Engineering 2 (2016) 225–229

Contents lists available at ScienceDirect

Engineering

journal homepage: www.elsevier.com/locate/eng

Research
iCity & Big Data—Article

Industry 5.0—The Relevance and Implications of Bionics and Synthetic Biology

Peter Sachsenmeier [a,b]

[a] Hertford College, University of Oxford, Oxford OX1 3BW, UK
[b] International Innovation Center, Hankou University, Wuhan 430212, China

ARTICLE INFO

Article history:
Received 3 May 2016
Revised 27 May 2016
Accepted 6 June 2016
Available online 30 June 2016

Keywords:
Bionics
Synthetic biology
Bio-engineering
Biological sensors
Biofuels
Bio weapons
Virtual evolution
Protocells
Xeno cells
Economic significance
Industry 5.0
Germany
China

ABSTRACT

Bionics (the imitation or abstraction of the "inventions" of nature) and, to an even greater extent, synthetic biology, will be as relevant to engineering development and industry as the silicon chip was over the last 50 years. Chemical industries already use so-called "white biotechnology" for new processes, new raw materials, and more sustainable use of resources. Synthetic biology is also used for the development of second-generation biofuels and for harvesting the sun's energy with the help of tailor-made microorganisms or biometrically designed catalysts. The market potential for bionics in medicine, engineering processes, and DNA storage is huge. "Moonshot" projects are already aggressively focusing on diseases and new materials, and a US-led competition is currently underway with the aim of creating a thousand new molecules. This article describes a timeline that starts with current projects and then moves on to code engineering projects and their implications, artificial DNA, signaling molecules, and biological circuitry. Beyond these projects, one of the next frontiers in bionics is the design of synthetic metabolisms that include artificial food chains and foods, and the bioengineering of raw materials; all of which will lead to new insights into biological principles. Bioengineering will be an innovation motor just as digitalization is today. This article discusses pertinent examples of bioengineering, particularly the use of alternative carbon-based biofuels and the techniques and perils of cell modification. Big data, analytics, and massive storage are important factors in this next frontier. Although synthetic biology will be as pervasive and transformative in the next 50 years as digitization and the Internet are today, its applications and impacts are still in nascent stages. This article provides a general taxonomy in which the development of bioengineering is classified in five stages (DNA analysis, bio-circuits, minimal genomes, protocells, xenobiology) from the familiar to the unknown, with implications for safety and security, industrial development, and the development of bioengineering and biotechnology as an interdisciplinary field. Ethical issues and the importance of a public debate about the consequences of bionics and synthetic biology are discussed.

1. Another paradigm shift

Industry 4.0 and similar concepts, such as Make in China 2025 or Digital Industries, are all still incompletely defined and awaiting more development before they become an industrial reality. These concepts and their implementation have followed a well-known path: Initially limited in scope, they became hugely enlarged after some time, as the political, academic, consulting, and finally enterprise communities latched onto them and re-interpreted them to suit their own agendas. Practical considerations were addressed by dozens of essentially similar books that mixed the original limited concepts with digital disintermediation theory and practice, and included high use of the word "transformation" in word counts. However, these concepts have not yet

E-mail address: Peter.Sachsenmeier@hertford.oxon.org

http://dx.doi.org/10.1016/J.ENG.2016.02.015
2095-8099/

deeply impacted the business models and shop floors of successful German and Chinese companies. Courses and programs to help companies implement these changes are now widespread. Predictably, public debates have begun on what Industry 4.0 and related concepts mean for societal change and, particularly, for jobs. The public appear to have shifted their attitude from indifference to mistrust, as April 2016 findings by the German Allensbach Institute show.

Cloaked at first as fairly harmless debates (often among human resources (HR) departments and unions) under headings such as "Industry 4.0 and the Future of Work," an alarmist variant of these debates now suggests that, at least in richer societies, we should immediately take action and provide everybody with a basic government-supplied income to prepare for the day when robots do all the work and essentially take over. Concrete figures for such a condition-less basic income are already being discussed.

This article explores at first bionics (the imitation or abstraction of the "inventions" of nature) and then focuses on synthetic biology—which, this author insists, will be as relevant to engineering development and industry as the silicon chip was during the last 50 years [1,2]. While concepts such as smart cities and Industry 4.0 shine a spotlight on the process states enabled by digital/Web-based technologies, the changes brought about by synthetic biology are more fundamental and foreshadow a tectonic, disruptive, and even geostrategic shift: Industry 5.0.

What have we learned from previous industrial transformations? Will our experiences help us to handle Industry 5.0 better, or will the transitions from one industrial paradigm to the next continue to be destructive, brutal, and socially upsetting? This author's action research with several industries, including Germany's premier industry, the automotive and mobility industry, indicates that the implications of these fields are still inadequately understood and hardly anticipated in strategic plans.

2. Bionics

Bionics is a conceptual precursor to synthetic biology. In bionics, we try to imitate structures and processes created by evolution that we consider to be useful or from which we hope to learn. Bionics is a multidisciplinary field that involves scientists, engineers, architects, philosophers, and designers. Based on their various insights, we systematically investigate how nature has successfully solved a problem; then we attempt to copy or redesign the process or object under study in a manner that is divorced from nature. Bionics has branched off into many specialized fields, including construction bionics, sensor bionics, structural bionics, dynamic bionics, neurobionics, building bionics, process bionics, climate bionics, anthropobionics/robotics, and evolution bionics [3].

When classifying the astonishing inventions of nature that are imitated in bionics, a distinction is made between analogies in processes or products, and abstractions. Examples of analogies include airplanes, spiroid winglets, new car tire profiles that are modeled on cats' paws, and spiderlike robots with autonomous legs. Examples of abstractions include the lotus effect for self-cleaning surfaces, building elements that are modeled like trees or bones, riblet foils to reduce friction (in imitation of sharkskin), and Velcro (in imitation of burrs). Other examples of abstractions include swarm intelligence and ant algorithms, which create ant-like autonomous system behaviors (sometimes with ant-like robots, as showcased recently at the 2016 Hanover Fair).

3. Bioeconomy

The so-called bioeconomy is not the focus of this contribution. However, a brief mention should be made of the concept of bioeconomy, in order to delineate it from synthetic biology. For example, Germany has established a National Research Strategy BioEconomy 2030 with five priority fields of action: global food security, sustainable agricultural production, healthy and safe foods, the industrial application of renewable resources, and the development of biomass-based energy carriers. The general idea is to position Germany as a dynamic research and innovation center for bio-based products, energy, processes, and services. Research is supposed to meet responsibilities for global nutrition, as well as for the protection of the climate, resources, and the environment. Numerous pillars of German bioeconomy research, such as the Helmholtz Association of German Research Centers (HGF), which include plant, environmental, geological, climate, biotechnology, and engineering research; the Max Planck Society (MPS) in life sciences; more than a dozen institutes in the Gottfried Wilhelm Leibniz (WGL) science community; and institutes within the Fraunhofer Society (FhG) have all pooled their resources to establish a broad research environment. Over 30 000 scientists in Germany are currently pursuing biotechnical questions and issues across more than 200 research facilities, which include 63 universities, 26 technical colleges, 104 non-university research institutes, and nine government-affiliated sites.

4. White biotechnology

White biotechnology, also called industrial biotechnology, applies science to living organisms and their products. In contrast to synthetic biotechnologies, white biotechnology uses the existing biodiversity of nature in order to establish industrial processes, which are often linked to expectations of ecologically beneficial effects. White biotechnology has old roots; humans have used living microorganisms in the production of breads, cheeses, beers, and wines for centuries. Today, enzymes and microorganisms are contained in many everyday items, ranging from detergents to creams, and including high-value chemicals, drugs, and vitamins; they are also used in textiles, paper and leather production, and the production of antibiotics. White biotechnology has strong links with bionics; for example, in the use of enzymes, the recreation of spider silk with the help of bacteria, and the production of highly elastic rubbers from plants other than rubber trees. It encompasses many disciplines, including the bio-sciences, chemistry, physics, information science, and the engineering sciences. The research landscape of white biotechnology typically consists of institutes in collaborating clusters.

5. Synthetic biology

Synthetic biology dramatically shortens the time required for evolution to occur [2,4]. In German popular newspaper headlines, this engineering science has been variously labeled "Tailor-made Life," "Lego of Life," "Life from Nothing," and, ominously, "Remedy and Horror." The field attracts more and more attention; Oxford University Press announced a journal devoted to it in April 2016. In Germany, the Biotechnology 2020+ project (www.biotechnologie2020plus.de) brings together the major research institutions and networks in this field.

Synthetic biology is an attempt to reshape creation, and is part of a long tradition [3]. Wheat fields, for example, are not a natural phenomenon, but a human artefact. As scientists, we are continuously developing our understanding of the artificial. The nanoscale world of cellular building blocks is awe-inspiringly complex, and would be impossible to access without modern computers, data analytics, and vast storage capabilities. One important discipline of synthetic biology, DNA sequencing and