Biomimetics meets Sustainability

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Summary

Sustainable development is a challenge that needs to be tackled by social consensus. Learning from nature is linked to the hope of learning from biological solutions that have extraordinary qualities. One focus of the publication is to refine the discussion about technology-derived and biology-derived developments by taking descriptive, normative and emotional aspects into consideration. Descriptive aspects are presented on the basis of a straightforward classification tool (decision tree) to clearly describe, distinguish and identify biology-derived and technology-derived developments.

A further focus of the article is the presentation of the concept of bio-inspired sustainability and the presentation of an evaluation tree for Bio-inspired Sustainability Assessment (BiSA).

Zusammenfassung

Nachhaltige Entwicklung ist eine Herausforderung, die nur im gesellschaftlichen Konsens gelöst werden kann. Das Lernen von der Natur ist mit der Hoffnung verbunden, von biologischen Lösungen zu lernen, die über besondere Qualitäten verfügen. Ein Schwerpunkt der Publikation ist es, die Diskussion über technische Entwicklungen mit und ohne biologischem Vorbild unter Berücksichtigung deskriptiver, normativer und emotionaler Aspekte zu verfeinern. Deskriptive Aspekte werden auf der Grundlage eines einfachen Entscheidungsbaums dargestellt, um technik- oder biologie-basierte Entwicklungen klar zu beschreiben, zu unterscheiden und zu identifizieren.

Ein weiterer Schwerpunkt des Artikels ist die Präsentation des Konzepts von bio-inspirierter Nachhaltigkeit und die Vorstellung eines Bewertungsbaums für bio-inspirierte Nachhaltigkeitsbewertung BiSA (Bio-inspired Sustainability Assessment).

Introduction

Biomimetics and sustainable development are paradigms, which formulate a realistic ideal picture and form the framework for strategies, goals and operative action. Biomimetics is defined as »Learning from living nature for technology«. One common definition for sustainability is »Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs« [1]. When biomimetics and sustainability meet, the following questions arise:

1. What is the difference between developments with and without a biological model?
2. Do biomimetic solutions have a specific potential to contribute to sustainability?
3. Can we learn from nature for sustainable development?
4. Can we develop a bio-inspired sustainability assessment from this?

Classification of Biology-derived and Technology-derived Developments

Over the past years numerous and diverse terms showed up, whereby all describe the whatsoever inspiratory flow from nature to technical solutions such as bio-inspiration, biomimetics, bionics, biomimicry, biomimetic promise, nature-based solutions and many more. In the framework of supervised learning, a dataset of 70 biology-derived and technology-derived examples was compiled, which are characterized by 9 attributes and their respective values (Table 1).

According to the 9 attributes and two values each, a total of 29 = 512 different combinations are theoretically possible.

Tab. 1: Attributes and their values to describe biologically and technologically derived developments [2].

Attribute	**Respective values**
model	none, biological
direct use of living organisms	no, yes
bio-inspiration	no, yes
application of biomimetic algorithm	no, yes
transfer of morphology	no, yes
transfer of functional principle	no, yes
natural appearance	no, yes
same function*	no, yes
status	product, algorithm

**Function in a technical context being understood in the sense of a specific process, action or task [3] and in a biological context being understood in the sense of traits evolved that contribute to fitness [4].*

Each example of the dataset is assigned to one unique class of the overall 17 different and unambiguous classes. Four classes belong to the technology-derived developments and 13 classes belong to the biology-derived developments (Table 2).

On the basis of the aforementioned dataset a straightforward classification tool in the form of a decision tree was generated using the Iterative Dichotomiser 3 (ID3) algorithms [2].

Interestingly, in this context sustainability is not a necessary attribute or value and thus not a descriptive, but rather a normative aspect of biologically and technologically derived developments. This leads directly to the next question about the specific qualities of bio-derived developments.

Tab. 2: Classes of technology-derived and biology-derived developments and one representative example of each (adapted from [2]).

#	Class	Example	Ref.
	Technology-derived developments		
1	technical product	vacuum cleaner	[5]
2	technical product developed in parallel to biology	suction cup	[6]
3	technical product with natural appearance	Beijing National Stadium (“Bird’s Nest”)	[7]
4	algorithm	ID 3 algorithm	[8]
	Biology-derived developments		
5	biotechnological product	synthetic insulin	[9]
6	bio-inspired product	reinforced concrete	[6]
7	biomimetic algorithm	evolutionary algorithms	[10]
8	biomimetically optimised product	orthopedic screw (CAO-optimised)	[11]
9	biomorphic product	PH Artichoke lamp	[12]
10	functional biomimetic product	Velcro®	[13]
11	structural biomimetic product	Flectofin®	[14]
12	functional biomimetic and biomorphic product	bone-like ceiling (Freiburg)	[15]
13	structural biomimetic and biomorphic product	piezo-actuators in bee honeycomb form	[16]
14	functional biomimetic and biotechnological product	acceleration of biomimetic engineering by RNA sequencing	[17]
15	structural biomimetic and biotechnological product	3D micro patterned hydrogels to guide cellular organization	[18]
16	functional biomimetic, biomorphic and biotechnological product	tissue-engineered jellyfish with biomimetic propulsion	[19]
17	structural biomimetic, biomorphic and biotechnological product	synthetic spider silk	[20]

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The Biomimetic Promise

In 2007 von Gleich coined the term "biomimetic promise", which implies that, precisely because of their inspiratory flow from biological models to technical products, biomimetic solutions seem to have extraordinary qualities such as a specific potential to contribute to sustainable technology development [21]. However, nature itself would have to be sustainable for this to happen. In contrast to the paradigm of sustainability, nature is neither anthropocentric nor teleological and therefore bio-derived products are not per se sustainable. Antony et al. [15] presented an approach how to prove whether the biomimetic promise is kept or not. The operationalization of already completed developments consists of two steps: first, the verification that the development is biomimetic and second, the analysis of its contribution to sustainability.

Tab. 3: Descriptive, normative and emotional contents of biomimetics [2].

Content	**Biomimetic developments**
The descriptive content describes the reality.	- Definitions (VDI- and ISO-Guidelines) - Classifications (decision tree) - Biomimetic approaches (bottom-up process and top-down process)
The normative content describes the ought.	- Extraordinary quality - Contribution to sustainability - Biomimetic promise
The emotional content describes the emotional attitude.	- Feelings, moods, hopes - Symbolic character - Aesthetics

In summary, it can be said that sustainability is not an intrinsic characteristic of bio-derived developments, but that they ought to be sustainable, which is a typical normative aspect (Table 3). This answer leads to the next question: If nature itself is not sustainable, can we nevertheless learn from nature for sustainability and derive a bio-inspired sustainability assessment?

Bio-inspired Sustainability and Bio-inspired Sustainability Assessment

Even if nature is not sustainable in the sense of an anthropocentric and teleological paradigm, we can still learn from nature for sustainable development [2,22]. In this context bio-inspired sustainability is understood as »the continuous ability of society to provide specific functions through utilizing resources and ensuring their future availability«.

Tab. 4: The six-fold structure of BiSA includes the following intended functions and unintended burdens (= resource demands) [23]:

1. Social function:	the primary design function, calculated with restriction to the intended building physical function (e.g. load bearing, enveloping, supply and disposal)
2. Economic function:	the economic viability, calculated as economic profitability and competitiveness
3. Environmental function:	the positive impact on the environment, calculated based on environmental life cycle assessment (e.g. waste treatment systems)
4. Social burden:	the impact on human society, calculated based on life cycle assessment (e.g. human capabilities, human health)
5. Economic burden:	the life cycle related costs, calculated based on life cycle assessment (e.g. variable and fixed costs)
6. Environmental burden:	the impact to the environment, calculated based on environmental life cycle assessment (e.g. global biophysical system stability, global resource stock)

Based on this definition, the newly created Bio-inspired Sustainability Assessment (BiSA), which is tailored for the building sector, has been developed to quantitatively assess the self-imposed claim of sustainability through biologically derived developments. Inspired by the common denominator between biological and technical systems, namely the relationship of function fulfillment and the respective resource demand, a suitable basis for assessing bio-inspired sustainability had been found. BiSA focusses on the assessment of environmental, social and economic functions and the corresponding burdens within a consistent, quantitative framework based on life cycle thinking (Table 4).

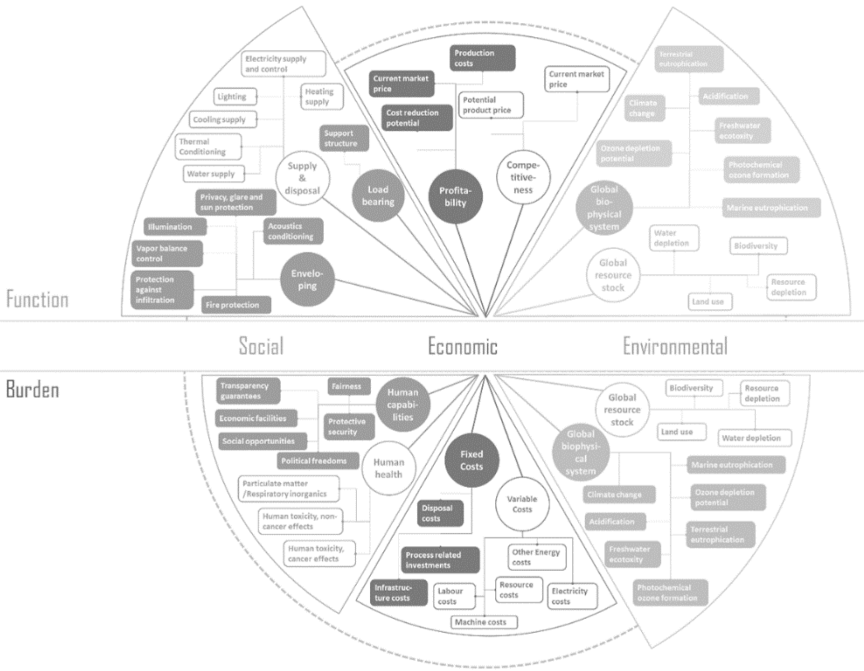

Fig. 1: Generalized schematic drawing of the evaluation tree of BiSA, presented as a pie chart. Resources (= burdens) and functions are divided into social, economic and environmental dimensions. The respective categories and indicators of each element are displayed within the corresponding cake pieces. Each element is of equal weight and its size indicates its evaluation compared to the reference system, which is represented by the dotted circle [23].

Figure 1 outlines the evaluation tree including the respective categories and indicators of each element, summarized as a pie chart. Within each pie chart element, the indicators and categories are aggregated to derive a single value. The intended function is shown on the upper half of the pie chart and resource consumption on the bottom half. Each of the six elements is represented in relation to a selected reference product represented by the dotted circle. In summary, it can be said that the comparable product is all the more sustainable if the three cake pieces of the function are larger than the grey circle and/or if the three cake pieces of the resource consumption are smaller [23].

Conclusion

In recent years, the systematic approach of knowledge transfer from biological idea generators to technical applications has become increasingly important, especially as biologically derived developments are often claimed to be sustainable. A classification to clearly describe, biology-derived and technology-derived developments (dataset, decision tree) showed that sustainability is not a self-evident by-catch of bio-derived developments. On the contrary, the contribution to sustainability must be actively and systematically aimed at in the development of a product, regardless of whether it has a biological model or not. Analogous to the situation in living nature, where a trade-off can be found between the fulfilment of a function and the resources invested for it, a bio-inspired sustainability was defined and thus the basis for the bio-inspired sustainability assessment was laid. However, the BiSA method has so far been limited to the construction sector. An extension to other fields as well as the inclusion of multifunctionality and function change, as found in living systems, would be desirable.

Acknowledgments

This work has been funded by the German Research Foundation (DFG) as part of the Transregional Collaborative Research Centre (SFB/Transregio) 141 'Biological Design and Integrative Structures'/project C01. The project was supported by the Cluster of Excellence Living, Adaptive and Energy-autonomous Materials Systems (*livMatS*).

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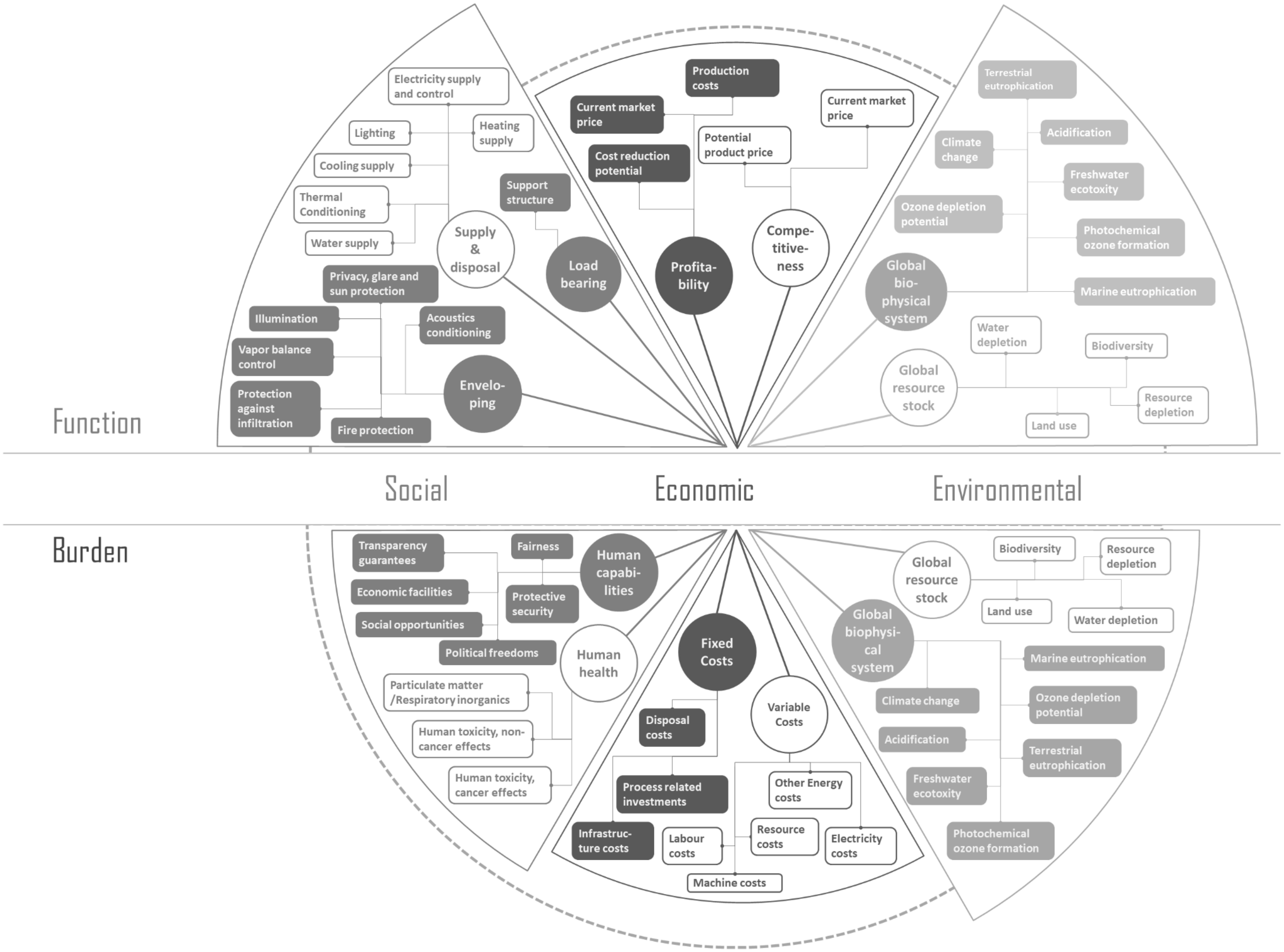
Function
Social
Economic
Environmental
Burden
Electricity supply and control
Lighting
Heating supply
Cooling supply
Thermal Conditioning
Water supply
Supply & disposal
Support structure
Load bearing
Privacy, glare and sun protection
Illumination
Acoustics conditioning
Vapor balance control
Protection against infiltration
Fire protection
Envelo-ping
Production costs
Current market price
Cost reduction potential
Profita-bility
Current market price
Potential product price
Compe-titive-ness
Terrestrial eutrophication
Acidification
Climate change
Freshwater ecotoxity
Ozone depletion potential
Photochemical ozone formation
Global bio-physical system
Marine eutrophication
Water depletion
Biodiversity
Global resource stock
Resource depletion
Land use
Transparency guarantees
Fairness
Human capabi-lities
Economic facilities
Protective security
Social opportunities
Political freedoms
Human health
Particulate matter /Respiratory inorganics
Human toxicity, non-cancer effects
Human toxicity, cancer effects
Fixed Costs
Disposal costs
Variable Costs
Process related investments
Other Energy costs
Infrastruc-ture costs
Labour costs
Resource costs
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Machine costs
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