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Clinical Approaches of Biomimetic: An Emerging Next Generation Technology

Kirti Rani

Abstract

Biomimetic is the study of various principles of working mechanisms of naturally occurring phenomena and their further respective integrations in to such a modified advanced mechanized instruments/models of digital or artificial intelligence protocols. Hence, biomimetic has been proposed in last decades for betterment of human mankind for improving security systems by developing various convenient robotic vehicles and devices inspired by natural working phenomenon of plants, animals, birds and insects based on biochemical engineering and nanotechnology. Hence, biomimetic will be considered next generation technology to develop various robotic products in the fields of chemistry, medicine, material sciences, regenerative medicine and tissue engineering medicine, biomedical engineering to treat various diseases and congenital disorders. The characteristics of tissue engineered scaffolds are found to possess multifunctional cellular properties like biocompatibility, biodegradability and favorable mechanized properties when comes in close contact with the body fluids in vivo. This chapter will provide overall overview to the readers for the study based on reported data of developed biomimetic materials and tools exploited for various biomedical applications and tissue engineering applications which further helpful to meet the needs of the medicine and health care industries.

Keywords: Biomimicry, Biomimetic, Regenerative medicine, Tissue engineering

1. Introduction

The “biomimetics” originated from the Greek words “bios” (life) and “mimesis” (to imitate) and well known from ancient times to take ideas and inspirations from nature or surrounding environmental natural phenomena and various creatures like birds, animals, plants and insects for further transforming them in to most preferable and most promising practical and functional applications for the betterment of human mankind. Biomimetics consisted of new innovated urban design, innovative information technologies to facilitate understanding of the complex mechanisms of ecosystems and further followed with the mimicry of such systems in urban planning and management. Biomimetic is also called the most advanced the process of applying biological principles that underlie morphology, structures and functionality of biological entities to man-made design or models for the most efficient solution of existing challenges. For further proposed innovations, other

relevant analysis of organisms and their respective ecosystems and biodiversity were also studied like their respective functions and associated processes based on exhibited scientific knowledge from biology and ecology. Most recently, biomimetic materials have been synthesized like Se-modified carbon nitride nanosheets, magnesium–strontium hydroxyapatite, dimethylglyoxime–urethane polyurethane, polydimethylsiloxane, Ag/Ag@AgCl/ZnO and PDTC(COOH)4/HA. Applications of biomimetic and biological materials are inevitable in various fields such as biomedical, oil–water separation, sensors, tissue engineering, genome technology

Research papers	Categorized under	Study focus	Highlights
1	Organism Level, Behavior Level, Ecosystem Level	Achieving more sustainability and creating a regenerative built environment	Framework is used to discuss various forms of biomimicry as a design methodology. (Realization process)
2	Ecosystem Level	Biomimicry’s role in addressing climate change in the built environment	Certain ecosystem biomimicry principles for architecture have been deduced
3	Organism level	Principles have been used in compression structures	The potential use of tessellation and possibility of a modular building in the micro and macro scale
4	Organism level	Breathing facades , mimicking skin properties of flora and fauna	Enhancing cooling and ventilation systems and achieving thermal comfort in the buildings
5	Organism level	How termite mounds work and application of this concept in building design	A termite mound is a lung (Realization design, Object design)
6	Organism level	Analyses mathematical patterns and structures in biology and nature	A possibility of use of human bone in structure. Use of fiber reinforced concrete in building to achieve load bearing function.
7	Ecosystem Level	Ecosystem based design theory	A regenerative design approach (Realization process)
8	Ecosystem Level	A novel optimization technique inspired by natural ecosystems	Improving effectiveness of the user base
9	Organism level	Concept which deals with the ability to collect water, sunlight and wind	Outcome of Living building.
10	Ecosystem Level	An ecological replacement scheme using traditional concepts of natural landform, natural orientation and climatic resources.	Ecology principles in building design

Table 1.
Tabular documentation of key Highlights in biomimetic studies (reproduced by Desh SP, 2018) [14].

and ultrasound imaging [1]. Biomimetics has been proposed for developing various most novel nanotechnology technologies to find out many clinical and medical solutions to understand structural and functional properties of various biological components like proteins, amino acids and phospholipids to develop protein functionalized nanoparticles, peptide-functionalized gold nanoparticles, and carbohydrate-functionalized nanoparticles [1–3]. First, very well-known biomimetic based model named flying machine was invented by Leonardo da Vinci's (1452–1519) based on the most fundamental example of inspiration of birds to design “flying machine” and another named, “turtleship,” a warship model was built to fight Japanese raiders during invasions [3–5]. The well-known, the Wright brothers (1867–1948) were also inspired to plot the note of the wings of eagles and made a powered airplane which succeeded in human flight for the first time in 1903 [6, 7]. A protein-driven nanocarrier device was composed of chemically modified nanocarrier consist of protein entities. Protein-based biomimetic nanocarriers were considered the effective biosafety carrier to be used in treatment of tumor having great success to carry out more effective targeted delivery of anticancer drugs and the gene therapy especially [8, 9]. Several modern clinical practices have been adopted to combat sudden increase in antimicrobial resisting bacteria with biomimetic strategies due to having inherent compatibility with physiologically relevant environments. The biomimetic based technologies have raised interest as an emerging field to have potential in treatment of tumor. Clinical Strategy has been proposed for combining nano-technology with biomimetic technology that has found to be gain increasing attention for developing more advanced bioinspired, environmentally benign, and promising diagnostic and therapeutic devices. And, developments of surgical needles had been done to make them safer by using biodegradable polymer and polylactic acid which significantly contribute for the advancement of biomimetics and biomedical engineering [10, 11]. Previously reported methods of fabrications of tissue engineering scaffolds were found to have many advantages over other conventional methods where biomaterials in micro/nano based surface modifications have chosen as for designing of biomimetic materials consisted of 3D printing and stem cells which have observed more effective for tissue engineering of bone and cartilage tissues [12, 13]. 3D printing has emerged as a critical biomimetics based fabrication process for bone engineering due having good control bulk geometry and internal structure of tissue scaffolds. Improved bioprinting methods and biocompatible ink materials for bone engineering have been observed potent optimal hybridized 3D scaffolds for bone defect repair including improved cellular function, cellular viability, mechanical integrity, biological activity, mechanical strength, easy fabrication and controllable degradation (**Table 1**). And, 3D printing might be helpful for next generation of bone grafts clinical practices to create on-demand patient-specific scaffolds [15, 16].

2. Clinical approaches

Antireflective coatings were developed by taking inspiration from phenomenon of moth's eyes called “Areflexia” which method involved refraction of the light significantly decreasing allows the moth to avoid predators and to see prey in the darkness. Hence, this robotic method is used for various military operations to develop the solar cell light-emitting diodes. Most interesting concept of biomimetic technology is to fabricate optical, electric and electronic properties of nanoparticles by controlling their size and shape by using simple preparatory protocols having less toxicity and trustworthy applications. Bio-inspired technology was found to most promising to develop biodegradable polymeric nanoparticles which can easily

circulate through the blood for extended periods of time and also act as detoxification device [17, 18]. By mimicking red blood cells, both physical and chemical biomimicry are integrated to improve the biological function of nanomaterials in-vitro and in-vivo systems. The anisotropic shape and membrane coating are found to synergize for resisting the cellular uptake and reduce clearance from the blood. This approach is observed for enhancing the detoxification of nanoparticles and the anisotropic membrane-coated nanoparticles have enhanced biodistribution and therapeutic efficacy. These biomimetic biodegradable nanodevices and their derivatives have promise for applications ranging from detoxification agents, to drug delivery vehicles, and to biological sensors [19, 20]. High-strength carbon nanotubes (CNTs) were prepared by taking inspirations from “Mussels” called byssus composed of the crosslinking of collagen fibers and a protein known as Mefp-1. This innovative development of high strength was proposed in modern clinical approaches for stitching wounds and successful surgeries. In past decades, various biomimetic technologies have been opted to design the vaccine adjuvants to achieve better immune protection efficiency which could easily mimic the physical and chemical properties of natural pathogens when their interaction is taken place with antigen-presenting cells (APCs) (**Figure 1**).

By mimicking natural pathogens, these particles possess the ability to increase the cellular uptake of antigens, activate APCs, and promote the lysosomal escape of antigens [22]. Newly proposed carriers are synthesized with better biocompatibility, biodistribution and targeting characteristics by taking inspiration biological molecules, organisms, cells, drug vector performances. These prepared protocells are found to exhibit compartmentalized microarchitectures coded with the assembly of protein-polymer nanostructure conjugates used for encapsulation to articulate the proposed design of protein and its related enzymatic activities. The cell-derived biomimetic drug delivery systems are combined with most advantageous synthetic nanoparticles and a natural bio-membrane for providing enhanced efficacy in the treatment of atherosclerosis. The most considerable advantages of this combined system are to provide more options for the design of specific cell membrane coated nano-drugs for imparting good biocompatibility, long course time and inflammatory site targeting. These nanovehicles having protein-based biomimetic nanocarriers have many superior capabilities such as good biocompatibility, low toxicity, low side effects and improved chemotherapy effect. Newly innovated synthetic DNA-based nanoparticles have been synthesized by using biomimetic technology which are found to have full control over the trafficking of internal cargo cellular delivery of loaded compounds to targeting vectors which requires robust endosomal escape from the cellular degradation pathway to facilitate therapeutic mRNA or CRISPR/Cas9 action [23]. These days, the advanced drug delivery methods have been focused for achieving more successful targeted novel drug involving enhanced capacity of drug loading in drug carriers, cellular uptake of drug carriers and the sustained release of loaded drugs to the target cells. Six groups of therapeutic drug carriers are reported which including biomimetic hydrogels, biomimetic micelles, biomimetic liposomes, biomimetic dendrimers, biomimetic polymeric carriers and biomimetic nanostructures. Artificial chemically modified fabrication of biomimetic nanocomposite drug carriers could noticeably deliver the effective targeted concentration of loaded drugs in targeted drug delivery systems. Biomimetic hydrogels have emerged the most promising tissue engineering scaffold materials and their versatile chemistry can sum up various multiple physical and chemical features to integrate cells, scaffolds, and signaling molecules for tissue regeneration. Due to having highly hydrophilic nature hydrogels can design the nutrient-rich aqueous environments for cells and soluble regulatory molecules can be readily incorporated for achieving cell proliferation and differentiation. Novel in-situ

chondroitin sulfate (CS) hydrogel was also synthesized by using phosphine-mediated Michael type addition reaction by adding precursor solutions of CS-acrylate and CS-tri(2-carboxyethyl)phosphine (TCEP) which was thermally stable and biocompatible [24]. The most important is their respective controlled dynamic parameters and spatial distribution of chemical signals in hydrogel scaffolds are critical for cell–cell communication, cell-scaffold interaction, and cell morphogenesis. Biomimetic hydrogels could be proposed for providing the supporting cells with spatiotemporally controlled chemical signals as tissue engineering scaffolds. These artificially designed hydrogels are found be helpful for clinically probing the temporally controlled growth factor-release abilities, spatially controlled conjugated bioactive molecules/motifs, and targeting delivery and reload properties for tissue engineering applications including exhibiting improved clinical characteristics like injectability, self-healing ability, stimulus-responsiveness and pro-remodeling features Multifunctional fibrous scaffolds have been also synthesized having high potential for bone regeneration which composed of poly d,l-lactide-co-trimethylene carbonate (PLMC) and worked as biomimicking attributes of poly d,l-lactideco-trimethylene carbonate nanofibers having improved efficacies and potency as scaffold materials for tissue repair and regeneration (**Figure 2**) [25]. Another new advanced technology based on cell membrane-covered or coated biomimetic nanovehicles for biomedical application has been seeking increasing attention involving membranes from red blood cells, platelets, leukocytes, tumor/cancer, and stem cells which are proposed as biomimetic coatings.

of nanoparticles for eluding the stimulated immune system to maintain their respective targeting capability. Biomimetic technology has also been incorporated in many robotics innovations to make robotic legs and feet for handicapped patients. Most recent, highly advanced biomimetic medical approach was reported for designing 5-degree-of-freedom robotic exoskeleton for upper limb therapy as most hi-tech rehabilitation robots by using CATIA software which inspired by the morphology of the bones and the muscle force transmission of the upper limbs [26, 27]. Scientists have been proposed various protocols for mimic the biological systems for achieving molecular scale control via self-assembly and directed assembly techniques via computerized fabrication and biochemical modification

Figure 2. Biodegradable and biomimetic elastomeric scaffolds (reproduced by Xue et al, 2017) [25].

with molecular precision to develop novel nanoscale devices to carry out diagnostic and therapeutic applications. Biomimetic technology has been adopted for designing and synthesis of a family of chiral and conformationally constrained involving preparation of a 160,000-member library of diverse tetramers via split-and-pool methods and from this library, a non-covalent ligand to the DNA-binding domain of p53 was invented for finding out its most feasible biomedical applications [27]. Nanozymes have been exploited in biomedicine and biomolecular detection which found to exhibit natural enzyme-mimicking catalytic activities to be used as specific nanocatalytic tumor therapy. The construction of an efficient biomimetic dual inorganic nanozyme-based nanoplatform is found to helpful for tumor microenvironment responsive nanocatalytic tumor therapy which triggers cascade catalytic reactions based on micro/submicron/nanosized Au and Fe^3O^4 NPs coloaded dendritic mesoporous silica nanoparticles. Various reported in-vitro and in-vivo clinical interpretations have found higher nanocatalytic-therapeutic efficient and safe with a desirable tumor-suppression rate (69.08%) based on their respective biocompatible composite nanocatalysts. Due to having observed high efficiency of in-vitro nanocatalytic therapy for killing cancer cells, the prolonged blood circulation, and potent tumor accumulation effect, the in vivo nanocatalytic therapeutic efficiency of DMSN-Au- Fe_3O_4 NPs was assessed against the 4 T1 breast tumor xenograft on nude mice. Hence, these proposed DMSN-Au- Fe_3O_4 composite nanosystems have also been evaluated for further clinical translation assessments. Therefore, proposed biomimetic dual inorganic nanocomposite-triggered cascade reaction strategy for TME-responsive and effective nanocatalytic tumor therapy is found to accepted paradigm of toxin-free-drug endogenous and noninvasive nanocatalytic biomedicine by adopting multienzyme mimicking catalytic activities for tumor-specific therapies [28, 29]. Recently, Inflammatory eye diseases including dry eye disease, uveitis, allergic conjunctivitis, scleritis, glaucoma, retinopathy and Age-Related Macular Degeneration (AMD) are treated by using biomimetic based ophthalmic drug delivery of immunomodulatory agents to improve vision-threatening ill effects in subjected patients as safe and easy controlled-release of loaded formulation with improved patient compliance and treatment efficacy. This proposed biomimetic ophthalmic drug delivery practice has pacifying symptoms in subjected patients with negligible dangerous side effects [30–33]. Three dimensional nanofibrous extracellular matrix mimicking structures are proposed to be found suitable to be used as tissue engineering scaffolds composed of biochemically modified natural and synthetic polymers to develop more advanced biomedical tools and devices which have potential of replication of the biomineralization and bone formation as well as tissue regeneration [34–36].

3. Conclusions

Hence, Biomimetic based technologies have been considered the most advanced alternative methods of chemically and bio-engineered drug delivery vehicles and devices. And, it needs lots of innovative inputs and related interpretations to make them more efficient and cost effective [36, 37]. Taken together, these findings indicate that biomimetics is becoming a dominant paradigm for robotics, materials science and other technological disciplines, with the potential for significant scientific, societal and economic impact over this decade and into the future. Hence, biomimicry is novel science stream which studies nature's models and further imitates or takes inspiration from these designs and their respective processes to solve human problems through engineering tools and artificial intelligence protocols (**Figure 3**) [37–39]. So, this innovative perspective fastened the scope of biomimetics (three

Figure 3.
Study mapping of biomimetics associated strategies (reproduced by dash SP, 2018) [14].

levels of biomimicry named, the organism level, behavior level and ecosystem level) to design its space to carry out most promising and novel solutions. So, environment inspiring biomimicry based robotic innovations could might have more potential to carry out more potent clinical and medical outcomes than any chemical and artificial alternative for developing more safe artificial intelligence technology-based products. And, biomimetic study can be evolved as more safe and efficient technology in future to develop human and environment friendly robotic products through integration with fields of applied chemistry, metabolomics, nano-technology, biomedical engineering [40–43]. Therefore, the developments of novel biomimicked biomaterials are observed for more responsive against stimulus could be considered the next choice to generate smart three dimensional biomimetic scaffolds that designed to perform more effective interaction with biological systems. So that, they can be used for a wide range of biomedical applications like delivery of loaded bioactive molecules and cell adhesion mediators to perform better cellular functioning to treat targeted diseases [44, 45].

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References

- [1] Speck O, Speck T. An overview of bioinspired and Biomimetic self-repairing materials. *Biomimetics*. 2019, 4(1): 26. <https://doi.org/10.3390/biomimetics4010026>.
- [2] Kumar NS, Suvarna RP, Naidu KCB, Banerjee P, Ratnamala A, Manjunatha H. A review on biological and biomimetic materials and their applications. *Applied Physics A*. 2020; 126, 445.
- [3] Perera AS and Coppens AO. Re-designing materials for biomedical applications: from biomimicry to nature-inspired chemical engineering. *Philosophical Transactions of the Royal Society A*. 2018. <https://doi.org/10.1098/rsta.2018.0268>.
- [4] Shimomura M. The new trends in next generation biomimetics material technology: learning from biodiversity. *Sci Technol Trends Q Rev*. 2010; 37:53-75.
- [5] Jakab PL. Visions of a Flying Machine: The Wright Brothers and the Process of Invention. *Smithsonian Institution Press*; 1990.
- [6] Pemsel H. A History of War at Sea: An Atlas and Chronology of Conflict at Sea from Earliest Times to the Present. *Naval Institute Press*; 1977.
- [7] Boxerbaum AS, Shaw KM, Chiel HJ, Quinn RD. Continuous wave peristaltic motion in a robot. *Int J Robot Res*. 2012;31(3):302-318.
- [8] Freedman R. The Wright Brothers: How They Invented the Airplane. *New York: Holiday House*; 1991.
- [9] Altendorfer R, Moore N, Komsuoglu H, *et al*. RHex: a biologically inspired hexapod runner. *Auton Robots*. 2001;11(3):207-213.
- [10] Choi J, Hwang MP, Lee J-W, Lee KH. A glimpse into the interactions of cells in a microenvironment: the modulation of T cells by mesenchymal stem cells. *Int J Nanomedicine*. 2014;9(suppl 1):127.
- [11] Li M, Huang X, Tang TD, Mann S. Synthetic cellularity based on nonlipid micro-compartments and protocell models. *Curr Opin Chem Biol*. 2014; 22:1-11.
- [12] Chen, C., Bang, S., Cho, Y. *et al*. Research trends in biomimetic medical materials for tissue engineering: 3D bioprinting, surface modification, nano/micro-technology and clinical aspects in tissue engineering of cartilage and bone. *Biomater Res*. 2016; 20: 10 <https://doi.org/10.1186/s40824-016-0057-3>
- [13] Lee KBL, Hui JHP, Song IC, Ardany L, Lee EH. Injectable mesenchymal stem cell therapy for large cartilage defects—A porcine model. *Stem Cells*. 2007; 25:2964-71.
- [14] Dash, P. S. Application of Biomimicry in Building Design. *Int J Civil Engg Tech*. 2018, 9 (2), 644-660.
- [15] Chia HN, Wu BM. Recent advances in 3D printing of biomaterials. *J Biol Eng*. 2015; 9:4.
- [16] Zhang L, Yang G, Johnson BN, Jia X. Three-dimensional (3D) printed scaffold and material selection for bone repair. *Acta Biomater*. 2019, 15;84:16-33. doi: 10.1016/j.actbio.2018.11.039. Epub 2018 Nov 24. PMID: 30481607.
- [17] Feng Y, Zhu S, Mei D, Li J, Zhang J, Yang S, Guan S. Application of 3D Printing Technology in Bone Tissue Engineering: A Review. *Curr Drug Deliv*. 2020 Nov 12. doi: 10.2174/1567201817999201113100322. Epub ahead of print. PMID: 33191886.
- [18] Wilke P, Helfricht N, Mark A, Papastavrou G, Faivre D, Börner HG.

- A direct biocombinatorial strategy toward next generation, mussel glue inspired saltwater adhesives. *J Am Chem Soc.* 2014;136(36): 12667-12674.
- [19] Hong S, You I, Song IT, Lee H. Material-independent surface modification inspired by mussel-adhesion. *Polym Sci Technol.* 2012; 23(4):396-406.
- [20] HoonáKim B, YoungáKim J, OukáKim S. Directed self-assembly of block copolymers for universal nanopatterning. *Soft Matter.* 2013; 9(10):2780-2786.
- [21] Li M, Huang X, Tang TD, Mann S. Synthetic cellularity based on nonlipid micro-compartments and protocell models. *Curr Opin Chem Biol.* 2014; 22:1-11.
- [22] Lee BP, Messersmith PB, Israelachvili JN, Waite JH. Mussel-inspired adhesives and coatings. *Annual review of materials research.* 2011, 41:99.
- [23] Bao M, Lou X, Zhou Q, Dong W, Yuan H, Zhang Y. Electrospun biomimetic fibrous scaffold from shape memory polymer of PDLLA-co-TMC for bone tissue engineering. *ACS Appl Mater Interfaces.* 2014; 6(4): 2611-2621.
- [24] Gong Y-K, Winnik FM. Strategies in biomimetic surface engineering of nanoparticles for biomedical applications. *Nanoscale.* 2012;4(2): 360-368.
- [25] Jo S, Kim S, Noh I. Synthesis of in situ chondroitin sulfate hydrogel through phosphine-mediated Michael type addition reaction. *Macromol Res.* 2012; 20: 968-76.
- [26] Xue Y, Sant V, Phillippi J, Sant S. Biodegradable and biomimetic elastomeric scaffolds for tissue-engineered heart valves. *Acta Biomaterialia*, 2017; 48, 2-19. <https://doi.org/10.1016/j.actbio.2016.10.032>.
- [27] Kim Y-C, Park J-H, Prausnitz MR. Microneedles for drug and vaccine delivery. *Adv Drug Deliv Rev.* 2012;64(14):1547-1568.
- [28] Paul Dominick E. Baniqued, Jade R. Dungao, Michael V. Manguerra, Renann G. Baldovino, Alexander C. Abad, and Nilo T. Bugtai.. Biomimetics in the design of a robotic exoskeleton for upper limb therapy. *AIP Conference Proceedings*, 2018; 1933, 040006. <https://doi.org/10.1063/1.5023976>.
- [29] Aquino C, Sarkar M, Michael J. Chalmers, Mendes K, Kodadek T, Glenn C. Micalizio. A biomimetic polyketide-inspired approach to small-molecule ligand discovery. *Nature Chemistry*, 2012; 4: 99-104. doi:10.1038/nchem.1200
- [30] Gao S, Lin H, Zhang H, Yao H, Chen Y, Shi J, Nanocatalytic Tumor Therapy by Biomimetic Dual Inorganic Nanozyme-Catalyzed Cascade Reaction. *Advance Science*, 28 November 2018. <https://doi.org/10.1002/advs.201801733>
- [31] Ratay ML, Balmert SC, Acharya AP, Greene AC, Meyyappan T, Little SR. Controlled release of an HDAC inhibitor for reduction of inflammation in dry eye disease. *Acta Biomater.* 2018; 71:261-270. doi: 10.1016/j.actbio.2018.03.002.
- [32] Hwang, Jangsun & Jeong, Yoon & Park, Jeong & Lee, Kwan & Cho, Dong-Woo & Choi, Jonghoon. (2015). Biomimetics: Forecasting the future of science, engineering, and medicine. *International journal of nanomedicine.* 10. 5701-5713. 10.2147/IJN.S83642.
- [33] Ratay ML, Bellotti E, Gottardi R, Little SR. Modern Therapeutic Approaches for Noninfectious Ocular Diseases Involving Inflammation. *Adv Healthc Mater.* 2017; 6(23). doi: 10.1002/adhm.201700733.
- [34] Reddy R, Reddy N. Biomimetic approaches for tissue engineering.

- J Biomater Sci Polym Ed.* 2018; 29(14):1667-1685. doi: 10.1080/09205063.2018.1500084. Epub 2018 Sep 26. PMID: 29998794.
- [35] Khan F, Tanaka M. Designing Smart Biomaterials for Tissue Engineering. *Int J Mol Sci.* 2017 Dec 21;19(1):17. doi: 10.3390/ijms19010017. PMID: 29267207; PMCID: PMC5795968.
- [36] Ravichandran R, Sundarajan S, Venugopal JR, Mukherjee S, Ramakrishna S. Advances in polymeric systems for tissue engineering and biomedical applications. *Macromol Biosci.* 2012 Mar;12(3):286-311. doi: 10.1002/mabi.201100325. Epub 2012 Jan 25. PMID: 22278779.
- [37] Zare, M.; Falahat, M. Characteristics of reptiles as a model for bionic architecture. *Adv. Civ. Environ. Eng.* 2013, 1, 124-135.
- [38] Lopez, M.; Rubio, R.; Martin, S.; Croxford, B. How plants inspire facades. From plants to architecture: Biomimetic principles for the development of adaptive architectural envelopes. *Renew. Sustain. Energy Rev.* 2017, 67, 692-703.
- [39] Buck, N.T. The art of imitating life: The potential contribution of biomimicry in shaping the future of our cities. *Environ. Plan. B Urban Anal. City Sci.* 2017, 44, 120-140.
- [40] Al-Obaidi, K.M.; Ismail, M.A.; Hussein, H.; Rahman, A.M.A. Biomimetic building skins: An adaptive approach. *Renew. Sustain. Energy Rev.* 2017, 79, 1472-1491.
- [41] Elmeligy, D.A. Biomimetics for ecologically sustainable design in architecture: A proposed methodological study. *Eco-Archit. VI Harmon. Archit. Nat.* 2016, 161, 45-57.
- [42] Fujii, S.; Sawada, S.; Nakayama, S.; Kappl, M.; Ueno, K.; Shitajima, K.; Butt, H.-J.; Nakamura, Y. Pressure-sensitive adhesive powder. *Mater. Horiz.* 2016, 3, 47-52.
- [43] Khelil, S.; Zemmouri, N. Biomimetic: A new strategy for a passive sustainable ventilation system design in hot and arid regions. *Int. J. Environ. Sci. Technol.* 2019, 16, 2821-2830.
- [44] Gao, R.; Liu, K.; Li, A.; Fang, Z.; Yang, Z.; Cong, B. Biomimetic duct tee for reducing the local resistance of a ventilation and air-conditioning system. *Build. Environ.* 2018, 129, 130-141.
- [45] Liu Z, Li H, Cao G. Quick Estimation Model for the Concentration of Indoor Airborne Culturable Bacteria: An Application of Machine Learning. *Int J Environ Res Public Health.* 2017;14(8): 857. doi: 10.3390/ijerph14080857. PMID: 28758941; PMCID: PMC5580561.