A Sympoietic Ocean. Design research with/in the marine holobiont

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Abstract

In the face of profound human impact on planetary systems, the global ocean, as the main source of life, is fundamentally transforming its interactions, flows, and ecologies. These critical changes raise questions of other-than-human cohabitation beyond the terrestrial. In response to these radical ecological changes, a growing branch of the design discipline is currently struggling to free itself from a production-oriented paradigm of industrial modernity and reorganizes its methods toward forms of interspecies collaboration with/in environments of anthropogenic change.

In this paper, I argue for activating the evolutionary theory of Symbiogenesis (Margulis, Kozo-Polyansky, Meresch-kowsky) and its relevance for a holistic view of the ocean as a starting point for challenging and reinventing our disciplinary protocols. The article follows Haraway's notion of sympoïesis, adopting it for the design discipline. The evolutionary model of Symbiogenesis offers a new perspective on the role of design as a facilitator for collaborative forms of making and shared survival.

The coral reef, as a prototypical space for symbiotic system relationships, serves as an experimental contact zone for designing these interspecies encounters. Design research in underwater environments, could help us to align the design discipline with a new conceptual framework that I propose to call *Sympoïetic Design*.

Keywords

Sympoïetic Design, ocean, design research, symbiogenesis, scuba diving, Biorock, sympoïesis, Cybertecture, designing habitats, materials research.

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A Sympoïetic Ocean

“We are symbionts on a symbiotic planet. And if we care to, we can find symbiosis everywhere.” [1] *– Lynn Margulis, Symbiotic Planet, 1998.*

Imagine a coral reef. The damselfish flicks its fins as it hides among stony corals to support its photosynthesis. The green-brown algae that live on the spider crab’s back help it to camouflage. The currents transport nutrients across limestone structure where corals spawn and settle. The zooxanthellae inhabit coral tissue and metabolize organic matter to provide energy for their hosts. The stony coral animal absorbs calcium carbonate from seawater to form its habitat. The microbiome of the reef binds Co_2 and produces the oxygen of the planet’s atmosphere – it pulses with life.

The coral reef can be considered a prototypical ecology for symbiotic system relationships. Symbiosis governs the marine microbiome at all levels, from species-based networks to the microbiological level [2]. As former biologist and professor of feminism and technoscience Donna J. Haraway points out, the marine biome in general, and the “critical zone” of the coral reef in particular, serve as model organisms for symbiotic evolutionary processes [3] within the planetary holobiont [4].

In chapter 3 of *Staying with the Trouble* (Haraway 2016) “*Sympoiesis. Symbiogenesis and the Lively Arts of Staying with the Trouble.”* Haraway invokes the seminal work of biologist Lynn Margulis, who revived the evolutionary theory of symbiogenesis based on the preliminary work of Russian evolutionary biologists Boris Kozo-Polyansk [6] and Konstantin Mereschkowsky [7]. When Margulis published her theory in the 1960s, she provoked and disturbed the male-dominated scientific discourse not only as a female academic, but also through her decisive rejection of the then widespread Neo-Darwinian concept of evolution. Her theory challenged the idea of evolutionary competition – the hypothesis of random mutation as driver for *“selfish”* survival of the fittest [8] – and relied on a cooperative model of survival through symbiosis [9].

Margulis’ impassioned plea for symbiosisas an overlooked facilitator of evolutionary adaptation and her uncompromising proposal for a taxonomy of species which gives bacteria, animals, plants, fungi, and protoctista an equal position in the evolutionary Tree of Life, is nowadays generally considered as one of the most decisive contributions to ecological thinking. One could argue that Magulis’ theory resurrects Charles Darwin's alternative representation of evolution in the form of the coral: an anarchically growing form *“that no longer upholds mankind as the ‘crown of evolution’”*[10], as sketched in Darwin's early notebooks [11]. The Coral of Life can be seen as closely related to Mereschkowsky’s endosymbiotic Tree of Life and Lynn Margulis’ later extension to the Five Kingdoms [12].

Figure 1 Field research at "Biorock" reef installed by Mike Duss (in the picture) and Tom Goreau. Location: Sun Reef, Curaçao (AN). Photo: Rasa Weber, 2022.

Philosopher Donna Haraway’s outstanding contribution in Staying with the Trouble consists in turn, amongst other things, of applying Margulis’ theory of symbiogenesis to philosophy and system theory. She introduced a form of thinking and making, which she called sympoïesis [13]—“together creation”—with human and other-than-human actors. While Haraway argues for transferring sympoïetic forms of production to the humanities and the arts, activating her theory for the design discipline holds the potential to reorganize a human-centered approach to design toward highly relational forms of creation through interspecies collaboration.

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A growing branch of design is currently struggling to break free from a production—and profit-oriented paradigm of industrial modernity (Mareis & Paim 2021). By bringing the agency of troubled environments and their (other-than-) human inhabitants to the foreground of a design methodology, we might foster a reinvention of our disciplinary protocols in response to our current ecological and socio-political struggles, which can never be addressed separately (Stengers 2010).

Figure 2 Underwater prototype by Rasa Weber. Diver: Mike Duss. Location: Sun Reef, Curaçao (AN). Photo: Rasa Weber, 2022.

Designing (with/in) Marine Ecosystems

As a design researcher and diver, I am concerned with material processes, their production cycles, and their resulting impacts on environmental systems. I am deeply moved by the question of developing and establishing post-extractive models of production within our challenged planetary networks.

This question led me to the ocean, the largest life-giving (Helmreich 2009; Latour 2019) and dramatically transforming system on our planet (Lohmann et al. 2017; Heinze et al., 2021). Together with biologists from the Max Planck Institute of Animal Behavior (Jordan Lab), I conduct most of my design research in the field, below sea level. I develop immersive underwater methods [14] (Helmreich 2009; Raycraft 2020; Swanson & Levy 2021; Jue 2022) for design research, prototyping sympoïetic material experiments underwater, and research on the design ontological implications of my aquatic practices (Neimanis 2017, Åsberg 2020).

Although designing underwater habitats looks back at a long history (See: e.g. Cousteau's Conshelf Project 1962-1965), most of these early interventions still follow a human-centered design approach. My project takes the historical material technology of Biorock [15] as a starting point and seeks to convey a different notion of habitat design in ocean environments as a culturally embedded, interspecies, and collaborative process.

My research is based on the preliminary work of the German architect and oceanographer Wolf Hilbertz and his colleague in biochemistry Tom Goreau. As early as 1970, their research introduced a process of underwater electrolysis triggered by low-voltage electricity (6-12 V) that causes limestone to "grow" on conductive steel scaffold in the sea—a technology that was patented under the name Biorock. Naturally dissolved minerals in seawater (primarily aragonite and brucite) are slowly deposited on the conductive steel, which provides an ideal medium for the colonization by marine life. The technology is now widely used to restore coral reefs in tropical marine areas.

In spring 2022, I visited one of the Biorock projects on the island of Curaçao (AN) with the aim of learning more about the technological implications, ecological consequences, and maintenance methods of such an underwater garden and subsequently build my own first prototypes (Figure 1).

My own design contribution explores the possibilities of applying the Biorock technology to contemporary materials, combining a practice-based design approach with situated, collaborative, and craft-oriented design methods. Based on the principle of electrodeposition of minerals in seawater, I construct underwater prototypes as Interspecies Architecture which are neither exclusively for a human audience nor solely for marine critters. The prototypes function as contact zones between species and question the role of architecture as a human-centered practice. Instead of the historically used material—reinforcing steel—my work focuses on reducing material consumption and applies filigree conductive yarns to construct lightweight marine prototypes with the help of solar energy. When the conductive yarns are exposed to electricity, a limestone-like material forms on their surface, transforming a formerly flexible textile surface into a solid substrate that supports the growth of marine life; A technology that literally allows me to weave stone.

My prototypes mediate between the marine geosphere and biosphere. The spun steel nets provide a *bioreceptive surface* (Cruz & Beckett 2016) for multiple forms of marine life to slowly colonize on the mesh (Figure 4). Rather than taking a strictly selective approach to coral reef conservation, as classically the case in coral nurseries (which host a limited number of pre-selected coral branches), these prototypes should be viewed as an invitation for various forms of marine life to proliferate and thrive. The wild colonization of corals, sponges, algae and even marine neophytes is a desired outcome of these biological material experiments. For me, designing Architectures of Cohabitationmeans inviting all symbiotic forms of marine life to actively participate in the design process. They co-design their own habitat and subsequently change the appearance and species composition of the prototype. Thus, the design process takes place not only in the sea, but together with the marine ecosystem.

In my designs, I try to give the sympoïetic growth processes of the marine biome the decisive voice. Marine species shape the underwater architecture, distort it, overgrow it, make it invisible, possibly even cause it to collapse.

The environments that will eventually serve as testing grounds for my marine Interspecies Architectures are neither the "pristine" and endangered coral reefs of Hilbertz's previous work nor the marine protected areas of my first field experiments. The seascapes I want to study and which I regard as ideal environment for my prototypes are areas of high anthropogenic impact, or as Clouette and Fabien call them, an 'AnthropOcean' (2018)—The harbor, the former industrial mine, the canal, the marine military zone or the tourist beach are the damaged, contaminated, and conflicted zones of marine survival that I will engage with in order to design habitats "amidst ruins" (Tsing 2015).

I consider these slow-growing structures as Architectures of Co-habitation, as they provide a habitat for multiple marine species and temporary human visitors alike. Based on Tsing's and Barua's notion of "feral ecologies" (2021), sympoietic ecological worlds emerge in the Anthropocene when other-than-human beings become entangled with human infrastructure in urban environments (Tsing et al. 2021). My underwater prototypes are located precisely in these conflicted zones—they are breeding ground, ecological niche, and site of human infrastructure, interest, and intervention.

Figure 3 Underwater prototype by Rasa Weber (in the pic- ture). Location: Station de Recherche Océanographiques et sous-marines, Calvi, Corsica (FR). Photo: Anja Wegner, 2022.

Designing Habitats

"How much longer will we agree to step aside in silence as masters of the universe [...] *? How much longer will you and I choose extinction?"* [16]

– Gan, Tsing, Swanson & Bubandt 2017.

If design takes its fundamental contribution to the unruly times of the Anthropocene seriously and begins to "*care for that which is non-human"* [17], it will encounter a series of troubling questions. A design practice that is not only interested in advocating for human agency, but also includes **other species** and **conflicted environments** in its processes of making, must be brave enough to propose new *"modes of production and cooperation that escape from the evidence of economic growth and* *competition."* [18] If design advocates **conviviality** and **shared survival**, it must formulate strategies to *"positively cohabit a thriving biosphere"* [19], and inevitably comes into contact with fundamental systemic issues of our assigned human role in the ecological fabric.

In his early publications, Wolf Hilbertz refers to his marine engineering intervention as "**Cybertecture**" [20]. The neologism is a reference to Hilbertz' understanding of architecture as a logical extension of the principles of cybernetics [21] to the built environment (CYBERnetics + archiTECTURE). Most likely inspired by Norbert Wiener's famous concept of Cybernetics as *"the science of control and communications in the animal and machine"* [22], Hilbertz thought of complex systems controlled by a purposive model of causality and feedback. Such a biogenetic model, "*that employs self-improving software and hardware* [and] *can draw 'unorganized' matter into its system"* [23], suggest a revolutionary notion of architecture as constantly adaptive and self-improving. However, the cybernetic core of his theory also, perhaps unintentionally, places the human in the center of system control. The concept of the designer as a "helmsman" (ky-bernētēs Greek = helmsman), who has full control over a system and is responsible for its well-being, must be seen in the context of the unbridled techno-optimism of the 1960s and the concomitant rise of the human-centered design movement (e.g. Arnold, Stanford University design program, 1958). It should be kept in mind that when Hilbertz developed his theory of Cybertecture, the discourse of architectural theory was just beginning to address environmental consciousness for the first time, also triggered by the ecological discourse of prominent voices such as a.o. Rachel Carson (1962).

With the Biorock system, Hilbertz and Goreau introduced an extremely bold ecological technology that was far ahead of its time and made it possible to build with and within the ocean ecosystem. However, given what we now today about the cumulative impacts of humans on the world's ocean systems, we need to reevaluate the system's useful technological capabilities [24] in relation to its potential consequences.

"The planet takes care of us, not we of it", [25] Margulis states in her influential book A Symbiotic Planet(1998).Rather than trying to regulate the incredibly complex system relationships of an ecology, or even going so far as to *"cure"* the ocean as *"a sick patient"* [26], Margulis' perspective suggests questioning the role of human control in favor of a much modest and highly interconnected perspective. From this thought, we designers must accept our small part as humans within larger ecological relationships that transcend the influence of human intentions.

In this sense, the Biorock principle could shape and inform contemporary design discourse to conceive "*evolutionary environments"* [27] that adapt to their environmental conditions and grow responsively with the marine ecosystem. Today, Goreau and Hilbertz' concept could serve as a starting point for developing a form of sympoïetic making that views the designed "product" not just as the result of planned human intervention, but as relational, highly connected, and life-giving habitat.

Towards Sympoïetic Design

A design practice that sees the agencies of all life forms as central to shaping the design process may be able to move beyond a product-driven and extractive notion of design and open up to collaborative forms of design that transcend species barriers.

I propose to call these practices Sympoïetic Design. The evolutionary model of symbiogenesis lays the groundwork for conceptualizing design processes as long-term collaborations between humans and other-than-human beings. These sympoïetic processesextend over unimagined time spans and situate design practices in troubled environments. Design becomes an action of shaping "invitations" (Stahl & Lindström, 2016) for animals, bacteria, proctists, et al. The resulting prototypes I present here suggest that mineralized limestone mesh can serve as a *"bioreceptive medium"* (Cruz & Beckett, 2018) for a variety of marine species to settle on them (Figure 4 & 5). Sympoïetic Design provides habitats as contact zones for coevolution between different species.

Figure 4 (above): **(left)** Underwater prototype by Rasa Weber, conduct. steel yarn after installation, Sun Reef, Curaçao (AN). Photo: Rasa Weber, 2022. **(right)** Underwater prototype by Rasa Weber, conductive steel yarn after 2 months in the ocean, mineral accretion and pioneering organisms, Sun Reef, Curaçao (AN). Photo: Mike Duss, 2022.

Het Niewe Instituut recently introduced the term "Zoöps" to describe a *"cooperative legal entity in which humans and multispecies ecological communities are partners"* [28](zoë Greek = life). The idea is intriguing because it views habitats as an assembly of symbiotic entities that engage humans in their "naturecultural" [29] relationships within an anthropogenic ecology. As humans, we impact habitats, but at the same time are inevitably a part of them. Designing for ecological impact, then, means designing *in* and *with* the habitats that assure our own survival. Applying this concept to marine habitats and thus creating convivial zones of protection and experimentation as Marine Zoöps should become a central task for design in the ocean.

A number of young designers and researchers are beginning to design systems *with* and *for* other-than-humans. The Symbiotic Spaces Collective is working on 3D-printed architectures located in local wetlands that provide multispecies habitats for urban wildlife. Designer Marie Griesmar, biologist Ulrike Pfreundt, and marine scientist Hanna Kuhfuss, founders of Rrreefs e.V., developed a 3D-printed clay brick that serves as a module for coral reef restoration. The biologist Anja Wegner and the artist collective Superflex collaborate on their "Pink Elements" to create "fish architecture"[30] for damselfish, and designer David Enon experiments with growing underwater furniture from limestone structures as coral habitat with his "Mineral Accretion Factory" [31].

Despite these early beginnings, deep reflection on the benefits and limitations of working with/in ecological systems is urgently needed. Sympoïetic Design raises new questions for our discipline that call for further discussion:

– ***How does Sympoïetic Design affect the role of the designer as author?***

– ***What agency does it give to other-than-human creators in the design process?***

– ***What forms of (disciplinary) knowledge are needed to implement and evaluate it?***

– ***What timespans are needed to facilitate it?***

– ***Who are we designing for?***

– ***How structured or "messy" will the result be?***

Working with/in the marine biome can be a first experimental approach to discuss the potentials and challenges of Sympoïetic Design. With my underwater prototypes, I work on creating contact zones between multiple forms of marine life. These Architectures of Cohabitation mediate between animate and inanimate matter, between human-made and naturecultural ecosystems, between human and environmental agency. Rather than restoring "pristine" nature, these co-created habitats encourage the designer to relinquish control of the system and invite the wildly proliferating and uncurated, unexploited life forms to the process of creation.

Sponges, algae, coral, electrical circuits, marine biologists, fish, cameras, limestone, polyps et al. become part of these multispecies marine eclogies of sympoïetic making. Sympoïetic Design opens the door to design practices that transform human-centered design projects into an evolutionary practice of share survival. Towards a *sea change* [32] in design.

Figure 6 Underwater prototype by Rasa Weber after 6 months in the ocean, conductive steel yarn, mineral accretion and pioneering organisms. Location: Sun Reef, Curaçao (AN). Photo: Pavel Siman, 2022.

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References

Books

Horst Bredekamp, *Darwin's Corals. A New Model of Evolution and the Tradition of Natural History,* Berlin, Boston, De Gruyter, 2019, https://doi.org/10.1515/9783110680317.

Rachel Carson, *Silent Spring,* New York, Fawcett Crest, 1962.

Donna J. Haraway, *The Companion Species Manifesto. Dogs, People, and Significant Otherness,* Bristol, Prickly Paradigm Press, 2003.

Stefan Helmreich, *Alien Ocean: Anthropological Voyages in a Microbial Sea,* Seas Berkeley, CA, University of California Press, 2009.

Boris M. Kozo-Polyansky In: *Symbiogenesi,. A new principle of evolution,* Translation from the Russian by Victor Fet, Eds. By Victor Fet, Lynn Margulis, Cambridge, Harvard Univ. Press, 2010.

Bruno Latour, Foreword, In: *Prospecting Ocean*, ed. Stefanie Hessler, Cambridge, Massachusetts, London, England, The MIT Press, 2019, 11-13.

Claudia Mareis & Nina Paim (Eds.), *Design Struggles. Intersecting Histories, Pedagogies, and Perspectives,* Amsterdam, Valiz, 2021.

Lynn Margulis, *The Five Kingdoms: Illustrated Guide to the Phyla of Life on Earth,* San Francisco, W.H. Freeman & Co Ltd., 1982.

Lynn Margulis, *Symbiotic Planet, A New Look on Evolution,* Amherst, Massachusetts, Brokman inc., Basic Books, revisited edition, 1998.

Astrida Neimanis, *Bodies of Water: Posthuman Feminist Phenomenology, Environmental Cultures.* London, New York, Bloomsbury Academic 2017.

Isabelle Stengers, *Cosmopolitics I.,* Minneapolis, London, Minnesota Press, 2010.

Isabelle Stengers, *In Catastrophic Times - Resisting the Coming Barbarism,* Open Humanities Press, Meson Press 2015.

Anna L. Tsing, *The Mushroom at the End of the World: On the Possibility of Life in Capitalist Ruins,* Princeton, Princeton University Press, 2015.

Anna L. Tsing, Heather A. Swanson, Elaine Gan & Nils Bubandt (Eds.), *Arts of Living on a Damaged Planet: Ghosts and Monsters of the Anthropocene,* Minneapolis, University of Minnesota Press, 2017.

Ron Wakkary, *Things We Could Design: For More Than Human-Centered Worlds,* Cambridge, MA, MIT Press, 2021.

Norbert Wiener, *Cybernetics, or, Control and communication in the animal and the machine.* The Massachussets Institute of Technology, orig. 1948, Cambridge Massachussets, The MIT Press, 1985.

Chapters in Books

Richard Dawkins, “Chapter 4: The Gene Machine”, In: *The Selfish Gene,* Oxford, Oxford University Press, 1976, 46-65.

Donna J. Haraway, Chapter 3: Four Critical Zones. In: *Staying with the Trouble: Making Kin in the Chthulucene;* Durham and London, Duke University Press, 2016, 72-76.

Donna J. Haraway, “Chapter 3: Sympoiesis. Symbiogenesis and the Lively Arts of Staying with the Trouble”, In: *Staying with the Trouble: Making Kin in the Chthulucene,* Durham and London, Duke University Press, 2016, 58-98.

Åsa Ståhl, Kristina Lindström, “Politics of Inviting: Co-Articulations of Issues in Designerly Public Engagement”, In:*Design Anthropological Futures,* Rachel C. Smith et al. (Eds.), London, Routledge, 2016.

Jonathan P. Zehr, David A. Caron, “Symbiosis in the Ocean Microbiome”, In: *The Marine Microbiome: An Untapped Source of Biodiversity and Biotechnological Potential*, Lucas J. Stal & Mariana S. Cretoiu (eds.), Springer, 2016, 535-577.

Journal article (online)

Cecilia Åsberg, “A Sea Change in the Environmental Humanities”, In: *Ecocene: Cappadocia Journal of Environmental Humanities* Vol. 1, No. 1, 2020, 108-122.

Maan Barua, “Feral ecologies: the making of postcolonial nature in London”, *Journal of the Royal Anthropological Institute*, Vol. 28, No. 3, 2021, 896-919.

Jeremie Brugidou, Clouette Fabien, “‘AnthropOcean’: Oceanic perspectives and cephalopodic imaginaries moving beyond land-centric ecologies.” *Social Science Information*, Vol. *57* No. 3, 2018, 359–385, DOI: https://doi.org/10.1177/0539018418795603.

Marcos A. da Silva Cruz, Richard Beckett, “Bioreceptive design: a novel approach to biodigital materiality”, *Architectural Research Quarterly* Vol. 20, No. 1, 2016, 51-54.

Ricardo Guerrero, Lynn Margulis, Mercedes Berlanga, “Symbiogenesis: the holobiont as a unit of evolution.” *Microbiol.* Vol. 16, No. 3, 2013, 133-43.

Benjamin S. Halpern, Melanie R. Frazier, Jamie Afflerbach, et al. “Recent pace of change in human impact on the world’s ocean”, *Scientific Reports* Vol. 9, No.1, 2019, Doi:10.1038/s41598-019-47201-9.

Wolf Hilbertz, “Toward Cybertecture.” *Progressive Architecture, The Architect as Developer* (1970), Wolf Hilbertz Website, accessed February 14, 2024, http://www.wolfhilbertz.com/downloads/1970/hilbertz_t_cybertecture_1970.pdf.

Wolf Hilbertz, “Strategies for Evolutionary Environments”, *The Responsive House*, Edward Allen (Ed.), MIT Press, 1972.

Wolf Hilbertz Website, accessed online February 14, 2024, http://www.wolfhilbertz.com/downloads/1970/hilbertz_t_cybertecture_1970.pdf.

Wolf Hilbertz, “Electrodeposition of Minerals in Sea Water: Experiments and Applications”, *IEEE Journal on Oceanic Engineering,* Vol. OE-4 Vol.3 1979, 94-113.

Wolf Hilbertz Website, accessed online February 14, 2024, https://globalcoral.org/_oldgcra/IEEE_JOUR_1979small.pdf.

Melody Jue, “Scuba Diving as Praxis: A Field Guide for Underwater Orientation by Melody Jue”, *Fieldwork for Future Ecologies*, ed. Bridget Crone, Sam Nightingale, and Polly Stanton (Onomatopee, 2023), accessed February 14, 2024, https://static1.squarespace.com/static/545596ece4b0717418ebf8e6/t/642de8963cdc9f603863cdc3/1680730265157/Melody+Jue_Scuba+diving+praxis.pdf.

Klaus V. Kowallik & William F. Martin “The Origin of Symbiogenesis: An annotated English translation of Mereschkowsky’s 1910 paper on the theory of two plasma lineages”, *Bioystems,* Vol. 199, No. 104281, 2020, Doi: 10.1016/j.biosystems.2020.104281.

Johannes Lohmann, Daniele Castellana, Peter D. Ditlevsen, and Henk A. Dijkstra “Abrupt climate change as a rate-dependent cascading tipping point.” *Earth System Dynamic*, Vol. 12, No. 3, 2021, 819–835.

Justin Raycraft. “Seeing from Below: Scuba Diving and the Regressive Cyborg.” *Anthropology and Humanism*, Vol. 45, No. 2, 2020, 301-321.

Lynn Sagan, “On the origin of mitosing cells.” *J. Theoretical Biology* Vol. 14, No. 3, 1967, 255-274, doi:10.1016/0022-5193(67)90079-3.

Marie E. Strader, Kate M. Quigley, “The role of gene expression and symbiosis in reef-building coral acquired heat tolerance”, *Nature Communications* Vol. 13, Article number, 4513, 2022.

Heather A. Swanson, Sonia Levy, “A (Highly) Partial Field Guide to British Canals: Introducing some processes and beings", TBA21-Academy, 2021.

Websites

Thomas J. Goreau, “A review of John Todd, 2019: Healing Earth: An ecologist’s journey of innovation and environmental stewardship (2019)”,Global Coral Reef Alliance Website, accessed: November 17, 2022, www.globalcoral.org/a-review-of-john-todd-2019-healing-earth-an-ecologists-journey-of-innovation-and-environmental-stewardship/.

Nieuwe Instituut, “Zoöp Nieuwe Instituut (2022)”, Nieuwe Instituut Website, accessed: December 9, 2022, https://zoop.hetnieuweinstituut.nl.

Anna L. Tsing, Jennifer Deger, Alder Keleman Saxena & Feifei Zhou, *Feral Atlas: The More-Than-Human Anthropocene,* Redwood City, Stanford University Press, 2022), Feral Atlas Website (2022), accessed December 9, 2022, http://feralatlas.org.

Conference Proceedings

David Enon, “Mineral accretion factory: An underwater production process with a positive impact on the environment”, *Figshare, Journal contribution, Conference*, RTD, 2019, DOI: https://doi.org/10.6084/m9.figshare.7855775.v2.

Christoph Heinze, Thorsten Bleckner, Helena Martins et al. “The quiet crossing of ocean tipping points.” *Proceedings of the National Academy of Sciences* Vol. 118, No. 9, 2021, DOI: https://doi.org/10.1073/pnas.2008478118.

Anja Wegner, Superflex & Alex Jordan, “Fish Architecture – A framework to create Interspecies Spaces.” *Proceedings of Politics of the machines* - Rogue Research 2021, (POM 2021).

Anja Wegner, Rasa Weber, “Attunement to the Ocean. Underwater field methods between marine biology and design research”, *Counterparts: Exploring Design Beyond the Human, Swiss Design Network Conference 2022.* (Forthcoming).

Design Works

David Enon, *Mineral Accretion Factory,* since 2011.

Marie Griesmar, Ulrike Pfreundt, & Hanna Kuhfuß, *The rrreef bricks.* Rrreefs e.V., since 2020.

Laurin Kilbert & Joana Schmitz, *Symbiotic Spaces*. Symbiotic Spaces Collective, since 2020.

Rasa Weber, *Symbiocean*, since 2022.

Anja Wegner & Superflex, *Pink Elements,* since 2019.

Notebooks

Charles R. Darwin, “Sketch: Coral of Life.” Page 26 of *Notebook B*, (1837–1838). Cambridge University Library MS DAR.121.26.

Endnotes

1 Lynn Margulis, *Symbiotic Planet. A New Look on Evolution,* Amherst, Massachusetts, Brokman inc., Basic Books, revisited edition, 1998, 5.

2 Jonathan P. Zehr, David A. Caron, "Symbiosis in the Ocean Microbiome." In: *The Marine Microbiome*: An Untapped Source of Biodiversity and Biotechnological Potential, Lucas J. Stal & Mariana S. Cretoiu (eds.), Springer, 2016, 535-577.

3 Donna J. Haraway, Chapter 3: Four Critical Zones. In: *Staying with the Trouble: Making Kin in the Chthulucene,* Durham and London, Duke University Press, 2016, 72-76.

4 Holobiont def. = *The entire community of living organisms.* In: Michael Allaby, *Dictionary of Ecology,* Oxford, Oxford University Press, 2015.

5 Symbiogenesis def. = *The result of the permanent coexistence of various bionts to form the holobiont (namely, the host and its microbiota).* In: Ricardo Guerrero, Lynn Margulis & Mercedes Berlanga, "Symbiogenesis: the holobiont as a unit of evolution." *Microbiol.* Vol. 16, No. 3, 2013, 133-43.

6 Boris M. Kozo-Polyansky In: *Symbiogenesis. A new principle of evolution.* Translation from the Russian by Victor Fet, Eds. By Victor Fet and Lynn Margulis, Cambridge, Harvard Univ. Press, 2010.

7 Klaus V. Kowallik, William F. Martin "The Origin of Symbiogenesis: An annotated English translation of Mereschkowsky's 1910 paper on the theory of two plasma lineages", *Biosystems,* Vol. 199, No. 104281, 2020, Doi: 10.1016/j.biosystems.2020.104281.

8 Richard Dawkins, "Chapter 4: The Gene Machine", In: *The Selfish Gene,* Oxford: Oxford University Press, 1976, 46-65.

9 Margulis outlined "*the astounding details of the microbes (...) in their tendency to survive by making symbiotic evolutionary commitments,"* arguing for her central theory on the origin of eukaryotic cells from prokaryotic organisms, In: Lynn Margulis, *Symbiotic Planet,* Basic Books 1989, 72.

10 Horst Bredekamp, *Darwin's Corals. A New Model of Evolution and the Tradition of Natural History,* Berlin, Boston, De Gruyter, 2019, https://doi.org/10.1515/9783110680317.

11 Charles R. Darwin, "Sketch: Coral of Life." Page 26 of *Notebook B*, 1837–1838, Cambridge University Library MS DAR.121.26.

12 Lynn Margulis, *The Five Kingdoms: Illustrated Guide to the Phyla of Life on Earth,* San Francisco: W.H. Freeman & Co Ltd., 1982.

13 sympoïesis def. = *"Σύν, sún = greek 'together' and ποίησις, poíēsis = greek 'creation, production'".* In: Donna J. Haraway *Staying with the Trouble. Making Kin in the Chthulucene,* Duke University Press, 2016, p.58.

14 Anja Wegner, Rasa Weber, "Attunement to the Ocean. Underwater field methods between marine biology and design research", *Counterparts: Exploring Design Beyond the Human, Swiss Design Network Conference 2022.* (Forthcoming).

15 Wolf Hilbertz, "Electrodeposition of Minerals in Sea Water: Experiments and Applications", *IEEE Journal on Oceanic Engineering,* Vol. OE-4 Vol.3 (1979): 94-113. Wolf Hilbertz Website, accessed online February 14, 2024, https://globalcoral.org/_oldgcra/IEEE_JOUR_1979small.pdf.

16 Anna L. Tsing, Heather A. Swanson, Elaine Gan & Nils Bubandt (Eds.) *Arts of Living on a Damaged Planet: Ghosts and Monsters of the Anthropocene,* Minneapolis, University of Minnesota Press, 2017, G4.

17 Ron Wakkary, *Things We Could Design: For More Than Human-Centered Worlds,* Cambridge, MA, MIT Press, 2021, 1-2.

18 Isabelle Stengers, *In Catastrophic Times - Resisting the Coming Barbarism,* Open Humanities Press, Meson Press 2015, 24.

19 Ron Wakkary, *Things We Could Design* (2021), 2.

20 Wolf Hilbertz, "Toward Cybertecture." *Progressive Architecture, The Architect as Developer* (1970), Wolf Hilbertz Website, accessed February 14, 2024, http://www.wolfhilbertz.com/downloads/1970/hilbertz_t_cybertecture_1970.pdf.

21 Cybernetics def. = *The term cybernetics comes from the ancient Greek word* κυβερνήτης, *kybernetikos = "good at steering", referring to the art of the helmsman.* In: Britannica Website, accessed February 1, 2022, https://www.britannica.com/science/cybernetics.

22 Norbert Wiener, *Cybernetics, or, Control and communication in the animal and the machine,* The Massachussets Institute of Technology, orig. 1948, Cambridge Massachussets, The MIT Press, 1985.

23 Wolf Hilbertz "Toward Cybertecture", 1970, 99. [Addition by the autor.]

24 Benjamin S. Halpern, Melanie R. Frazier, Jamie Afflerbach, et al. "Recent pace of change in human impact on the world's ocean." *Scientific Reports* Vol. 9, No.1, 2019, Doi:10.1038/s41598-019-47201-9.

25 Lynn Margulis, *Symbiotic Planet,* 1998, 115.

26 Thomas J. Goreau, "A review of John Todd, 2019: Healing Earth: An ecologist's journey of innovation and environmental stewardship (2019)",Global Coral Reef Alliance Website accessed: November 17, 2022, www.globalcoral.org/a-review-of-john-todd-2019-healing-earth-an-ecologists-journey-of-innovation-and-environmental-stewardship/.

27 Wolf Hilbertz, "Strategies for Evolutionary Environments." *The Responsive House*, Edward Allen (Ed.) (MIT Press, 1972), Wolf Hilbertz Website, accessed online February 14, 2024, http://www.wolfhilbertz.com/downloads/1970/hilbertz_t_cybertecture_1970.pdf.

28 Nieuwe Instituut, "Zoöp Nieuwe Instituut (2022)", Nieuwe Instituut Website, accessed: December 9, 2022. Link: https://zoop.hetnieuweinstituut.nl.

29 Natureculture def. = *a synthesis of nature and culture that recognizes their inseparability in ecological relationships that are both biophysically and socially formed.* In: N. M. Malone & Kathryn "Natureculture", In: *The International Encyclopedia of Primatology,* John Wiley & Sons. See also: Donna J. Haraway, *The Companion Species Manifesto. Dogs, People, and Significant Otherness.* (Bristol: Prickly Paradigm Press, 2003).

30 Anja Wegner, Superflex, Alex Jordan, "Fish Architecture – A framework to create Interspecies Spaces." *Proceedings of Politics of the machines* - Rogue Research 2021, POM 2021.

31 David Enon, "Mineral accretion factory: An underwater production process with a positive impact on the environment." *Figshare. Journal contribution. Conference*, RTD, 2019, DOI:https://doi.org/10.6084/m9.figshare.7855775.v2.

32 Cecilia Åsberg, "A Sea Change in the Environmental Humanities." In: *Ecocene: Cappadocia Journal of Environmental Humanities* Vol. 1, No. 1, 2020, 108-122.