ISO/TC 266 WG 1 Terminology and Definitions

Introduction

The ISO/TC 266 initiative can help facilitate communication and collaboration within the community by providing a compelling, insightful, inclusive and rigorous description of the biomimetic landscape that reflects its diversity while at the same time building a consensus around key terminology, concepts and methods. This could create opportunities for biomimetic research and practice by helping community members understand how their work relates to the broader field, find collaborators and facilitate synergy. Such a document could also communicate the underlying concepts of biomimetics outside the biomimetics community.

Clear and generally accepted terminology is essential in any emerging field. Terms often have different meanings depending on specialization or geographical area. This can lead to differing perceptions about the concepts that the terms describe. Although diversity is essential in the early stages of a field, it can also lead to misunderstanding, isolation and missed opportunities.

The Canadian ISO/TC 266 mirror committee conducted a survey of how five terms related to nature-inspired design were perceived by a broad range of respondents. The resulting definitions try to answer the question “How do communities of biologists, engineers, and designers perceive and define the terms biomimetics, biomimicry, bionics, bio-inspired design, and cradle-to-cradle?” A definition for ‘systems’ was added since this term was frequently referenced.

The following definitions reflect the diversity of perspectives and usage while exploring the underlying commonalities. It is clear that all the terms are highly interdisciplinary in nature, yet are linked through the unifying discipline of biology. A full set of definitions using this approach would provide a foundation and framework for other ISO/TC 266 Working Groups.

Biomimetics

Biomimetics is a discipline that seeks to transfer qualities of biological materials, structures, functions, processes, patterns, and systems into the technical, social and business domains of human communities and systems that exist as elements of broader natural systems.

Biomimetics entails four broad categories of activity that can be considered as representing increasing “maturity”:

1. **copying/imitating/emulating/adapting:** covers an arguably superficial replication of evolved responses of biological systems in human domains.
2. **finding/studying/learning:** covers the scientific/analytic aspect of gaining knowledge about biological systems for the sake of transferring that knowledge into human domains of activity.
3. **designing/implementing/evaluating:** covers the development and assessment of interventions intended to address shortcomings in as-is situations for the sake of moving them to more preferred situations.
4. **being mentored by/inspiring:** covers the paradigmatic/cognitive changes that can occur in a community as a result of making biomimetics ubiquitous/embedded throughout a community and the quality of its environment.

It appears that biomimetics is not well differentiated from related terms, such as bionics or bio-inspired design" Some people regard biomimetics as an "umbrella" term.

The term is widely used in design, science, and engineering, in both academic and business/industrial sectors, but with a range of diverse meanings. There are also differences in connotation of the term by country. It is often used in the popular press in the sense that the application of biomimetics results in "better" solutions and situations. However, some advocates of the superiority of technological solutions have represented biomimetics as resisting technological progress.

Biomimicry

Biomimicry is defined as a conscious emulation of nature by Benyus (1997) and Baumeister et al. (2012). By appreciating the capacity of living beings to find optimal and sustainable ways of performing functions in a specific context, it provides a methodology to identify biological strategies that can help us solve human problems. Biomimicry argues that human creations should create conditions conducive to all forms of life.

The three key elements of biomimicry are:

- Ethos: captures the goal of "fitting in" with respect to all life on Earth.
- (Re)connect: reinforces the intertwined relationship of humans and nature.
- Emulate: translates the functional patterns of biological strategies into designs to produce sustainable innovation (technical, technological, economic, social, etc). Emulate is the most commonly used element, often independently of Ethos and (Re)connect.

Biomimicry recognizes three levels of emulation (form, process and systems) but proposes that all are needed to truly emulate natural systems and encourage sustainable design.

The perception of biomimicry varies widely depending on the goal and field of application. The broadness and depth of a technological, economic or social challenge determine the limits and scope of emulation. Biomimicry as a sustainability practice is more compelling for ecologically conscious designers and innovators within social and economic fields than for practitioners focused on technical problems.

Bionics

Bionics is the application or emulation of biological functions, processes, and systems in order to design robotics, medical devices, implant technologies and engineering solutions for the purpose of medicine-related advancements.

The term appears to have been coined by Jack Steele of the US Air Force Medical Division in 1960 (Bar-Cohen, 2006) based on the work of Norbert Wiener on cybernetics (Wiener, 1948) and the Biological Computer Laboratory (BCL) established by Heinz Von Foerster at the University of Illinois at Urbana-Champaign in 1958. The German biologist Werner Nachtigall independently founded the field in 1960s and, along with Carmelo di Bartolo, Jurgen Hennicke and Gabriel Songel, formulated a set of principles that would guide bionics practitioners in their collaborative process (Nachtigall, 1997).

As the decades advanced, bionics matured into a well-defined field in Europe (Wahl, 2006) with the establishment of the 'Society for Technical Biology and Bionics' and the 'Bionics Competency Network'. Italian design educator Carmelo di Bartolo extended the applicability of the principles from engineering to industrial design and "urged a restructuring of the industrial design process that would better take into account environmental concerns" (Birkeland, 2002).

In contrast, the original concept of bionics has largely disappeared from North America. As a result of the popular culture in 1970s such as The Six Million Dollar Man television series, the term 'bionics' has lost its appeal in North American scientific communities.

Bio-Inspired Design

Bio-inspired design is the conceptualization or interpretation of biological principles including function and systems in order to design products, processes, and systems for the purpose of addressing human problems.

The Center for Biologically Inspired Design (CBID) at the Georgia Institute of Technology is often credited as the source of the term as a result of their extensive research into inter-disciplinary education, analogical reasoning, methodologies and computation tools. According to CBID, bio-inspired design is guided by analogy-based design methodology (Nelson, Wilson, & Yen, 2009) and is largely concerned with a context from which to teach innovative design. In 2007 CBID related the term to biomimicry and described it as a field that uses "biological principles to inform engineering designs and applications" (Yen & Weissburg, 2007). The latest publications are also associating the term with biomimetics and are freely embracing the principles of sustainability: "BID provides a promising paradigm to help address the increasingly critical and urgent problem of environmental sustainability" (Goel, 2013).

The term is often related to either biomimetics or biomimicry with a tendency towards closer association with biomimetics. Bio-inspired design is used by some as a broader and more descriptive umbrella term for nature-inspired design that may or may not result in sustainable solutions.

Some people emphasize the 'inspired' aspect, believing that inspiration allows for broader applications, abstraction and more distant analogies, rather than direct 'imitation' of a biological model. Others think 'inspiration' may result in a solution driven by a vague methodology, rather than an in-depth understanding of the natural phenomenon being studied.

Cradle to Cradle

The Cradle-to-Cradle concept was first described in a 1976 report by Walter Stahel and Genevieve Reday. It was further developed by William McDonough and Dr. Michael Braungart as the Cradle to Cradle™ sustainable product design strategy. Rather than focusing in efficiency, it strives for "eco-effectiveness" through industrial processes that emulate natural cycles where ‘waste’ becomes ‘food’ (de Pauw, Kandachar, Karana, Peck, & Wever, 2010). Industrial Ecology and Zero Emissions Research and Initiatives (ZERI) are other examples of the ‘circular economy’ concept.

Key objectives are:

- Employing ‘healthy’ materials (elimination of toxic components, sustainable/renewable sourcing)
- Enabling safe reuse (separate biological/technological nutrient cycles, avoiding down-cycling)
- Using renewable, clean energy
- Protecting/regenerating water reserves
- Improving social/environmental capital

These objectives are the core of the Cradle to Cradle Certified™ Product Standard. Originally proprietary, the standard has since 2010 been administered by the non-profit Cradle to Cradle Products Innovation Institute.

The goal of Cradle to Cradle™ is not merely to reduce or even eliminate harmful substances but to have a beneficial and regenerative impact on the environment. Although Cradle to Cradle™ is inspired by nature and shares many of the goals of other nature-inspired approaches, a specific product that meets the Cradle to Cradle™ criteria may not necessarily be biomimetic.

The Cradle to Cradle™ approach has been a key element of several innovative buildings such as Ford Motor‘s River Rouge plant. Particularly with the launch of the certification program, it is gaining traction amongst a wide range of product designers, engineers and corporate strategists as a way to increase innovation, economic development and sustainability.

Systems

A system is a collection of interacting components that has an identifiable/definable function and is crisply distinct from its environment. Systems interact by exchanging matter, energy and information across their boundaries. An interface is where the boundaries of two systems adjoin. Systems need not be in physical contact to have interfaces: the Earth and its Moon form a gravitational system (Karnopp, Margolis, & Rosenberg, 1990), (Meadows, 2008).

Systems interact by exchanging matter, energy and information across interfaces or adjoining system boundaries. Whether a particular flow is modelled as matter, energy or information depends on what is known about the system and the purpose of developing the system model. Consider a calculus textbook given to a student by an instructor (a flow between two systems). The book may be modelled as a mass (can act as a door-stop), as energy (it can be burned to generate heat) or as information (if the student needs to learn calculus).

A system **component** may itself be a sub-system. This gives rise to hierarchies of nested subsystems and super-systems. Biological systems are often restricted to working at limited temporal and spatial scales. The hierarchy of biological systems from molecules to the biosphere supports a wide range of scales and increasing organizational complexity. The importance of scale in biology suggests that biomimetic knowledge transfer needs to respect scale as well as context.

Whether a component is taken to be a system or an “atomic” unit depends on the purpose of the system model. System components may be thought of as atomic “black boxes” either because their internal operation is irrelevant to the goals of the system model or because the nature of the component’s internals has yet to be determined.

The **boundary** of a system is the region where a property significant to the intent of the system model changes value. Examples include the boundary between skin and atmosphere, between two mated objects one of which moves with respect to the other, or between pressure waves in the air and the oscillatory motion of the human eardrum.

The **environment** is the super-system in which the system being studied or designed exists. The degree of interaction between the environment and the system in question depends on whether the system is open or closed.

Systems have the following attributes:

- **Structure**: a set of properties taken as invariant for the purposes of the systems analysis. These properties could include dimension, mass, material properties, thermal/electrical coefficients, modularity and color. Biological materials are often more structurally complex than technological materials, leading to properties such as toughness combined with hardness that are hard to duplicate in man-made materials.
- **Behaviour**: the responses (outputs) of a system to specific stimuli (inputs). Put a load on a table, and the table resists the load but deforms in response. Put a flame to the table and it ignites or melts. Engineered systems are often design to working within close tolerances while biological systems are typically more tolerant to input variability which can lead to greater adaptability and fault tolerance.
- **Function**: the role played by the behaviour of a system in an environment. A table can support loads in a classroom or provide a source of energy to keep lost campers warm. Biological systems are often multi-functional both across contexts and within the same context.
- **Purpose**: One or more functions that were intended by the object’s designer. The inherent complexity of natural systems makes attributing ‘purpose’ risky and research tends to focus on functional characteristics.

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