Morphogenesis – "The Riddles of Form" in Twenty-First Century Science

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Over the past decades, the notions of organic form and morphology—a scientific field historically associated with the eighteenth century polymath Johann Wolfgang von Goethe (1749–1832)—have stealthy re-assumed a central role in various scientific disciplines. Although the study of organic form was apparently excluded from the main stage of evolutionary theory and biological sciences during the second half of the twentieth century, since morphology was considered as a descriptive and ancillary science unable to contribute to the neo-Darwinian synthesis of evolution[1], morphological concepts and approaches have now been re-brought onto the central stage of mainstream science.[2]

In fact, several interdisciplinary Clusters of Excellence[3] have been for instance established in Germany to investigate the enigma and power of

1. See Ghiselin 1980, 2006; Mayr 1980. For an alternative view see Hopwood 2003; Nyhart 1995; Love 2006; Tamborini 2020c, under contract; Levit, Hossfeld, and Olsson 2014.

2. On the philosophical question of using old issues to pose new questions see, for example, Gutmann and Tamborini 2020; Baedke 2019.

3. As part of the Excellence Initiative the German Universities Excellence Initiative supports pioneering research. Through a massive financial support, the Clusters of Excellence aim at reaching outstanding research and obtaining international recognition and visibility. As the German Research Foundation DFG reported on its website, "[c]lusters of excellence enable German university locations to establish internationally visible, competitive research and training facilities, thereby enhancing scientific networking and cooperation among the participating institutions." For morphological-oriented clusters see, for instance, the Clusters of Excellence "Integrative Computational Design and Construction for Architecture" led by Achim Menges at the University of Stuttgart and the Cluster of Excellence "Matters of Activity. Image Space Material" lead by Wolfgang Schäffner at Humboldt University in Berlin and "Living, Adaptive, and Energy-autonomous Materials Systems" led by Jürgen Rühe at the University of Freiburg.

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form transformations. These clusters recall and expand Goethe's and Romantic definition of form, this meant as a complex and ever-changing phenomenon. Within biological disciplines, new research programs have been put forward to explicitly investigate what has been disqualified in biology over the past decades: the very concept of organic form. For example, according to Austrian evolutionary biologist Gerhard Müller, "Evolutionary developmental biology (evo–devo) emerged as a distinct field of research in the early 1980s to address the profound neglect of development in the standard modern synthesis framework of evolutionary theory, a deficiency that had caused difficulties in explaining the origins of organismal form in mechanistic terms (Müller 2007, p. 943). Furthermore, synthetic biologists and nanoscientists are now producing and manipulating a multitude of forms to design and control their possible genesis (e.g., Gramelsberger 2020).

In addition to the renaissance of morphological studies in evolutionary biology, the notion of organic form has deeply influenced twentieth- and twenty-first century architectural and computational design. In the mid-1970s, German biologist Johann-Gerhard Helmcke (1908–1993), who collaborated with German architect Frei Otto (1925–2015) in establishing two Collaborative Research Centers[4] (*Sonderforschungsbereiche* – short SFB), wrote: "I wondered if the architects could recognize the beauty of biological objects and then finally build something more aesthetically, and if engineers could understand the many innumerable, biological forms of evolution of constructions in order to learn from them and to build better (and perhaps also more economically)" (Helmcke[5]).

Helmcke's hope was rooted in a deep history of interaction and entanglement between architecture and organic morphology (e.g., Steadman 2008). This collaboration found partial international recognition with the establishment of two Collaborative Research Centers in West Germany between early 1970 and late 1980. In 1970, the so-called SFB 64 on "*Weitgespannte Flächentragwerke*" [Wide Span Surface Structures] was established in Stuttgart. This developed into the SFB 230 on "*Natürliche Konstruktionen*" [natural constructions] starting from 1984. The peculiarity of these Collaborative Research Centers was that biologists, engineers, architects, artists worked together to investigate form's intrinsic dynamics (see Tamborini 2020a). The intertwinement between architecture and biology, or rather

4. In the German system, Collaborative Research Centers "are long-term university-based research institutions, established for up to 12 years, in which researchers work together within a multidisciplinary research programme" (DFG).

5. Nachlaß 135. Staatsbibliothek zu Berlin – Stiftung Preußischer Kultur-besitz.

between a technical and a biological study of form transformation and manufacturing, reached its heyday in the development of architectural and computational design during the 2010s.

Commenting on these recent developments in an article emblematically entitled *Digital Morphogenesis*, British architect and theorist Neil Leach noted that "architecture [...] is no longer so preoccupied with style and appearance. It is as though a new paradigm has emerged [...] the more contemporary architects operating within the new morphogenetic paradigm can be seen more as the controllers of processes, who facilitate the emergence of bottom-up form-finding processes that generate structural formations" (Leach 2009, p. 34).

Furthermore, alongside fostering the production of bio-inspired constructions, the biological notion of organic form is shaping the current advancement of computational design. Today, architects and designers are proposing a shift from a modernist notion of form analysis, which emphasized the design of well-adapted forms, towards computational research, which seeks to set the organizational rules responsible for form generation. In fact, by means of computational tools, architects design the code whose guides form development. Within this computational perspective, "form [becomes] a subsidiary component of environment, and environment ... a complex web of influences" (Menges and Ahlquist 2011, p. 10). This move, as architects Achim Menges and Sean Ahlquist noted, "represents an accumulation of multilayered concepts ranging from system theory and cybernetics, to morphogenesis and developmental biology" (Menges and Ahlquist 2011, p. 10; see also Greg Lynn's works, for instance, Lynn 1999).

What is the implication of this renewed interdisciplinary interest in form transformation and production? Is it a mere return to a romantic-holistic conception of nature, or rather does it foster a new standpoint on nature according to which nature is meant as the product of engineering design? What kind of knowledge and practical skills are associated with such bio-technical understanding of organic forms? How did digital technologies and different engineering approaches to biology impact and shape the classical morphological traditions? Succinctly, what is so enigmatic in the concept of organic form?

This special issue investigates in-depth all these questions by presenting a more nuanced picture of the twentieth and twenty-first century study of form. It analyzes to what extent morphological knowledge production is tied with and rooted in different technological settings and broader philosophical frameworks. In all the cases mentioned above, knowledge production and product design and manufacturing are deeply rooted in romantic-holistic morphological concepts. These concepts were re-formulated and expanded to emphasize the idea of a possible technical or engineering control of form changes.[6]

Famously, Goethe defined morphology as the science [*Wissenschaft*] able to "recognize living formations as such, to grasp their externally visible, tangible parts in relation to one another, to take these parts as indications of what lies within and thus to acquire a degree of mastery over the whole in intuition" (Goethe 1817 (2000), p. 56; translation in Steigerwald 2002, p. 314). The German polymath meant though this discipline in a very dynamic way. He, in fact, emphasized a strong linguistic and conceptual difference between two different German expressions for form: "The German has a word, *Gestalt*, for the complex existence of an actual being. He abstracts, with this expression, from the moving and assumes a congruous whole to be determined, completed, and fixed in its character … But … we find that independence, rest, or termination nowhere appear, but everything fluctuates rather in continuous motion. Our speech is therefore accustomed to use the word *Bildung* pertaining to both what has been brought forth and the process of bringing forth" (Goethe [1817] 2000, p. 55; translation in Zammito 2017, p. 483).

By so doing, Goethe rejected a static form definition. He emphasized, conversely, its dynamic and ever-changing status. As a result, the German poet and polymath conceived morphology as morphogenesis. That means as the study of the dynamics of form formation and change over time. As he put it, morphology was "the theory of form [*Gestalt*], formation [*Bildung*] and transformation [*Umbildung*] of organic bodies" (Goethe [1817] 2000, p. 124, translation in Steigerwald 2002, p. 295).

Following Goethe's ideas, at the end of the nineteenth century, morphology was considered by most biologists as "the first evolutionary science" (Bowler 1996, p. 17) because of its pivotal role in analyzing and understanding evolutionary changes thorough time (Rieppel 2016; Tamborini 2019). During the twentieth century, pushed by morphology's exclusion from the so-called modern synthesis of evolution several morphologists became increasingly less interested in bringing out historical and phylogenetic explanations. They lost their interest in drawing phylogenetic trees or series of forms, though still elevating Goethe as their patron saint[7]. In redefining and expanding their disciplinary space of knowledge, many morphologists started adopting new technologies and developed so-called engineering approaches to the study of evolution.

6. On the intersection between romantic conceptions of life and technology see also Esposito 2016; Peterson 2016; Harrington 1999; Tamborini 2020b.

7. As Olivier Rieppel noted, they appreciated Goethe's theory of morphology in its original version as ahistorical investigation of form's structures (Rieppel 2020).

The Scottish polymath D'Arcy Thompson (1860–1948) epitomized this engineering interest in the form study. He expanded the Goethean notion of morphology and morphogenesis to both natural and organic phenomenon: "The waves of the sea, the little ripples on the shore, the sweeping curve of the sandy bay between the headlands, the outline of the hills, the shape of the clouds, all these are so many riddles of form, so many problems of morphology" (Thompson [1917] 1942, p. 10). All these riddles of form could be technically grasped. They were generated as "a quasi-mechanical effect on Matter of the operation of chemico-physical forces" (Thompson [1917] 1942, p. 81). In fact, Thompson supported the idea that "Form [...] of any portion of matter, whether it be living or dead, and the changes of form which are apparent in its movements and in its growth, may in all cases alike be described as due to the action of force. In short, the form of an object is a 'diagram of forces'" (Thompson [1917] 1942, p. 16).

The transition from a purely biological, and historical, study of form towards a hybrid one, in which engineering and biological sciences worked together, culminated in the establishment of bionics and biomimetics as autonomous scientific disciplines. These were in turn considered as essential components of the broader research agenda pursued by architects and biologists—for instance, architect Frei Otto invited biologist Werner Nachtigall, founder of the field of bionics in Germany, to formally participate in his SFBs. Furthermore, biologist Helmcke set up with German engineering Heinrich Hertel, professor of Aeronautical Engineering at the Technical University of Berlin, a "marriage between engineering and biology" which led to the battle cry 'TUB' [short for: Technologie und Biologie], technology and biology (e.g., Hertel 1963; Tamborini 2020a).

By bringing together historians of science, philosophers of science, design theorists, and cultural historians, the papers collected in this special issue problematizes the encounter between the romantic tradition of form study, the engineering approach to evolution, and to biological approach to form design and manufacturing. The analysis of this intertwinement will help us reconsider classical philosophical notions, such as representation, model, mechanism, and organicism. Furthermore, it will shed light on the dynamics of knowledge production in nature inspired sciences, like biomimetics, synthetic biology, and computational architecture.

Alfred Nordmann opens the special issue with some general reflections on what biotechnology. He takes up categories from aesthetics to investigate to what extent synthetic biology is copying natural form. He argues that synthetic biologists do not copy the organic world, but rather they create its parody. In his essay, he develops this idea further presents "a vocabulary for the parodistic qualities of Synthetic Biology, genome editing, or other bioengineering practices."

In his paper, Ulrich Krohs aims to better understand the epistemology of biomimetics. He first reconstructs the biomimetic copying practice. After having proposed a four-step model to understand how biomimetic copying activity does work, he investigates the differences between biological robustness, system's ability to "maintain its functionality across a wide range of operational conditions", and robustness in technical and artefacts. This distinction enables him to examine the possibility of transferring robustness from a biological to a technical system. Working on the transferability process in synthetic biology, Krohs points out the differences between morphogenesis in technical and biological systems. He concludes by asserting that "transferability between biological and technological systems is by and large a one-way system". That means that there is a sort of mimetic asymmetry. The transfer "of the implementation of the function from the technical to the biological realm" nicely works, but the transmission of "the means to achieve robustness" miserably fails.

Carolin Höfler examines recent changes in the concept of organic forms in architecture. In particular, she focuses on the structural architecture of the 1960s and the computer-based architectural systems since the 1990s. She shows that from the mid-20th century onward, a renewal of architectural design practice was sought through the reformulation of classical morphological questions at the intersection of biological and cybernetic discourses.

George Toepfer argues that morphology can fulfill an important explanatory function and it constitutes the fundamental explanatory level of biology as a distinct science. He further argues that the forms of organisms and their parts provide the only specifically biological causal factors. After a classification of four types of morphology, he develops the thesis that organic "forms can be viewed as forces or causes. They are the only other forces of life beyond the forces of physics."

Marco Tamborini situates his contribution at the intersection between Krohs' and Toepfer's discussion of biomimetics and Höfler's analysis of models. He examines the features of twenty-first-century robots-inspired morphology. After having distinguished biomimetics, or nature-inspired engineering, from robotics-inspired morphology as two complementary disciplines, he investigates in-depth what role do robots play in the current study of form. This brings him to focus on the features of what he named "the recent material turn in morphology". This turn is marked by the hybrid co-existence of technologies, robotics, and living organisms in studying form's structures and changes.

Mathias Gutmann concludes the special issue with a broader methodological and philosophical reflections on the notion of form. He develops a conceptual framework for the notion of "form" useful to understand to what extent this is still central in current biology. If form is meant as a meta concept, argues Gutmann, we are able to better understand the practices, procedures, and argumentative framing that characterize twentieth- and twenty-first-century biology.

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