









Additionally, it should be highlighted that, unlike our current synthesis or sintering procedures, which often need severe circumstances, the amazing structure-forming mechanism in living organisms rapidly and correctly fabricates bio-systems under such settings. For instance, the shell structure-forming process is performed at room temperature and results in a well-defined structure with strong mechanical characteristics (particularly good toughness) made up of 5% organic layer and 95% inorganic layer. In the calcification of the shell, certain proteins with a well-organized mix of -chitin, flexible polymer gel and asp-rich proteoglycans play fundamental roles. The mechanism by which shark teeth are formed is the most intriguing example. Shark teeth may alter and develop in many days. Throughout its lifespan, a shark will replace 20,000 teeth.

How come shark teeth come into being so much hard before humans' teeth do? This is due to the factor of development, a distinct biological environment, or just a more straightforward crystallization process? Perhaps there is more to the story, and we can learn more about the structure-to-forming process of sharks' teeth for ceramics manufacturing. It was argued that the remarkable biological structure-to-forming approach of bio-materials is worth learning from to effectively produce unique synthetic approach for more advanced technologies, which would ultimately evolve to bioprocess-inspired industrialization as a further research field. The term "bioprocess-inspired fabrication" has been defined as "developing novel synthesis and processing methods by drawing ideas and inspiration from natural processes that give rise to structure." It is evident from **Fig 1** that bioprocess-inspired manufacturing draws inspiration from biological processes or the relationship between biological processes and biostructures.

Biomineralization, photosynthesis, and other common bioprocesses are worth studying about by chemists and manufacturing engineers. In light of this, we propose that works on bioprocess-inspired manufacturing be organized into three categories: biomineralization-based manufacturing and synthesizing, bioprocess-inspired synthesizing and manufacturing, and photosynthesis-inspired synthesizing and manufacturing. In reality, as shown in **Table 1**, fascinating work has been accomplished over the last several decades in the development and manufacture of sophisticated materials through a comprehension of natural bioprocesses. Different techniques stimulated by biological biomineralization approaches have been evaluated to established materials with sophisticated frameworks or characteristics, starting with the groundbreaking studies on the in vivo productions of gold nano-materials within natural alfalfa seeds, and onto in-vitro SiO<sub>2</sub> metamorphism stimulated by the silaffin extracted from diatoms.

Shafirovich, Khannanov, and Shilov [13] have created inorganic compounds with distinctive forms and characteristics as a result of photosynthesis, another significant natural bioprocess. In order to manufacture oxides, dimethyl sulfide, reduced graphene oxide (rGO), sulfides, metal phosphides and metal phosphates, the photosynthesis-inspired method has steadily been used since the authors revealed that photo-inspired holes and electrons could stimulate a redox reaction. Recent research has produced some intriguing findings by taking lessons from other biological bioreactors. To our understanding, no publications has critically addressed "bioprocess-inspired fabrications" of bio-materials, irrespective of the fact that significant development has been attained in the developments and manufacturing of materials stimulated by natural processes. The novel term "bioprocess-inspired manufacturing" is formally suggested and comprehensively discussed for the first time in our study.

The study strategies and directions we recommend in detail are shown in **Table 1**. There has already been a large amount of study done in several areas. Nevertheless, other paths are only hypotheses and recommendations for which little or no study has yet been done. The authors as well as other scientists from across the globe will present their major findings in the subject of bioprocess-inspired manufacturing in this publication, and we will also explain and comment on the recommended future paths. Materials with distinctive structures and/or functionalities have been created using manufacturing techniques inspired by bioprocesses at room temperature. This approach, in our opinion, has the potential to lead to the creation of fresh methods for the manufacture and processing of materials.

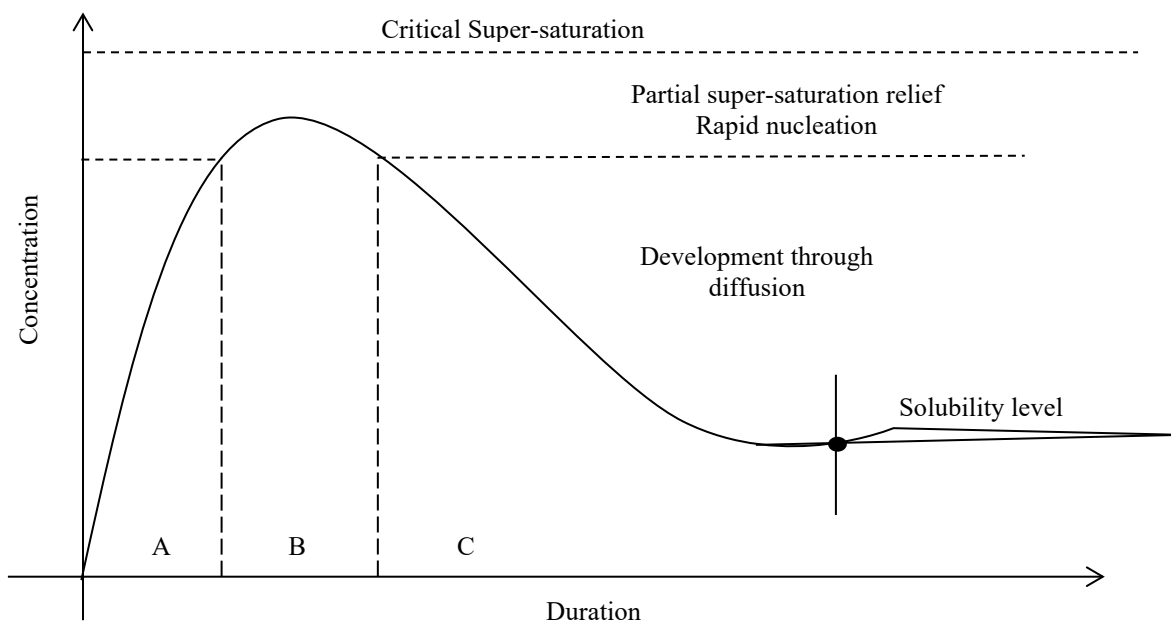
**Table 1. Overall Techniques Within Bioprocess-Inspired Fabrication**

<b>Bioprocess-inspired fabrications</b>	Biomineralization inspired	Bioprocess-inspired additive processing
		Novel design-based mineralization
		Organics simulation natural organism-based synthesis
		Recombinant protein-based synthesis
		Chosen organism-induced synthesis
		Biological organism-induced synthesis
	Photosynthesis inspired	Bioprocess-inspired additive processing
		Application of biological photo-systems or/and materials simiilating PS and for inorganic synthesization
		Application of single inorganic model for the material fabrications
	Others	Photosynthesis and biomineralization processes
		Application of physiological processes within biological organisms as platforms

### III. BIOMINERALIZATION-INSPIRED SYNTHESIS AND PROCESSING

Biomaterialization, which is employed by living things to create biomaterials (such as shells, teeth, bones, and diatoms) made up of organic and inorganic stages and often displaying extraordinary features. Proteins, peptides, and polysaccharides are examples of organic compounds that often control crystal formation and nucleation, modulating its appearance and characteristics. In comparison to our prevailing technological domain, where more extreme factors are often needed to produce synthetic fibers, these processes take place under ambient circumstances. Using self-assembly and organic-inorganic recognition to assemble multiscale building pieces into precise nanostructures, biosystems create high performance biomaterials. Hence, understanding the natural mechanisms involved in the synthesis of biomaterials might provide fresh insights required to create novel synthetic techniques. For instance, the delicate and complex design of the nacre's inorganic (hydroxyapatite tablets) and biological (protein-polysaccharide) layers offers hints as to how artificial structures may be enhanced. Similar to this, developing new methods for putting together various nanocomposites and structures would result from studying the crucial elements throughout the structure-forming procedures of these nanocomposites.

The primary biomaterialization processes (biomacromolecules within nucleation and crystals development, collections of nano-structured inorganic or artificial element into distinct different hierarchical dimensions, and exquisite natural manufacturing, etc.) have sparked a wave of research into the creation of novel methods for synthesizing sophisticated substances and nanomaterials with the appropriate architectures and characteristics, particularly at room temperature. As a term, "biomaterialization-inspired synthesizing and processing" refers to methods and techniques developed with the help of insights gained from studying biomaterialization. Our goal in this overview is to provide an advent to the biomaterialization-inspired fabrication field, which uses biological systems, microbes, and natural matrices like transgenic proteins or peptides, natural proteins, and polymers as either "process-directional" and "structure-directional" agents to regulate the initiation, development, and final form of inorganic compounds.



**Fig 2.** Super-Saturation Process Defining the Development by Diffusion

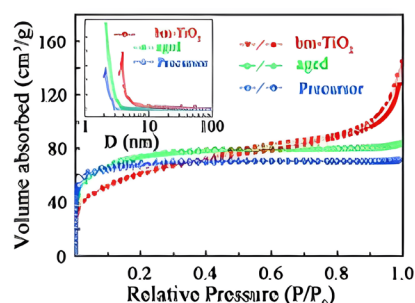
Biomaterialology is the study of how organic-inorganic materials, such as shells, bones, and teeth, are formed by living creatures, with a hierarchical structure. Our capacity to recognize the many macromolecules and their interactions in biomaterialization has increased during the last several decades. More recently, attempts have been made to replicate key fabrication processes and structural aspects of biomaterials in advanced materials as we gain a better understanding of the processes by which they are generated. Here we provide a high-level overview of the fundamentals underlying the assembly of biomaterials, or the guidelines that regulate the accumulation of inorganic solids. Depending on their overall shape, biomaterials may be broken down into three distinct categories. (i) Amorphous crystals are the biomaterials with the most morphological flexibility, since they may be easily shaped into any desired form. The siliceous diatoms and radiolaria have a wide distribution of them. (ii) Polycrystalline biomaterials come in a broad variety of morphologies as well, with complex shapes easily assembled from their tiny crystalline building pieces. A priori, it may be assumed that single crystals are geometric structures with regular, symmetrical faces, where the exterior shape is a mirror of the crystal lattice's interior symmetry. In comparison, single crystals formed during biological calcification may exhibit morphologies that are unrelated to their underlying crystal structures.

Four distinct variables have been identified as critical control points for achieving the desired process output. They are soluble, the degree of condensation, the nucleation process, and the crystal growth. Biomaterials always react with

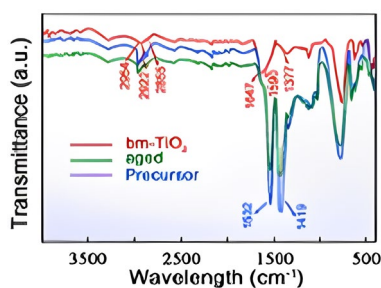
biomolecules during their creation, usually proteins and phospholipid-protein complexes found in biological cuticles. Supersaturation of the solutions is the primary driver for the creation of a new stage (the precipitate) during biomineralization, which starts with dispersion of various ions. Typical of every super-saturation process is the curve shown in **Fig 2**, which shows the crystallization of sulfur in ethanol. Precipitation occurs automatically once the sulphur content reaches a threshold supersaturation. The sulphur content returns to its original value over time, allowing the precipitated nanoparticles to expand in the solution if they contain a nucleus. Homogeneous nucleation occurs when a nucleus develops spontaneously from the solution, but heterogeneous nucleation requires an outside source, such a surface (like a protein or membranes), airborne particles, or crystal seeds. Having uniformly sized nucleated nanoparticles before they develop by diffusion is only possible if the germination burst is brief.

#### Natural Living Organism Directed Synthesis

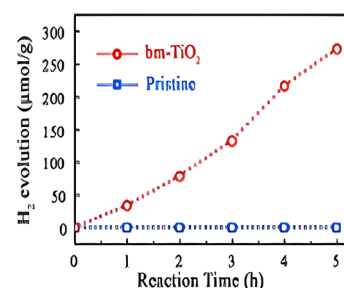
Biomineralization-inspired fabrication approaches that use biomolecular identification and nucleation characteristics for inorganic synthesizing nanoparticles have made considerable strides in recent years. Biomolecules are used as regulatory agents in many of these procedures, which are carried out in vitro under carefully manipulated settings. Unfortunately, the complexity and inventiveness of natural organisms are beyond the scientific community's ability to replicate with only one or a few proteins used in these procedures. For instance, the production of biominerals often involves fine-tuned biomolecular coordination and cellular functioning inside living systems. What makes living systems special, cellular processing, is not present in in vitro component manufacturing. Moreover, the distribution, mobility, dissolution, hydration, deposition, and development of crystals throughout each step of mineral formation are all controlled and regulated by the complex biological circumstances present in living systems. Using natural living creatures as a console to immediate synthesizing nanoparticles is a good starting point and an effective strategy in this regard because it takes advantage of the characteristics intrinsic in biological systems, e.g., molecular arrangement and identification, a great level of development, organization modulations, easiness in the treatment of chemicals, and cell processing.



**Fig 3.** Isotherms of nitrogen gas adsorption and desorption onto  $\text{TiO}_2$  samples



**Fig 4.** Distributions of relative pore sizes are shown in the inset. Sample spectra of  $\text{TiO}_2$  obtained through Fourier Transform Infrared Spectroscopy (FTIR)



**Fig 5.** Hydrogen generation after photoelectrochemical water reduction in  $\text{TiO}_2$  samples exposed to visible light. This is an authorized reprint

The first nanomaterials were created by harnessing the natural physiological processes of living creatures. Research advancements have allowed scientists to forego genetic modification and instead employ live creatures to manufacture compounds incompatible with their physiology. Using live mussels as a direct platform, Fu's team has devised an intriguing approach for the production of nitrogen-doped anatase  $\text{TiO}_2$ . Several researchers have spent time and energy trying to find ways to reduce the huge band gap (3.2 eV) in  $\text{TiO}_2$  by nonmetallic or metallic doping in order to increase its efficiency as a visible-light converter. In addition, a hierarchically permeability has been incorporated into  $\text{TiO}_2$  to increase its photocatalytic activity by giving an increased surface area, reduced transport distance, and more active sites. Yet, it is still challenging to develop an optimum synthetic approach that simultaneously introduces a hierarchical highly porous structure and periodic doping, particularly at room temperature. We utilized a method similar to pearl cultivation in which an amorphous precursor was inserted into the *Cristaria plicata* (water mussel). A hierarchically porous nanocrystal anatase  $\text{TiO}_2$  formed after 3 months of in vivo condensation (see **Fig 3**). Chemical changes in the bio-mineralized Titanium dioxide (bm- $\text{TiO}_2$ ) sample were discovered throughout the procedure.

The acetic acid-treated precursor has signature stretching oscillations at 1419 and 1532  $\text{cm}^{-1}$ . The protein bands in bm- $\text{TiO}_2$  are very prominent, especially at 1590, 1647, and 1378  $\text{cm}^{-1}$ . These findings show that Ti-acetate chemical within the precursor is currently being substituted by proteins from live mussels (see **Fig 4**).  $\text{TiO}_2$  nanocrystals also formed nitrogen intercellular spaces at room temperature due to self-doping with nitrogen from protein sources. Visible-light photocatalysts capabilities in waste treatment and hydrogen synthesis (56  $\text{mol h}^{-1}\text{g}^{-1}$ ) are shown by the bm- $\text{TiO}_2$  nanocrystals, which are difficult to obtain with traditional techniques at cellar temperature (see **Fig 5**). Moreover, this work uncovered the intriguing fact that internal proteins, as opposed to external proteins, serve as protonation catalysts to aid in the crystallization process at room temperature. The researchers also investigated the oxidation of additional inorganic minerals in mussels, including  $\text{MgO}$  and  $\text{Fe}_2\text{O}_3$ . With these findings, it may be possible to exploit live creatures for the

direct production of elements not essential to their physiological functions. The work has significantly advanced our understanding of biomineralization mechanisms by shedding insight on the structural alteration of these well-studied minerals in natural systems.

In situ synthetic techniques have been used to create metal-organic frameworks (MOFs) by mineralizing around single-celled organisms in moderate aqueous environments. In a groundbreaking study published in 2018, Richardson and coworkers proved for the first time that MOFs may be synthesized in situ, in vivo, within plants. Sufficiently small to be taken up by adhesive and cohesive forces, metal salts and natural connectors were added to plants in this method. These MOF precursors collected around plant biomolecules to promote MOF development. One-phase or two-phase synthesis approaches, might be utilized dependent on the synthesizing rate of MOFs. Even though Zn (MeIm)<sub>2</sub> forms so slowly in water, it was just a one-step process when it was exposed to plant trimmings. On the other hand, the inorganic Tb<sub>2</sub>(BDC)<sub>3</sub> and MOFs (Eu<sub>2</sub>(BDC)<sub>3</sub>) were generated in dual phases, first by hatched with larger precursor, and consequently with a minor one. Plants modified with luminous MOFs may be used as functional materials in the detection of tiny molecules. If the antecedents are tiny enough to travel and the environment are suitable for plants, the discovery suggests that additional useful materials may potentially originate within live plants.

Using living creatures to make valuable materials not necessary in their physiological functions is where the above work's relevance and intriguing qualities really shine. Complementary noble metal oxide nano-elements, such as gold (Au), platinum (Pt), and silver (Ag) have previously been produced by scientists using plant physiology (Pt). Researchers led by Dr. Gardea-Torresdey have made significant strides in understanding the in vivo creation of Ag and Au nanostructures inside of live alfalfa plants. Even though these methods can only produce a limited number of metal nanoparticle kinds, they are nevertheless interesting and worth investigating. There has been some advancement in this area in recent years. When Mukhorov first considered photosynthesis in plants in 2017, it was a major breakthrough. In order to create Au nanostructures in vivo, the green sea algae *Ulva armoricana* was introduced to diluted standard solutions of Au (III) ions, and then the mixture was subjected to sunlight. Gold nanoparticles founded on the U substrates *armoricana*, throughout particular cellular membrane, and in the chlorophyll activity shown superior catalytic performance in the degradation of 4-nitrophenols.

#### *Chosen Organism-Based Synthesis*

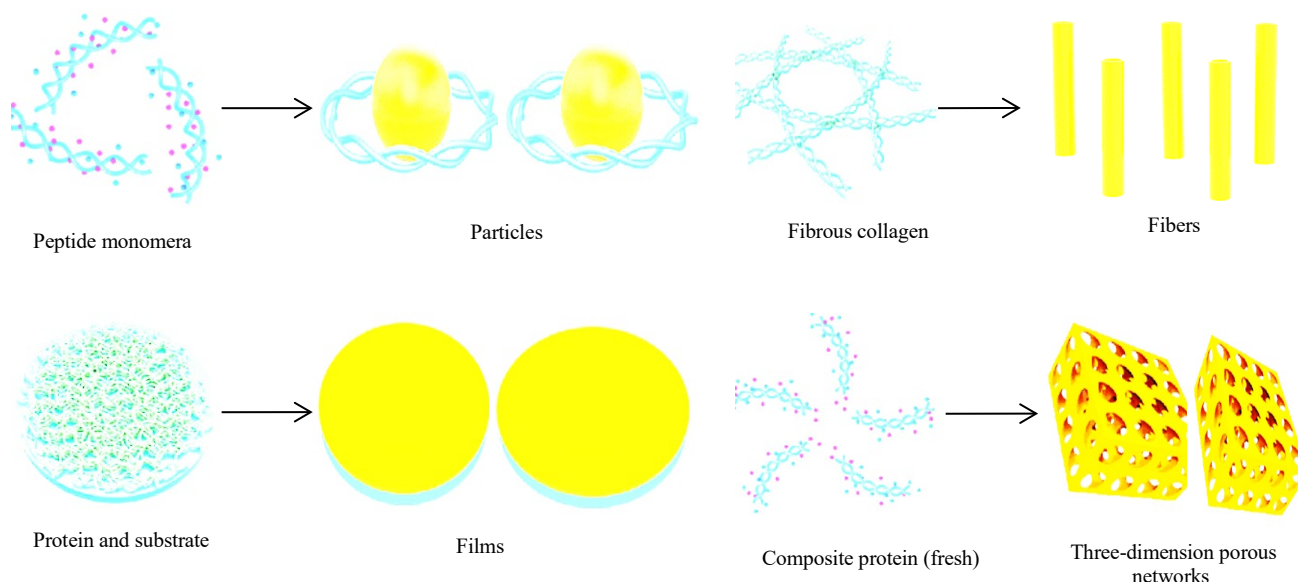
Using natural live creatures as a platform for material synthesis has been shown to provide some very promising outcomes. In order to rationally design materials, however, a thorough comprehension of the bioprocesses used in these in vivo chemistries is required. Exploring the fundamental processes of biomineralization relies heavily on research into the interactions among organic matrix and inorganic nanocrystals. To better understand the connections between supporting microorganisms, reaction circumstances, and resulting materials, many research have been conducted out employing a broad range of isolated biomolecules or/and biological microbes to determine vitro inorganic synthesis, elements with distinctive architectures, for a variety of techniques. Nanostructures with complex, optimized, and productive topologies may be produced by naturally occurring organisms. Comparatively to manmade structural templates like silica nanoparticles or supermolecular microcapsules, these biological resources are frequently low-cost, plentiful, ecologically benign, and inexhaustible. This makes them useful for the fast, efficient production of high-quality biomaterials of specific design.

#### *Natural Biomolecules (DNA), Proteins-Induced Synthesis*

At the macro-molecular scale, biomolecular identification and self-assembly play a crucial role in mineralization driven by living systems by precisely assembling molecular components into complex structures. It is hypothesized that the biomolecules play a vital role ("process-directing agent" or structure-directing agent" role) during the process of biomineralization. Extracting them from living creatures is the most efficient way to get hold of natural biomolecules with high levels of decomposition in vitro. Silaffins, a diatom peptide made up of the amino acids arginine and lysine, were initially found by Natarajan, Rajan, and Das [14]. Systematic research revealed that silaffins exhibit two activities, one of which is a calcification function that immediately deposits silica (SiO<sub>2</sub>), and the other of which just aids other biomolecules in this process. The microstructure, crystallographic behavior, and mechanical characteristics of inorganic materials may be influenced by a broad variety of natural macromolecules, including proteins, catalysts, DNA, phytate, and sodium alginate, as shown by subsequent research. Many thorough assessments have been written to describe these efforts.

The increased urgency with which we must address our planet's energy and environmental crises has refocused interest on nanostructured materials. There has been a lot of excitement in recent years about the prospect of developing innovative biomaterials with beautiful nanostructures, and novel capacities, which could be tuned at a particular nano-scale. Natural biomolecules such as proteins, polysaccharides, collagen type, and fibers might be utilized as process-orienting reagents to control the production of nanostructured materials (see **Fig 6**) with a wide range of morphologies, including those used as photocatalysts, transistors, and electrodes. Limiting this overview to only the past decade's worth of research on biological protein-directed manufacturing of nanostructured materials employed as photocatalysts and conductors was necessary due to space constraints.





**Fig 6.** Demonstration of Different Products and Processes Stimulated by Natural Biomolecules

### Peptide Monomers

Peptides represent the shorter polypeptide chains constructed with amino acids connected through the peptide bond (the term "peptide" comes from the Ancient Greek meaning "digested," "peptós"). Amino acid chains link together to form proteins, a kind of polymer. Oligopeptides are peptide chains that are fewer than 20 amino acids in length. This includes dipeptides, tetrapeptides and tripeptides. In this context, "polypeptide" is an abnormally lengthy peptide chain without any branch points. Chemically, peptides have characteristics with nucleic acids, polysaccharides, and oligosaccharides all of which are other types of biological oligomers. Proteins are large, complex macromolecular assemblies composed of one or more polypeptides that have been organized in a physiologically useful fashion and are commonly attached to ligands like co-factors and co-enzymes. Amino acids, which have been incorporated into peptides, are known as residues. When an amide bond is formed, one water molecule is sacrificed. Every peptide contains an amine grouping (N-terminus) and the carboxyl grouping (C-terminus), with the exception of cyclic peptides.

Each peptide type has been classified according to its function and source. Peptides found in plants, bacteria, fungi, invertebrates, amphibians, skin, venom, vaccines, immune/inflammatory responses, the endocrine and nervous systems, the digestive system, the cardiovascular system, the kidneys, and the respiratory system. Some ribosomal peptides are processed by proteolysis. In most multicellular organisms, they play a role as a hormone or signaling molecule. Some microorganisms create peptide antibiotics, e.g., antimicrobial and microcins peptides. Typical post-translation changes to peptides include phosphorylation, sulfonation, hydroxylation, palmitoylation, disulfide formation, and glycosylation. Peptides have been found to have the rare yet interesting lariat structure. For example, L-amino acids in platypus venom undergo racemization to become D-amino acids.

When the ribosome is unable to synthesis a peptide, enzymes are responsible for its construction. The non-ribosomal glutathione peptide has a significant role in antioxidant defence of different aerobic organisms. Mostly identified in unicellular plants, animals, and fungi, the non-ribosomal peptides are generated by the modular enzyme complexes known as the non-ribosomal synthetases peptide. The complexes have a similar framework, and they might include several modules, each of which is responsible for a different phase in the creation of the final product. The cyclic structures of the common peptides they form are often exceedingly intricate. The presence of linear nonribosomal peptides, however, is not uncommon. Hybrid molecules are common because this process is linked to the machinery, which constructs polyketides, and fatty acids. The availability of thiozoles or oxazoles in the chemical structure is often used as a marker for molecules made in this manner. Peptones are the byproduct of protein digestion and may be found in dairy and meat products. The byproduct contains a plethora of biological compounds, such as vitamins, minerals, fatty acids, lipids, metals, and more. Peptones are a common supplement to nutritional media used for growing bacteria and fungi. Peptides are tiny fragments of proteins that may be used in place of the full-length protein for analysis or identification. They often occur from laboratory-controlled enzymatic breakdown, although in the case of forensic or paleontological materials, they might potentially have formed naturally.

Sandwich carbon nano-fibers ( $C@SnO_2@C$ ) were synthesized using collagen, a typical glycoprotein, as both a structure-directing reagent and source of carbon and energy. Ambipolar diffusion is made possible by the  $C@SnO_2@C$  nanofiber bundle, which has a special hierarchical structure that ensures concordance between electron transportation kinetics and  $Li^+$  dissemination kinetics. This volume shift of  $SnO_2$  is efficiently accommodated by the peculiar "breathing" behavior brought on by the  $C@SnO_2@C$  arrangement. As such, the as-synthesized  $C@SnO_2@C$  nanofibrous bundle offers clear benefits in rate capability and cycle stability in comparison to traditional carbon/ $SnO_2$  nanocomposite.

The established bio-inspired technique has the potential to be used to the synthesis of various high-performance electrochemical devices, in particular for metal oxides with significant volumetric transitions and lower electric conductivity. Moreover, it has been discovered that the naturally generated protein polymers *Bombyx mori* silk fibroin may guide the regulated mineralization of diverse nanomaterials because of its distinctive self-assembly behavior, high cytocompatibility, and biomechanical capabilities. In order to create more efficient lithium (Li-ion) cells, Martínez-Rodríguez et al. [15] used a biomineralization approach based on the effective framework of silk proteins to create hierarchical olive-like organized magnetite and carbon nanomaterials. Cai and Larese-Casanova [16] also showed that they could use this method to make electrocatalyst for high-performance Li-ion batteries. Rape pollen protein was used to facilitate and control the development of hierarchical meso/macroporous TiO<sub>2</sub> systems in three dimensions.

#### IV. CONCLUSION

The purpose of this paper was to go over the principles, techniques, and applications of bioprocess-inspired manufacturing and synthesis. This paper also discussed the process of biomineralization, which is a bioprocess-inspired fabrication technique used by living organisms to create biominerals such as shells, bones, diatoms, and teeth. This survey aims to critically discuss bio-process-inspired research in order to fill a gap in the literature in this field. The use of bio-inspired materials is heavily emphasized in bio-inspired technology. The incredible micro/macro architecture of biosystems contributes to their remarkable ability to endure and adapt to their surroundings. As a result, these functions and structures have served as a tremendous source of inspiration for the development of biomaterials with novel functionalities and structures, spawning the fascinating study area of bio-inspired materials over the last two decades. Even more impressive, unlike the high pressures or temperatures required for artificial synthetic processing, the structure-forming activities of biosystems can frequently be established at room temperature. As a result of scientists drawing inspiration from the processes by which biosystems generate their structures and applying those lessons to the manufacture of man-made materials, a new field of study known as bioprocess-inspired fabrication has emerged. Others have proposed that we can use what we learn about bioprocesses in nature to inspire the development of cutting-edge fabrication tools for entirely new forms of functionality.

#### Data Availability

No data was used to support this study.

#### Conflicts of Interests

The author(s) declare(s) that they have no conflicts of interest.

#### Funding

No funding was received to assist with the preparation of this manuscript.

#### Competing Interests

There are no competing interests.

#### References

- [1]. S. H. Chu, M. Khan, X. Deng, and C. Unluer, "Bio-inspired self-prestressing concrete (SPC) involving basalt fibers and expansive agent," *Cem. Concr. Res.*, vol. 155, no. 106735, p. 106735, 2022.
- [2]. C. Kim, Y. Lee, S. Kim, M. Kang, and S. Kim, "Diverse synaptic weight adjustment of bio-inspired ZrO<sub>x</sub>-based memristors for neuromorphic system," *Mater. Sci. Semicond. Process.*, vol. 157, no. 107314, p. 107314, 2023.
- [3]. S. Ganeshkumar, B. K. Singh, R. Suresh Kumar, and A. Haldorai, "Digital Twin Framework for Lathe Tool Condition Monitoring in Machining of Aluminium 5052," *Defence Science Journal*, vol. 73, no. 3, pp. 341–350, May 2023, doi: 10.14429/dsj.73.18650.
- [4]. C. T. Murphy, R. Müller, and S. Jung, "Sample digitization techniques for bio-inspired engineering," in *Biomimicry for Materials, Design and Habitats*, Elsevier, 2022, pp. 215–246.
- [5]. "Marine organisms and adaptations," Science Learning Hub. [Online]. Available: <https://www.sciencelearn.org.nz/resources/142-adaptations-of-marine-organisms>. [Accessed: 18-Feb-2023].
- [6]. Z. Chen, X. Lan, and Q. Wang, "DNA origami directed large-scale fabrication of nanostructures resembling room temperature single-electron transistors," *Small*, vol. 9, no. 21, pp. 3567–3571, 2013.
- [7]. M. M Khalaf, H. M Abd El-Lateef, V.-D. Dao, and I. M. A. Mohamed, "Electrocatalysis of methanol oxidation in alkaline electrolytes over novel amorphous Fe/Ni biphosphate material prepared by different techniques," *Nanomaterials (Basel)*, vol. 12, no. 19, p. 3429, 2022.
- [8]. H.-X. Zhang et al., "Fabrication of high-performance PP/graphene nanocomposites via Friedel–Crafts," *J. Inorg. Organomet. Polym. Mater.*, 2023.
- [9]. S. Karamikamkar, S. Rezaie, H. E. Naguib, and C. B. Park, "Bio-inspired polyethylene-based composite reinforced by thermoplastic polyurethane (TPU) fiber for aerogel production," 2019.
- [10]. S.-Y. Yang and M.-J. Lee, "Poly (methyl methacrylate)-containing silver-phosphate glass exhibits potent antimicrobial activity without deteriorating the mechanical and biological properties of dental prostheses," *Polymers (Basel)*, vol. 15, no. 2, p. 297, 2023.
- [11]. G. á Norði, R. N. Glud, K. Simonsen, and E. Gaard, "Deposition and benthic mineralization of organic carbon: A seasonal study from Faroe Islands," *J. Mar. Syst.*, vol. 177, pp. 53–61, 2018.
- [12]. Y. Kimura, H. Katsuno, and T. Yamazaki, "Possible embryos and precursors of crystalline nuclei of calcium carbonate observed by liquid-cell transmission electron microscopy," *Faraday Discuss.*, vol. 235, no. 0, pp. 81–94, 2022.
- [13]. V. Y. Shafirovich, N. K. Khannanov, and A. E. Shilov, "Inorganic models of photosystem II of plant photosynthesis. Catalytic and photocatalytic oxidation of water with participation of manganese compounds," *J. Inorg. Biochem.*, vol. 15, no. 2, pp. 113–129, 1981.

- [14]. G. Natarajan, T. P. Rajan, and S. Das, "Application of sustainable textile finishing using natural biomolecules," *J. Nat. Fibers*, vol. 19, no. 11, pp. 4350–4367, 2022.
- [15]. P. Martínez-Rodríguez, I. Sánchez-Castro, J. J. Ojeda, M. M. Abad, M. Descostes, and M. L. Merroun, "Effect of different phosphate sources on uranium biomineralization by the *Microbacterium* sp. Be9 strain: A multidisciplinary approach study," *Front. Microbiol.*, vol. 13, p. 1092184, 2022.
- [16]. N. Cai and P. Larese-Casanova, "Facile synthesis and reuse of magnetic black carbon magnetite (BC-Mag) for fast carbamazepine removal from water," *Nanomaterials (Basel)*, vol. 10, no. 2, p. 213, 2020.