, biomimicry also represents an approach that allows for sustainable proposals, since, at a more complex and systemic level, suggests adjustments in the production cycles, in order to meet the basic principles of the natural environment (Baumeister et al., 2014; Stickdorn &, Schneider, 2012).

However, it should be noted that as this is a growing and expanding area - especially regarding the consolidation of its methods and tools - some resources provided by biomimicry are still being tested and explored. Among them, it is possible to mention: Biomimicry Design Lens; Life's Principles Matrix; AskNature platform; Design by Analogy to Nature Engine platform, GEMS of SAPPhIRE req sol; and the heuristic matrix called BioTRIZ, which will be the focus of this research (Abdala et al., 2017; Ask Nature Team, 2016; Baumeister et al., 2014; DANE, 2021; Srinivasan et al., 2011).

It is worth explaining that BioTRIZ is a resource derived from the Theory for Resolution of Inventive Problems (TRIZ matrix), developed by Altshuller, that allows the transfer of solutions and knowledge from one area to another where similarities are identified (Cunha, 2015; Vincent et al., 2006).

Essentially, it is a contradiction matrix proposed by Vincent et al. (2006), which allows to recognize and resolve conflicts between parameters of a system in order to create a new design proposal. It combines processes for the abstraction of biological information. In other words, the challenges of a design are outlined by the opposition of pairs of contrasting characteristics that appear in the six organizing axes of the matrix: time, space, structure, substance, information and energy. In total, BioTRIZ covers 500 biological phenomena, with more than 270 functions, which allows the investigation of approximately 2,500 contradictions. An additional quality of this tool is its relative ease of use in teams that are not endowed with individuals with extensive biological knowledge (Srinivasan et al., 2011).

According to Craig et al. (2008), based on studies using BioTRIZ, when comparing human and natural processes, it is possible to observe that humanity prioritizes energetic factors in its technological creations, while the natural world mainly uses the domains of information and structure.

Considering the aforementioned assumptions, a survey of the specialized literature on the use of BioTRIZ in creative projects was carried out.

Method

The bibliographic search was conducted on 10/11/2020 using the descriptor 'BioTRIZ' in three databases: Web of Science, Scopus and Google Scholar. The temporal scope was not determined, therefore, corresponding to the period of the oldest publication identified in the databases until the most recent contributions found. Consequently, the period obtained for this research was equivalent to the interval between 2008 and 2020. No other exclusion criterion was used for Web of Science or Scopus. With regard to Google Scholar, only works in Portuguese that studied, analyzed or applied the BioTRIZ tool were selected.

The following categories of publication were admitted in this survey: articles, master's thesis and proceedings papers. With the aid of the VOSviewer software, the data obtained were submitted to co-citation and co-occurrence analyses. To build the word clouds, the TagCrowd platform was used.

It is important to clarify that the keyword-focused investigations aimed at highlighting the terms cited together by frequency and thematic grouping. The citation analysis intended to verify the most prominent works, and the co-citation revealed the contributions that were cited together, thus presenting an overview of the literature and the essential contributions.

Results and Discussion

Table 1 shows the data extracted from each of the databases, organizing it into general categories.

Categories	Web of Science	Scopus	Google Scholar
Works	(*n* = 6)	(*n* = 8)	(*n* = 4)
Countries	USA (*n* = 3) All other countries (*n* = 1)	USA (*n* = 3) All other countries (*n* = 1)	Only Brazilian works
Authors	Linsey; McAdams; Tsenn (*n* = 3) All other authors (*n* = 1)	Linsey; Tsenn (*n* = 3) Glier; McAdams (*n* = 2) All other authors (*n* = 1)	Camargo; Cunha; Neves; Boelter (*n* = 1)
Institutions	Texas A&M Univ. (*n* = 3) All other institutions (*n* = 1)	Texas A&M Univ. (n = 3) All other institutions (n = 1)	Fed. Univ. of Paraíba Federal Univ. of SC Fed. Univ. of São Carlos Pontif. Cath. Univ. of SP (*n* = 1)
Journals	J. of Bionic Eng.; J. of Eng., Design and Tech.; J. of Mech. Design; Int. Design Eng. Tech.; Proc. of the ASME Int. Design Eng. Tech.; Proc.of the ASME Int. Mech. Eng. (*n* = 1)	J. of Bionic Eng. (*n* = 2) All other journals (*n* = 1)	Fed. Univ. of Paraíba Federal Univ. of SC Fed. Univ. of São Carlos Pontif. Cath. Univ. of SP (*n* = 1)

Table 1: Comparisons between databases.

There is a prominence of the United States in research and projects that adopt the BioTRIZ tool. It is also noted that there is a concentration of publications by author,

since Linsey, McAdams and Tsenn are highlighted, and they share authorship in 3 articles. In Brazil, all four authors are linked to a single publication each. These results corroborate the comment, made in the Introduction, that biomimicry is an expanding area of study and the use of tools such as BioTRIZ can be further explored in creative projects.

Institutions located in the United States were more representative in the survey carried out on the Web of Science and Scopus. In Google Scholar, there is a clear highlight of public universities.

In Brazil, all publications consist of master's thesis in Google Scholar. However, it is worth mentioning that in the two other databases there is a work conducted by a team of researchers from the Federal University of Santa Catarina (Brazil) and of the RWTH Aachen University (Germany), published in the ASME Journal of Mechanical Design (Abdala et al., 2017). This article, entitled "Creative Contributions of the Methods of Inventive Principles of TRIZ and BioTRIZ to Problem Solving" investigated the stimulation of creativity in the design practice through a comparative analysis of the TRIZ and BioTRIZ tools.

Analyzing the articles identified in both researched international bases, there is a predominance of journals associated with bionic engineering, design and technology.

Figure 1 shows the word clouds elaborated with the keywords of the 18 works found since 2008. When examining the illustration, it is possible to verify that the words with the highest frequency of citation in the Web of Science were: 'design' (*n* = 65), 'methods' (*n* = 32) and 'bioinspired' (*n* = 15). Regarding Scopus, the main words were: 'design' (n = *16*), 'method / methods' (n = 9), 'model', 'problem' and 'solving' (*n* = 4). In Google Scholar, the prominent terms were: 'design' (*n* = 12); 'innovation', 'generate' and 'method' (n = 9); 'planning' and 'products' (*n* = 8). When grouping these words, it is possible to highlight the use of BioTRIZ as a method to generate ideas to solve problems and develop innovative, bioinspired and sustainable products.

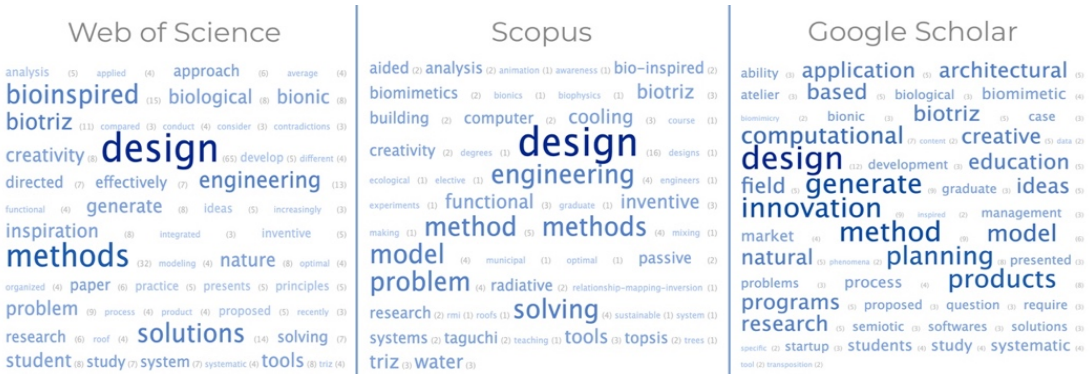

Figure 1: Word clouds created with keywords from the three databases.

Table 2 presents the works found through the Web of Science, according to authorship, title and number of citations.

Authorship and Title	Citations
Craig et. al. (2008) BioTRIZ suggests radiative cooling of buildings can be done passively by changing the structure of roof insulation to let longwave infrared pass	29
Huang, Siao (2016) Development of an integrated bionic design system	7
Abdala et al. (2017) Creative contributions of the methods of inventive principles of TRIZ and BioTRIZ to problem solving	5
Glier et al. (2011) Methods for supporting bioinspired design	4
Glier et al. (2012) Evaluating the directed method for bioinspired design	1
Durand, et al. (2015) Teaching students to innovate: evaluating methods for bioinspired design and their impact on design self-efficacy	0

Table 2: Articles with the highest number of citations in Web of Science.

This specific survey showed that the main research initiatives consist of an analysis of tools applicable in the stages of observation, assessment and conceptual design. From reading articles that addressed the matrices TRIZ and BioTRIZ, a complementarity of the functional perspective of the first, and the emphasis on biological and sustainable aspects, related to the second was observed, which justifies the use of both during projects (Abdala et al., 2017; Glier et al., 2011; Huang & Siao, 2016). It is worth mentioning that these works studied other pertinent resources for bioinspired design creations, such as: direct method approach, functional modeling, case study method, keyword translation and biological analogy search tools.

In order to distinguish the main research focuses on the BioTRIZ tool, a density map was generated for the co-citation analysis. Thus, publications that have conceptual similarities are arranged in each cluster, the most relevant being located at the center (reddish and orange areas). Furthermore, the larger the size of the names of authors, the greater their relevance. It should be noted that this illustration is not limited to the works obtained in the survey, as it is a view of citations in common (see Figure 2).

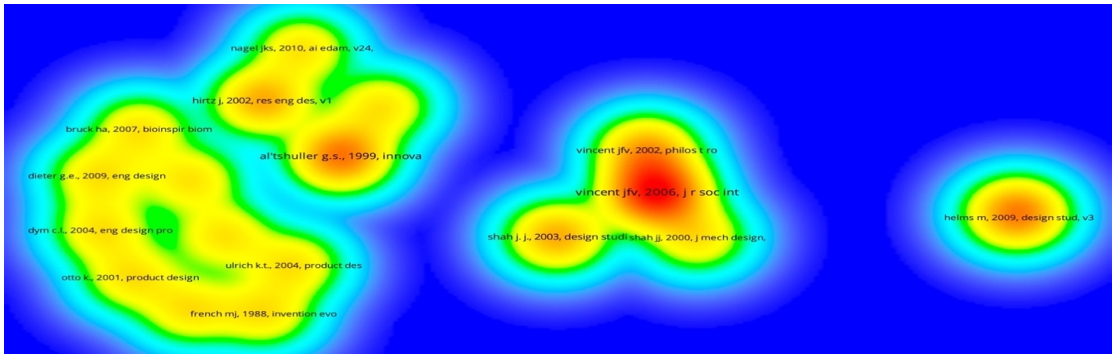

Figure 2: Co-citation map created with data from Web of Science.

When examining each cluster in Figure 2, it is observed that the nucleus concentrated around Vincent et al. (2006) comprises works with stronger convergence between them. In the article “Biomimetics: its Practice and Theory”, these authors presented the BioTRIZ tool, analyzing its advantages compared to the TRIZ matrix, originally proposed by Altshuller (1999). They warned that in the TRIZ tool there is little correspondence between biological and technological principles. Consequently, Vincent et al. (2006) aimed to supply the need for greater integration and investigation of nature in their proposal of a matrix that prioritizes structural and informational transformations, in contrast to the energy expenses – emphasized in projects based only on the TRIZ matrix. Thus, by analyzing an extensive number of biological phenomena and functions, Vincent et al. (2006) expanded and extrapolated the TRIZ matrix, creating BioTRIZ. For the authors, the insertion of biological parameters and fields favors solutions that are more adapted and harmonized with the biosphere.

On the right side of Figure 2, there is a focal point on the publication entitled “Biologically Inspired Design: Products and Processes" by Helms, Vattam and Goel (2008). The article was based on the study of bioinspired approaches in the exploration of analogies to develop solutions for products. The authors revealed that this perspective tends to produce more significant multifunctional and independent results. Helms, Vattam and Goel (2008) discussed two main approaches for bioinspired design: one focused on the problem and the other on the solution. The work also warned of common mistakes in biomimetic practices, which should be avoided during the execution of a project, such as: vague and broad definition of design challenge; inadequate combination between the design proposal and the selection of biological element; inappropriate simplification of complex biological functions and the use of pre-formulated solutions without due consideration of the context.

In the upper left corner of Figure 2, there is a grouping around the publication by Altshuller (1999): The Innovation Algorithm. This book comprises a series of essays on the development of the 40 inventive principles belonging to the TRIZ matrix. It is a work that portrays the constructive history of this tool, complemented by the thoughts and arguments of its author. Therefore, the focus of this cluster is centered on the TRIZ tool itself, which supported the creation of the BioTRIZ matrix.

Another visualization of the data from Web of Science is presented by the co-occurrence map (Figure 3), which organizes the keywords of the articles by thematic proximity groups, respectively represented by the colors red, green and blue.

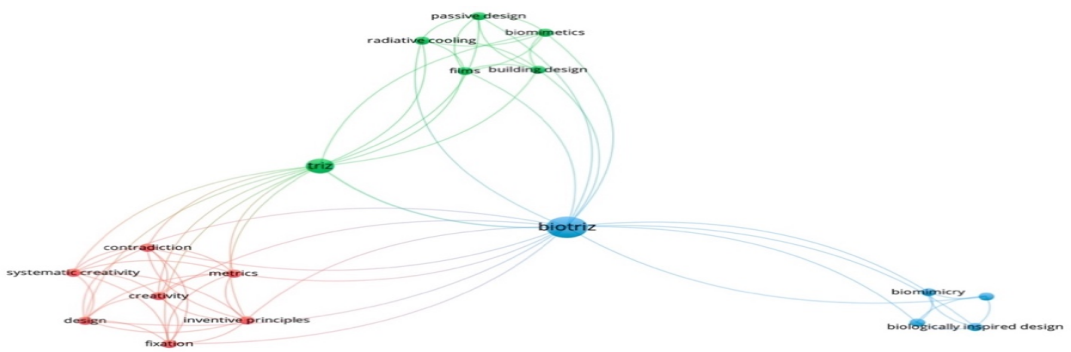

Figure 3: Co-occurrence map created with data from Web of Science.

In the image above, it is possible to perceive the existence of three clusters. In the lower right corner, words directly related to the practice of biomimicry and bioinspiration are grouped. Keywords associated with the applications of BioTRIZ are located at the top of the figure (example: effects of passive ventilation and the study of radiative cooling in buildings). On the left side (red), there is a concentration of terms related to the stimulation of creativity and the investigation of inventive principles.

Regarding the international Scopus database, Table 3 shows the articles identified in the survey and the number of citations per work.

Authorship and Title	Citations
Craig et. al. (2008) BioTRIZ suggests radiative cooling of buildings can be done passively by changing tine structure of roof insulation to let longwave infrared pass	40
Glier et al. (2011) Methods for supporting bioinspired design	11
Huang, Siao (2016) Development of an integrated bionic design system	8
Glier et al. (2012) Evaluating the directed method for bioinspired design	8
Abdala et al. (2017) Creative Contributions of the Methods of Inventive Principles of TRIZ and BioTRIZ to Problem Solving	7
Ji et al. (2013) BioTRIZ-based product innovative design process	5
Durand, et al. (2015) Teaching students to innovate: evaluating methods for bioinspired design and their impact on design self-efficacy	3
Evans-Pughe (2014) Learning from birds and bees	0

Table 3: Articles with the highest number of citations in Scopus.

Initially, it is important to mention that publications coincide with those found on the Web of Science. Considering this overlap, the authors decided to focus on the two texts that were not listed on the basis previously analyzed. Thus, the article by Ji et al. (2013) discloses a model for product design, called Relationship Mapping-Inversion (RMI), composed of two general stages: functional and technical mapping, and a phase of biological inversion. In order to observe the use of RMI, the authors applied this feature in a folding helmet design.

As for the second work, by Evans-Pughe (2014), it is interesting to note that an overview of biomimicry and related creations was presented, as well as an example of

the application of BioTRIZ for making tires for snowy regions. The benefits of renewable and sustainable approaches in biomimetic projects were also discussed, highlighting the need to metamorphose the current industrial system, especially with regard to the use of chemical additives, structures, materials and energy.

In summary, the repertoire of publications repertoire obtained with the Scopus database is associated with: a) an investigation of bioinspired methods and tools; b) case studies; c) the applications of biomimetic knowledge in products; d) the use of BioTRIZ as a teaching resource and improvement of functionality and sustainability in design scenarios; and e) an investigation of brainstorming processes.

Figure 4 illustrates the co-citation analysis and the five research clusters from 2008 to 2020.

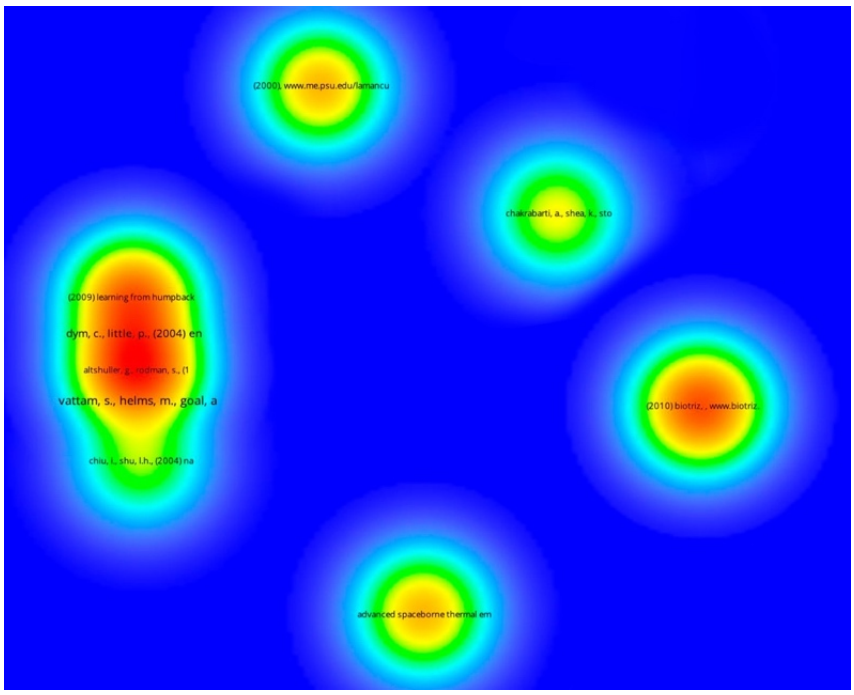

Figure 4: Co-citation map created with data from Scopus.

It is observed that the most relevant nucleus in this figure, is composed of Vattam, Helms and Goel (2008), Dym, Little and Orwin (2003) and Altshuller (1999). In "Biologically-Inspired Innovation in Engineering Design: A Cognitive Study", Vattam et al. (2008) dedicated themselves to understanding the application of biomimetic design tools in teaching and learning in design and engineering. In a course aimed at students of these areas, the authors sought to apprehend and disseminate the cognitive bases associated with bioinspired innovation. They also endeavored to develop computational tools in order to make biomimetic projects viable. According to the authors, for bioinspired innovations to be effective, it is necessary that the 'design problem' is clearly defined and it also requires an adequate degree of abstraction. Vattam et al. (2008) also consider essential to have a good understanding of the project's constraints and limits.

"Engineering Design: A Project-based Introduction" is a book by Dym, Little and Orwin (2003), which describes project management methods and conceptual design tools. Among the main issues addressed throughout the publication, the following can

be mentioned: definition of an engineering design process; establishment of objectives and required functions; generation and selection of alternatives and prototyping; design directed to use and sustainability; and ethical values involved in the production process.

Shown previously in Figure 2, generated from the search on the Web of Science, it can be observed that, in Figure 4, Altshuller's work, the “Innovation Algorithm” is now located in the most relevant cluster.

In Figure 5, the map of co-occurrences may be visualized.

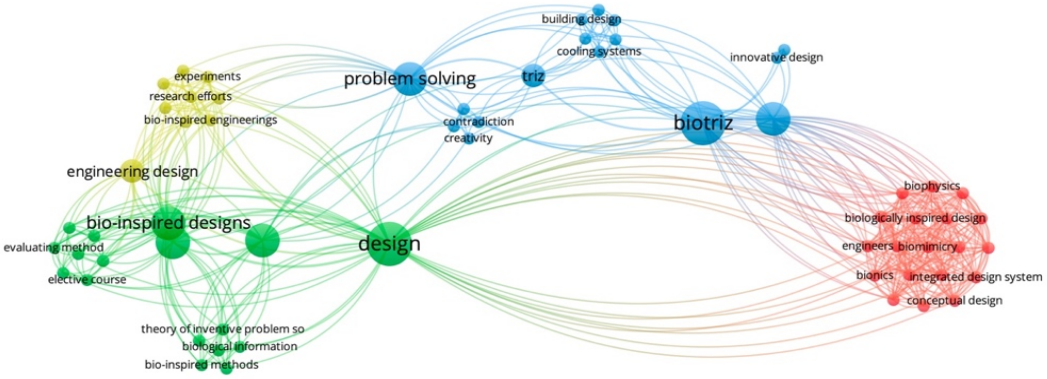

Figure 5: Co-occurrence map generated with data from Scopus.

The image shows: a concentration related to bioinspired design and the insertion of biological knowledge in creative projects (in green); a nucleus focused on experimentation and research (in yellow) and a cluster on problem solving and the development and research of technical aspects of projects (in blue). On the right side, the density of the nucleus formed by research on biomimicry, bionics and conceptual design is noteworthy (in red).

The oldest work obtained in both the Web of Science and Scopus was the article entitled “BioTRIZ Suggests Radiative Cooling of Buildings Can Be Done Passively by Changing the Structure of Roof Insulation to Let Longwave Infrared Pass” (Craig et al., 2008). This publication consists of a study on the application of BioTRIZ in a project for thermal control and environmental comfort in buildings (cooling through the incidence of infrared radiation waves and their combination with structures that promote passive ventilation) and has the highest number of citations in both databases (Table 2 and Table 3). More specifically, the work compares the matrices TRIZ, PRIZM and BioTRIZ. It was found that BioTRIZ made interesting suggestions for altering the structure of a design, unlike the other matrices that are directed towards changing the use of certain materials and finishes.

Brazilian scenario: brief considerations

Below, Table 4 lists the Brazilian production collected on the Google Scholar platform.

Authorship and Title	Citations
CEP de Camargo (2014) Semiotic transposition method for biomimetic computational modeling	1
RE Cunha (2015) Verification of the suitability of the BioTRIZ method in the application of biomimetics in the teaching of architectural design	0
JCL Neves (2015) Framework for incorporating biomimicry and product vision properties as an innovation strategy	0
NM Boelter (2018) Bionic-oriented product planning: use of bioinspirators	0

Table 4: Brazilian articles with the highest number of citations in Google Scholar.

More recent than the eight articles published in international scientific journals, the set of Brazilian works on BioTRIZ corresponds to master's thesis.

In the period stipulated for the search, only Camargo (2014) was cited (n = 1) with the work entitled “Semiotic Transposition Method for Biomimetic Computational Modeling”, in which the author presents biomimetic software for simulating biological factors in a restricted computational environment. To that end, he included biological-inspired algorithms in digital systems and also carried out a case study centered on the particularities of the species *Aplysia californica*. The model developed by Camargo (2014) operates in order to recognize and distinguish useful and non-useful information, and can be applied in other projects, especially in the context of the 'internet of things'.

The verification of publications in the Google Scholar database demonstrated that the research initiatives consist mainly of proposals on the adoption of new tools, among them the BioTRIZ matrix, in the development of products, computer systems and educational dynamics in design, architecture and technology. Other aspects investigated were: brainstorming techniques; theories of semiotics and the structural and behavioral study of organisms.
It is important to elucidate that it was not possible to build co-citation and co-occurrence maps using the VOSviewer software since Google Scholar does not provide adequate metadata for such visualizations. As for the combination of keywords in the word cloud already presented in Figure 1, it can be seen that BioTRIZ is related to the generation of innovative proposals for project management and product design.

Discussion

In summary, the bibliographic research in the three databases evidenced a general tendency to use BioTRIZ in the areas of design, sustainability, architecture and engineering. Another finding that resulted from reading the 18 identified works is that biomimicry encourages the incorporation of practices and knowledge that can stimulate the preservation of biodiversity, as well as improving the quality of life.

Furthermore, the innovation principles derived from biological systems tend to provide more numerous and creative contributions in terms of idea generation and problem solution.

The BioTRIZ tool demonstrates greater adaptability to ecological and sustainable practices compared to the TRIZ tool. One of its advantages lies in the greater variety of inventive principles and in proposing other resources for projects, such as, for example, the evidence of possibility of modifications in the structural and spatial aspects of a design.

By adopting biomimetic aspects in their repertoire of methods and tools, professionals start to integrate the vast natural knowledge that demonstrates the potential to disseminate original design proposals based on the conservation of biodiversity and that can also stimulate the quality of life, since in nature clean energy, raw material savings, non-toxic manufacturing and modularity are often valued and preferred. These are only a few of the many other factors linked to the Earth's Operating Principles, as highlighted by Baumeister et al. (2014).

Conclusion

The principles of innovation derived from the study of biological systems tend to promote more creative alternatives for projects. In addition, BioTRIZ is a tool that allows greater integration of ecological and sustainable practices and principles, compared to the TRIZ tool, which incorporates only information from patents on technological products. In summary, the BioTRIZ matrix contributes to the systematization of the use of natural elements in creative projects, facilitating the operationalization of information and biological knowledge in design (Vincent el al 2006; Helms et al., 2008).

However, as evidenced by Vattam, Helms and Goel (2008), there is still a limited understanding of bioinspiration processes in design practices. Although for hundreds of years humanity has used nature as a source of general inspiration for its creations, there is no normative or formally consolidated process that specifies the practice of biomimetic design. So, it is concluded that, as it is a recently developed resource, there is still little research on BioTRIZ. It is recommended, for future research, to carry out more experiments and case studies using this matrix in design and architecture projects in the most varied contexts.

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