TOOLS TO INCORPORATE BIOMIMETIC INTO PRODUCT DESIGN- A REVIEW

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ABSTRACT: This paper reviewed available biomimetic tools which are being utilized to enhance and aid the design of products. So far, tools that have been used to gain insight of biomimetic products include DANE databases and IDEA-INSPIRE, Natural Language analysis tool and Asknature.org website. This review focused on the representations, characteristics and biomimetic information retrieval process of each search tools studied by previous researchers. Finally, the conclusions and important summaries were presented accordingly in the form of a table. Based on the findings, there are still problems and challenges regarding the applications of each tool in the bio-inspired design process. Some suggestions have been made to further improve the conditions.

KEYWORDS: *Biomimetic Tools; Environmental Engineering; Product Design*

1.0 INTRODUCTION

Biomimetics refers to contribution or emulation of thoughts from nature which is then being delivered and implemented to technology [1]. There are additionally other terms similar to biomimetics which are biomimicry, biomimesis, bionics that can be referred as bionical inventiveness engineering, biognosis, technical, biology, biologically inspired and bio-inspired design (BID) [2]. At the moment, implementations of biomimetics can be found in engineering disciplines like robotics, aerodynamics, material science, bio- sensors and biomedical engineering [3]. In biomimetics, biological systems act

as a model for the design and engineering of material and devices where often the structure and functions of the systems become the guidelines in product design process. Although biomimetics led to design a complex system to solve human problems which are not an ill-structured and unorganized but they perform as if they were well structured in solving human problems [4]. Humans have been picking inspiration from nature to solve mind-boggling and straightforward issues since their existence.

Human has been picking up motivation from nature to take care of mind-boggling and straightforward issues since their reality. Moreover, as stated by Vincent et al. [5], human have sought nature to obtain inspiration for more than 3000 years, since the Chinese first tried to make an artificial silk. The historical samples of biomimetics consist of Velcro inspired from a plant called burdock leaves, Crystal Palace, and barbed wire that copies thorn structure, while the recent examples are Lotusan paint that imitates lotus leaves, termite-mound-inspired architecture, the Beijing Olympic Swim stadium and Gecko tape inspired from Gecko's foot [6].

Despite the successful inventions, the design of biomimetics product is often being performed casually in view of incidental observations and reports without any methodical and systematic tools. Concepts have been used by most of the designers to design and solve design issues related to the dispersed information of design from nature or biomimetic that makes merely certain designers are conscious of the achievements in biomimetic designs. In addition, generally biomimetic requires product designers to have both understandings of biological system and engineering to guarantee its success [7]. Thus, it increases the intricacy of the design process making biomimetics design concept less favorable to designers. Besides that, product designers are lack of sources for visual samples from nature to help in product design that can enhance creativity and improve production of innovative new products.

Lately, systematic approaches have been created to help in biomimetic product design [8-11]. Outstanding reviews on tools and methods to consolidate biomimetic into product design have been provided by past researchers concentrates on alternate perspectives [7, 10, 12-13].

Glier et al. [7] have introduced several methods and concept that includes functional modeling, biological keyword searches, BioTRIZ and an online repositories. Since their paper emphasis on incorporation of biomimetic design methods and tools for biomimetic design courses, available biomimetic courses at the University of Maryland and Georgia Institute of Technology are also discussed briefly. Fu et al. [12] has highlighted the design-by-analogy perspectives of bio-inspired design methods and tools in their paper and suggested that understanding of particular properties of BID and mechanisms by empirical means is important to develop methods and tools that best suit human understanding, besides stating that serious considerations should be made on accessibility and scaling factors to obtained large stimuli databases. Meanwhile, other than reviewing current methods for bio inspiration, Salguiredo [13] in his research utilized the framework of C-K design theory and presents a model to apply bio-inspiration systematically in companies by explaining the inspiration process that can lead to design solutions.

Other than that, Glier et al. [10] offered an empirical examination of some methods available for bioinspiration in engineering design that includes BioTRIZ, online websites, functional modelling and biological keyword searches. The evaluation is made by examining the usages and difficulties encountered by students in utilizing each method to generate ideas and solve engineering design problem. It demonstrated that there would be no advantage for designers in applying biology to engineering design without a systematic approach. Besides that, it is noted that greater number of design concepts is generated while using functional modelling and bio-keyword search compare to BioTRIZ.

In the current paper, Glier et al. [10] try to in-depth review computational tools to incorporate biomimetic into product design that has been produced previously and suggest some improvement for future works with emphasis on biomimetic product design at its conceptual stage. To the best of authors' knowledge, there is no extensive literature regarding this matter.

2.0 DATABASE

Primarily, biologists at the Design Table scheme suggest that the search, retrieval, and representation of biological phenomena for design, include integration of biologists in the design process or the development of knowledge bases that contain biological phenomena [15]. Therefore, in this paper computational tools that have been developed to aid biomimetic design process have been structured into three sections comprises of databases, online website, and natural language analysis tool.

2.1 IDEA-INSPIRE & DANE Databases

The IDEA-INSPIRE and Design by Analogy to Nature Engine (DANE) are interactive design tools built to aid as databases for both engineering and biological systems [10, 16]. Qualitative models of both biology and engineering system can be found present in the databases in the form of multimedia like texts, figures, and schematics [10]. Nevertheless, there exist some differences in how the presentation of information takes place and in how the biology and engineering system are modelled in both databases.

Chakrabati et al. [9] developed IDEA INSPIRE with the purpose of supporting the production of novel solutions to product design. By using inspirations from natural and artificial systems, IDEA INSPIRE enables relational reasoning at various stage of abstraction [17-18]. Biomimetic systematic search is carried out whereby users have to make a straightforward description of the design issue in the database either in the form of verb-noun-adjective or by breaking the problem in the form of sub-problems. Browsing of entries and searches of different level of complexity is supported in IDEA INSPIRE database by inserting SAPPhIRE, the causal description language that corresponds to seven elementary constructs: State-Action-Part-Phenomenon-Input-Organ-Effect [12].

Although the entries in the database were limited, IDEA INSPIRE has accounted for 47% of ideas generated when case study of the design problem is conducted using the database [12]. Meanwhile, DANE implements Structure-Behavior-Function (SBF) models of engineering and biological system containing design case library [19]. By using

Dane, users can also add new models of SBF system and attach them to the library. DANE is built on Glassfish application server whereby data is placed in MYSQL database and EJB technology is utilized to control persistence and connection pooling. Thus, in order to access the database, execute application and updates, the user has to launch websites using Java Web Start [20]. Although DANE is primarily built as a design library, feedback from designers of it recent states shows that it is more likely suitable as a tool to conceptualize biological systems [21].

2.2 Asknature

In term of online database or website, the Biomimicry Institute provides an accessible repository of biological information that can act as inspiration for bio-inspired design process in multi-disciplinary fields known as Asknature [22]. Figure 1 shows the main page of the website. It is a portal containing research articles on biomimetic design indexed by a general function which is then linked to a more specific biological term. The terms 'general function of an organism' mentioned in the portal refers to the role carried by the organism's adaptations or behaviors that enable it to survive [23].

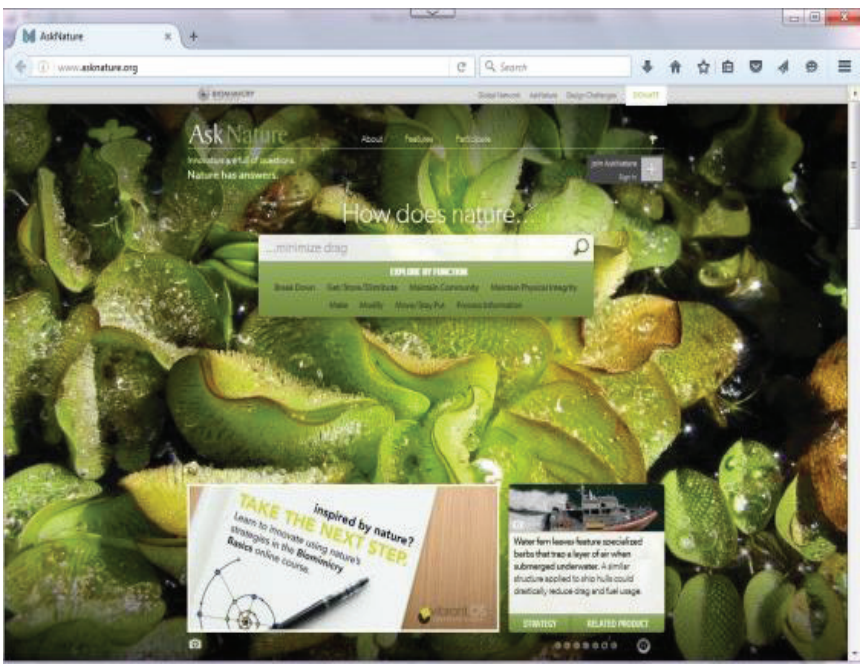

Figure 1: Main page of Asknature.org [14]

Since the pages are accessible to public users for free, this tool is more widely known and used compared to other tools. Moreover, the user does not need to acquire any specific knowledge to handle this tool as it is similar to every other webpage commonly used. In order to retrieve information from the website, the user is given two alternatives either to explore by function or using the search box that is stimulated by the inquiry. Exploring the website by function allows the user to browse through information and products of bio-inspired design categorized by seven functions presented in the biomimicry taxonomy that is again separated into sub-categories. Even though using the second option or search box looks more unconstrained, the results are less different since in both cases the information is based on the structure of Biomimicry Taxonomy. There may be several possible keywords and queries used by users, but they must be recognizable and acceptable by the website's database in order to retrieve relevant information [24]. For example, typing "designing a racing car" unable to show any useful results. If the search is refining to functional keywords such as "reducing drag" or "movement", high probability useful biomimetic information will appear. Moreover, Fu et al. [12] stated that despite employing the taxonomy, users tend to use the website as similar to a web keyword search. Therefore, it is necessary for users to understand that the website retrieves biomimetic information using functional keywords as offered in the biomimicry taxonomy to retrieve relevant information. Thus, to make full use of the website, the users will also have to identify their desirable product function before proceeding with the website search tool.

2.3 Natural Language Analysis Tool

Design-by-analogy is identified as another effective method for bio-inspired design [25-27]. Relating to this, researchers at the University of Toronto have proposed a generalized methodology that identifies analogous biological phenomena to be applied systematically to any design issues [28]. The approach is developed as a computational search tool of biological solutions based on Natural Language Transformation [29-33]. By using this tool, the biological text is retrieved based on functional keywords describing engineering problem.

Fundamentally, this tool is different to databases that involve cataloging biological phenomena for engineering since it takes advantages of diverse biological information in available natural language format and directly searches for relevant phenomena [28].

The natural language analysis tool is primarily based on information in the reference text of introductory course in biology at University of Toronto named Life, the Science of Biology [34]. The text is selected as it is easily understood even by people without biological study background. Moreover, the information available is of multi-organizational levels, from molecular to ecosystem, so that possible results are not focused on particular levels only. This will benefit designers since they can choose the class of biological knowledge they needed to solve design issues either it includes replicating whole biological system or just some part of the system. Besides that, this tool uses verbs as keywords to starts the biological information retrieval process. This is because searching for verbs that describe the desired function will indicate biological forms that may not have occurred to users instead of using nouns that result in pre-conceived solutions [12]. The difficulty in this technique happens when there are fixations on specific biological phrases that may contrarily affect the information retrieval process since it can't identify with terms in different fields. In this way, it has been found that to be completely benefited with this tool; designers require more techniques and clear heading to allow the exchange of information from biology to target engineering design issues [27].

3.0 DISCUSSION

A summary of the computational tools described in this paper is summarized in Table 1. In the near future, it is suggested that the tools developed should include more entries for complex searches relating to engineering design problem. Furthermore, it is highly beneficial to enable open access to the tools to target users or designers in order to provide more innovative solutions to design problem. Records of successful bio-inspired invention based on the available tools can also be created and tracked in the future to shows success rate of employing biological knowledge in design problems.

Table 1: Summary of Biomimetic Design

Tools	Representations	Characteristics	Limitations	Literature-sources
IDEA INSPIRE And DANE Databases	Organizes biological design stimuli in form of databases	*IDEA-INSPIRE uses Sapphire model repository of strategies *DANE uses SBF model and repository of cases *Presents information in a various multimedia format	*Needed access to certain software *Size is limited by resources of entries	[9, 10, 12, 15-24, 35]
Ask nature Website	Open access website built based on Biomimicry Taxonomy	*Search based on function *Minimal preparation required *Readily available	*Classification is broad but not closely present engineering design perspective	[12, 22-24, 36, 38, 39]
Natural Language Analysis Tool	Tools to search existing biology texts for relevant solutions	*Based on Natural Language Transformation *Search using verb keywords	*Requires access to certain software * There are fixations on some biological phrases that are difficult to directly relate to other fields.	[12, 25-34, 37]

A tool that can fulfill these criteria will surely reduce the gaps between biological knowledge to other fields. Thus, in addition to the available tools, the authors would like to propose a development of another biomimetic features database that highlights products inspired by nature. The information in the database will be presented in a way to inspire product design at its conceptual phase and it can act as an alternative source for product designers in solving design problems.

The review presented in this paper is of the initial stage for the development of database comprises of the biomimetic element to support conceptual product design in the near future.

4.0 CONCLUSION

In conclusion, there are various tools to incorporate biomimetic into product design based on three sections comprises of databases, online website, and natural language analysis tool. The presentations, characteristic, and limitations of each tool are identified. Based on the result, the issues and challenges regarding the applications of each tool in the bio-inspired design process varied according to the selection. Suggestions have been made to address the issues and further improve the tools mentioned. It is noted that a tool that has free access to the public, user-friendly and easily understood is desirable in transferring of biological information to solve design problems.

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REFERENCES

[1] T. Speck and O. Speck, "Process Sequences in Biomimetic Research," *WIT Transactions on Ecology and the Environment*, vol. 114, no 9, pp. 3 - 11, 2008.

[2] J. M. O'Rourke, "Environmentally Sustainable Bioinspired Design: Critical Analysis and Trends." M.S. thesis, Department of Mechanical Engineering, The University of Texas, Austin, 2013.

[3] S. Vattam, M. Helms and A.K. Goel, "Biologically Inspired Design: A Macrocognitive Account," in Proceedings of the ASME 2010 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference, Montreal, Canada, 2010, pp. 129-138.

[4] S. Vattam, M. Helms and A. K. Goel. (2007). *Biologically inspired innovation in engineering design: a cognitive study* [Online]. Available: https://pdfs.semanticscholar.org/bcd7/179dbccccc4e333d53318778fc332d7c91f0.pdf

[5] J. F. V. Vincent, O. A. Bogatyreva, N. R. Bogatyrev, A. Bowyer and A. K. Pahl, "Biomimetics: Its Practice and Theory", *Journal of Royal Society Interface*, vol. 3, no.9, pp. 471–482, 2006.

[6] L. Jiang and L. Feng, *Bioinspired Intelligent Nanostructured Interfacial Materials*. China: Chemical Industry Press, 2010.

[7] W. Glier, "Evaluating Methods for Bioinspired Concept Generation", in 24th International Conference on Design Theory and Methodology, Chicago, Illinois, USA, 2012, pp. 1-19.

[8] A. K. Goel, "Biologically Inspired Design: A New Paradigm for AI Research on Computational Sustainability", *IEEE Intelligent Systems*, vol. 28, no. 3, pp. 80-84, 2013.

[9] A. Chakrabarti, P. Sarkar, B. Leelavathama and B. S. Nataraju, "A Functional representation for Aiding Biomimetic and Artificial Inspiration of New Ideas," *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, vol. 19, no.2 pp. 113-132, 2005.

[10] W. Glier, "Concepts in Biomimetic Design: Methods and Tools To Incorporate into Biomimetic Design Course," in Proceedings of the ASME 2011 International Design Engineering Technical Conference & Computers and Information in Engineering Conference, Washington DC, USA, 2011, pp. 655-660.

[11] T. Peters, "Nature as measure: The biomimicry guild,"*Architectural Design*, vol. 81, no.6, pp 44-47, 2005.

[12] K. Fu, D. Moreno, M. Yang and K. L. Wood, "Bio-Inspired Design: An Overview Investigating Open Questions From the Broader Field of Design-by-Analogy," *Journal of Mechanical Design*, vol. 136, no.11, pp. 9-27, 2014.

[13] C. F. Salgueiredo. (2013). *Modeling Biological Inspiration for Innovative Design* [Online]. Available: http://i3.cnrs.fr/wp-content/uploads/2016/05/Freitas__conferenceI32013.pdf

[14] J. Benyus, (2017). *Biomimicry Institute* [Online]. Available: https://biomimicry.org/

[15] J. K. S. Nagel, "An Engineering to Biology Thesaurus for Engineering Design," in Proceedings of the ASME 2010 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference IDETC/CIE0, Montreal, Quebec, Canada 2010, pp. 117-128.

[16] A. K. Goel, S. Vattam, B. Wiltgen, and M. Helms, "Cognitive, collaborative, conceptual and creative—Four characteristics of the next generation of knowledge-based CAD systems: A study in biologically inspired design," *Journal Computer-Aided Design*, vol. 44, no.10, pp. 879–900, 2012.

[17] K. Tsujimoto, "A Method for Creative Behavioral Design Based on Analogy and Blending from Natural Things," in ASME 2008 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, Brooklyn, New York, 2008, pp. 3–6.

[18] M. Grandas, "Supporting Creativity across Products, Services and Product-Service Systems through Design by Analogy," in International Conference on Engineering Design ICED '15, Milan, Italy, 2015, pp. 3-4.

[19] B. Wiltgen, "Learning Functional Models of Biological Systems for Biologically Inspired Design," in Proceedings of the 2011 IEEE 11th International Conference on Advanced Learning Technologies., GA, USA, 2011, pp. 355-357.

[20] M. Helms. (2011). *DANE: Design by Analogy to Nature Engine* [Online]. Available: http://dilab.cc.gatech.edu/dane/

[21] S. Vattam, "DANE: Fostering Creativity in and through Biologically Inspired Design," in Proceeding of 1st International Conference on Design Creativity, Kobe, Japan, 2010, pp. 115-122.

[22] J. Benyus. (2006). *The Biomimicry Institute – Inspiring Sustainable Innovation* [Online]. Available: https://biomimicry.org/

[23] J. E. Strassmann, E. Joan and D. C. Queller, "Insect societies as divided organisms: the complexities of purpose and cross-purpose," in Proceedings of the national academy of sciences, vol. 104, 2007, pp. 8619-8626.

[24] J. M. Deldin and M. Schuknecht, *The Ask Nature Database: Enabling Solutions in Biomimetic Design*. London: Springer, 2013.

[25] I. Chiu and L. H. Shu, "Biomimetic Design through Natural Language Analysis to Facilitate Cross-Domain Information Retrieval," *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, vol. 21, no.1, pp. 45-59, 2007.

[26] H. Cheong, "Biologically Meaningful Keywords for Functional Terms of the Functional Basis,"*ASME Journal of Mechanical Design*, vol. 133, no. 2, pp. 1-11, 2011.

[27] H. Cheong, L. H. Shu, R. Stone and K. L. Wood, "Translating Terms of the Functional Basis into Biologically Meaningful Keywords," in ASME 2008 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, Brooklyn, New York, USA, 2008, pp. 138-148.

[28] L.H. Shu, "Generalizing the Biomimetic Design Process," in Proceedings of the Canadian Design Engineering Network Conference, Canada, 2011, pp.1-6.

[29] K. Murray, "Classification of Biological Phenomena to Aid in Search and Retrieval for Biomimicry," M.S. thesis, Department of Mechanical Engineering, Clemson University, South Carolina, USA, 2013.

[30] H. Cheong, "Extraction and transfer of biological analogies for creative concept generation," in ASME 2010 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, Quebec, Canada, 2010, pp. 1–16.

[31] H. Cheong and L. H. Shu, "Automatic Extraction of Causally Related Functions From Natural Language Text for Biomimetic Design," in ASME 2012 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, Illinois, USA, 2012, pp.1–10.

[32] L. H. Shu, "A natural-language approach to biomimetic design," *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, vol. 24, no. 4, pp 507–519, 2010.

[33] H. Cheong, and L. Shu, "Supporting Creative Concept Generation by Engineering Students with Biomimetic Design," in Proceedings of the Canadian Engineering Education Association, Ontario, Canada, 2010, pp. 1-6.

[34] W.K. Purves, D. Sadava, G. H. Orians, and H. C. Heller, *Life: The Science of Biology, 10th Edition*. Texas: W. H. Freeman, 2001.

[35] J. Reap, D. Baumeister and B. Bras, "Holism, Biomimicry, and Sustainable Engineering," in ASME 2005 International Mechanical Engineering Congress and Exposition, Orlando, USA, 2005, pp. 423-431.

[36] A. D. Rosemond and C. B. Anderson, "Engineering Role Models: Do Non-Human Species have the Answers?," *Ecological Engineering*, vol. 20, no. 5, pp. 379-387, 2003.

[37] J. Todd. (2004). *Restorer Eco-Machines for the Culture of Aquatic Animals and the Restoration of Polluted Aquatic Environments* [Online]. Available: http://biomimicry.typepad.com/bioinspire/files/BioInspire.19-08.19.04.pdf

[38] S. A. Wainwright, W. D. Biggs, J. D. Currey and J. M. Gosline, *Mechanical Design in Organisms*. New York: Wiley, 1976.

[39] B. H. Eilouti, "Environmental Knowledge as Design Development Agent," *Journal of Systemic, Cybernetics & Informatics*, vol. 10, no. 3, pp. 111-121, 2012.