Bio-Augmented Materiality, Towards the Next Biomimicry

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ABSTRACT

The paper joins the debate on the emerging material revolution that extends computational and biological principles to matter itself, becoming intrinsically sensitive, active, programmable. It aims to explain how the informed relations between digital, physical and biological worlds are today changing the design practice, as well as the sustainability paradigm. The new concept of "Bio-Augmented Materiality" is presented, which refers to future products no longer made of parts but as "material systems" in which material-product-performance are designed as a single entity through information, growth and adaptation to the context. Finally, this conceptual mutation paves the way to the next biomimicry in which multidisciplinary research strategies and the ability to code and decode life principles are helpful for sustainable scenarios, not simply aimed to reduce the human impact on the ecosystem, rather enhance nature through original forms of cooperation and integration between human, biology and artifice.

Keywords: Bio-digital Industry, Material Systems, Intelligence of Nature, human-nature-artifice cooperation, physical-digital-biological integration

INTRODUCTION

For a couple of years, we have joined the third decade of the "Century of Biotechnology", so-called by Walter Isaacson in Time magazine in 1999. Venter and Cohen – two of the world's most famous geneticists – states that, while the 20th century is that of physics and we have transformed the silicon into computational power; the 21st century will be that of biology by referring to the possibility of science to learn about nature till its deepest fibres thanks to genome mapping (Venter and Cohen 2004). Arthur Olson, meanwhile, calls our current "bioatomic" age, where living things can be understood in a continuum from the atom to the organism: we are not simply able to break up the living in its base units, but we can see also continuities across scales (nano, micro, meso, macro) (Kinney 2017).

Moreover, it is not just about understanding nature but being able to manipulate it as a consequence. The same term Biotechnology – from Ancient Greek *βίος* (life); *τέχνη* (expertise) and *λόγος* (investigation) – denotes "any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products or processes for specific use" helpful for satisfying society's needs (ONU 2008). Right in 2020, the Nobel Award in chemistry was awarded to Emmanuelle Charpentier and Jennifer Doudna, developers of CRISPR-Cas9. This economic and flexible genomic editing method, allows us to create new biological entities or modify the existing ones by cutting DNA pieces and replacing them with what we want. Takes such a vital momentum the Synthetic Biology, expansion and evolution of biotechnologies, with which nature becomes programmable and reproducible. It enshrines the final changeover of biology from a prevalently descriptive science to a quantitative or engineering discipline, acquiring an unprecedented transformative power and promising tangible applications in various fields (De Lorenzo 2014).

So, in other words, it will be the combination of computational power – given by informatics and digital technologies – with a biological one – provided by biotechnologies, increasingly diffused, available and economical – to upset the previous patterns and revolutionize the next future in healthcare, industry and economy.

Therefore, new scenarios and opportunities for innovation open up to design, given both by innovations and new experimental domain of convergence with contemporary biosciences. In fact, on the one hand, a new form of "bio-digital industry" is emerging in which, thanks to increasingly sophisticated, digitized, nano and biosynthetic technologies, it becomes possible to analyze and reproduce the generative, chemical, physical and molecular processes underlying natural mechanisms (Estèvez and Navarro 2017). On the other, the gradual transition of biosciences to engineering disciplines leads to tools (hardware and software), interest and working ways that bring the scientific field closer to the design one as never before. The results are the increasing possibilities to materialize new hybrid concretizations, placed in the space between the synthetic and biological dimensions and that – exploiting the chance to confer objects, buildings and cities the characteristics and functionalities of the living – aim to design a more sustainable future from an environmental and ecological, but also ethical, social and cultural points of view.

NEW DESIGN APPROACHES

At the same time, we can say to live in the biological era because organic considerations increasingly inform all the processes, and the culture is becoming "wet", driven by a new awareness for biology and the ecosystem. As in a reverse process, sophisticated technological innovations bring us back to nature and its complexity: the mechanisms of the living – made of systemic transformations, mutualisms and collaborative synergies – cease to be simple theoretical models but appear as the laws of operation applied transversely to almost all the human activity's sectors. Relevant in these terms are the fading borders between the physical, digital and biological domains, which are integrating phenomena and technologies in systemic changes, so much to talk about a Fourth Industrial Revolution (Schwab 2016). These new conditions change the design approach, in which both the methodologies and the objectives become more complex and holistic.

From a methodological point of view, Neri Oxman offered a clear frame in her "Krebs Cycle of Creativity", a diagram representing the ideal interdisciplinary design practice (Antonelli 2020). She shows how the interactions between knowledge domains and their base units – physical (atom), digital (bit), biological (gene), metaphysical – are changing the relationships between disciplines, which constantly interact instead of occasionally overlapping. So, as in a metabolic cycle, design and other modalities of human creativity (science, engineering, art) feed each other and definitely change.

Instead, as regard objectives, the shift in values in contemporary society is re-centering the design approaches from being human-centric to becoming more-than-human. This does not mean that design no longer aims to improve human well-being and quality of life. Still, we realized that our condition is strictly interrelated to our surroundings and if we want to evolve toward a better future, we'll have to shift our attention from ourselves to the whole system we belong to. This thesis, argued by various eco-philosophers as Tim Morton and Arne Naess; post-humanists as Donna Haraway; other scientists and sociologists as Bruno Latour, James Lovelock and Fritjof Capra, have a strong influence also on the concept of environmental sustainability. It is no longer seen as reducing the human impact on the ecosystem or conserving resources but as developing new forms of human cooperation and integration with nature. In this regard, designers are now seeing in these synergistic relationships new forms of innovation and combining instead of dividing the growth and the built, the natural and the artificial, the organism and its environment, try novel ways to sustain, nourish and augment our Planet (Antonelli 2020).

NEW DESIGNING AND IMAGINING WAYS

In addition to new opportunities and approaches, technological and cultural changes also lead to new ways of designing and imagining products. In particular, the interactions and integrations between the physical, digital and biological spheres have led to a material revolution, which overcomes the boundaries between material-product-performance and extends computational and biological principles to matter itself.

Physical + Digital

First of all, the connection between digital and physical (material) spheres results in aesthetically and functionally augmented “materialities”, in which living and intelligent qualities are given by the intrinsic properties of the matter itself (Tibbits 2017). In fact, besides objects equipped with artificial intelligence, materials themselves may be informed and rewritten by computational facilities (e.g. cognitive computing, next-generation computer visualization) and digital procedures (e.g. digital fabrication techniques, digital material representations, algorithmic form-generation methods), able to work at multiple scales (e.g. 3D microfabrication). The results are hybrid, mono-material but heterogeneous systems able to react, adapt and elaborate data as natural ones.

In the last years, a lot of definitions for functional materials have been elaborated, from the Smart Materials able to sense and respond to external stimuli through reversible changes (Ritter 2006), to the Augmented Materials, able to adapt to the environment through a constant interaction thanks to a network of miniaturized sensors and actuators perfectly integrated into the matter (Razzaque 2013). However, new materials are different, and they are not given by the stratification of computational and support layers, but starting from the properties that the material has at a molecular level, it is structured, informed and formed in a way that it becomes intrinsically performative, sensitive, reactive and programmable. And suppose we add the current possibilities to manipulate every kind of material and multi-material systems in every shape and dimension we want, opportunities multiply, and the boundaries between the final product, its materiality and behaviour definitely fade.

This is an aspect that brings nature and artifice close together as never before. Natural systems start from a relatively small palette of molecular components and construct an extensive array of functional materials, which “intelligence” not simply derives from the ability to sense and respond to stimuli but to behave efficiently in a specific context or situation (Schrödinger 2012). Examples can be the products designed through the parametric approach and manufactured with additive manufacturing techniques. As in nature, a process guided by the code ("genetic code") models the evolutionary morphogenesis logics of products as a function of information flows, parameters, relationships and algorithms, while additive "growth" processes enable their realization (Langella and Santulli 2017). In Kinematics Project (2013), the Nervous System design studio pairs a constructional logic of hinged panels with a simulation strategy of folding and compression to produce customized garments that can be fabricated efficiently by 3D printing. These garments are generated from body measurements or scans, simulated to understand their movement and find efficient folded forms for fabrication and finally, 3D printed as a single piece that requires no assembly and less printing space. Another example, more complex that acts in both dimensions and at more scales, is the Aguahoja project by Neri

Oxman and The Mediated Matter Group at MIT (2018). It is a Water-Based Digital Fabrication platform that converts abundant biopolymers (cellulose, chitosan, pectin) into high-performance, sustainable materials which become printable once mixed with water. On a physical level, they analyzed multi-scale mechanical properties and different degradation rates of biopolymers, also depending on the water quantity. On a digital level, they experimented with a collection of hardware, software, and wetware tools and technologies to alter and control the properties of the substances with computational patterns and structures, like transparency, strength and decomposition modality. The final result was a pavilion, entirely 3D printed and biodegradable, from water to water as in nature.

From these examples, we can clearly deduce how the design practice and the product imagination is changing. In particular, the designers begin to interface with a new language, that of material systems. These are not aesthetically pleasing products, conceived and then designed starting from the physical and intuitive exploration of materials or the assembly of parts with distinct functions. Instead, they result from a new creative process, given by a dialogue between the designer and a system capable of autonomous decisions and functional adaptation to certain conditions. A permanent confrontation of information and materialization takes place, where digital programming influences the material, and the specific parameters of the material influence the digital models. Designers can thus rely on a new form of digital mediation between "real" matter and "virtual" information, leading to new formal and functional impulses and contexts (Johns 2014).

Physical + Digital + Biological

Moreover, developments in scientific disciplines as molecular biology, genetics or synthetic biology extend the properties of the digital world to nature itself, which becomes understandable to the last detail, programmable and manipulable. This opens the future possibility to use biological matter and organisms as interactive interfaces (bio-sensors and bio-actuators) instead of synthetic ones. At the same time, biological and biomechanical processes through which nature functions, can be transferred to products from the material itself (like growth, repair, mutation, replication, biodegradability) and can be inspirational for intelligent behaviors. The biological sphere comes into contact with the previous ones of digital and physical, bringing the material revolution to take a step forward and consequently the practice of design to explore further ways of innovation. In this case, it is not the digital that gives the living qualities, but it is the matter itself that brings them into the material system, with consequent advantages from the point of view of environmental sustainability, but also with new aspects to understand and manage. In fact, living organisms' behaviour is complex and brings in the system a new variable: a fourth time dimension (4D). Becoming alive, this kind of material system grows, evolves, varies, adapting to changing conditions (biotic and abiotic, inside and outside) and extending in time all the intelligent behaviors we have listed before.

On one side, this can be relevant to design more complex and long-lasting interactive materialities, exchanging information and feedback loops with other entities and the environment. Examples are self-healing materials such as Bioconcrete, developed by scientist Jank Hinkers and his team at TU Delft University (2011). They overcome the traditional concrete's tendency to crack by using alkaliphilic bacteria, able to survive in the high pH level of concrete and produce calcite. So, the material is able to conceal cracks for 50-100 years, with enormous environmental and safety advantages.

On the other side, a vital component of unpredictability comes out and – besides the rise of ethical issues to which we have to answer – the programmability of these new entities will depend on our capability of establishing a synergistic relationship with them, given by an information exchange from us to the system and vice-versa. Again, dialogue between the designer and the system is necessary, this time with an entity not only autonomous and able to adapt to specific conditions, but also less predictable and acting in a slower period. Of course, digital facilities can help designers to prevent and control such complex processes with, for example, simulations or scaffold engineering.

In any case, the entry of the living in the creative and productive processes gives designers' imagination new scenarios and experimentation ways of synergistic collaborations between physical, digital and biological dimensions, nourishing a renewed more-than-human culture. If the "trinity's" mediations are well managed, foreshadow-owing ideas and projects will rise, prefiguring a really sustainable future in which man-nature-artifice cooperate and hybridize to augment the Ecosystem they belong to. For example, professor Marcos Cruz and his team at Bartlett School of Architecture (UK) have developed a bioprinting technique for large-scale, custom-printed immobilization of microalgae (Malik et al. 2019). They combine physic exploration of alginate-based hydrogel under printing conditions, digital exploration of algae's growth pattern and printer's parameters, biological understanding of surviving abilities and absorbency capacity of algae. Many innovative and sustainable scenarios arise from this research: they imagine a future in which algae ramifications cover buildings' facades, insulate, guide rainwater, purify cities air and establish new aesthetics. Starting from similar experimentations, in the Alcyon project (2018) by the Materiability research group in collaboration with Audi, a central console for future cars is imagined, on which grow reindeer lichens used as bio-indicators for habitable air quality. Also by Materiability is the Responsive Manifolds project (2016), realized in collaboration with the Institute for Advanced Architecture of Catalonia. This project develops environmentally responsive walls starting from clay casting and non-harmful bacteria as responsive elements. Thanks to computational possibilities in the heavy-data digital world and materialization of complex geometries, specific surface qualities (texture, roughness, porosity) are designed for a material system able to host, control and manipulate bacterial growth. These highly interdisciplinary and future-oriented examples are a fraction of the scenarios opening to design in what we are going to define Bio-Augmented Materiality.

BIO-AUGMENTED MATERIALITY

Bio-Augmented Materiality is a futuristic concept and, maybe within "anticipation", the third and most sophisticated level of Futures Studies. After the more traditional levels of "forecasting" and "foresight", intended respectively as the statistical extrapolation of plausible futures and as a visualization of possible futures through scenarios, anticipation translates these models into strategic decisions and actions that act now for preferable futures (Poli 2017). The aim is to consider the deep analysis of contemporary phenomena affecting design discipline and future scenarios offered by the experimental projects developed by designers worldwide to stimulate strategic thinking that considers opportunities and responsibilities deriving from the wide and fast transformations.

"Bio-Augmented" means not only the future possibility to augment materials through biological interfaces, but that biological characteristics and functionalities enter in a product's generative processes and performative elements, changing their understanding and conception. Instead, "Materiality" indicates future scenarios in which we will be surrounded by material systems rather than products (or buildings) made of assembled parts, materials and mechanisms. So, we can state that:

"*The concept of Bio-Augmented Materiality refers to future products as hybrid material systems, customizable and context-specific, able to embody almost all the degrees of freedom of a natural phenomenon. Grown rather than assembled, computerized rather than adapted, biological rather than synthetic, they will be able to experience complex behaviour in time, changing and adapting. As in nature, material-product-performance will be designed as a single entity through information, growth and adaptation to context, changing the way these products are thought, designed and manufactured*".

In particular, we can summarise three main adjectives for Bio-Augmented Materiality, suitable for a more precise definition of such complex concept: hybrid, autopoietic, emergent. They also act as vectors of strategic actions that should characterise the design practice in the next future.

"Hybrid" identifies complex entities made up of interdependent components belonging to diversified, even contrasting nature. In fact, in bio-augmented materialities, natural and synthetic; physical and digital; analogue and computational; inert and living, feed and blend each other. Designers should leave the past dichotomies and increasingly rely on this interaction across dimensions. The new bio and digital technologies will facilitate this process, allowing the information exchange between human-nature-artifice, but also conceptually will be essential to find new collaborative ways in such a way one does not prevail on the others.

"Autopoietic" refers to systems that continually redefine, sustain and reproduce themselves from within (Maturana and Varela 1992). It refers to the autopoietic nature of the systems we came into contact with, as biological systems and artificial intelligence, with which we should establish a dialogue rather than attempt to control them. It also refers

to the same material system we will design that will support and modify itself when the (external and internal) conditions vary, which is good but needs a reflection.

"Emergent" is the characteristic behaviour of complex systems (biological, social, economical), not predictable based on the behaviour of simple individual entities (agents), but given by their synergist operation in a specific environment (Bridgman 1927). It is a comprehensive concept of previous ones and is strictly interrelated to the nowadays necessary consilience between disciplines and to more-than-human culture. If we want a more sustainable future, we should innovate not by the simple use of increasingly sophisticated technologies but by a collective behaviour, made by a lot of cooperation and integration forms between humans, nature and artifice.

CONCLUSION: THE NEXT BIOMIMICRY

The concept of Bio-Augmented Materiality is part of my doctoral research project, which focuses on new hybrid manufacturing techniques given by integrating biological processes in additive manufacturing (cf. bioprinting) and their possible futures. I present it in this paper to underline how a clear conceptual vision of the changes can constitute a space for discussion with enormous potential and importance. In fact, it facilitates designers to contextualize their projects in the future, which will lead to many technologies, but also many aspects of investigating (such as biosecurity).

According to the futurists, the accelerated changes of contemporaneity lead to the need to combine anticipation with strategic actions of the present to find ourselves ready in the future and not forced to reactive (expensive and inefficient) measures. From the design point of view, material experimentation as strategic, speculative or service design is a fundamental area in which to discuss the future. Although very advanced material solutions remain at an experimental and academic level, they are a way to put pen to paper scenarios that lie ahead. For this reason, we should exploit them to apply increasingly sophisticated and sustainable technologies, but also to reconcile different apects of our civilization (ethics, morals, economy, society and collective well-being). We should think, from now, on how our project would behave in the different contexts that could arise. This is the cultural role of design, and again, the biological example can help us.

In nature, there are many models of cooperation and synergy that can be good strategic examples for creating products and processes integrated with the environment and facing contemporary complexity, such as distributed agency, agential realism, emergent properties, swarm intelligence, etc. If up to now, biomimicry has used these conceptualizations to transfer the functionalities of the living to products (e.g. swarm robotics) or to create complex material systems (e.g. as the Agent-Based Models (ABM), usually used to design with living matter thanks to their capability to predict its behaviour), now extends the reference to the broader ecosystem and strategic considerations.

The paper so paves the way to the next biomimicry in which multidisciplinary research strategies and the ability to code and decode life principles are helpful for sustainable scenarios, not simply aimed to reduce the human impact on the ecosystem, rather enhance nature through original forms of cooperation and integration between human, biologic and artificial intelligence.

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