Materials science meets life: Redefining materials for the future


[1]


[2]

KID: 20250109

People often think of materials as passive, such as steel (metals and alloys), glass (ceramics), and plastic (polymers), but "living materials" challenge that view. They are not passive at all; they are active, evolving, and sometimes even intelligent. From the probiotic bacteria in yogurt to the yeasts that make bread rise and beer bubble, humans have long used living organisms as functional materials. But what's new today is that we can design and engineer these organisms, embedding them in materials to create active systems that sense, respond, adapt, and sometimes even heal. Living materials are more than just a new chapter in materials science; they are the beginning of a new kind of material logic where biology is not just an application domain for materials, but an integral part of the material itself.

The field of living materials often encompasses several of the systems partially or wholly, such as the biohybrid living materials, bio-engineered living materials, engineered biohybrid materials, living materials with self-generating matrices, living biotherapeutic products, and living therapeutic materials. We can imagine a future where the medications we take, the bands we wear, the sensors that monitor us, and parts of our house and clothing are living things that can heal themselves, react to external stimuli, and even change or evolve over time.

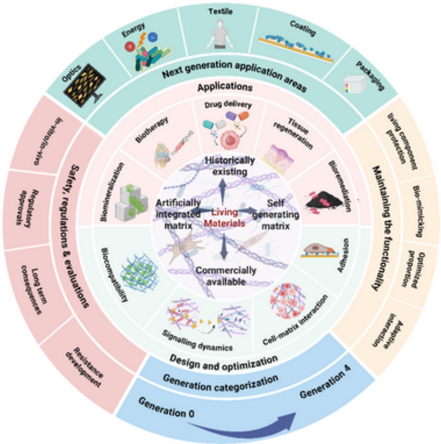

Figure 1: Evolution of living materials, along with design parameters, safety aspects, functionalities, and future advancements

The materials of the future aren't just durable or smart, but they are alive, and what makes them living is the incorporation of microbial cells or even mammalian cells into a structure or scaffold. These cells aren't just passengers, but they play a central role, allowing the material to respond to environmental cues, produce chemicals on demand, or even regenerate itself. With modern tools in synthetic biology and materials science, researchers are creating far more advanced and programmable systems. However, the emphasis is always on the holistic view of what it takes to build these systems, where the biocompatibility of the matrix material, cell-matrix interactions, adhesion, and proliferation of the cells, and signaling dynamics of the entire system come into play. Whether embedding cells into polymers or growing cells with their self-generated matrices, the design must balance engineering precision with biological complexity.

The living materials can be categorized in the generation to trace how the field is evolving, much like the way we talk about generations of other technologies. Early "first-generation" materials are largely static, while newer generations (generation 2 and 3) are interactive, self-regulating, and the upcoming generation (generation 4) may even be capable of learning over time. The further developments of living materials on this line aren't just experimental curiosities, but they are already making inroads into several applied areas: (a) Bioengineered tissues and smart drug-delivery systems that release therapeutics in response to body signals, (b) Engineered microbes embedded in filters to clean up oil spills or heavy metals, (c) Bacteria/fungi/algae-infused concrete that repairs cracks over time, etc. One of the most intriguing aspects of their continuous development can be their application in such areas where living materials are only beginning to be imagined; such as, living lenses and biofilms that dynamically respond to light, biodegradable films that can self-repair or resist contamination, smart surfaces that respond to microbial threats or environmental stress, biohybrid systems for power generation or storage, and clothings that breathe, adapt, or even grow with us. These domains represent a major leap from the current biomedical and environmental focus of most living material research, and a bold invitation to material scientists, biologists, designers, and investors to explore what's next.

Before living materials become part of everyday life, key challenges remain preserving viability, gaining public acceptance, and understanding long-term impacts on the individual and society. This demands advanced testing models and robust regulatory frameworks, strongly overlapped with materials characterisations. As we increasingly blur the line between user and material, we must ask: are we ready to accept smart, responsive, living materials in our lives? And if so, what are the limits of that acceptance? While in-situ methods, real-time monitoring, and correlative studies are seeing new heights, it becomes indispensable to pursue characterisation of the "living" aspects of these materials. Engaging diverse stakeholders and real-world case studies is essential to guide responsible integration and foster informed, interdisciplinary dialogue.

[1] Mr Aszad Alam
Research Scholar,
IITH-SUT Joint Doctoral Program,
Department of MSME.
[2] Dr Mudrika Khandelwal
Associate Professor
Department of Materials Science
Metallurgical Engineering
Cellulose and Composites Group