UTOPIA COMPUTER

The »New« in Architecture?

Nathalie Bredella, Chris Dähne,
Frederike Lausch (Eds.)

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The critical concern of the book "Utopia Computer" is the euphoria, expectation and hope inspired by the introduction of computers within architecture in the early digital age. With the advent of the personal computer and the launch of the Internet in the 1990s, utopian ideals found in architectural discourse from the 1960s were revisited and adjusted to the specific characteristics of digital media. Taking the 1990s discourse on computation as a starting point, the contributions of this book grapple with the utopian promises associated with topics such as participation, self-organization, and non-standard architecture. By placing these topics in a historical framework, the book offers perspectives for the future role computation might play within architecture and society.

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NATHALIE KERSCHEN

Towards a New Understanding of the Animal

Drawing from the phenomenological tradition in architecture, this paper critically engages with the Cartesian concept of the "animal-machine," embedded in contemporary bio-inspired approaches to computation. The translation of animals' morphological properties and behaviour into algorithms, or the use of living animals during the fabrication design process, created innovative design and "new materials." This paper will contextualize these developments alongside the history of architectural computation and cybernetics. Yet it will also challenge the assumptions underlying these new methods. Using phenomenology and recent advances in embodied cognition, I will present an alternate account of the animal, one that conceives of the animal as a living being within its Umwelt [milieu].

Introduction

Since the 2000s, thanks to the rapid development of computing hardware and software, architects have questioned Nature through the lens of computation.[1] Architect's design of complex geometries and their production of "new materials" (such as composite fibre materials) through scripting techniques and customized robotic fabrication[2] have enabled what Neri Oxman, architect and leader of the Mediated Matter Group at

1 I write Nature with a capital letter to challenge the reduction of its essence to mere "matter" in the Cartesian sense of the term.

2 Jan Knippers and Achim Menges, "Fasern neu gedacht – Auf dem Weg zu einer Konstruktionssprache," Detail, no. 12 (2015): 1241.

the Massachusetts Institute of Technology (MIT), calls the "reexamin[ation of] nature's well-kept secrets."[3] Characteristic of these "new ways of thinking about form and its generation"[4] are architects' combination of computation as a form-finding technique with data gathered through scientific observation. These bio-inspired approaches to computation integrate information on "natural systems," translating functional and mathematical principles from biomimetics, synthetic, theoretical, and/or evolutionary biology into form-finding algorithms. Some architects have even transferred their studies on animal behaviour into code or script. They have developed empirical in-house experiments with plants and animals to generate data used for their computational design processes. These recent developments, combined with a file-to-factory approach, have sparked renewed interest in the cybernetic and systems culture of the post-war era,[5] and have propelled the animal forward as a "driver" of design.

The diving bell spider and the ICD/ITKE Research Pavilion (2014–15)

The growing interest in the living organism is demonstrated by the fibrous composite pavilions built by students of the Institute for Computational Design and Construction (ICD) and the Institute of Building Structures and Structural Design (ITKE) at the University of Stuttgart from 2012 to 2015.[6] Of particular interest

3 Neri Oxman, "Per Formative: Toward a Post-Formal Paradigm in Architecture," Perspecta 43 (2010): 20.

4 Ibid., 26.

5 Several important historical studies on computation and architecture in the wake of the Second World War have been published recently. For instance, Orit Halpern, Beautiful Data: A History of Vision and Reason since 1945 (Durham: Duke University Press, 2014). Molly Wright Steenson, Architectural Intelligence: How Designers and Architects Created the Digital Landscape (Cambridge/MA: MIT Press, 2017). Theodora Vardouli, "Graphing Theory: New Mathematics, Design, and the Participatory Turn" (PhD diss., Massachusetts Institute of Technology, 2017).

6 The ICD is led by architect Achim Menges and the ITKE by engineer Jan Knippers. As indicated on their website, designing and constructing a "full scale research architectural prototype" constitutes an integral part of the two-year Master program ITECH. See "International M.Sc.Programme: ITECH | Brochure 2020–21," Institute for Computational Design and Construction, University of Stuttgart. Accessed August 1, 2020, https://www.icd.uni-stuttgart.de/public/ITECH/ITECH_Brochure.pdf.

Fig. 1: View of the ICD/ITKE Pavilion 2014–15 in front of the University of Stuttgart, Germany, 2015. Source: reproduced with permission from the ICD/ITKE, Dt. UrhR: ICD/ITKE University of Stuttgart

to my investigation is the last pavilion in this series (2014–15),[7] which was modelled on the behaviour of the diving bell or water spider (*Argyroneta aquatica*).[8] The ICD/ITKE 2014–15 pavilion (fig. 1) consisted of a load-bearing structure made of composite fibre materials and a transparent Ethylene tetrafluoroethylene (ETFE) membrane.[9] This quasi-pneumatic structure spanned

7 In total, three fibrous composite pavilions, built between 2012 and 2015, drew inspiration from biological "role models." While the 2012 pavilion builds on "the structural performance through changes in fibre arrangement, density and orientation" of a lobster's exterior skeleton, the 2013–14 pavilion was modelled according to biomimetic principles underlying the fibre organization in the beetle's elytron or wing case. See Knippers and Menges, "Fasern neu gedacht," 1241–1242. I will use the term "role model" in the sense meant by the ICD in this article. For more, see Menges et al., "Behavioral Design and Adaptive Robotic Fabrication of a Fiber Composite Compression Shell with Pneumatic Formwork." (Presented at the ACADIA 2015: Computational Ecologies, Cincinnati, Ohio, 2015), 298.

8 The *Argyroneta aquatica* spends most of its time underwater. To survive in fresh water, the animal builds a "diving bell" and fills it with dissolved oxygen. It uses the fine hair which covers its abdomen and rear legs to transport oxygen from the water's surface to its underwater habitat. The bubble remains open at the bottom and consists of silk fibres that the animal spins around aquatic plants. See Roger Seymour and Stefan Hetz, "The Diving Bell and the Spider: The Physical Gill of Argyroneta Aquatica," The Journal of Experimental Biology 214, no. 13 (2011): 2175.

9 Knippers and Menges, "Fasern neu gedacht," 1241–1242.

7.5 meters. To construct it, 45 kilometres of carbon fibres were covered with epoxy resin and placed onto a weather-resistant membrane.[10] According to the design team, each fibre was individually positioned by a robotic arm from within an enclosed and pre-pressured ETFE space. This air space served as a “formwork” (mould) until the membrane and the fibres merged into a self-supporting structure of qualitatively differentiated fibre composite filaments.[11]

The pavilion mimics the transparent skin of the spider’s underwater silk bubble, which reminds visitors of the animal’s natural habitat (fig. 2). However, the commonalities between the spider’s aquatic “dome” and the ICD/ITKE pavilion extend beyond formal and structural analogies, to encompass what Knippers and Menges call a “contemporary approach to architectural biomimetics.”[12] This method seeks to transfer “the [biological] principles underlying the creation of structural forms” to the digital design process.[13] Although the overall goal was “to create a wide range of performative geometries with minimal material investment,”[14] the ICD/ITKE’s design and construction process differed from previous pavilions. For the 2012 and 2013–14 pavilions, the designers focused on the morphological (that is, the shape and structural) characteristics of an animal’s bodily constitution to generate its form and determine its materiality.[15] However, this time the team also concentrated on the “set of behaviors that the spider employs, the order of the construction sequence, and the hierarchical arrangement of fibers which exhibit performative structural characteristics.”[16] In collaboration with biologists from the University of Tübingen,[17] the designers examined the “underlying behavioral patterns and design rules” of the spider’s natural

10 Ibid., 1242.

11 Menges et al., “Behavioral Design,” 298.

12 Jan Knippers and Achim Menges, “Fibrous Tectonics,” in Material Synthesis: Fusing the Physical and the Computational (London: John Wiley and Sons, 2015), 45.

13 Knippers and Menges, “Fasern neu gedacht,” 1241.

14 Menges et al., “Behavioral Design,” 298.

15 Knippers and Menges, “Fibrous Tectonics,” 45.

16 Menges et al., “Behavioral Design,” 299.

17 Knippers and Menges, “Fibrous Tectonics,” 45.

Fig. 2: Close-up view of the *Argyroneta aquatica* in its underwater bell, ICD/ITKE Pavilion 2014–15, Germany, 2015. Source: reproduced with permission from the ICD/ITKE, Dt. UrhR: ICD/ITKE University of Stuttgart

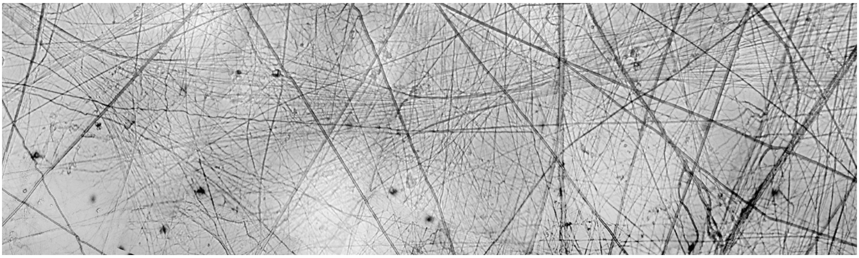

Fig. 3: Microscopic image of the water spider's silk fibre net, ICD/ITKE Pavilion 2014–15, Germany, 2015. Source: reproduced with permission from ICD/ITKE, Dt. UrhR: ICD/ITKE University of Stuttgart

silk-laying process to stabilize the bell structure of its underwater habitat.[18] For example, they differentiated between the performance of compact fibre arrangements that retain oxygen, fibres that branch, and fibres that solidify the overall structure by filling the surfaces in-between the branches[19] (fig. 3). Once the necessary data was extracted from the biomimetic analysis, they "abstracted" this information into a set of form-finding algorithms to generate the pavilion's overall geometry.[20] Other material, structural, and technical constraints affected the final shape of the pavilion. As the designers emphasize in one of their publications, the maximum reach of the six-axis robot, the geometrical properties of the structure, and the behaviour of the inflated ETFE membrane during the fibre placement had an impact on the pavilion's form and materiality.[21]

The biomimetic approach did not stop at the structural level. The designers also translated the spider's spinning behaviour into a "cyber-physical production system" for fibre placement.[22] Embedded within this technical expression is a cybernetic feedback circuit. An interface directly links the "computational

18 "ICD/ITKE Research Pavilion 2014–15," Institute for Computational Design and Construction, University of Stuttgart, accessed July 21, 2021, https://www.icd.uni-stuttgart.de/projects/icditke-research-pavilion-2014-15/.

19 Achim Menges et al., "Fibre Placement on a Pneumatic Body Based on a Water Spider Web," in Material Synthesis, 63.

20 Menges et al., "Behavioral Design," 299.

21 Ibid., 298, 300.

22 Achim Menges, "The New Cyber-Physical Making in Architecture," in Material Synthesis, 28.

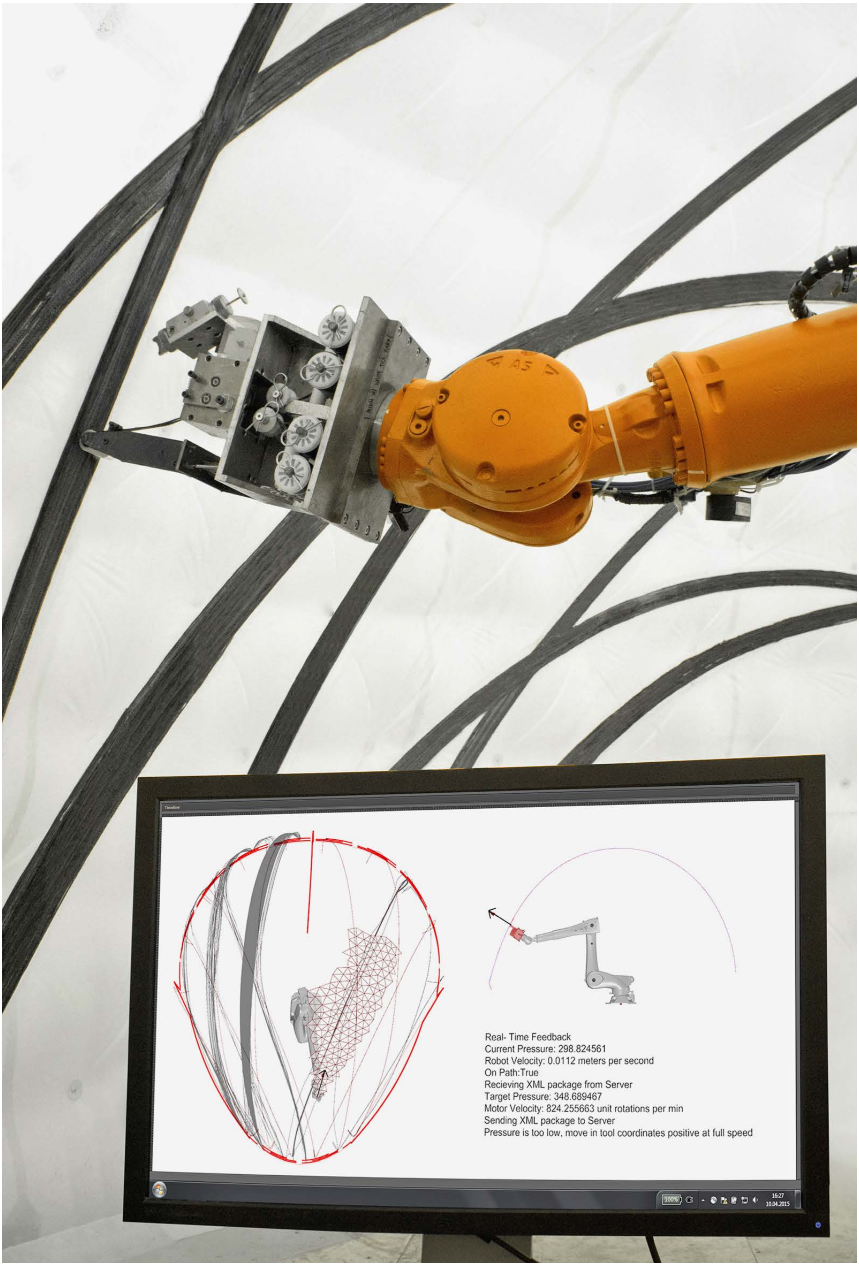

Fig. 4: View of the robotic fibre layering process from within the enclosed ETFE structure, ICD/ITKE Pavilion 2014–15, Germany, 2015. Source: reproduced with permission from ICD/ITKE, Dt. UrhR: ICD/ITKE University of Stuttgart

system"—the digital matrix containing all the information about the pavilion's geometrical, structural, and material properties—to the robotic fabrication process. This is what Menges calls a "physical system"[23] (fig. 4). Key to the success of this "behaviour-based approach" was a computational tool developed by the designers.[24] This "agent" mediated in "real time" between the robot's pressure sensors and effectors, the pavilion's simulated geometry, and its changing form as wet carbon fibres were placed onto the temporary ETFE mould.[25] As its creators describe, "[s]imilar to the spider, a digital agent navigate[d] the surface shell geometry," and constantly adjusted the design system to the fabrication process's environmental, structural, and material constraints.[26]

Silkworms, Silk and the Mediated Matter Group (2013)

Around the same time, another compelling research project, the Silk Pavilion, was built by the Mediated Matter Group (MMG) under the direction of architect Neri Oxman at MIT.[27] Sharing an interest in "new materials" with the ICD/ITKE, the Boston group has experimented with fibre materials, computation and robotic fabrication processes since the lab's foundation. In contrast to their German peers, however, they have taken a further step by examining "the relationship between digital and biological fibre-based fabrication on an architectural scale."[28] They have developed new fibre composites by combining naturally fibrous

23 Ibid., 32.

24 Ibid.

25 Menges et al., "Behavioral Design," 298, 302.

26 Institute of Computational Design and Construction, "ICD/ITKE Research Pavilion 2014–15."

27 The Mediated Matter Group was part of the Media Lab at the MIT. The Media Lab grew out of the Architecture Machine Group that ran from 1967 to 1985 under the guidance of Nicholas Negroponte and Leon Groisser. See Steenson, Architectural Intelligence, 165.

28 Neri Oxman et al., "Silk Pavilion: A Case Study in Fibre-Based Digital Fabrication," in FABRICATE: Negotiating Design & Making, ed. Fabio Gramazio, Matthias Kohler, and Silke Langenberg (London: UCL Press, 2017), 248.

materials (among them, cellulose, chitin and pectin) with additive manufacturing techniques to produce natural biopolymers, as seen in the Aguahoja I pavilion's vertical leaf-like structure (2018).[29] For the Silk Pavilion,[30] a suspended half-dome made of natural and synthetic silk fibres, the group studied the behaviour of the living silkworm (*Bombyx mori*) to generate the pavilion's geometry and materiality before putting the animal to work as a "biological multi-axis multi-material 3D 'printer'" during the production process.[31]

As the design team notes in their 2014 conference paper "Silk Pavilion: A Case Study in Fibre-Based Digital Fabrication,"[32] they developed a multi-step process. First, the designers conducted empirical research into the silkworm's spinning characteristics during the pupae stage before translating their findings into an actual pavilion. In a laboratory setting, they traced the animal's path using magnetometer motion sensors attached to the silkworm's head during a three-day spinning period. They also analysed the cocoon's morphological properties by producing high-resolution images with an electron scanning microscope and microtomography. Additionally, they experimented with the environmental conditions surrounding the silkworm's spinning process, inciting the animal to produce horizontal "patches" for the pavilion instead of its natural cocoon form. Using data from the tests, the MMG developed a computational tool that generated both the geometry of the pavilion's temporary structure and the synthetic "thread geometry" which underlaid the silkworms' future filaments.[33] The goal, as the designers write elsewhere,

29 Neri Oxman and The Mediated Matter Group, "Aguahoja I," in The Neri Oxman Material Ecology Catalogue, ed. Emily Hall and Jennifer Liese (New York/NY: The Museum of Modern Art, 2020), 75.

30 A newer version of the Silk Pavilion was on display as part of the exhibition "Neri Oxman: Material Ecology" at the Museum of Modern Art in New York in 2020. Instead of presenting a dome-shaped pavilion, this time the team opted for a form based on hyperbolas. For further information, see Oxman and The Mediated Matter Group, "Silk Pavilion II," in The Neri Oxman Material Ecology Catalogue, 106–115.

31 Oxman et al., "Silk Pavilion," 249.

32 The description of Silk, including the methods and techniques used by the MMG, in this section are based on Oxman et al., "Silk Pavilion," 248–255, unless indicated otherwise.

33 Ibid., 251.

was to improve "the structural performance and material optimization of robotically deposited fibre structures"[34] by developing a parametric matrix that grouped together physical, biological, and material constraints in one system.[35]
Once the primary geometry was defined, the team began to fabricate the suspended dome, a process realized in two phases. However, before placing the silkworms to spin, the MMG had to build a temporary framework. This structure consisted of 26 polygonal aluminium frames that were each covered with synthetic silk thread by a CNC machine following the computer-generated spinning path. Not until the temporary structure was suspended and the aluminium frames released were the approximately 6500 silkworms, on the verge of pupation, installed, one by one, at the base of the pre-spun dome. For ten days, the animals almost closed the pre-designed gaps between the computationally-simulated and numerically-positioned threads.[36] Migrating from the bottom towards the top of the structure, mostly selecting the shady areas, the silkworms progressively covered the dome's surface with naturally positioned "skin," before being taken off the pavilion after two to three days to finish the natural process of their metamorphosis.[37]

On the animal's status in bio-inspired approaches to computation

Although promising in terms of formal and material innovation, these bio-inspired approaches to computation and robotic fabrication hardly enhance our conception of the animal as a *living being*. On the contrary, they only increase our confusion. Comparing the spider's spinning efforts to maintain an adequate oxygen level within its underwater bubble to the feedback loops

34 Neri Oxman et al., "Biological Computation for Digital Design and Fabrication" (eCAADe 2015 – 33rd Annual Conference, Vienna University of Technology, 2015), 1.

35 Oxman et al., "Silk Pavilion," 250–251.

36 Note that the designers installed a safety net underneath the suspended structure in case the silkworms fell.

37 Oxman et al., "Silk Pavilion," 254.

exchanged between "computational systems" and robotic arms, or equating the silkworms' spinning activity to "biological systems… that 'compute,'"[38] reduces animals to machines. However, in contemporary design cultures, this Cartesian conflation has been taken for granted. This begs the question: Do architects, who adopt these techniques, not only *form*, but also *deform* our conception of animals when they emulate what Merleau-Ponty calls the "objective body," or the body as determined by the sciences, instead of the "phenomenal body,"[39] that is, the lived body as it moves and perceives within its surroundings? Even if I present an alternate approach to the Cartesian concept of the "animal-machine,"[40] one that builds on the animal's "phenomenal body" in Merleau-Ponty sense, my goal in this paper is not to define what animality *per se* is. Rather, what drives my inquiry is whether the mischaracterization of the animal body as a design instrument points towards a deeper problem in architectural theory and practice, a problem originating in the idea of "architecture as biology"[41] or "architecture as science."[42]

38 Oxman et al., "Biological Computation," 1.

39 "[T]he phenomenal body [is] the body insofar as it projects a certain 'milieu' around itself, insofar as its 'parts' know each other dynamically and its receptors are arranged in such a way as to make the perception of the object possible through their [embodied] synergy." See Maurice Merleau-Ponty, Phenomenology of Perception, trans. Donald A. Landes (Abingdon: Routledge, 2012), 241.

40 In *Treatise of Man*, Descartes described the functioning of the animal and the human body in purely mechanical terms. See René Descartes, "Treatise on Man," in The World and Other Writings, trans. Stephen Gaukroger (Cambridge: Cambridge University Press, 2003), 99–170.

41 According to the architectural scholar Catherine Ingraham, the reification of the animal through the sciences can be traced back to the Renaissance. However, it was not until the advent of the positive sciences, for example, 19th century biology and psychology, that a scientific conception of non-human beings was systematized. See Catherine Ingraham, Architecture, Animal, Human: The Asymmetrical Condition (London: Routledge, 2006), 18.

42 Similar to Ingraham, the architectural scholar Alberto Pérez-Gómez notes that, although the idea of architecture "as applied science" has become "institutionalized" during the 19th century, its origins go back as far as the epistemological changes in Cartesian philosophy and Galilean science. See: Alberto Pérez-Gómez, "Architecture as Science: Analogy or Disjunction?" in Timely Meditations: Selected Essays on Architecture, vol. II (Montreal: RightAngle International, 2016), 63–64.

The "new" in computational architecture?

Before elaborating on the animal's entwinement with the new sciences and computer environments,[43] I will briefly contextualize present-day claims about novelty in computational design involving biomimetics and/or bionics, and the relationship between architecture, biology, and computation. Despite the overwhelming literature on "paradigm shifts," "turns" and "digital revolutions" popular within the architectural community over the last thirty years,[44] the use of computers, sensors, and effectors, such as the ones employed in the ICD/ITKE pavilion's fabrication process, is not new *per se*. The architectural scholar Larry D. Busbea, for instance, links the mechanisms underpinning the ICD/ITKE's 2016 Elytra Filament Pavilion to the 1970s "responsive environments" movement, which emerged in the wake of architects' growing interest in computation, cybernetics, and the body's physical surroundings.[45]

Using animals and plants as architectural role models is not a recent novelty, either. According to the architect and theorist Philippe Steadman, the idea of "biotechnics" or "biotechnique" emerged in the 1920s and 1930s when architects used "the engineering of nature" to enhance the "structural, mechanical, even chemical, and electrical" properties of the built environment.[46] As he explains, the goal behind this design approach was to extract

43 I use the term "computer environments" as a derivative of SEEK's other title, "Life in a Computerized Environment," in the "Software" exhibition catalogue. I will return to this idea when discussing SEEK. See Software – Information Technology: Its New Meaning for Art (New York/NY: The Jewish Museum, 1970), 20.

44 For example: Mario Carpo, The Second Digital Turn: Design beyond Intelligence (Cambridge/MA: MIT Press, 2017). Peter Eisenman, "Visions Unfolding: Architecture in the Age of Electronic Media," in The Digital Turn in Architecture 1992–2012, ed. Mario Carpo (Chichester: Wiley, 2013), 16–27. Charles Jencks, The New Paradigm in Architecture: The Language of Post-Modernism (New Haven/CT: Yale University Press, 2002).

45 By "responsive environments," Busbea means "technologically mediated spaces that alter their physical or ambient properties based on various inputs or status changes." These changes are mainly computer-controlled. See Larry D. Busbea, The Responsive Environment: Design, Aesthetics, and the Human in the 1970s (Minneapolis/MN: University of Minnesota Press, 2020), 89–90, 124–125. Note that the 2016 pavilion by the ICD/ITKE is a more elaborate version of the 2014–15 pavilion in terms of a "behaviour-based approach" to computational design.

46 Philip Steadman, The Evolution of Designs: Biological Analogy in Architecture and the Applied Arts (London: Routledge, 2008), 153.

→

from Nature "a great variety of 'inventions,' [already] embodied in the designs of organs or in the adaptations of the limbs" that have evolved under evolutionary stresses, and, therefore, were proven to be efficient.[47] These early attempts to "copy" Nature, Steadman elaborates, resulted in enormous progress in the aviation sector, before this body of knowledge was absorbed by the recently founded field of "bionics"—a new science that emerged in the 1960s and was particularly embraced by proponents of cybernetics and information theory.[48] Since then, he concludes, the focus has shifted away from empirically observing plants and animals and towards an "abstract and codified… generalized theory of behaviour," while the functioning of Nature and human-made mechanisms has become "interchangeable."[49]

Even before the bio-technical approach discussed by Steadman, architects were turning to the natural world to find precedents for their designs. Architectural historian Adrian Forty draws a parallel between the 19th century conception of biological "function" and the performance of bodily organs with 19th century architects' use of these functionalist metaphors.[50] In *Architecture, Animal, Human: The Asymmetrical Condition*, the architectural scholar Catherine Ingraham makes a similar point. She, too, traces biology's encroachment into architecture, and vice versa, to the 19th century, when historians of architecture and biologists began to appropriate one another's metaphors, using "structure, typology, organization, evolution and development," in their respective disciplines.[51] This tendency to conflate biology with architecture, and the organic with the inorganic, Ingraham argues, has regained momentum with the advent of computation as an architectural design technique.[52] Ingraham does not discuss the ICD/ITKE or MMG's bio-inspired approaches to computation *per se*,

47 Ibid.

48 Ibid., 161.

49 Ibid., and 162.

50 Adrian Forty, "Function," in Words and Buildings: A Vocabulary of Modern Architecture (New York/NY: Thames & Hudson, 2000), 175, 177–178.

51 Ingraham, Architecture, 23.

52 Ibid., 26–27.

instead focusing on the intertwined development of computation, cybernetics and genetic biology through the lens of the human body.[53] However, she points to the risks inherent in a "mechanization of the flesh" which may arise when architects stop differentiating between "biological life and machine life and the idea of an informational system that acts as an 'organic system.'"[54]

To return to "novelty," what may have changed when it comes to bio-inspired approaches to computation are the new technological possibilities which have allowed architects to conduct proto-scientific experiments in-house. Architect's acquired data can be instantly implemented into robotically-fabricated products, which enables them to override the traditional division of labour between design, fabrication, and construction phases, another new possibility of the digital age. According to Hensel and Menges, "a decisive shift away from biological metaphor and superficial biomorphism towards a literal biological paradigm for a performance-orientated architecture" has influenced the design process, too.[55] This development is tied to sophisticated technological apparata, such as the electronic scanning microscope or microtomography used for the observation of animals and plants. Moreover, computing power and computation as a design technique have facilitated the transfer of data from one discipline to another. Knippers could not be more correct when he attributes the success of "computational" over "physical form-finding" processes to the "'digital model' [as] a common basis for the exchange of knowledge across the disciplines… enabl[ing] direct communication between, so far, widely separated fields of science."[56] This particularly applies to the information exchange between biology, architecture and engineering.[57]

53 Ibid., 305.

54 Ibid., 302, 307.

55 Michael Hensel and Achim Menges, "The Heterogenous Space of Morpho-Ecologies," in Space Reader: Heterogeneous Space in Architecture (Chichester: Wiley, 2009), 208.

56 Jan Knippers, "From Minimal Surfaces to Integrative Structures – The SFB-TRR 141 in the Light of the Legacy of Frei Otto and the SFB 230 'Natürliche Konstruktionen,'" in Biomimetic Research for Architecture and Building Construction, ed. Jan Knippers, Thomas Speck and Klaus G. Nickel (2016), 8–9.

57 Ibid., 9.

Also noteworthy is that scripting as a design technique and digital fabrication processes have become more accessible in universities over the last decades.
However, the philosophical foundations undergirding the living organism conceived of as an "animal-machine" have certainly not evolved. According to Steadman, the roots of the animal's "mechanization" in architecture, which is pervasive in biomimetics and bionics, have their origins in *the biological idea* of an "organism as machine" that first emerged in the wake of Cartesian philosophy, before being adopted by 19th century biologists.[58]

The cybernetic "animal-machine"

The philosophical and biological lineage of the Cartesian "animal-machine" can still be felt in contemporary architecture. While "the commonalities between computation and biology run deep,"[59] so do those between systems thinking, cybernetics and the life sciences, as Ingraham pointed out.[60] Consider cybernetics, which originated in the wake of the Second World War. Its theory was based on the idea of the animal as a Cartesian "animal-machine" or "automaton,"[61] functioning as mere "mechanism" without a "rational soul."[62] The title of Norbert Wiener's notorious book *Cybernetics or Communication and Control in the Animal and the Machine* provides a compelling example of this reduction of animals to machines. Likewise, Walter Cannon's biological concept of "homeostasis," which describes "those processes through which the material and energetical situation of the organism is maintained constant,"[63] has been widely used

58 Steadman, Evolution, 11, 13.

59 Christina Cogdell, Toward a Living Architecture: Complexism and Biology in Generative Design (Minneapolis/MN: University of Minnesota Press, 2019), 4.

60 Ingraham, Architecture, 320.

61 Norbert Wiener, Cybernetics or Control and Communication in the Animal and the Machine (New York/NY: MIT Press, 1961), 40.

62 Peter Harrison, "Descartes on Animals," The Philosophical Quarterly 42, no. 167 (1992): 223–224.

63 Ludwig von Bertalanffy, General System Theory: Foundations, Development, Applications (New York/NY: G. Braziller, 1973), 78.

in cybernetics to describe the “self-regulation” and “feedback” mechanisms that operate in machines and animals.[64] Biologist and system theory founder Ludwig von Bertalanffy attempted to break away from this mechanistic conception of the animal by advancing an “organicist position”—the idea of an “organism as a whole or system,”[65] but his efforts did not succeed. Although Bertalanffy posited “the organism [as] a basically *active* system [emphasis mine]”[66]; in *General System Theory*, he applied the same logico-mathematical formulations and principles that governed non-living “systems” to “living systems.”[67] In other words, despite his biological and philosophical attempts to do otherwise, he still reduced the living animal to a set of abstract and disembodied “relations.”

These early attempts at “cybernetics to appear as a unified theory of behavior of living organisms and machines, viewed as systems governed by the same physical laws”[68] and architects’ post-war experiments with computers will clarify the status of the animal in my initial case studies: the MMG’s use of silkworms as “printers” or “systems” to realize the Silk Pavilion, or the diving bell spider’s behaviour as a role model for the design of the 2014–15 research pavilion, which formed a “cyber-physical systems” in the sense meant by Menges. To address the conflation of animals and machines, I will discuss one of the first computer-controlled environments in the history of architecture, which tested the interactions between computers, animals—used as stand-ins for humans—and robots to generate spatial designs: SEEK.[69]

64 Ibid., 15–16.

65 Ibid., 12.

66 Ludwig von Bertalanffy, Problems of Life: An Evaluation of Modern Biological Thought (London: Watts, 1952), 18.

67 Von Bertalanffy, General System Theory, 13, 153.

68 Roberto Cordeschi, “Cybernetics,” in The Blackwell Guide to the Philosophy of Computing and Information, ed. Luciano Floridi (Malden/MA: Blackwell Publications, 2004), 186.

69 This has been confirmed by the contemporary scholar Theodora Vardouli, who writes that SEEK “invoked, conflated, embodied cybernetic experiments with living beings and the relentlessly abstract ‘blocks worlds’ settings proliferating in AI machine-learning trials.” See Theodora Vardouli, “SEEK,” in The Architecture of Closed Worlds: Or, What Is the Power of Shit?, ed. Lydia Kallipoliti (Zürich: Lars Müller Publishers, Storefront for Art and Architecture, 2018), 116.

Gerbils, SEEK and the Architecture Machine Group (1969–70)

SEEK is the title of an installation created by students of the Architecture Machine Group (AMG), under the direction of Leon Groisser and Nicholas Negroponte, for the 1970 "Software" exhibition at the Jewish Museum in New York.[70] The term also refers to the agent of this project: a "sensing/affecting device"[71] or robotic arm hovering above an elevated "building-block city."[72] This quasi-architectural space was filled with two-inch blocks covered with metal foil[73] and enclosed by a glass frame to contain its inhabitants:[74] gerbils, chosen because of their "curiosity"[75] and their physical resemblance to laboratory rats.[76]
Equipped with sensors and effectors, and connected to an Interdata processor, SEEK's robotic arm operated like "[f]ingers into the real world" responding to the gerbils' actions.[77] The electromagnetic device towering above the animals' new habitat had a dual purpose. Firstly, its sensors and effectors allowed SEEK to detect, move, pick up and rearrange the cubes. Secondly, the mechanism was designed to deal with "unexpected events."[78] In Groisser and Negroponte's words, SEEK's goal was to "show how a machine handled a mismatch between its model of the world and the real world – in this case, five hundred metal-plated cubes."[79] It was the gerbils' role, as Negroponte emphasizes, to provoke these conflicts,[80] and, in doing so, to challenge SEEK's

70 Nicholas Negroponte, Soft Architecture Machines (Cambridge/MA: MIT Press, 1975), 47.

71 The Architecture Machine Group as cited in Noah Wardrip-Fruin and Nick Montfort, "Software," in The New Media Reader (Cambridge/MA: MIT Press, 2003), 253.

72 Leon Groisser and Nicholas Negroponte, Computer Aids to Participatory Architecture (Cambridge/MA: Massachusetts Institute of Technology, 1971), n.p.

73 Negroponte, Soft Architecture, 47.

74 Software – Information Technology, 22.

75 Negroponte, Soft Architecture, 47.

76 Vardouli, "SEEK," 116.

77 The following description of SEEK, including the AMG's methods and techniques, is drawn from Groisser and Negroponte's grant proposal, unless indicated otherwise. SEEK as cited in Groisser et Negroponte, Computer Aids, n.p.

78 Ibid., n.p.

79 Negroponte, Soft Architecture, 47.

80 Ibid.

"computed remembrances."[81] However, the little mammals, usually known for their "docile" and "quiet" nature,[82] far exceeded the designers' expectations for anticipated "mismatches," along with SEEK's memory processing capacities.

Ironically, Negroponte and Groisser's characterization of the gerbils as "dwellers… with their own ideas of where things should be" could not be more accurate.[83] Despite the architects' expectations that this experiment would demonstrate SEEK's capacity to respond to the animals' action, the gerbils never accepted their new environment. How could they? SEEK was not designed to respond to the animals' behaviour. SEEK's purpose, as previously mentioned, was not to harmoniously interact with the animals, but to prove the machine's capacity to respond to "inconsistencies" caused by users of its *own* kind.[84] This discrepancy concerning the real "protagonist" of the experiment may explain the chaotic and unforeseeable events that followed.

Technically, SEEK operated in one of six modes: "generate, degenerate, fix it, straighten, find, error detect."[85] As Groisser and Negroponte explain, the system mainly ran in "fix it mode" which dealt with the cubes' orientation and placement.[86] Generally, SEEK was able to differentiate between "slightly askew" and "substantially dislocated" cubes, which could be either "realigned" or "placed (straight)" during the gerbils activities.[87] For a worst-case scenario in which the cubes were "way out of line," the designers configured SEEK to switch to "straighten mode"; it would carry the cubes to the "straightener"—a box within the box capable of

81 SEEK in Groisser et Negroponte, Computer Aids, n.p.

82 Maryanna F. Fisher and Gerald C. Llewellyn, "The Mongolian Gerbil: Natural History, Care, and Maintenance," The American Biology Teacher 40, no. 9 (1978): 558.

83 SEEK in Groisser et Negroponte, Computer Aids, 76.

84 Negroponte emphasized that "SEEK's role is to deal with these inconsistencies … inasmuch as the actions of the gerbils are not predictable and the reactions of SEEK are modeled on a probabilistic basis programmed specifically to correct or amplify (not both) gerbil-provoked dislocations." See Groisser and Negroponte, Computer Aids, n.p

85 Ibid., 138.

86 Ibid., 140.

87 Negroponte, Soft Architecture, 47.

setting the blocks in the right position.[88] If the cube remained misaligned, the computer would "turn… on a vibrator" to solve the problem.[89] Yet despite its variety of "modes," SEEK could not handle the gerbils. They soon became distressed by the robotic arm. It did not take long until the installation turned into a catastrophe for both the museum and the animals.[90] Disorientated by SEEK's actions, the gerbils eventually attacked the device[91] before turning on each other.[92]

While for Negroponte, "SEEK exhibit[ed] inklings of responsive behaviour" in a quasi-architectural setting,[93] others were more critical of the project. On the gerbils' discomfort, pioneer of information technology Ted Nelson wrote: "I remember watching one gerbil who stood motionless on his little kangaroo matchstick legs, watching the Great Grappler rearranging his world. Gerbils are somewhat inscrutable, but I had a sense that he was worshipping it. He did not move – until the block started coming down on top of him."[94]

Although the system was equipped with an "error mode" to signal problems in the computers' hardware and software,[95] and Negroponte warned of poorly designed machines' inherent risks,[96] SEEK simply went out of control. The communication between the machine and the animals broke down. Yet SEEK did not fail to engage with the gerbils solely due to a lack of technological advancement. Rather, the SEEK debacle occurred because of the logic embedded in SEEK's program: the idea that any user's "performance of actions" can be broken down to the "behaviour" of a Cartesian "automat[on]" as described by Wiener.[97]

88 SEEK in Groisser et Negroponte, Computer Aids, 140–141.

89 Ibid., 141.

90 Noah Wardrip-Fruin and Nick Montfort, "Software," 247.

91 Vardouli, "SEEK," 116.

92 Noah Wardrip-Fruin and Nick Montfort, "Software," 247.

93 SEEK in Groisser et Negroponte, Computer Aids, n.p.

94 Ted Nelson as cited in Wardrip-Fruin and Nick Montfort, "Software," 247.

95 SEEK in Groisser et Negroponte, Computer Aids, 142.

96 Steenson, Architectural Intelligence, 186.

97 Wiener, Cybernetics, 42–43.

In post-war cybernetic circles, it was common to compare the "behaviour" of living organisms to "living machines,"[98] and to describe the animal functioning as an "input-output relation" between an object, its environment, and a "goal" to be achieved.[99] Therefore, from a cybernetic viewpoint, the gerbils "perform[ed]" well within SEEK's feedback-driven environment. They attained the designers' "goal" by creating unforeseen "events" for SEEK. From an alternate viewpoint, SEEK illustrated the limits of the cybernetic conflation of animals and machines. It showed that the gerbils did not "regulate" their behaviour to suit their environment: an abstract space of geometrical forms and mechanical displacements. Neither did SEEK "self-regulate." How could it? SEEK was programmed to respond to the "model" of "gerbil-machine" or "user-machine" behaviour, but not to actual living beings. In other words, its "model," which determined its behaviour towards users' actions, lacked a holistic understanding of what a living being is.

This is significant because "architecture machines" were not intended to encompass every kind of machines. They were "intelligent" machines. They exemplified a particular "behaviour," designed to form a "symbiosis… through the dialogue" with their users.[100] As Groisser and Negroponte write: "The prime function of the machine is to learn about the user… whatever knowledge the machine has of architecture will have been imbedded [sic] in it; the machine will not 'learn' about architecture. The machine will indeed build a model of the user's new or modified habitat. But it is simultaneously building a model of the user and a model of the user's model of it."[101]

The "architecture machine's" (intelligent system) capacity to develop what the contemporary architectural historian Molly W. Steenson calls the "model of models" or "metamodel"[102] of its

98 Wiener, Cybernetics, xv, 39, 43.

99 Arturo Rosenblueth, Norbert Wiener, and Julian Bigelow, "Behavior, Purpose and Teleology," Philosophy of Science 10, no. 1 (1943): 18.

100 Nicholas Negroponte, The Architecture Machine (Cambridge/MA: MIT Press, 1970), 1, 9.

101 SEEK in Groisser et Negroponte, Computer Aids, 7.

102 Steenson, Architectural Intelligence, 172.

users' actions is Cartesian in principle. Consequently, each time contemporary designers use present-day computational design techniques and fabrication processes, they revive the cybernetic idea, essentially Cartesian idea of the "animal-machine." They do this in two ways: firstly, by the methods and techniques they use; secondly, by the way they represent animality.

The animal's Umwelt in Merleau-Ponty

As SEEK reveals, the animal is neither an "animal-machine" nor a Cartesian "automaton." On the contrary, as the French philosopher Maurice Merleau-Ponty observes, "the animal body is a relation to an *Umwelt* [milieu] circumscribed by it, but without its knowing (*N*, 216)."[103] In the second and third courses of *Nature* (1957–58, 1959–60), Merleau-Ponty makes a compelling argument for the ontological difference between machines and organisms, despite our "natural tendency" to think of the animal body in mechanical terms (*N*, 150). He reminds us that the philosophical and scientific conflation of "life" and "artifice" is human made (*N*, 162). At the end of his critique of the first cybernetic robots, he notes that confusion between what is alive and what is not can be traced to a "sort of drunkenness of thought" (*N*, 162) which appeared after the advent of Cartesian philosophy. Merleau-Ponty argues that the idea of the (animal) body as a "mechanism" not only led to the disappearance of the lived body, but also to a denial of "artifice" itself, which was henceforth "posited as nature" (*N*, 162). Against the cybernetic conception of the "animal-machine," Merleau-Ponty maintains that although "[t]he machine *functions*, the animal *lives* – that is, it restructures its world and its body [emphasis mine]" (*N*, 162) according to its surroundings.

103 This section of the article is based on Merleau-Ponty's posthumously published course notes on the theme of Nature, held at the Collège de France between 1956–60, with particular reference to the second and third courses. Although the notes are attributed to the philosopher, the first (1956–57) and second (1957–58) course were recorded in students' notes. Only the third course (1959–60) consists of Merleau-Ponty's original notes. For clarity, the in-text citation includes the exact reference whenever possible by using the capital letter *N* and the page number in brackets. See: Maurice Merleau-Ponty, Nature: Course Notes from the Collège de France, ed. Dominique Séglard, trans. Robert Vallier (Evanston/IL: Northwestern University Press, 2003).

The philosopher ascribes foundational importance to the "animal body" as the condition which enables its existence-in-the-world, and to the "relation" it forms with its natural surroundings. Its living body is "a body that moves [and] a body that perceives" (*N*, 209). It engages in a "relation of meaning" to its surroundings or *Umwelt* (*N*, 175). For Merleau-Ponty, this corporeal relation between the animal and its surroundings cannot be equated with a cybernetic feedback loop connecting an organism to an environment, which remains "exterior" to the animal's experience (*N*, 14). Neither does the animal body perceive its *Umwelt* as a "goal" to attain (*N*, 175). On the contrary, through its bodily constitution: that is, through its nervous system and motor capacities, the animal body *actively* explores its "milieu," and, in doing so, provokes a quasi-reaction from it. In the philosopher's words: "There is no stimulation from the outside that had not been provoked by the animal's own movements. Each action of the milieu is conditioned by the action of the animal; the animal's behaviour arouses responses from the milieu. There is an action in return for that made by the animal." (*N*, 175)

Merleau-Ponty's philosophical understanding of the "relation" between the animal body and its surroundings builds upon the notion of *Umwelt* put forward by the early 20th century zoologist Jakob von Uexküll. Along the same lines, Merleau-Ponty argues that *Umwelt* only emerges at the intersection between the animal's movements, its perceptions, and its surroundings (*N*, 175). For Merleau-Ponty, *Umwelt* is not put "in front of" the animal body like an object, nor does it act as "cause" (*N*, 178) as stipulated by cybernetics. Neither is it merely a philosophical "principle" (*N*, 177). Instead, *Umwelt* "emerges" between the animal body as it is lived and "a milieu of events … which opens on a spatial and temporal field" (*N*, 177). Merleau-Ponty also likens this form of attunement between the animal body and its surroundings to Uexküll's famous expression of "the unfurling of an *Umwelt* as a melody that is singing itself" (*N*, 173).

Aside from its expressive dimension, melody, for Merleau-Ponty, has above all a philosophical meaning. "[W]hen the melody begins," he writes, "the last note is there, in its own manner. In a melody, a reciprocal influence between the first and last note takes place, and we have to say that the first note is possible only because of the last, and vice versa" (*N*, 174). The melody describes a reciprocal "relation" between a beginning and its end, without, as the scholar Véronique M. Fóti clarifies, reducing it to a linear sequence of events.[104] For Merleau-Ponty, the melody only comes into existence during the embodied act of singing or humming: that is, when "the melody is incarnated and finds in the body a type of servant" (*N*, 174). The animal's relationship to its *Umwelt* is similar: both produce each other mutually. By shifting the focus from the animal body as "mechanism" to the animal body's corporeal experience *in relation to* its surroundings, Merleau-Ponty's philosophical interpretation of *Umwelt* challenges the Cartesian concept of the "animal-machine."

Embodied approaches to animal cognition

Recent findings on embodied approaches to animal behaviour and cognition seem to confirm Merleau-Ponty's conception of animality. In *Beyond the Brain*, the anthropologist Louise Barrett builds upon various case studies to demonstrate that animal perception is "an active process […] and not merely a passive reception of information from the environment" as SEEK previously conveyed.[105] Animal behaviour, animal "intelligence," and "flexible behaviour," she counters, result from the animal's genetic baggage, which defines its morphology, and the "mutual relationship" between its brain, its perception and movement, and its environment.[106] Similar to Merleau-Ponty's philosophical description, Barrett writes that the animal's "psychological processes are 'embodied': they are not somehow things that 'float free' from the animal, but are firmly grounded in the physical actions of the

104 Veronique M. Fóti, Tracing Expression in Merleau-Ponty: Aesthetics, Philosophy of Biology, and Ontology (Evanston/IL Northwestern University Press, 2013), 77.

105 Louise Barrett, Beyond the Brain: How Body and Environment Shape Animal and Human Minds (Princeton/NJ: Princeton University Press, 2015), 22.

106 Ibid., 76–77, 79.

animal body both as it observes other animals, and of course, as it moves around the world itself."[107]
Barrett adds that the animal's actions do not take place in a vacuum. She stresses the impact of the environment on the animal's behaviour. Building upon Uexküll's pioneering work, the anthropologist confirms that *Umwelt* is a useful concept to determine "both the scope and the limits of species' flexibility, while at the same time preventing us from getting too big for our boots; we, too, have to recognize the limits of our own umwelt [sic]."[108] Against the "mechanization" of animals, she invites us to consider them in their totality, including their *Umwelt*. Until then, Barrett concludes, we risk "asking scientific questions that simply reflect our own concerns" instead of getting to know the "animal's experience of the world" in a non-epistemological way.[109]

Conclusion: Utopia Computer?

This article has critically discussed the link between cybernetics and the Cartesian concept of the "animal-machine" which have guided contemporary bio-inspired approaches to computation. While the projects examined have provided insights for form-finding techniques and material fabrication processes, they still operate on the Cartesian premise that Nature is a mere "resource" (*res extensa*) at humans' disposal, which is problematic. This is best exemplified by architects' conception and use of animals as machinelike "systems," "printers" and "computations" to realize their computationally-driven designs. Whether their methods and techniques are a form of scientism, as Cogdell suggests in her recent book on complexity in architecture,[110] or whether the choice of their words is mere rhetoric intended to target a certain audience, is not the topic of my inquiry. Rather, what is at stake is *architecture's* conception *as biology qua computation*, and the

107 Ibid., 35–36.

108 Ibid., 81.

109 Ibid., 3, 145.

110 Cogdell, Toward a Living Architecture, 33–34.

ideological distortions this position causes to our perception of Nature.

Consider Oxman's suggestion to view "Nature as client."[111] Her position makes the Silk Pavilion look like "nice" in the face of the environmental challenges, to borrow an expression from philosopher Timothy Morton.[112] However, despite laudable intentions, it fails to overcome the object—subject dichotomy undergirding the concept of the "animal-machine." Yet how could it have been otherwise when computer usage has become synonymous with Oxman's "new ways of thinking" about design, and architecture has become synonymous with "architecture machines" in the sense meant by Negroponte? SEEK's failure to understand the animals' actions as qualitatively different from the computer's automatic processes shows that the computer's Cartesian framework has "disappeared" behind computational architecture's utopian intentions.[113] As Barrett reminds us, post-war computer development was driven by John von Neumann's metaphor of the "brain as computer," which led to the computational model of cognition.[114] While this contributed to the digital computer's success, Barrett stresses that it also "generated a view of cognition as a process that has no real link to the body or the outside world, taking place purely in the brain alone."[115] In other words, it only perpetuated the Cartesian split between "mind" (*res cogitans*) and "matter" (*res extensa*) by turning the functioning of the "animal-machine" into a variant of the "thinking machine," to use Alan Turing's expression.[116]

111 Paola Antonelli, "The Natural Evolution of Architecture," in The Neri Oxman Material Ecology Catalogue, 20.

112 Timothy Morton, Dark Ecology: For a Logic of Future Coexistence (New York/NY: Columbia University Press, 2016), 21.

113 Here I refer to Merleau-Ponty's idea of the disappearance of the "artificial" as discussed earlier. For more, see Merleau-Ponty, Nature, 162.

114 Barrett, Beyond the Brain, 121. The computational or representational model of cognition builds upon the premise that the brain functions similarly to a computer that processes information. Mental processes are conceived of as "computations made by the brain using an inner symbolic language." See Evan Thompson, Mind in Life: Biology, Phenomenology, and the Sciences of Mind (Cambridge/MA: Belknap Press of Harvard University Press, 2007), 4–5.

115 Barrett, Beyond the Brain, 124.

116 Alan Turing, "Computing Machinery and Intelligence," in The New Media Reader, ed. Noah Wardrip-Fruin and Nick Montfort (Cambridge/MA: MIT Press, 2003), 51.

I want to address another utopian moment in this article: namely, the conflation of biology and Nature. Although biology provides invaluable insights into the natural world, we should remain wary of directly applying its methods, techniques, and theories to architecture as a "driver" of architectural form and materiality. Biology is not Nature. Nor should scientific constructs and technologies, which are enabled by human experiences of *Umwelt*, falsely reduce animal or human embodied experience to scientific data alone. The projects I have discussed were achievable because architects equipped with scanning electron microscopes and other apparata zeroed in on the material properties and behaviours of animals at a microscopic level to "abstract" information. Even if the animals directly participated in the process, they did so in our *Umwelt*, but not necessarily in theirs. While scientific, technological, and computational methods certainly enabled the design of these pavilions and installations, they also consolidated the myth of the "animal-machine."

However, this subjugation of living beings, and, by extension, of Nature, to architects' intentions seems increasingly problematic considering the environmental challenges we face, and architects' responsibility to provide a habitat for *all*. Put differently, the bio-inspired approaches to computation bear the question how architects intend to tackle the ecological crisis. Will they simply use technology elevated to a "second nature" to produce designs that emulate a disembodied and disembedded attitude towards human and non-human life? Or, alternately, will contemporary architects aim at creating an architecture of "ceaseless exchange and oscillation between milieu and body"[117]: that is, an architecture that addresses *Umwelt* as it is lived?

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117 Ingraham, Architecture, 6.

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The critical concern of the book “Utopia Computer” is the euphoria, expectation and hope inspired by the introduction of computers within architecture in the early digital age. With the advent of the personal computer and the launch of the Internet in the 1990s, utopian ideals found in architectural discourse from the 1960s were revisited and adjusted to the specific characteristics of digital media. Taking the 1990s discourse on computation as a starting point, the contributions of this book grapple with the utopian promises associated with topics such as participation, self-organization, and non-standard architecture. By placing these topics in a historical framework, the book offers perspectives for the future role computation might play within architecture and society.

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