

Bio Inspired Design Research Inspirations and Future of Medical Sciences: Mapping Review of Recent Developments

Ujjawal Shukla

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Abstract

The recent developments in the field of bio-inspired design have been inspiring greatly the direction of research in the modern times. To promote maximum efficiency in proposed solutions for modern problems, it is imperative that inspiration should be taken from natural sources, as nature has spent millions of years perfecting the organisms to deal with their various circumstances. This research area has resulted in ideal solutions to multiple problems that have the capability to be actually applied in multiple situations, hence the versatility provides for cost efficiency. Not to mention, the presence of the solution in nature allows for an easy proto type. The methodology involved in these researches is simple analyse a certain phenomenon in nature and then relate it with a problem in real life. The present study is outcome of rigorous review of literature with the help of scholarly reliable databases such as Web of Science and Google Scholar to find put the vast amount of literature. Major findings focus on the analogical aspects, hence concerned with the aspects of bio inspired design and bio computing. Microbial research has been a prime area as well to realize real life solutions of chemo-pathological problems. DNA and proteins can be better analysed for structural problems. The paper concludes with the idea that these are just some of the basic issues that can be solved through bio-inspired design where future belongs to more intricate researches.

Keywords: Bio-Inspired design; Nature; Microbes; Biotechnology; Bio-computing; India.

INTRODUCTION

Nature has frequently been the focus of designers and scientists, who get inspired by the aesthetic qualities and functional qualities respectively. The most important factor determining the pace and placement of this research

should be avoidance of harmful by products that end up harming the environment immensely. Inter disciplinary brain storming along the lines of ecology and systems theory has shown that it is possible to develop alternate modes from biology. Uncountable instances of organisms utilizing various natural situations and adaptations to their advantages can be found and then taken inspiration from for the same. Researchers then would use modern technology to understand these activities and then apply the findings for creation of new and better products. Innovation forms the founding pillar of success for all companies. Innovation can be defined simply as an idea successfully conceived and produced for the company and customer. Therefore, a very basic stepping stone for success is the formation of new ideas that display hints for this

Author Affiliation: B. Tech Bioengineering Scholar, School of Bioengineering, Vellore Institute of Technology, Bhopal 466114, Madhya Pradesh, India.

Corresponding Author: Ujjawal Shukla, B. Tech Bioengineering Scholar, School of Bioengineering, Vellore Institute of Technology, Bhopal 466114, Madhya Pradesh, India.

E-mail: ujjawal.shukla2021@vitbhopal.ac.in

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innovation. Nature has provided in various aspects of life, some notable examples of viable innovations existing to deal with the various adversities faced, and all readily available to be utilized by humans in modified form. The application of knowledge gained from various natural sources in technological innovations is called Bio-Inspired design. In a prominent study, Stone et al.¹ (2014) brought out the idea that bio-inspired design (BID) has a purpose to “systematically mine biological knowledge to solve existing design problems”. The present study has aimed to review the multifarious research directions through literature based on the search results from Google Scholar and other databases. The discussion in the study would move with the purpose to visualise the BID research direction in the present time through various sections framed in this article.

Conceptual Background

Bio inspired design cannot be directly utilized in the technical factions and demands proficiency in both biology and engineering for attaining mastery. But, contrary to this requirement, most professionals lack any special education in biology, hence hindering this field. Lest things change, bio-inspired design “will remain the domain of a few innovators skilled and interested enough to decipher the primary biological literature”.² A number of criteria and methods have been attempted to promote this biological knowledge among engineering students, such as C-K models and interdisciplinary teams.³ Information that has been already modified can be viewed in digital databases and catalogues, however while these only show information that has been deemed worthy, more basic research is also readily accessible. However, someone skilled in biological knowledge is necessary to interpret the information. Bio-inspired design is highly related with the appropriate movement of analogies, whose formulation as well as the creation of new ideas to provide solutions requires an in-depth knowledge in biology as well as engineering⁴, with the added importance of gaining technical knowledge. A smoother transition into this field is dependent upon collaborations between engineers and biologists, to inspire a combination of their respective fields.

Modern Society and Bio Inspired Design

A single utility is not enough to justify the solutions of engineering problems arising in these modern times. However, the old, usual methods to derive solutions for these problems will simply not satisfy the purpose. Therefore a new design process has been discovered to be implemented for bio-

inspired design.⁵ The whole design process consists of various steps, that is:

1. Identification of biological solutions and their definition.
2. Major understanding and extraction of biological solution.
3. Coordination of extracted solutions and related principles.
4. Designing and reframing of biological solution along with the target/problem search.
5. Application as well as implementation of Biological solution.

One of the most modern methods of handling engineering problems is to utilize analogies from biological creatures, this has led to multiple innovations such as Velcro, and conceptual design of a bionic car.⁶⁻⁸ For example: superhydrophobic coatings inspired from lotus leaves and their cleaning mechanisms,⁹⁻¹² body temperature regulating clothes inspired from pinecones¹³⁻¹⁵ and water walking microbots replicating the basilisk lizard.^{16,17} Soft materials have taken the lead spot in the race for bio-inspired designing, as they have high adaptation to environment, diversity of functions, etc. However, the advantage they provide is covered by their lack of accuracy and reliability. Reconfigurable design of these materials⁵ however, can help in both, achieving accuracy and reliability as well as the adaptability and other functions.

Bio Inspired Design: Concept and Earlier Prominence

Bio-inspired designs have emerged in modern times to be utilized in multiple fields, such as shock resistance for advanced aero-spaces, flying robots and much more. They have also proven useful for organ/implant substitutions to provide for better and more accessible implants and bone reconstructions. The beginning of millennium observed the developments of flapping wing micro air vehicles¹⁸, dynamic materials and robotics.^{19,20} The research led into the function integration aspects, damage tolerance and patterns.²¹⁻²⁴ The last decade witnessed the intricate aspects such as design by analogy and characterisation and its links with problem solving tools.²⁵⁻²⁷ The components such as BID and additive manufacturing, metal anode cycling have applied the structure function methods. Various studies²⁸⁻³² brought out the complexity of BID³³⁻³⁵ in the simplest descriptions. Analogy analysing, power networks and solution findings have also been core to this field. Better materials for artificial joints and tissues have also

been increasingly discovered to aid the cause. Hence, the field is highly productive, both mean while and in the future.

Bio Inspired Design and Indian Contribution

Various researches to attempt people find their bio-inspiration and helping in their analysis for a variety of fields such as joint augmentations, asymmetric supra-molecular solutions, etc have also been made. In all and all, bio-inspired design has taking a turn for the future. The contribution of Indian researchers is reflecting a wide range. The bio inspired design of nanocages³⁶⁻³⁹, molecular recognition among the bio-inspired design strategies with the application of molecular interactions, computer aids, is contemporary.

The facets such as visual representations and collaborations of engineers and biologists have done a tremendous job. BID is possible due to emerging interests from various subject fields.^{40,15,41,42} The chemical incarnations and BID have gone hand-in-hand⁴³⁻⁴⁵ and traversed to various research directions. The aspects such as bench marking of BID and providing conceptual tools for knowledge proliferation such as the sauri and architecture.⁴⁶⁻⁴⁸ The increased usage of computer aids and basic engineering principles has paved way for previously unimagined research areas. The literature is reflecting the inspiration and sources in the recent times.^{49,31,4} The design and analysis at the most intricate levels could become reality.^{50,51} The recent studies have focused on interdisciplinary approaches of BID research.

Bio Inspired Design and VIT India

A brief overview of the research conducted on Bio-Inspired Design in VIT, India show cases interests in DNA cryptography, neural networks and operations algorithms. A lot of emphasis has also been placed on bio-computing for various factors such as applications in swarm problems⁵² and information retrieval. Recent studies have presented a composite picture of varied aspects of BID researches.⁵³⁻⁵⁶ The observations from the studies^{57,58} presented the BID applications into the wireless sensor networks and information retrieval at the core of digital platforms. Bio inspired "glass fiber reinforced polymer sandwich" core and 3D printed "bio inspired sandwich beam" are few of the examples from the innovative research.^{59,60} The upcoming times will watch the upsurge in the BID research in India.

Objectives and Methodology of the study

The present study is based on review of literature to provide a glimpse into Bio Inspired Design (BID)

research. The background literature was searched through Google Scholar to build the conceptual background in the beginning of the article. To map the BID research since the long past and in recent times, the following objectives were framed to conduct the study:

1. To find out the recent trends in Bio Inspired Design research.
2. To observe and relate the interdisciplinary nature of Bio Inspired Design research.
3. To compare the highly cited BID research and its recent proliferation since the Web of Science data available.
4. To find out trends and contribution of India in Bio Inspired Design research.

METHODOLOGY

Mapping reviews: Mapping research and reviewing is "a systematic approach to understanding the map of a profession, theory, research question, or practice. The term mapping is also used for concept mapping, which shows how concepts are related in a visual way. Similarly, mapping studies can show how literature is disseminated through journals, books, websites, and other channels". Mapping reviews usually intend to provide an overview of "what is out there" on a particular topic "but does not focus on where literature may be found".⁶¹ Mapping research is performed in various disciplines, including engineering, science, medical and biological issues, research policy, and more. These are done to support further research, and are aimed to "classify the primary research papers in that specific domain".⁶² Mapping reviews provides assessment of research papers in a subcategory, and synthesize the included works, specifically in bio inspired design.^{63,64} Mapping studies include vast areas and number of citations due to broader research objectives. Data was collected from Web of science Core Database in June 2022 with the following keywords/string:

1. Bio Inspired Design
2. Bio Inspired design in India
3. Bio Inspired design in India during 2020s
4. Bio Inspired Design and Bio-engineering
5. Bio Inspired Design in India and VIT

The repeat search was made on last week of June 2022 where no change in the results was observed. The repeated results and numbers were same; hence the data analysis was initiated.

The following steps were taken as mapping

study method practice:

1. *Determination of the topic:* The review of literature and background literature survey has reflected that no recent mapping review has been conducted in the research areas of Bio Inspired Design. The literature is vast so there has been a need to review the literature and observe the direction of research in the present study.
2. The present study has provided the background information about the specialty of Bio Inspired Design research so that the novice readers could also grasp the idea of this specific filed.
3. Identification of highly cited studies has been done by consulting and browsing the Web of Science Database.
4. In the next phase of the study, core literature was displayed in the spread sheets (Microsoft Excel). The inclusion and exclusion of information materials was already determined and it was limited to only research articles.
5. Calculated numbers and percentage were expressed in the tables to reflect the data and analyze the same for the topic being mapped.

Significance of the research mapping

Using “concept maps” and “visualizations for data presentation” is addressed with data analysis in study. Researcher has used visualizations

(Appendix 1) to illustrate various BID concepts and complex connections, and reflecting the frame works of inter related research processes, and presents findings.

Statistical method and analysis:

The study has carried out count of differences, descriptive statistics, and linear trend analysis to depict the change over the time. The study has also presented the line and bar charts for the visualization of data. The MS-Excel software has been used for preparation of figures and visualizations.

Data Analysis

Data was collected from Web of science database and has been arranged in various tables though Excel sheets. The data analysis is presented following under the sections given as:

a. Bio Inspired Design:

Upon using the keywords ‘Bio Inspired Design’ in Web of science core database, 10 highly cited articles as main results had been taken into consideration (Fig. 1). The researches have been arranged in the decreasing order of citations, with the top result peaking out at 2242 citations, mean while the bottom result still yielding an impressive 800+ results. Most citations show an increasing number from 2018 to 2021 this is the general trend. Bio Inspired Design in Web of Science Categories (Table 6) is reflected as data shed light on the keywords found for the topic ‘Materials Science Multidisciplinary’ topping the list with 2118 counts (Table 1) whereas ‘instruments instrumentation’ at

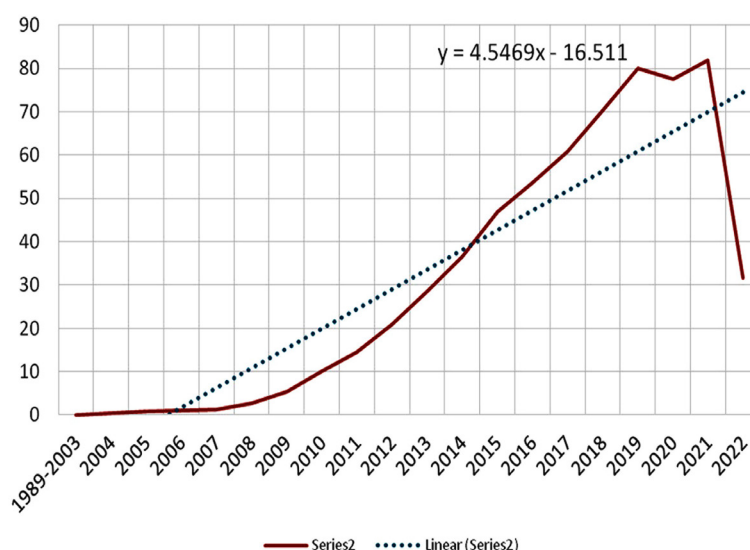


Fig. 1: displays the trend analysis of bio inspired design over the past 30 years 1989-2022. The results indicate a positive trend (Beta = 4.5469), which shows an average increase of 4.54 bio design concepts every year. However, an exception during the last two years is an indication of the impact of pandemic due to COVID-19.

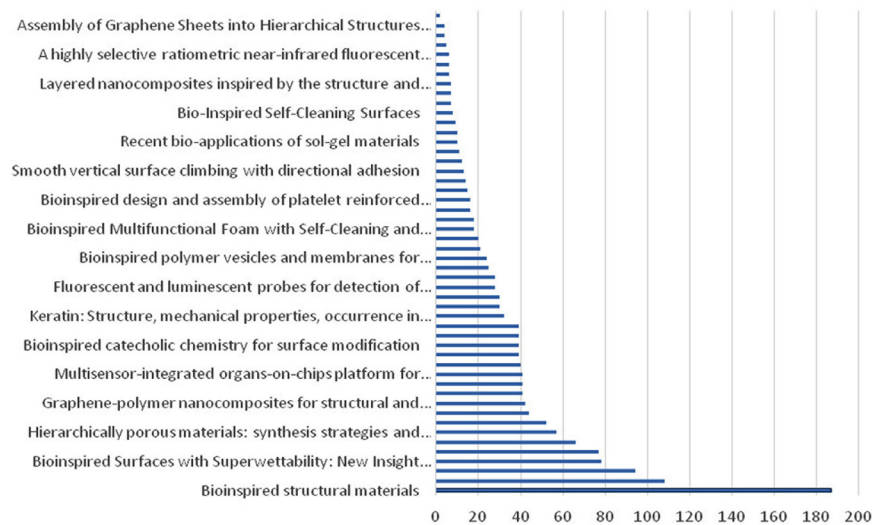


Fig. 2: presents the difference in number of subject relations over the past 30 years (1989-2003 to 2022) through web of science in the concept BID research designs (Table 1). The results show the maximum increase of 187 (count) in bio inspired structural materials, which was having no subject relations during 1989-2003.

Highly cited Publications from Web of Science Search Results

Table: 1 Bio Inspired Design Highly cited Publications from Web of Science Search Results

Citation	2018	2019	2020	2021	2022	Average Citation/Year	Total Citation
Bioinspired structural materials Wegst, UGK; Bai, H; (...); Ritchie, RO Jan 2015 Nature Materials 14 (1) , pp.23-36	321	376	396	438	187	280.25	2242
Biological materials: Structure and mechanical properties Meyers, MA; Chen, PY; (...); Seki, Y Jan 2008 Progress In Materials Science 53 (1) , pp.1-206	151	153	148	137	39	104.47	1567
Soft robotics: a bioinspired evolution in robotics Kim, S; Laschi, C and Trimmer, B May 2013 Trends In Biotechnology 31 (5), pp.23-30	161	194	203	152	66	109.8	1098
Bioinspired Surfaces with Superwettability: New Insight on Theory, Design, and Applications Wang, ST; Liu, KS; (...); Jiang, L Aug 26 2015 Chemical Reviews 115 (16), pp.8230-8293	168	173	165	191	78	122.63	981
A molecular ruthenium catalyst with water-oxidation activity comparable to that of photosystem II Duan, LL; Bozoglian, F; (...); Sun, LC May 2012 Nature Chemistry 4 (5) , pp.418-423	92	110	85	108	30	86.91	956
Bioinspired catecholic chemistry for surface modification Ye, Q; Zhou, F and Liu, WM 2011 Chemical Society Reviews 40 (7) , pp.4244-4258	121	119	110	75	39	77.33	928
Photochemical conversion of solar energy Balzani, V; Credi, A and Venturi, M 2008 Chemsuschem 1 (1-2) , pp.26-58	63	51	62	51	16	60.47	907
Bioinspired Design of a Superoleophobic and Low Adhesive Water/Solid Interface Liu, MJ; Wang, ST; (...); Jiang, L Feb 9 2009 Advanced Materials 21 (6) , pp.665-+	102	114	107	114	40	63.57	890
Nanoconfinement controls stiffness, strength and mechanical toughness of beta-sheet crystals in silk Keten, S; Xu, ZP; (...); Buehler, MJ Apr 2010 Nature Materials 9 (4) , pp.359-367	80	89	102	97	39	66.08	859
Bio-inspired, smart, multiscale interfacial materials Xia, F and Jiang, L Aug 4 2008 Advanced Materials 20 (15) , pp.2842-2858	63	64	42	51	21	53.73	806

Table 6: Bio Inspired Design in Web of Science Categories

Web of Science Categories	Record Count	% of 6,049
Materials Science Multidisciplinary	2118	35.014
Chemistry Multidisciplinary	1649	27.261
Nano science Nanotechnology	1290	21.326
Chemistry Physical	1222	20.202
Physics Applied	853	14.102
Materials Science Biomaterials	566	9.357
Physics Condensed Matter	557	9.208
Multidisciplinary Sciences	410	6.778
Robotics	393	6.497
Engineering Biomedical	322	5.323
Polymer Science	310	5.125
Engineering Multidisciplinary	272	4.497
Engineering Electrical Electronic	246	4.067
Engineering Chemical	184	3.042
Engineering Mechanical	167	2.761
Computer Science Artificial Intelligence	164	2.711
Biochemistry Molecular Biology	162	2.678
Mechanics	154	2.546
Energy Fuels	138	2.281
Instruments Instrumentation	137	2.265

the bottom with 137 mentions.

b. Bio Inspired design in India

For the word string 'Bio Inspired design in India, a total of 10 highly cited studies and their citations have been taken and analysed (Table 2); anti-bacterial and copper surface researches have been less frequent, meanwhile the trend has been hot towards Functional Mimics of Glutathione.

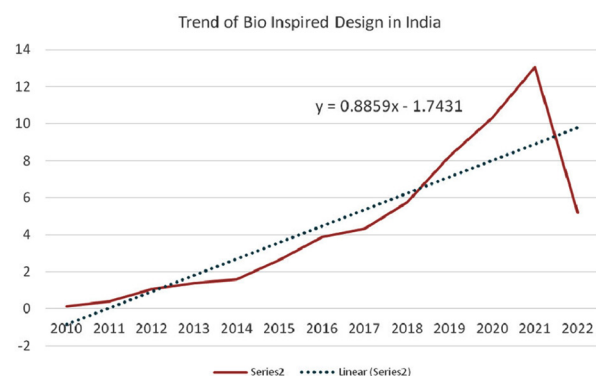


Fig. 3: displays the trend analysis of bio inspired design in India over the past 20 years 2010-2022. The results indicate a positive trend (Beta = 0.8859), which shows an average increase of 0.88 bio design in India concepts every year.

Peroxidase: Bio inspired Synthetic Antioxidants and bio inspired nano structural surfaces. The trend again has been increasing instances of citations from 2018 to 2022. Bio Inspired design in India in Web of Science Categories is observed as 'Materials Science Multidisciplinary' has been the top search category (Table 2, 7) in the web of sciences, mean while robotics has been the bottom most category.

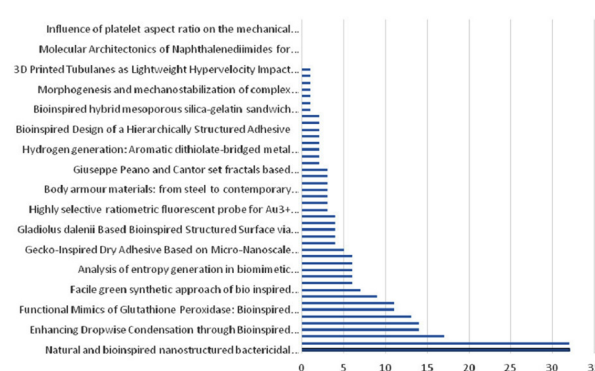


Fig. 4: presents the difference in number of subject relations over the past 30 years (1989 to 2022) through web of science in the concept BID research designs and India (Table 2). The results show the maximum increase of 32 (count) in Natural and bio inspired nano-structured bactericidal surfaces and applications of super hydrophobic nano-based coatings and surfaces, which was having no subject relations during 1989-2009.

Table 2: Bio Inspired design in India Highly cited Publications from Web of Science Search Results

Citation	2018	2019	2020	2021	2022	Average Citation/Year	Total Citation
Functional Mimics of Glutathione Peroxidase: Bioinspired Synthetic Antioxidants Bhabak, KP and Mugesh, G Nov 2010 Accounts Of Chemical Research 43 (11) , pp.1408-1419	37	46	31	35	11	29.31	381
Natural and bioinspired nanostructured bactericidal surfaces Tripathy, A; Sen, P; (...); Briscoe, WH Oct 2017 Advances In Colloid And Interface Science 248 , pp.85-104	34	36	72	70	32	41.33	248
Enhancing Dropwise Condensation through Bioinspired Wettability Patterning Ghosh, A; Beaini, S; (...); Megaridis, CM Nov 4 2014 Langmuir 30 (43) , pp.13103-13115	24	26	24	39	14	18.67	168
Recent progress in the preparation, properties and applications of superhydrophobic nano-based coatings and surfaces: A review Phuong, NT; Tran, HN; (...); Bajpai, AK Jul 2019 Progress In Organic Coatings 132 , pp.235-256	0	11	39	78	32	40	160
An Adaptive Wearable Parallel Robot for the Treatment of Ankle Injuries Jamwal, PK; Xie, SQ; (...); Parsons, JG Feb 2014 Ieee-Asme Transactions on Mechatronics 19 (1) , pp.64-75	21	17	18	14	4	14.89	134
Bioinorganic chemistry of molybdenum and tungsten enzymes: A structural-functional modeling approach Majumdar, A and Sarkar, S May 2011 Coordination Chemistry Reviews 255 (9-10) , pp.1039-1054	8	12	6	6	0	9.92	119
Organic Solvent-Free Fabrication of Durable and Multifunctional Superhydrophobic Paper from Waterborne Fluorinated Cellulose Nanofiber Building Blocks Baidya, A; Ganayee, MA; (...); Pradeep, T Nov 2017 ACS NANO 11 (11) , pp.11091-11099	14	31	26	31	13	19.17	115
DNA-Assisted beta-phase Nucleation and Alignment of Molecular Dipoles in PVDF Film: A Realization of Self-Poled Bioinspired Flexible Polymer Nanogenerator for Portable Electronic Devices Tamang, A; Ghosh, SK; (...); Mandal, D Aug 5 2015 ACS Applied Materials & Interfaces 7 (30) , pp.16143-16147	11	28	18	14	4	13.38	107
Recent advances in engineering topography mediated antibacterial surfaces Hasan, J and Chatterjee, K 2015 Nanoscale 7 (38) , pp.15568-15575	16	26	18	22	6	12.5	100
Bioinspired green synthesis of copper oxide nanoparticles from Syzygium alternifolium (Wt.) Walp: characterization and evaluation of its synergistic antimicrobial and anticancer activity Yugandhar, P; Vasavi, T; (...); Savithramma, N Oct 2017 Applied Nanoscience 7 (7) , pp.417-427	3	16	18	22	14	12.17	73

Table 7: Bio-inspired design in india in web of science categories

Web of Science Categories	Record Count	% of 172
Materials Science Multidisciplinary	46	26.744
Chemistry Multidisciplinary	44	25.581
Nano science Nanotechnology	26	15.116
Chemistry Physical	23	13.372
Materials Science Biomaterials	14	8.14
Physics Applied	12	6.977

Table cont.....

Polymer Science	11	6.395
Biochemistry Molecular Biology	10	5.814
Energy Fuels	10	5.814
Engineering Biomedical	9	5.233
Engineering Electrical Electronic	9	5.233
Multidisciplinary Sciences	8	4.651
Chemistry Inorganic Nuclear	7	4.07
Engineering Mechanical	7	4.07
Biotechnology Applied Microbiology	6	3.488
Chemistry Organic	6	3.488
Engineering Chemical	6	3.488
Green Sustainable Science Technology	6	3.488
Chemistry Applied	5	2.907
Robotics	5	2.907

c. *Bio Inspired design in India during 2020s*

An over whelming amount of research has been conducted in India in 2020s upon Bio-Inspired Design. Stem cell and multi sensor integrated organs on chips have been the most cited researches, meanwhile researches regarding melanin and photodynamic microbial killings have received

lesser citations (Fig. 5; Table 3). Bio Inspired design in India during 2020s in Web of science Categories as the Chemistry analytical has been the least common web of science categories, meanwhile multidisciplinary sciences (Table 3 & 8). have been the most popular categories, with over 25% of the total count.

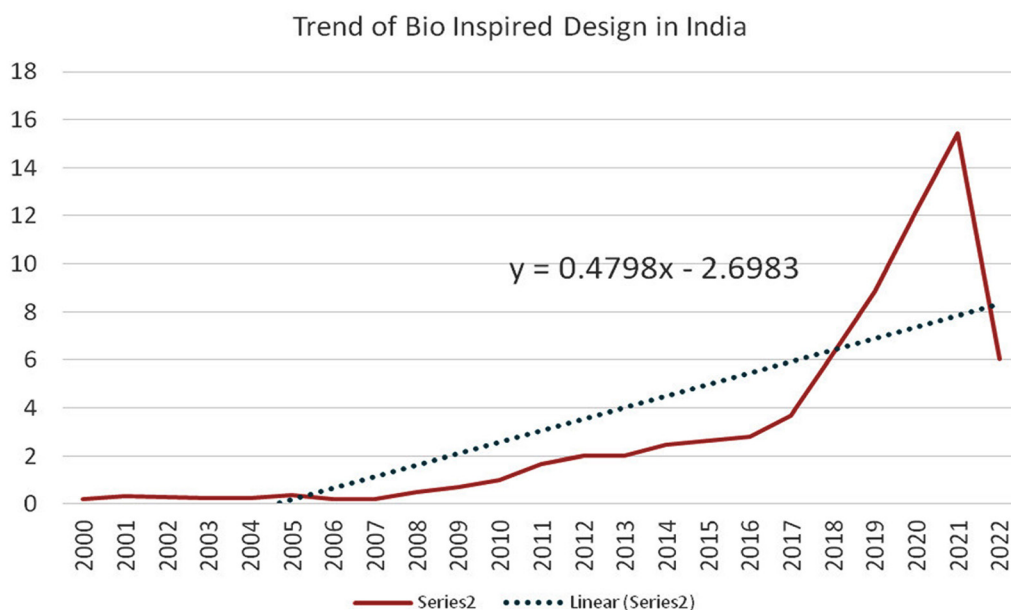


Fig. 5: displays the trend analysis of Bio Inspired design in India during 2020s over the past 20 years 2010-2022. The results indicate a positive trend (Beta = 0.4798), which shows an average increase of 0.47 bio design in India concepts every year.

Table 3: Bio Inspired design in India during 2020s Highly cited Publications from Web of Science Search Results

Citation	2018	2019	2020	2021	2022	Average Citation/Year	Total Citation
Multisensor-integrated organs on-chips platform for automated and continual in situ monitoring of organoid behaviors Zhang, YS; Aleman, J; (...); Khademhosseini, A Mar 21 2017 Proceedings of the National Academy of Sciences of The United States of America 114 (12) , pp.E2293-E2302	46	77	81	117	41	62	372
Bioinspired Materials for Controlling Stem Cell Fate Fisher, OZ; Khademhosseini, A; (...); Peppas, NA Mar 2010 Accounts of Chemical Research 43 (3) , pp.419-428	16	19	15	14	2	17.92	233
Nano measurements with micro-devices: mechanical properties of hydrated collagen fibrils Eppell, SJ; Smith, BN; (...); Ballarini, R Feb 22 2006 Journal of the Royal Society Interface 3 (6) , pp.117-121	17	14	11	6	5	10.65	181
Bioinspired polymeric materials: in-between proteins and plastics Barron, AE and Zuckermann, RN Dec 1999 Current Opinion in Chemical Biology 3 (6) , pp.681-687	3	3	3	3	0	7.46	179
Bioinspired neuron-like electronics Yang, X; Zhou, T; (...); Lieber, CMMay 2019 Nature Materials 18 (5), pp.510	0	24	44	64	16	37	148
Thermal gelation and tissue adhesion of biomimetic hydrogels Burke, SA; Ritter-Jones, M; (...); Messersmith, PB Dec 2007 Biomedical Materials 2 (4) , pp.203-210	9	17	7	12	4	8.63	138
Direct-Ink-Write 3D Printing of Hydrogels into Biomimetic Soft Robots Cheng, Y; Chan, KH; (...); Ho, GW Nov 2019 Acs Nano 13 (11) , pp.13176-13184	0	0	18	52	24	23.5	94
Bioinspired and Biomimetic Nanomedicines Chen, ZW; Wang, ZJ and Gu, Z May 2019 Accounts Of Chemical Research 52 (5) , pp.1255-1264	0	8	39	32	15	23.5	94
Melanin and Melanin-Related Polymers as Materials with Biomedical and Biotechnological Applications-Cuttlefish Ink and Mussel Foot Proteins as Inspired Biomolecules Solano, F Jul 2017 International Journal of Molecular Sciences 18 (7)	8	15	25	28	9	14.17	85
Targeting and photodynamic killing of a microbial pathogen using protein cage Architectures functionalized with a photosensitizer Suci, PA; Varpness, Z; (...); Young, M Nov 20 2007 Langmuir 23 (24) , pp.12280-12286	3	3	4	3	1	5.25	84

Table: 8 Bio Inspired design in India during 2020s in Web of science Categories

Web of Science Categories	Record Count	% of 104
Multidisciplinary Sciences	27	25.962
Nano science Nanotechnology	25	24.038
Biotechnology Applied Microbiology	24	23.077
Materials Science Multidisciplinary	24	23.077
Chemistry Physical	21	20.192
Chemistry Multidisciplinary	20	19.231
Materials Science Biomaterials	18	17.308
Engineering Biomedical	17	16.346
Physics Applied	13	12.5
Physics Condensed Matter	10	9.615
Pharmacology Pharmacy	8	7.692
Robotics	5	4.808

Biochemistry Molecular Biology	4	3.846
Cell Biology	3	2.885
Engineering Multidisciplinary	3	2.885
Polymer Science	3	2.885
Biochemical Research Methods	2	1.923
Biophysics	2	1.923
Cell Tissue Engineering	2	1.923
Chemistry Analytical	2	1.923

d. Bio Inspired Design and Bioengineering

Bio-inspired design and Bioengineering has been a less popular field, with the peak citation only having 7 citations (Fig. 6; Table 4), where as the lowest cited research has 2 citations in total. Bio Inspired Design and Bioengineering in Web of Science Categories is evident from the table, materials science biomaterials have 50% of the total count, with the rest of the categories (Table 4,9) amounting to 25% of the categories.

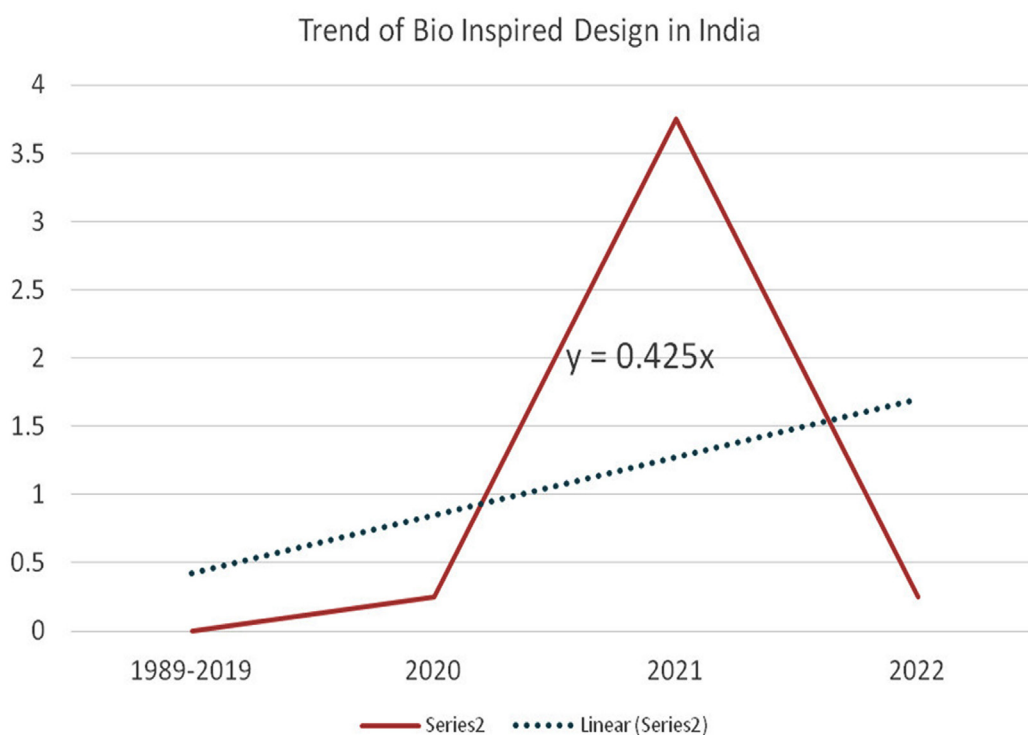


Fig. 6: displays the trend analysis of Bio Inspired design and Bioengineering over the past 30 years 2010-2022. The results indicate a positive trend (Beta = 0.425), which shows an average increase of 0.42 bio design and bioengineering during last three years.

Table 4: Bio Inspired Design and Bioengineering Highly cited Publications from Web of Science Search Results

Citation	2018	2019	2020	2021	2022	Average Citation/Year	Total Citation
Cutting mechanics of wood by beetle larval mandibles Kundanati, L; Chahare, NR; (...); Gundiah, N Dec 2020 Journal Of The Mechanical Behavior Of Biomedical Materials 112	0	0	1	5	1	2.33	7
Immobilization of Transglutaminase on multi-walled carbon nanotubes and its application as bioinspired hydrogel scaffolds Fatima, SW; Barua, S; (...); Khare, SK Nov 15 2020 International Journal Of Biological Macromolecules 163 , pp.1747-1758	0	0	0	5	0	1.67	5
Evaluating the Impact of Tailored Water Wettability on Performance of CO2 Capture Rather, AM; Srikrishnarka, P; (...); Manna, U Nov 23 2020 ACS Applied Energy Materials 3 (11) , pp.10541-10549	0	0	0	3	0	1	3
Bioinspired inorganic nanoparticles and vascular factor microenvironment directed neo-bone formation Kim, HD; Park, J; (...); Hwang, NS May 7 2020 Biomaterials Science 8 (9) , pp.2627-2637	0	0	0	2	0	0.67	2

Table 9: Bio Inspired Design and Bioengineering in Web of Science Categories

Web of Science Categories	Record Count	% of 4
Materials Science Biomaterials	2	50
Biochemistry Molecular Biology	1	25
Chemistry Applied	1	25
Chemistry Physical	1	25
Energy Fuels	1	25
Engineering Biomedical	1	25
Materials Science Multidisciplinary	1	25
Polymer Science	1	25

e. Bio Inspired Design in India and VIT

An analysis for the 8 articles found for the topic 'Bio Inspired Design in India and VIT' show cases that bio inspired ionic liquid tagged cobalt salophen complex has been the most cited research, with a sky high 5.33 citations per year. Meanwhile 'Classification of Electroencephalogram Signal for Developing Brain Computer Interface Using Bio inspired Machine Learning Approach' (Table 5) has been the least cited research. Bio Inspired Design in India and VIT in Web of Science Categories as observed Bio Inspired Design in India and VIT when searched yielded 18 categories (Table 5,10,11) in the web of science database, with the top 4 categories spans across 2 record counts each and the remaining categories contributing 1 record each.

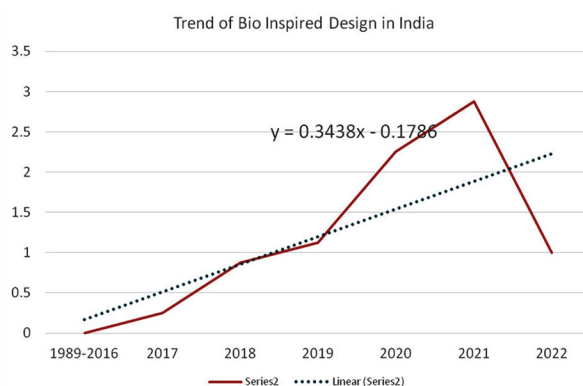
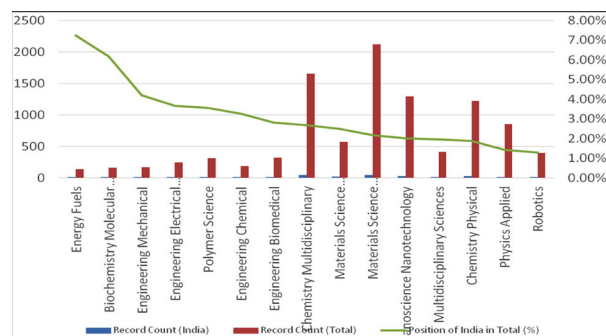

Fig. 7: displays the trend analysis of Bio Inspired design in India and VIT over the past 30 years 1989-2022. The results indicate a positive trend (Beta = 0.3438), which shows an average increase of 0.34 bio design in India and VIT contributions during last couple of years (2016-2022).

Fig. 8: presents the interdisciplinary nature and number of subject relations over the past 30 years (1989 to 2022) through web of science in the concept BID research designs and India. The results show the maximum increase of Chemistry Multidisciplinary (count=1649), Materials Science Multidisciplinary (count=2118), Nano science Nanotechnology (count=1290) and Chemistry Physical (count=1222) as conceptual relations and distributions of BID in modern research.

Table 5: Bio Inspired Design in India and VIT Highly cited Publications from Web of Science Search Results

Citation	2018	2019	2020	2021	2022	Average Citation/ Year	Total Citation
A bioinspired ionic liquid tagged cobalt-salophen complex for nonenzymatic detection of glucose Benjamin, M; Manoj, D; (...); Senthilkumar, S May 15 2017 Biosensors & Bioelectronics 91 , pp.380-387	7	5	6	10	2	5.33	32
Thermal Co-reduction engineered silver nanoparticles induce oxidative cell damage in human colon cancer cells through inhibition of reduced glutathione and induction of mitochondria-involved apoptosis Dasgupta, N; Ranjan, S; (...); Ramalingam, C Nov 1 2018 Chemico-Biological Interactions 295 , pp.109-118	0	4	9	8	2	4.6	23
Involvement of Bcl-2 Activation and G1 Cell Cycle Arrest in Colon Cancer Cells Induced by Titanium Dioxide Nanoparticles Synthesized by Microwave-Assisted Hybrid Approach Ranjan, S; Dasgupta, N; (...); Ramalingam, C Jul 15 2020 Frontiers In Bioengineering And Biotechnology 8	0	0	1	4	2	2.33	7
Evidences of Biomimetic and Nonantibiotic Characteristics of the Zinc-Carboxymethyl Chitosan-Genipin Organometallic Complex and Its Biocompatibility Aspects Mishra, AH and Mishra, D Feb 2020 Biomacromolecules 21 (2) , pp.688-700	0	0	2	1	1	1.33	4
Investigations on Bending Characteristics of Soft Mesh Structure using Shape Memory Alloy Spring Towards Bio-Inspired Robotic Applications Muralidharan, M; Brolin, A; (...); Palani, IA Dec 2021 May 2020 (Early Access) Iranian Journal Of Science And Technology-Transactions Of Mechanical Engineering 45 (4) , pp.927-937	0	0	0	0	1	0.33	1
Investigation of free and forced vibration of GFRP corrugated bio-inspired sandwich beam with HSDT: Numerical and experimental study Gunasegeran, M and Sudhagar, PE May 2022 (Early Access) Mechanics Of Advanced Materials And Structures	0	0	0	0	0	0	0
Free and forced vibration analysis of 3D printed bioinspired sandwich beam using HSDT: Numerical and experimental study Gunasegeran, M and Sudhagar, PE Jun 2022 Apr 2022 (Early Access) Polymer Composites 43 (6) , pp.3659-3677	0	0	0	0	0	0	0
Classification of Electroencephalogram Signal for Developing Brain-Computer Interface Using Bioinspired Machine Learning Approach Thilagaraj, M; Ramkumar, S; (...); Govindan, P Feb 25 2022 Computational Intelligence and Neuroscience 2022	0	0	0	0	0	0	0

Table 10: Bio Inspired Design in India and VIT in Web of Science Categories

Web of Science Categories	Record Count	% of 8
Biochemistry Molecular Biology	2	25
Biotechnology Applied Microbiology	2	25
Materials Science Composites	2	25
Polymer Science	2	25
Biophysics	1	12.5
Chemistry Analytical	1	12.5
Chemistry Organic	1	12.5
Electrochemistry	1	12.5
Engineering Mechanical	1	12.5
Materials Science Characterization Testing	1	12.5
Materials Science Multidisciplinary	1	12.5
Mathematical Computational Biology	1	12.5
Mechanics	1	12.5
Multidisciplinary Sciences	1	12.5
Nano science Nanotechnology	1	12.5
Neurosciences	1	12.5
Pharmacology Pharmacy	1	12.5
Toxicology	1	12.5

Table 11: Web of Science Categories and India

Web of Science Categories	Record Count (India)	Record Count (Total)	Position of India in Total (%)
Energy Fuels	10	138	7.25%
Biochemistry Molecular Biology	10	162	6.17%
Engineering Mechanical	7	167	4.19%
Engineering Electrical Electronic	9	246	3.66%
Polymer Science	11	310	3.55%
Engineering Chemical	6	184	3.26%
Engineering Biomedical	9	322	2.80%
Chemistry Multidisciplinary	44	1649	2.67%
Materials Science Biomaterials	14	566	2.47%
Materials Science Multidisciplinary	46	2118	2.17%
Nanoscience Nanotechnology	26	1290	2.02%
Multidisciplinary Sciences	8	410	1.95%
Chemistry Physical	23	1222	1.88%
Physics Applied	12	853	1.41%
Robotics	5	393	1.27%
Chemistry Inorganic Nuclear	7	—	—
Biotechnology Applied Microbiology	6	—	—
Chemistry Organic	6	—	—
Green Sustainable Science Technology	6	—	—
Chemistry Applied	5	—	—

Findings

1. Bio-computing has been an emerging field and will continue to dominate the bio-inspired design research field.
2. Robotics has been taking huge structural inspiration from bacteria and other microbes for design.
3. DNA, protein and other nano-structural researches have yielded important results in real life applications.
4. Bio-inspired design has been an extremely hot topic in the recent times, both worldwide and in India, and will continue to grow.
5. Most solutions provided are versatile and can actually deal with multiple issues at once, hence providing cost efficiency.
6. Neural and neuro-degenerative disorders are also being treated efficiently and have a visible future for cure.

CONCLUSION

Bio-inspired design research is being conducted at an immense pace to ensure that the solutions to modern problems are efficient in all aspects and are ideal in all situations. In India, the research on Bio-Engineering has been focussed on computer aided bio-inspired designs, in addition to architectural designs concerned with molecular interactions. Research was also conducted on fields concerning the mingling of biological professionals with engineers. Due to technology improving at an immense rate, the scope of this field is only expected to grow manifold. The various fields they manage to cover will be instrumental in increasing the popularity of this research, despite the fact that this research needs expertise in both biology and advanced engineering.

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