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Interdisciplinary Expansions in Engineering and Design With the Power of Biomimicry

Edited by Gulden Kokturk and Tutku Didem Akyol Altun

INTERDISCIPLINARY EXPANSIONS IN ENGINEERING AND DESIGN WITH THE POWER OF BIOMIMICRY

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Chapter 4

Biomimetic Design for a Bioengineered World

Irem Deniz and Tugba Keskin-Gundogdu

Additional information is available at the end of the chapter

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Abstract

Biodesign can be explained as a method that includes various researches and applications related to taking inspiration from natural functions, systems, components, or processes in solving a problem. Accordingly, biodesign is commonly used in the design of artificial devices, structures, and buildings in the field of bioengineering. The recent developments in the field of biotechnology and bioengineering bring out various products that are designed in collaboration with different engineering disciplines. In this chapter, the possible use of bacteria, microalgae, and fungi for biomimetic design and the role of biomimicry for these designs will be briefly discussed.

Keywords: bioengineering, biomimetic design, biodesign, microalgae, fungi, bacteria

1. Introduction

Biodesign, in which living organisms can be used as a design input, is a study field that takes nature as an example and aims to make sustainable, functional, durable, and nonhealth threatening products. In literature, biodesign appears together with concepts such as biomimetics, biomimicry, design inspired by nature and morphogenic design [1]. Bioengineering is the application of engineering's analytical, mathematical, and result-oriented approaches to the world of biology, while traditional engineering approaches focus on just mathematical and physical applications to solve the problems or produce a product; bioengineering uses all the information about life, human, and all living organisms. This area includes all the necessary sciences. Bioengineering deals not just with scientific knowledge but also with engineering approaches. In addition to this, biodesign is a methodological approach of new innovations inspired by nature or using the living organism itself to make life easier. The biodesign aims to be ecological, environmental friendly, and also economical. Bioengineering is a scientific discipline that fully encompasses the applications of biodesign [2].

Recently, researchers working in areas such as biology, engineering, architecture, and chemistry have come together to work on bioengineered design. The concept of bioengineered design must be absolutely interdisciplinary [3]. As is known, there are great differences between the language used by basic scientists and engineers. However, it is tried to find common points in these studies. With the accomplishment of this challenging task, a great new generation of biologically inspired design products emerges [4].

It is thought that the biologically inspired design process can take place in six steps. In the first step, the problem needs to be identified. At this point, there is a problem that has not been noticed before, or a solution that has been proposed before but considered inadequate, like reduction of water losses, more benefit from the sun, etc. The second step is to determine the boundaries of the problem. At this stage, the main objectives of reaching a solution point are determined by a biological solution that is sought in the third step. At this point, biologically based approaches that may be probing solutions are searched and possible solutions are identified. Accordingly, there will be some questions to be answered such as, Should a microorganism be used? Should living conditions of a living thing be imitated? In the fourth step, the biological solution is examined in detail. The information on this subject is compiled, and the outline of the work is settled, and the principles of the fifth step are determined. In the sixth step application, bioengineered material suitable for the target and purpose is realized [5].

An overview of biologically inspired design products emerging as the greatest indication that bioengineering and other sciences is harmoniously integrated into this chapter. The products and their areas of use emerged by the designers in this field were examined in general terms. Since our primary goal is to emphasize the importance of bioengineering approach in the field of biodesign and biomimicry, we have not mentioned the detailed metabolic pathways in the products and the issues discussed.

This chapter introduces the usage of microbiology, algal technology, fungal technology, and biomaterials into biomimicry and biodesign field. In each section, the approaches proposed by different researchers on the subject under the relevant heading and the resulting products are explained in detail. By the end of the chapter, the future prospects and potential applications of biomimetic design are discussed. Considering the recent trends across the globe, a full discussion of recent examples is included to raise the awareness of bioinspired and bioengineered materials.

2. Bacteria for biodesign

This section focuses on the role of bacteria in biodesign and biomimicry. The used biological processes with bacteria or using the properties of bacteria will be considered as important alternatives instead of industrial technologies. The given examples are related to direct bacterial production of some biodesign concepts or to use the biomimicry for a bacterial production or to model a bacterial behavior. In short terms, bacteria could take a very big role in biomimicry and biodesign and many of their abilities are waiting to be discovered.

According to the United Nations reports [6], desertification will be one of the important environmental crises of future life. Currently, 100–200 million people are threatened by the hard living conditions of desert life. The most affected countries are Sudan, Chad, and Nigeria. One of the solutions of desertification could be microbial-induced calcium production. The process occurs by using the bacteria, urea, and calcium source to solidify the sand at 24 h. The role of an architect with this process is to choose the best place for the structure. Using the ability of sandstone production of some types of bacteria is the most studied subject of biodesign concept. An interesting concept for the conditions of a desert life was proposed by Magnus Larsson from Architectural Association, London. Sandstone formation in the desert can be turned into architectural building structures from sand in a desert to act as a barrier to be protected against spread of desert (**Figure 1**). The ability of *Bacillus pasteurii* can be used to harden the very small sand particles into a nonintended but organized architectural structure. The shape of this structure designed by nature will serve as a protector for tress, collector of moisture, and a shelter for thousands of people with a very low cost [7]. Also, Turkey Biodesign Team, an interactive and creative platform built by the academicians of bioengineering, architecture, electrical & electronics engineering, and civil engineering, had studied hardening sand for structural materials [8]. The main aim of their first study is to build a children's playground made by biocalcification of sand, which will be totally biological and nontoxic. The ability of microorganism to harden sand will be the main process of this project. The playground will have tunnel like holes and some areas to slip down. It will be an ecological and economical alternative for plastic-based playgrounds, which are generally used worldwide.

Another application of the cementation ability of *B. pasteurii* is Biobrick proposed by BIOMASON (**Figure 2**). The brick is the smallest part of a building, and it is known as the oldest construction component that has been used for thousands of years. It has a very simple form, and there is no need for specialized engineering skills, materials, or technologies for production [9]. However, these conventional basic and old technologies have some disadvantages in the view of environment such as intense energy consumption in terms of heat, high amount of toxic gas release during production, and the usage of agricultural soil. These factors cause a

Figure 1. The schematic view of DUNE by Magnus LARSSON (taken from Flicker).

Figure 2. Biobrick that was built by Biomason.

very high-carbon footprint of brick formation industry. Biobrick uses the microbial cementation process by *B. pasteurii* to produce a rigid shape with high durability and strength similar to conventional bricks. The production times of Biobrick takes 3 days, which is the same as a conventional brick. Application of a comparison in terms of carbon footprint will be resulted in the superiority of Biobricks. In the view of environment and human health, Biobrick is the most ecofriendly solution for building industry [10].

The last application of the microbial cementation is to use their ability to produce $CaCO_3$ to heal the cracks of the buildings. The effect of nature such as wind, rain, and the temperature changes can be resulted in cracking of the conventional and also the biobricks. Application of a healing procedure will improve the durability and strength of the brick and also the lifetime of a building. Jonkers group in Delft University has a publication on the healing process of the cracks with different types of calcifying bacteria and the healing could be clearly seen from SEM shots clearly (**Figure 3**). Using a natural process for a building is the best environmental friendly and sustainable solution [11].

A sustainable world is the main focus of many researchers. The clean and renewable energy production is the first step of a sustainable environment and the world. The consumption of organic materials increased directly proportional to the population growth and the need of disposal of organic wastes is one of the main problems especially for developing countries. Bioenergy production is one of the important subjects of the sustainable environment, and the anaerobic digestion is the key step of bioenergy production. Anaerobic digestion is a biomimicry process. The ability of converting lignocellulosic biomass into methane by intestinal activity of herbivory animals is mimicked in an anaerobic digester for methane formation. About 200 billions of lignocellulosic biomass is produced, and considerable part of this biomass is disposed into environment without any treatment. The energy potential of these wastes can be used for bioenergy production in an anaerobic digester to improve the quality of life and a sustainable environment [12].

This biomimicry concept can be applied in a house for biodesign using these anaerobic bacteria. A microdigester can be designed to convert the food waste already released at home to supply the energy to cook the food, and the digestate from the anaerobic digester can

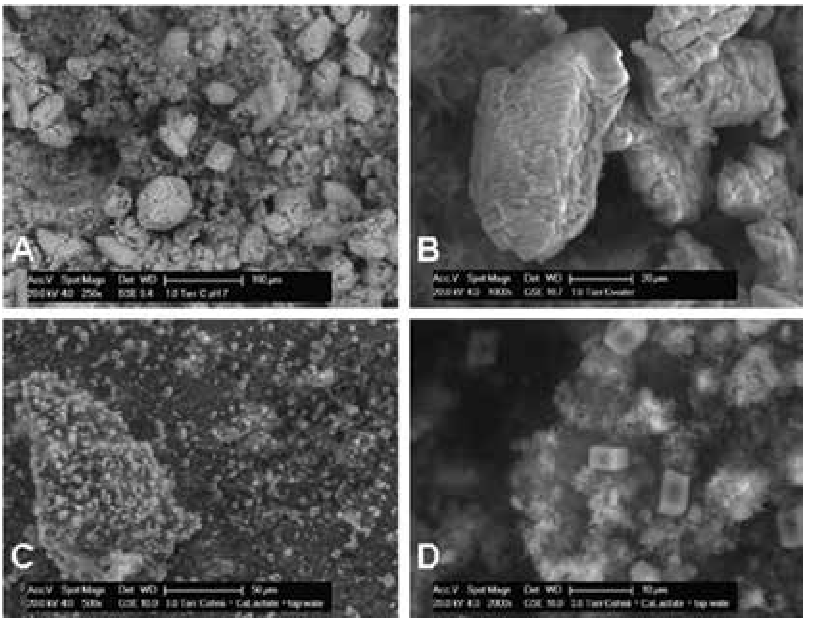

Figure 3. Self-healing cementation by Allain Jonkers. Cement stone specimens with incorporated healing agent (B. cohnii spores plus calcium lactate), cracked after 7 (panels A: 250× and B: 1000× magnification), or 28 days curing (panels C: 500× and D: 2000× magnification). The relatively large (20–80 μm sized) mineral precipitates visible on crack surfaces of young specimens (A and B) are presumably due to bacterial conversion of calcium lactate to calcium carbonate. The small (2–5 μm sized) precipitates on crack surfaces of older specimens (C and D), larger bacterial precipitates are not produced here likely due to loss of viability of cement stone embedded bacterial spores (taken from [2]).

be used as a fertilizer for the vegetable growth to increase the quality of soil and compost. Microbial Home concept is proposed by Jack Mama and Clive Van Heerden based on this idea (**Figure 4**). The components of the microbial digester work in a cyclic way that resembles an ecosystem of a house [13].

Cellulose and textile materials are known to be the main causes of environmental pollution. For the design of furnish of the house of any type of cover material bacterial cellulose and bacterial textile could be the biological and environmental friendly solutions [14]. Natural biopolymers produced by bacterial activity can also be used for medical applications [15]. Suzanne Lee used the microbial cellulose in her textile design (**Figure 5**). The microbial cellulose is combination of millions of bacteria grown in bathtubs of sweet green tee to produce clothing. Growing leather without an animal is one of the important applications of bacteria for biodesign.

The biomimicry of foraging strategy of the bacteria helps to find a way of optimization of bioprocess. The artificial potential field method in autonomous vehicle guidance has many similarities between foraging algorithms of a bacteria. The uninhabited autonomous vehicles generally used in military are optimized by an algorithm derived from the foraging behavior of *Escherichia coli*. The chemotaxis behavior of *E. coli* was used to derive the algorithm for these vehicles [16].

Figure 4. Microbial home by Philips Design (taken from deezen.com).

Biodesign and biomimicry is an emerging strategy to evolve the biological systems for application to create novel technologies for a sustainable world and environment. What types of products can be produced by bacteria? How bacteria reacts to a outer instigation? How their ability can be applied to bioprocess studies? There are a lot of questions waiting to be answered for biomimicry and biodesign world.

Figure 5. Biocouture by Suzanne Lee (taken from biocouture.com).

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3. Microalgal technologies for biodesign

The field of biodesign has risen as a stimulating new multidisciplinary field that merges the inspirer solutions from nature with the cutting edge of modern technology, encouraging technological discoveries that could let people to live sustainable and economic lives, more in unity with the environment. Microalgae are considered as the one of the most attractive bio-based sources with its specific properties.

Microalgae are photosynthetic microorganisms and they generally are adapted to live in extreme conditions due to their unicellular or simple multicellular structure [17]. Microalgae exist in almost all ecosystems, both aquatic and terrestrial. It is considered that there are more than 50,000 strains; however, only half of them have been defined and studied.

Microalgae play a great role in the removal of the CO_2, which makes them sustainable and environmentally friendly. They use inorganic carbon and light energy to produce fuel for the microalgal activities. This functional property attracted the bioengineers and architectures attention to investigate their possible usage in constructive structures for a sustainable inhabiting. As an example, designer Adam Miklosi was inspired by the concept of mutualism to create a futuristic oxygen bar called the Chlorella Pavilion where exhausted people can relax and fill up their energy with the oxygen-rich air (**Figure 6**). Basically, Miklosi aimed to design a piping system where living microalgae can be introduced through the structure to create an algae fountain. Humans relaxing (and breathing) in this structure would give the microalgae the CO_2 it needs to survive, and in exchange, the microalgae (strain *Chlorella* sp.) would give the visitors an extra oxygen push-up [18].

The BIQ House in Hamburg was defined as the world's first microalgae-powered building in the world. The SSC (Strategic Science Consult of Germany), a bioreactor technology company, Arup (Concept Design) an international design consultant and Colt International, a reactor design company are the three partners who developed biofacade concept. This facade is an example of a 200-m^2 building as residence with an integrated concept of microalgal photobioreactors, and with this building, heat can be produced from this reactor. Other important properties of this house are dynamic shading, thermal insulation, and abatement of noise. The three partners are developing new projects for production of larger scale buildings with commercial benefits [19].

Figure 6. Chlorella Pavilion by Adam Miklosi (taken from inhabitat.com).

The Algaevator, designed by Jie Zhang and Tyler Stevermer, can be given as another project example [20]. This structure basically composed of an microalgae farm to be used as a transparent roofing system that can be used in neglected buildings to help regenerate urban environments and with that unique structure, the Algaevator can be considered as gravity-based photobioreactor (**Figure 7**). This microalgal-roof can be used for various purposes as important products and alternative fuels. This funnel-shaped structure also optimizes sun exposure for microalgae production and can also harvest rainwater for additional sustainability [20].

Environmental concerns on nonsustainability and petroleum-based source decrease are considered as the main issues that we currently face. Microalgae-integrated buildings serve a sustainable solution to these problems. Several architects and designers have used these microorganisms in their conceptual constructive structures. The microalgae facades have functional properties conducted to take advantageous of microalgae considering its property to decrease CO_2 emission. The breathing-light-responsive facade, which can open and close according to temperature changes, is a part of Abu Dhabi towers (**Figure 8**). When it is dark (night), the windows would still be closed, whereas in the day time, it would be opened to let the aeration of the building [21].

Microalgae is not only used for their property of absorbing CO_2 emissions but also for other purposes. In a project conducted by HOK in LA, the algae facade was designed to clean wastewater and to filter throughway supporting shading for interior area. It was also targeted to produce lipids that can be converted into biofuel [22]. Another cognitive project is Algae Urban Farm in Tehran, Iran proposed by ecoLogic Studio (**Figure 9**). The project also conducted as a photobioreactor tube supplies cooling strategies through its shading effect with natural ventilation. Besides, this microalgal facade plays a role as a heat regulator [23]. In addition to these projects, Battery Park project in San Francisco was carried out to reduce the net energy to zero while reducing CO_2 levels [24].

Microalgae also have applications for esthetic purposes in architectural structures that lead to an impressive design outcomes with its different geometric variations and characteristic colors. Also, microalgae-based facades provide sustainable productions in such areas where

Figure 7. Algaevator (taken from domusweb.it).

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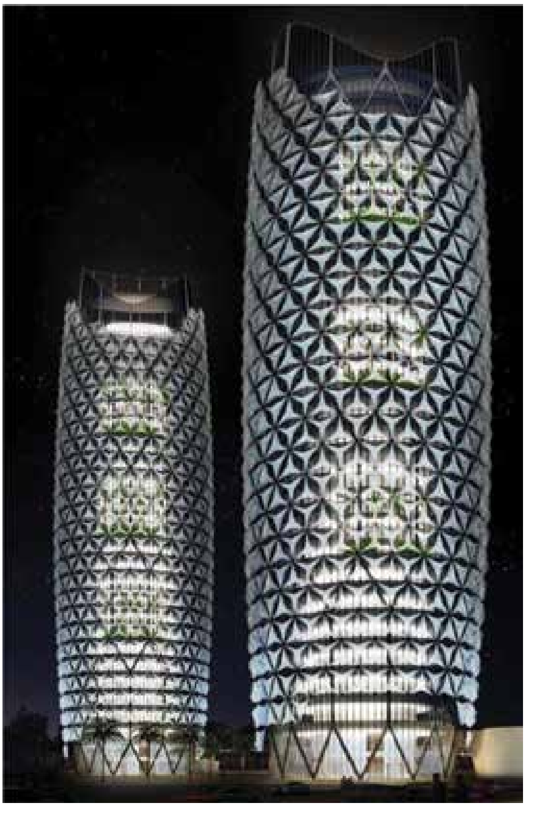

Figure 8. Abu Dhabi Towers (taken from ihabitat.com).

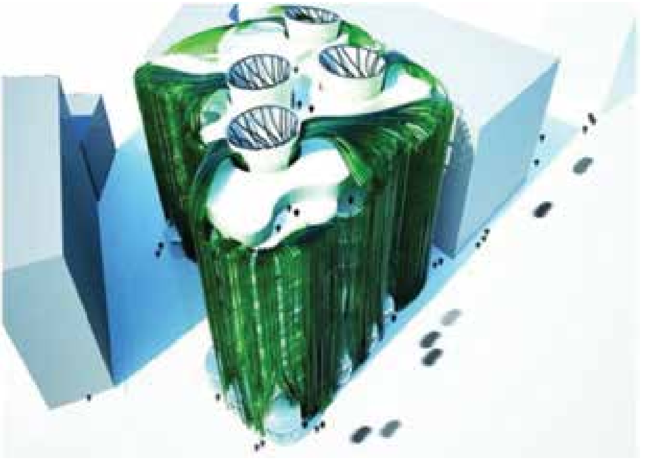

Figure 9. Algae Urban Farm in Tehran, Iran (taken from 33rdsquare.com).

no other structures can be built. The Biodesign Institute at Arizona State University was built, which is a new structure built in the desert called “tubes in desert” to produce energy engine fuel in a more sustainable way. The microalgae live in the tubes with enhanced light penetration to produce biofuel within an esthetic way [25].

4. Fungi for biodesign

Living organisms can provide a new approach for architectural structures. Bioengineers and architects are working on the research of biodegradable materials produced by microorganisms with novel functions. Fungus can also be considered as a biodesign material for durable and hard structures.

Fungi have approximately 100,000 known species, are eukaryotic, and belong to the kingdom *Fungi*, including molds, yeast, and mushrooms. Fungi are the most abundant organisms on Earth and have great applications for food and medical industry for centuries [26]. Recently, researchers used these organisms to build living structures for economic and environmental friendly designs. The living project, for example, is considered as one of the most comprehensive designs that was planned to build towers made from corn stalks and fungi (**Figure 10**). This structure is a product with a circular lifecycle in which fungi feeds using corn stalks. This tower first starts as fungus and plant matter, then transforms into bricks, finally biodegraded, and mixed into soil serving as fertilizers [27].

Moreover, fungi have the capability of being strong, water and fire resistant, and can be used as building materials. After drying, the mycelium can be used as a strong concrete material to obtain any kind of shape desired. From this point forth, designer Eric Klarenbeek in collaboration with researchers at the University of Wageningen produced 3D printed chairs out of mycelium (the vegetative part of a fungus) (**Figure 11**) that makes for a surprisingly solid, strong, lightweight, organic, compostable, and durable material for furniture [28].

Figure 10. The living project (taken from designboom.com).

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Figure 11. A fungus chair (taken from dezeen.com).

As another example for durable structures, a new small-scale company in Turkey, called Diploid Biotechnological Products, is working on a project to make an environmentally friendly insulation material out of fungi that is thinner and stronger than conventional substitutes [29].

Furthermore, New York-based nonprofits Terreform ONE and Genspace created Mycoform, a durable and 100% compostable material made from fungi, wood chips, gypsum, oat bran, and other biological materials (**Figure 12**). The mycoform production process is pollution-free, sustainable, and requires low energy. This material is produced by agricultural wastes and after inoculation with *Ganoderma lucidum* in a place with higher humidity, the fungi consumes the cellulose in the byproducts to create a branch-like network. Then, the branching mycelia grow rapidly into a weight-bearing structure [30]. Likewise, large-scale production examples for biodesign materials that use fungi are also available.

Ecovative Design in the United States commercially produce a packing material as a competitive alternative to petroleum polymer foam that represents 25% of waste landfill sites and contains toxins such as benzene. Their products are made from mycelium that is grown using local agricultural wastes and are uniquely rigid and dense [7]. As an another industrial application, Microbial Home Project developed by Philips in the Netherlands (**Figure 13**) provides various integrated appliances that refrigerate heat, generate food and help in treatment of wastes utilizing bacteria, fungi, and other naturally occurring organisms to mimic an ecosystem and to enable each natural process [7].

Slime molds and oomycetes (water molds) are fungus-like organisms, but they belong to kingdom *Chromista*; however, they are often called fungi, as well. Slime molds (*Physarum polycephalum*) are eukaryotic organisms that can grow as single cell or flocs in the dark. Unlike any other organisms, slime molds have discovered to have a unique intelligence and that they can learn and predict the laboratory conditions that are unfavorable [31]. Using those abilities, a group of researchers from Hokkaido University worked with the slime mold *P. polycephalum* in a humid plate, where they placed the mold in the central position of the plate of Tokyo map and

Figure 12. New Museum NYC grown of mycoform (taken from terreform.org).

Figure 13. A sustainable design product (taken from dezeen.com).

again put oat flakes for feeding the mold on the major cities of Tokyo. In the plate, illuminating materials were used to mimic mountainous area and as *Physarum* avoids bright light, it grew and spread through the pathway of water and oats in the plate. Firstly, the mold was filled in the plate with plasmodia (its living single form cell) and then thinned by the network creating branches to utilize the nutrition efficiently. The final network uniquely and strikingly resembled Tokyo's rail system [32]. Till then, several studies are performed and reported to show the unambiguous potential of the strain. Such as, a similar approach for Izmir map has been conducted as a new project by Turkish Biodesign Team. The same strain will be used for designing the walking ways of a special area of Izmir, Turkey. Besides, the studies of the unconventional computing through the practice of architecture for slime molds are still in development.

5. Biomaterials for biodesign

Biomedical engineering is one of the most comprehensive fields of study of bioengineering. Improvement in patient's health, the development of new creative and painless surgical techniques, the fight with disability, and even the design and production of vital replacements can be done by biomedical applications [33].

A biomaterial is any concept that is in interaction with biological systems. This concept can be a matter, a surface, or an artificial tissue. They can be provided directly from nature or synthesized by new, innovative bioengineering approaches. Regenerative medicine and tissue engineering are the main areas that cover biomaterials. A lot of new organs or replacements of human body can be produced such as prosthesis veins and heart valves, etc. [34].

It is thought that the first biomaterial applications were made in Mayans time. Findings show that Mayan's use some shells in dental operations. In the following years, metals, such as silver, gold, and titanium, have been used in some parts of the body. In the following years, biomaterials that are compatible with body tissues have been studied [34].

Biomaterials must carry many important criteria in order to adapt to living life:

- Be very resistant to environmental conditions such as heat, pressure, and humidity.
- Have low friction coefficients (for use in joints).
- It must be multifunctional.
- The conditions of products must be at ambient temperatures.
- Have the ability to self-heal and adapt to the neighborhood.

It is necessary to combine the principles of biodesign with a systematic bioengineering approach in order to produce biomaterials that are independent of each other but must be found together. Engineers are responsible for the design and production of a biomaterial, and life scientists should be responsible for the sustainability of vital activities and adaptation to the body [35].

One of the oldest biomimicry approaches known to be designed is black boxes, hoods, and other security elements in the air using shock absorptive capability of woodpeckers. Inspired by this approach, a shock absorber material was designed by Yoon and Park [36]. This material is formed by combining one rigid surface, one viscoelastic surface, one porosity structure, and another rigid structure like a skull representation. This biomaterial designed for degeneration in regions prone to impact in the body has found many applications in the medical field (**Figure 14**).

Another important biomaterial example is "bioglass" (**Figure 15**). It is a material designed by Hench and his colleagues to replace the broken bones of soldiers who were injured during the Vietnam War [37]. CaO, P_2O_5 is added to SiO_2, and hydroxyapatite is stimulated to form different forms. By varying the ratios of the molecules, different forms can be produced. Today, there are still many varieties that are used instead of bones or that can be used as base materials for the attachment of fibrous materials.

Tissue engineering is the most used field of biomaterials. Bioengineered scaffolds are the most important biomaterials that will be used to form a tissue or an organ. Scaffolds act like the extracellular matrix in the body, aiming to attach, replicate, transform, and actively function on the cells themselves. The porosity of these biomaterials is crucial so that the cells can easily access the minimum elements to survive for life. The biomaterial must disappear when cells complete their function and become an organ in practice. For this reason, the timing of biodegradation is a very important issue that needs to be addressed [35].

Many materials can be used as biomaterial raw materials.

- Extracellular matrix (ECM).
- Biopolymers: collagen, alginate, chitosan, etc.
- Sensitive polymers; polyglyconic acid, polylactic acid, etc.
- Hydrogels, polyvinyl alcohol.
- Ceramic materials, calcium phosphate, hydroxyapetite.

Another important issue in the biomaterial production is the formation of scaffold structure. Providing high porosity and adhesion area is very important in scaffold production, solvent casting, melt molding, and 3D printing.

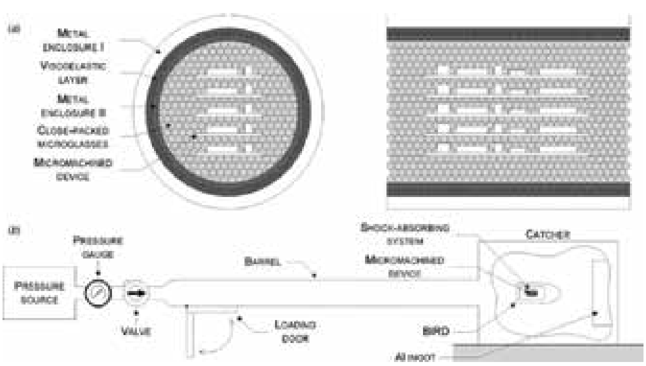

Figure 14. Bioinspired shock absorption system based on the head of the woodpecker (taken from iopscience.iop.org).

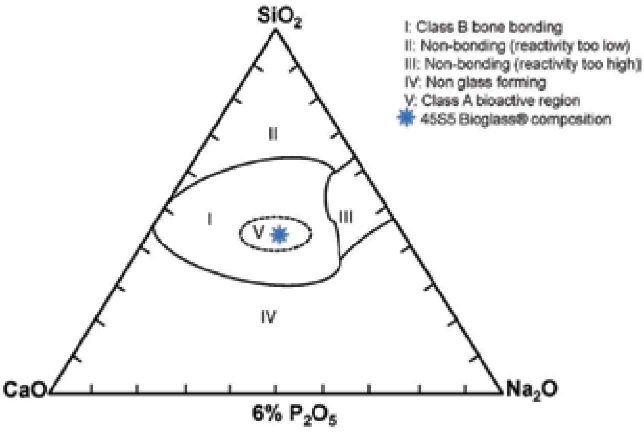

Figure 15. Bioglass composition [36].

Orthomimetics is an important biomaterial produced by Pek and the colleges [38]. It is an osteochondral scaffold. It is two sided and regenerates the bone-cartilage interphase. It is a 5 mm tape. One side includes type 1 collagen and minerals to support bone formation and the other side consists of type 2 collagen and glycosaminoglycan (GAG) to support the cartilage formation of the osteoblasts, which helps in the regeneration of bone deformations.

Biomimetic vesicles for drug delivery is very important for a controlled delivery of drug to human body. As it is known, cell boundaries are made up of a lipid barrier in which the necessary elements first dissolve in and then are released into the cell. This idea was applied to a new drug delivery system like in **Figure 16**.

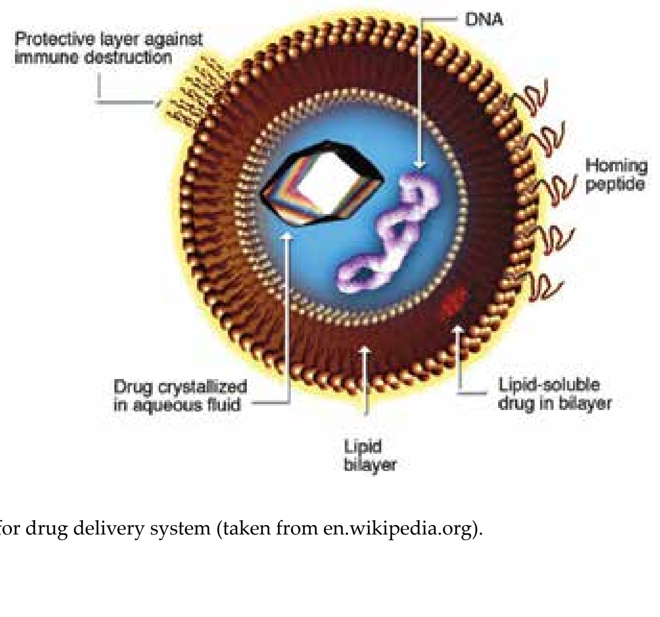

Figure 16. Liposome for drug delivery system (taken from en.wikipedia.org).

Another example of biomaterials is from cardiac studies proposed by Parker et al. In this study, artificial heart muscle prepared by 2D engineering from rat ventricular myocytes was formed. The data showed that increased systolic stress increased with increasing sarcoma compliance. Studies have suggested that the engineering process of the extracellular space is the mean of the self-organizing ability of the contractile apparatus maximizing the contractile force of cardiac myocytes. These results have significant implications for maximizing the physiological function of bioengineering tissues.

Biomimicry of the function and shape will probably result in novel treatments and to mimic such bioprocesses will be more difficult to success, but will have more effect. Another important project by Dr. Elvassore's group was developed in an in vitro cardiac tissue test, which uses human cardiomyocytes (hCMs) and microtechnologies. hCMs were grown on a polyacrylamide hydrogel with adjustable mechanical properties similar to tissues. The data showed that micromodeled hCM maintained the expression and functional properties of large cardiac markers (cTnT, cTnI, Cx43, Nkx2.5, and a-actinin). These studies are a proof that it is still a principle. However, when it is further developed, it may be an important influence on drug-based studies. As the researches in biotechnology and drug-development systems are increased, the possibility of biomimicry to take progress and take a greater role in these areas can deepen in biomedical field.

6. Future prospects

Minimum CO_2 emission technologies and sustainable solutions to the daily requirements are globally attracting the society and also the governments among developed and developing countries. Bioengineering presents a unique paradigm in various fields as a novel basis for technological thinking. It has been integrated with biomimicry through biodesign that involves nature as a massive database of mechanisms and strategies to be implemented in. Advancements in bioengineering have led to changes in biodesign approach since the last century where the terms of sustainability, environment, and ecological habitat have gained attention. The products of bacteria, fungi, and microalgal strains are generally cost effective, nontoxic, and natural, and those products can be utilized in daily-used structures/materials.

Bio-based products can be multifunctional, complex, and highly responsive solutions and thus can replace the concept of traditional strategies for a known process to improve energy performance into a new form. For example, live structural designs that use microalgae for input where buildings can adapt to changes through the environmental variations (temperature, etc.) have been realized to answer environmental concerns about greenhouse gases. This building can help future structures to be more responsive to both external and internal conditions and satisfies welfare levels for humans. However, there are still great challenges about the production of the structures planned to be built using biomimetic design approach. The transfer of knowledge and technology from bioengineers to architects is difficult. Interdisciplinary studies between those fields can employ a great role to develop bio-based products in the future.

7. Conclusion

Last decades, biodesign has gained more importance because of the need in reducing environmental impacts of synthetic and chemical productions. Thus, trends in biodesign are a result of the environmental and health-related concerns. For example, using microorganisms for biocalcification instead of chemical-based concrete to make concrete self-heal would extend the service life of the concrete while lowering the costs of maintenance. As another example, the illuminating capacity of microalgae can be used in roads and pathways to increase sustainability. Fungi can also serve as a great example for their usage in decorative home products. Consequently, using technologies, designs, and models that integrate nature into bio-activity in a way that is beneficial to both ecosystem and humanity, whether by bacteria or by fungi embedded in infrastructures or algae generating our energy, may be considered as the best, smartest, and most applicable way to avoid global ecological ruin.

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