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Performative Biotechnical Forms

Culturalizing the Microbiota from High-Tech to Bio-Tech Architecture

Claudia Pasquero and Marco Poletto

In the Anthropocene, an epoch when our civilization has impacted on metabolic processes at a planetary scale, we are depending, perhaps paradoxically, upon non-anthropocentric forms of intelligence. Without us noticing today we inhabit the Urbansphere, the global apparatus of contemporary urbanity, a dense network of informational, material and energetic infrastructures that sustain our increasingly demanding metabolism. In order to provide the required levels of resources in the right place at the right time the Urbansphere interrupts the fluctuating metabolisms of the other spheres of life on Earth.

The miniaturisation, distribution and intelligence of the networks of the Urbansphere and of its nodes have reached inhuman complexity, engendering evolving processes of synthetic life within itself. Endo-symbiotic relationships unexpectedly emerge among its heterogeneous components, especially when biologic evolution negotiates contaminated habitats and ubiquitous forms of artificial intelligence. Therefore, in the Anthropocene we need more than ever strategies to deal with such complexity and with the inhuman logics underpinning it.

In this chapter the authors suggest how such strategies may be developed within the realm of architectural and urban design through a combination of:

- Direct observation of living organisms that operate collectively at scales other than the human one
- Mediated interaction with related processes of material transformation and spatial morphogenesis
- Radical repurposing bio and digital technologies involved in these processes as tools of speculative design

The Urbansphere and its technological apparatus, in the form of synthetic biology, biotechnology, artificial intelligence and so on, opens scenarios where the boundaries between natural and artificial, landscape and city, human and non-human realms are blurred. The object of architecture becomes ambiguous and its aesthetic language now embodies feelings of estrangement, discomfort and disruption.

With this article we propose a productive form of alienation where micro-organisms such as bacteria, fungi, spiders and moulds can act both as a behavioural model for architecture and as active agents of architectural production. This notion has thus far led our practice, ecoLogicStudio, to experiment with processes of digital and biological computation often embedding material intelligence in architectural apparatus at 1:1 scale. In the past 10 years we have built more than 20 prototypes, installations and pilot projects to describe, test and experience architecture as a form of material life; some of the most significant ones are illustrated in the following pages.

These projects engage the evolving process of living matter, thus embedding the objecthood of architecture within its surrounding environment or milieu. We claim here a new meaning for the notion of "cultivation", no longer solely concerned with tending plants and natural landscapes such as in horticulture, but now involved in a more expanded field of analogue and digital design processes impacting upon our perception and understanding of urbanity.

As such *cultivation* also acquires critical relevance in re-framing our relationship to emergent digital technologies and becomes part of a broader process of "culturalization" of the inhuman systems that populate the Urbansphere and that are now brought into the scope and focus of architecture, intended in its aesthetic, performative and ecological aspects.

This shift has direct influence on the ever-critical relationship between form and performance in contemporary disciplinary discourse. With the goal of unpacking this influence let us begin by observing the effects of endo-symbiosis in collective formations like corals colonies.

Critical to the definition of endo-symbiosis and its relevance to architecture is the way parts relate to wholes, or in other words how do we conceptualize the Urbansphere as a whole in relationship to its architectural and techno-material components (Figure 10.1).

Deleuze and Guattari in one of their best-known passages (Deleuze and Guattari, 1987) referred to the relationship between the Wasp orchid and the Thynnie wasp; the orchid flower has evolved parts that resemble very closely the female wasp; the seduced wasp male tries to mate with the flower and by doing so it pollinates the plant; the two have evolved so inseparably that even their appearance has become similar despite being an insect and a plant. Despite them being obviously separate objects, belonging to separate realms of nature, the wasp is inherently part of the plant and of its reproductive mechanism. So much so that it becomes very hard to draw a frame around its identity; however, refraining from doing so allows us to conceptualize the pair as a larger ensemble, and their coupling as the process of reproduction of the machinic system itself.

Similarly, dunes can be seen as an immeasurable number of sorting machines creating coherent patterns of sand distribution that travel in space and time until final dissolution, while human beings may be better described as an assemblage of desiring machines, thousands of mechanisms that without us noticing are producing the dreams that we do notice and that surface to the level of consciousness.

It is a new notion of symbiosis that forces us to redefine the modern and linear understanding of cause–effect by re-describing the boundaries of an object within its environment and by taking into account the multiple interlocking feedback loops that define the behaviour of the individual unit within the larger apparatus of the Urbansphere. In the evolution of some organism the effect of such a relationship has become so close to be internalized in the morphology and behaviour of the host organism itself, so much so that the organism appears to contain multiple levels of machinic feedback. A significant and fascinating case are corals which are globally bleaching, and dying, as a consequence of global disruption of these feedback mechanisms.

> Corals are both collective organisms and an example of endo-symbiosis:
>
> An endosymbiont is a cell which lives inside another cell with mutual benefit. Eukaryotic cells are believed to have evolved from early prokaryotes that were engulfed by phagocytosis. That is when the engulfed prokaryotic cell remains undigested as it contributes new functionality to the engulfing cell. In the case of corals this new functionality is photosynthesis. Over generations, the engulfed cell lost some of its independent utility and became a supplemental organelle.
>
> *(Bioninja, n.d.)*

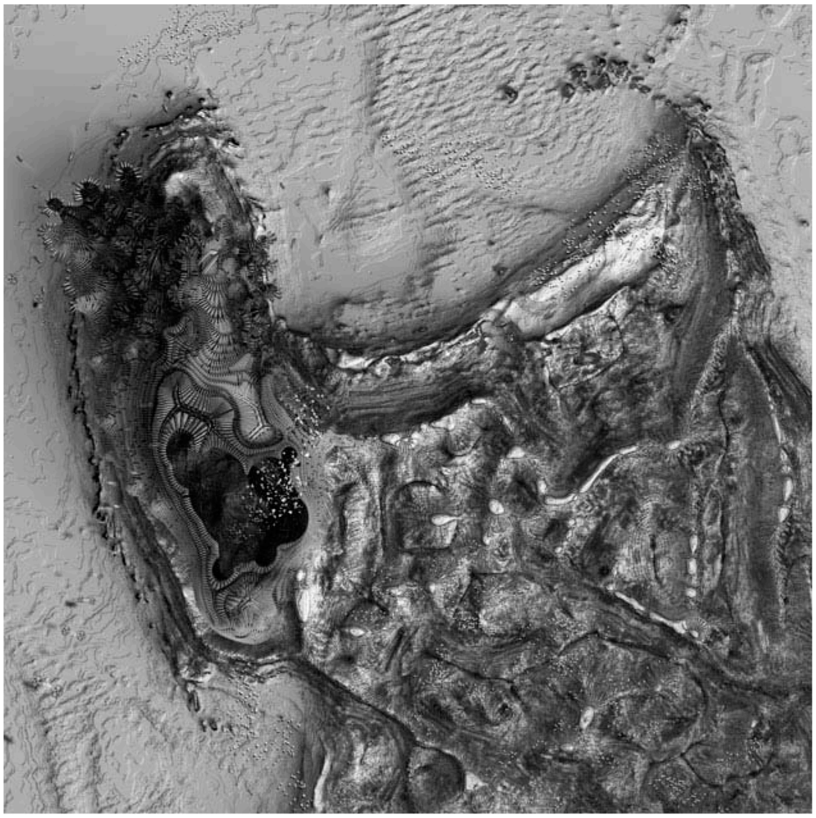

Figure 10.1 The Anthropocene Island Project, Tallinn Biennale 2017—Urban Design proposal for a new eco-city on the peninsula of Paljassarre. Top view.

Source: Copyright ecoLogicStudio

In the case of corals, the engulfed organisms are called zooxanthellae, a form of algae called dinoflagellate.

> Corals are usually colonies of polyps. Polyps are live coral tissue extensions that cover the calcium carbonate structure and are usually only a few millimetres thick. The tissue has two layers, the epidermis and the gastrodermis, where the zooxanthellae live. Zooxanthellae are unicellular and spherical with two flagella that fall off once they are incorporated within a host.
>
> *(Microbe Wiki, n.d.)*

The coral polyps do cellular respiration, thus producing carbon dioxide and water as by-products. The zooxanthellae then take up these by-products to carry out photosynthesis. The products of photosynthesis are used to make proteins and carbohydrates in order to produce calcium carbonate for the coral to grow their exoskeleton.

Polyps that are better exposed to sun light receive a competitive advantage via the zooxanthellae and are able to build their exoskeletons faster thus gaining even more exposure to precious solar energy. Polyps that are less exposed and remain locked in eventually die, while more exposed coral

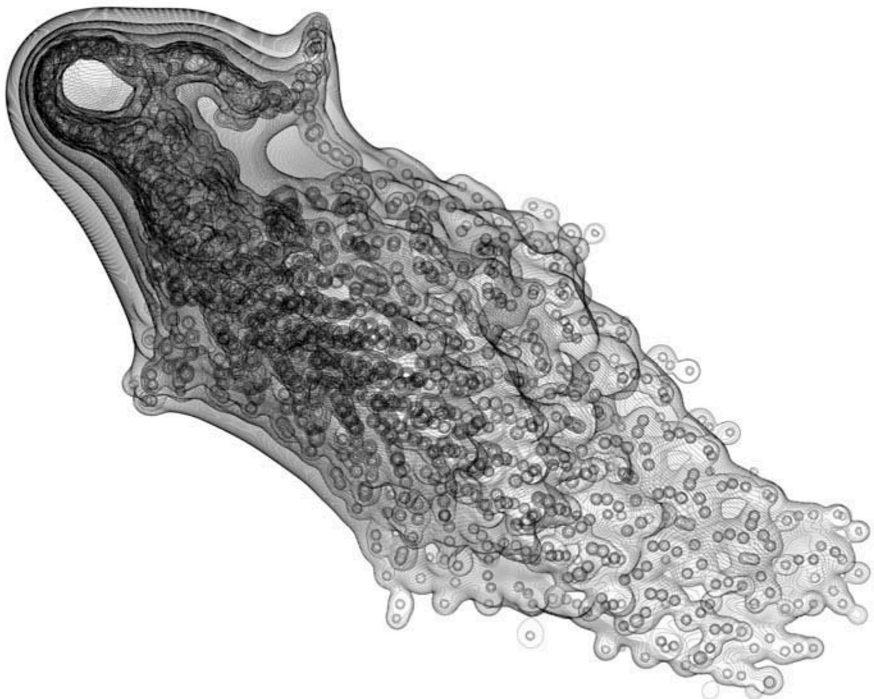

Figure 10.2 HORTUS XL, Thresholds, Centre Pompidou 2019. Iso-surfaces of variable light intensity.
Source: Copyright ecoLogicStudio

can reproduce and conquer larger areas. The particular morphogenesis of stony corals, for instance, and their convoluted bifurcations is an emergent effect of this complex multilayered process of symbiosis comprising multiple feedback loops between marine environment, colony, individual polyp and the algae inhabiting its gastrodermis. It is therefore impossible to capture the nature of corals' morphology without understanding the dynamic nature of this rather complex part-to-whole assemblage and its reason for being within a specific milieu.

The study of such complex interaction has fascinated scientists for decades, but it has only recently become possible to digitally simulate how such a kind of morphogenesis appears. That is by studying and visualizing how morphology emerges at a certain scale from multiple levels of interactions among parts that operate at a significantly smaller scale. In a paper dating back to 2004, Merks, Hoekstra, Kaandorp and Sloot studied and proposed the polyp-oriented modelling of coral growth.

In their words:

> The morphogenesis of colonial stony corals is the result of the collective behaviour of many coral polyps depositing coral skeleton on top of the old skeleton on which they live. Yet, models of coral growth often consider the polyps as a single continuous surface. In the present work, the polyps are modelled individually. Each polyp takes up resources, deposits skeleton, buds off new polyps and dies. In this polyp-oriented model, spontaneous branching occurs. We argue that

> branching is caused by a so called 'polyp fanning effect' by which polyps on a convex surface have a competitive advantage relative to polyps on a flat or concave surface.
>
> *(Merks, Hoekstra, Kaandorp and Sloot, 2004)*

It is interesting to note here how the discretisation of the model, i.e. considering polyps as individual agents, affords a new understanding of the emerging nature of some key traits in the whole colony. This model explains why morphologies that are species-specific also show high variability within one species and how this intraspecific variability is caused by environmental parameters, such as light availability and the amount of water flow.

It also explains how the characteristic bifurcations emerge as a consequence of the collective nature of the coral. At convex sites, the polyps fan out, thus getting better access to the diffusing resources. At concave sites, the polyps point towards each other, thus interfering in the uptake of resources. In this way, a curvature effect comes out as a natural consequence of the competition between the polyps to take up resources. It is possible to translate those findings into digital 3D meshes where polyps are vertices of the mesh with varied access to nutrients (represented as proximity to randomly moving points).

Two sets of considerations are particularly relevant here. Changing the nature of the environment (amount of resources, their speed or direction of movement) without any change to the "coral mesh" or to the rules of interaction of its "polyps' vertices" does generate a very large number of different morphological traits in the coral mesh. Thus, survival in an environment of scarce resources produces diversity and richness of forms. And the convolutedness of the resulting meshes reflects the one found in coral morphologies and results from the process of optimal solar exposure of a collective organism powered by photosynthesis. Small differences are amplified and lead to articulation of form.

Complexity of articulation is a consequence of economy of means.

Therefore, if we redefine our understanding of part-to-whole relationships and trans-scalar hierarchies as a continuum nesting of heterogeneous systems composed of individually interacting units immersed in a changing environment, we can come to understand performativity as a generative force of spatial and material articulation, a morphogenetic force. Within this paradigm competition for scarce resources leads to richness and diversity of forms, unlike in most engineering problem-solving methods where optimization leads to converging average solutions. And also, perhaps a new way to read the famous modernist credo of *Less is More*. Here it is *Less resources equals More articulation*.

Over the years our practice has become increasingly concerned with the actualization of this morphogenetic paradigm in architectural and urban design. This is how a series of projects and installations known as HORTUS was conceived (Figures 10.2–10.4).

This algorithmic protocol simulating coral morphogenesis can be deployed in a variety of ways as a generative design tool for architecture. We can accept its abstractions and simplifications and deploy it to design "coral-like" architectures or architectures inspired by corals. Here corals are what we may call biomimetic models that we take inspiration from to design an artefact that belongs to the world of man-made artificial structures.

Another methodological take is to focus the attention on the relationships between part-to-whole. This implies rejecting the metaphorical translation across scales and regimes to focus instead on the analogy between two models that may look and feel rather different but that share similar relational diagrams. What interests us is that traits such as bifurcations and surface convolutedness maintain in the architectural model their emergent nature in relationship to the specific milieu. The intelligence of the system is therefore embedded in the here and now and operates across scales and regimes, simultaneously in the virtual and material realms. The traits of the system are bred in time, iteration after iteration, during the design process, construction and usage. It is a significant shift from the model

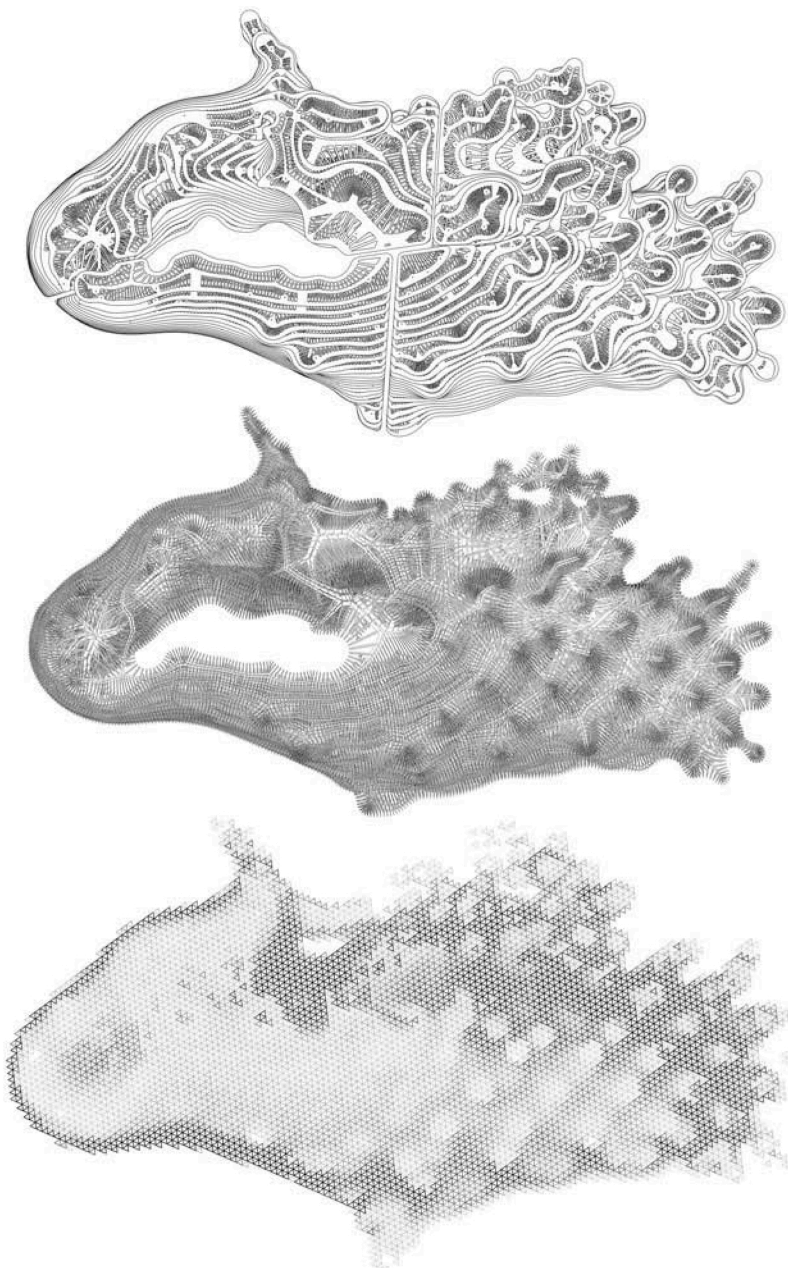

Figure 10.3 HORTUS XL, Actualization studies, Centre Pompidou 2019. Iso-surfaces of light intensity are actualized in a variety of ways. By planar contouring, by discretisation and by continuous three-dimensional articulation.

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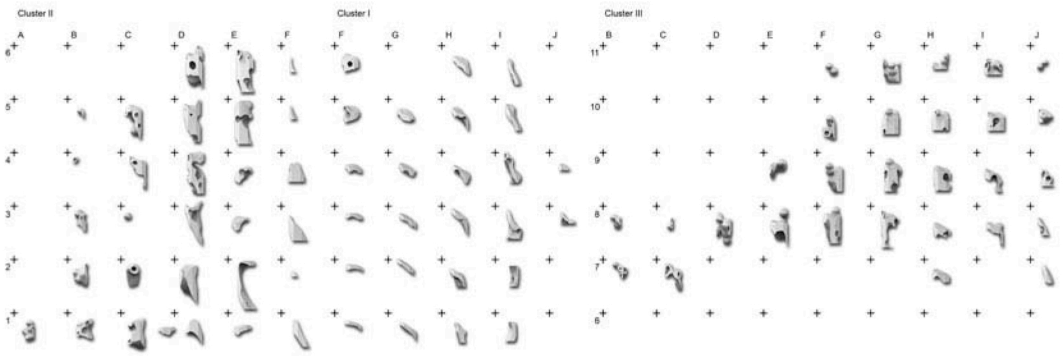

Figure 10.4 HORTUS XL, Actualization studies, Centre Pompidou 2019. The continuous three-dimensional articulation of space defined by iso-surfaces at two different light intensity thresholds is tesselated with an hexagonal grid. Each volume is then catalogued and studied for its 3D printing feasibility.

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typically adopted by the industry which clearly distinguishes the creative moment of digital morphogenesis from the technical challenge of actualizing it in the real world. This transition is worth investigating further.

Let us compare the methods of a bio-engineer synthesizing artificial tissues in a lab with the one of a gardener reviving a patch of dried land; while both are running generative protocols, the first requires a perfectly controlled testing ground for his procedures to acquire general applicability while the second needs to consider the unexpected fluctuations of the ecology of his garden. The gardener operates through a process of intensification of difference; his only chance to reconcile his desire of beautification and the natural expressivity of living processes resides in the movement, intended in its biological and physical sense.

Architect and philosopher Gilles Clément suggests that the formalization of the garden from this perspective becomes a process of formalized transmission of biological messages. Differences in slope, insulation, soil moisture and so on are registered and then exploited by the gardening protocol to promote the growth of different arboreal species; also, the growth, being itself a variable and partially unpredictable process, needs to be read, assessed and then considered in the formulation of future actions, or in the future lines of the gardening protocol.

The garden grows, and beautification progresses in loops; each step generating more difference and local complexity that can be in turn recognized and bred; the management of this generative process is what makes the garden a potentially beautiful and healthy organism.

In Clément's words:

> Reality is entirely contained within experience. Only. Without gardening there is no garden.
>
> *(Clément 2008)*

This sensibility was formalized in the realm of architecture by radical avant-garde movements in the 1960s, like Archigram with their Instant City in 1969. Its evolution appears in the years that followed in the exquisite drawings of bio-mechanical landscapes and architectures by Sir Peter Cook, which can be considered the precursors of a new paradigm of hybridization of technology and nature. Their aesthetical sensibility is ever more relevant today and it is certainly critical to the point we are making

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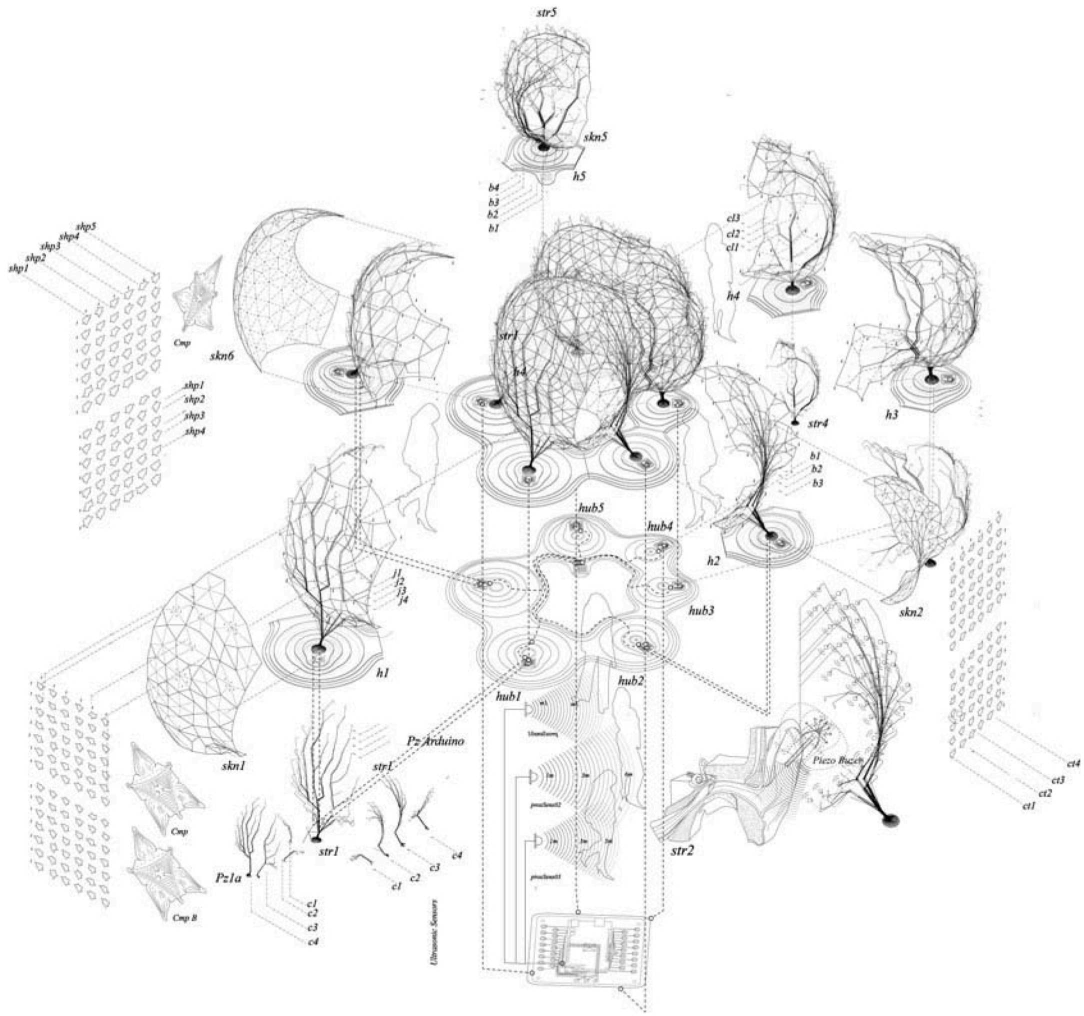

Figure 10.5 Meta-Folly, components diagram, FRAC Collection, Orleans, 2013–2018. This form of cybernetic diagram illustrates the spatial relationships among both digital and human component parts of Meta-Folly, defining the main feedback loops of interaction among them.

Source: Copyright ecoLogicStudio

here; in fact, it prefigures a renewed continuity between the act of simulating (i.e. depicting) nature while at the same time hosting living systems, including humans of course, within the ever-evolving fabric of architecture itself (Figure 10.5).

Contemporary to Archigram was architect Cedric Price. He made the most enduring attempt to expand architecture in the realm of computation and embedded intelligence, especially in his long-standing collaboration with cybernetician Gordon Pask. Unbuilt projects like Fun Palace (1964) and the Generator (1976), as well as the still-in-use London Zoo Aviary (1962), materialize in three dimensions the paradigm of second-order cybernetics and the related concept of Paskian environment.

In the words of Prof. Ranulph Glanville:

> Second order Cybernetics presents a (new) paradigm—in which the observer is circularly (and intimately) involved with/connected to the observed. The observer is no longer neutral and detached, and what is considered is not the observed (as in the classical paradigm), but the observing system […] Therefore, second order Cybernetics must primarily be considered through the first person and with active verbs: the observer's inevitable presence acknowledged.
>
> *(Glanville 2003)*

In architectural terms this notion suggests moving away from ideas of responsive or adaptive systems such as sun-tracking louvres, so dear to the hi-tech modernists, to consider a participatory framework where the observer is no longer a mere user but becomes an active co-creator of the spaces he or she is inhabiting. This shift makes novelty possible as a new kind of spatial conversation may emerge with unexpected consequences on the way space is perceived and utilized. Architecture become a morphogenetic system emerging from a meta-conversation between human and non-human system; it is no longer a question of how we make use of the environment and the space we inhabit but how we become co-creators of planetary space by interacting with other forms of intelligence.

Pask certainly understood the critical importance of the notion of circularity and its relevance to interaction and conversation theory, and for that reason he started building several devices that could interact with humans in space; these installations, such as the seminal The Colloquy of Mobiles at ICA in London in 1968, are known as Paskian Environments. In his own words:

> now we've got the notion of a machine with an underspecified goal, the system that evolves. This is a new notion, nothing like the notion of machines that was current in the Industrial Revolution, absolutely nothing like it. It is, if you like, a much more biological notion, maybe I'm wrong to call such a thing a machine; I gave that label to it because I like to realize things as artifacts, but you might not call the system a machine, you might call it something else.
>
> *(cited in Bateson, 1968)*

We began calling them cyber-gardens.

One of the first was StemCloud 2.0, a living bio-digital installation commissioned by the Seville Biennale of Architecture 2008 and precursor of the HORTUS series (Figures 10.6 and 10.7). Designed in the form of a coral-like landscape, it invited the public to climb up close and interact with its bio-reactors. Each hosting living microbial cultures, they were stacked into a curved formation which framed the gallery space, creating an accessible niche, screening light and releasing oxygen into the atmosphere. Itself a collective organism, the installation behaved as a self-regulating photosynthetic body where both "external conditions", so called environmental factors, as well as the particular micro-ecologies contained in the bio-reactors become integral parts of the cyber-gardening process.

Fast-forward almost 10 years and this line of research has evolved into our first permanent bio-digital sculpture, HORTUS Astana, now part of the Bio.Tech Hut we designed and built for Astana's new Museum of Future energy. Its morphology embodies the three-dimensional distribution of wide-spectrum light sources. The flow of energy emitted as wide-spectrum radiation is digitally simulated in space to visualize their intensive field. Cyanobacteria are then introduced, as bio-bits, their metabolic machines deployed to convert radiation into actual processes of photosynthesis, oxygenation and biomass. Their articulation in space is digitally mediated to arrange the photosynthetic organisms along

Figure 10.6 HORTUS Astana, Bio.Tech Hut Pavilion. Astana, 2017. View of the Living Hut hosting the HORTUS Astana living artwork. Visitors can feed the cultures with CO2 from their exhalations and release oxygen in the atmosphere.

iso-surfaces of optimal incoming radiation. A network of connecting paths is also computed, bringing nutrients and CO2 to the living cyanobacteria. Visitors are active part of the system, feeding it with CO2 with their exhalations and absorbing the released oxygen as it spreads in the surrounding atmosphere.

The project is recasting the practice of computational design into one we have defined as cyber-gardening, embedding biological computation in space. This effort represents an attempt to culturalize the inhuman; that is, to re-describe the boundaries of generative practices beyond what we have called the "Lab model" and towards an extended practice of bio-digital cultivation, the "cyber-Garden model" (Figure 10.8).

This model is reaching its highest definition in our latest incarnation HORTUS XL, commissioned by the Centre Pompidou in Paris in 2018. In HORTUS XL a digital algorithm simulates the growth of the exoskeleton that is then deposited in layers of 400 microns, triangular units of 46 mm and hexagonal blocks of 18.5 cm by digital 3D printing machines. Photosynthetic cyanobacteria are then

Figure 10.7 Bio.Tech Hut, Astana EXPO2017, Living Hut. HORTUS is hanging from the ceiling of the Living Hut as a cloud-like chandelier; its convolutedness responds to incoming light radiation. HORTUS is divided into four clusters which operate as an integral unit. Each part is made of a core structure of laser-cut aluminium sections, acrylic holders and PVC pipes creating the surface of the cloud. Algae circulate in close loops around the structure.

Photo copyright Naaro. © ecoLogicStudio

inoculated on a biogel suspension into the individual triangular cells forming the units of biological intelligence of the collective system. Their metabolic machines convert radiation into actual processes of photosynthesis, oxygenation and biomass production.

In HORTUS XL life proliferates by artificially breeding potentials of intensive difference and cyanobacteria are induced into evolving novel forms of biological intelligence in order to solve the survival problem at hand. In this sense the project re-casts the significance of global ecological issues affecting all systems on Earth in the new light of inhuman survival strategies. The relevance of such strategies to architecture has to be evaluated in relationship to our understanding and more broadly to our conception of the City as an Urbansphere. We then begin to question how the digital production of space through technologies such as 3D printing can enable the proliferation of novel models of inhabitation (human and non-human) and related forms of spatial intelligence.

We have now become aware that in order to evolve a resilient Urbansphere we should intensify its mechanisms of spatial intelligence while rescuing them from the conforming force of contemporary technology, digital and bio alike. It is a sensibility that architects are now loosely defining "post-digital" but that has older roots. In the words of Felix Guattari:

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Figure 10.8 SuperTree installation at Futurium, Berlin, 2018.
Photo copyright Naaro. © ecoLogicStudio

> So, wherever we turn, there is the same nagging paradox: on the one hand, the continuous development of new techno-scientific means to potentially resolve the dominant ecological issues, […] on the other hand the inability of organized social forces and constituted subjective formations to take hold of these resources in order to make them work.
>
> *(Guattari 2008)*

Embedding technology into autonomous forms of material organization augments architecture into a spatial interface, involved in everyday ecologic practices of "cultivation"; that is, of culturalization of the Urbansphere. Architecture can thus operate at multiple interconnected scales at once, from the micro-regimes of algae cells to the macro-behaviours of urban infrastructures, expanding both its scope and reach. It provides the spatial substratum required by extended participation which we have named "bio-citizenship", underlining the expanded role played by inhuman entities to future collective formations. Any architectural protocol in the future shall seek to enable extended participation, and as a consequence it must be able to grow in complexity in time and itself embody a form of artificial intelligence. One that is distributed into the fabric of the spaces we inhabit and that is co-evolutionary to them.

From this perspective microalgae are not only understood as biological organisms, as found for instance in symbiotic relationship with polyps influencing coral morphogenesis, but also as a fascinating repository of intelligent survival strategies evolved over millions of years and that can be embedded into future bio-smart architectures.

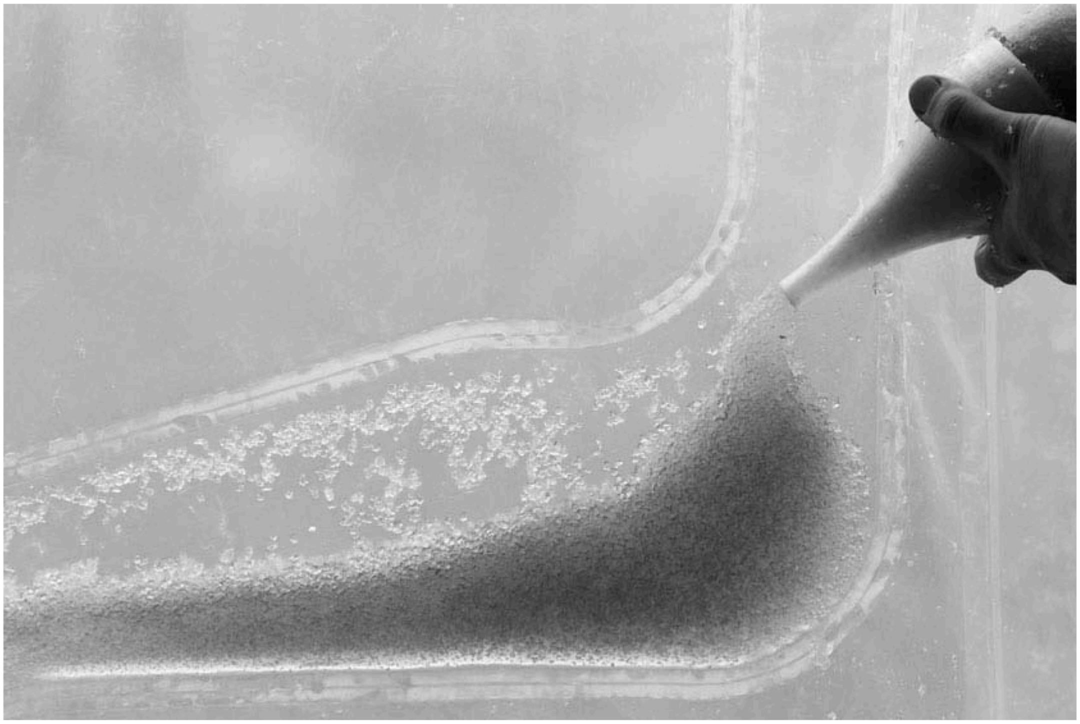

Figure 10.9 Photo.Synth.Etica, living urban curtain, test bed at the Printworks Building, Dublin Castle. Dublin, 2018. Detail of the inoculation process of the algae cultures on a jellified nutritious medium. Jellification creates an intermediate level of substructure in the photobioreactors, increases the levels of photosynthesis, optimizes the CO2/O2 exchange and reduced the overall weight of the system.

In our test beds we discovered that micro-organisms grow faster in artificial bio-digital environments than in the wild because they can be directly connected to the life of buildings which through heat and CO2 emissions stimulate the biomass to grow. Our most recent large-scale pilot scheme is the photosynthetic urban curtain called Photo.Synth.Etica (Figure 10.9). The 200 sq m curtain captures and stores CO2, removing from the atmosphere approximately 1 kg of CO2 per day, equivalent to the contribution of 20 large trees. In our pilot scheme at Dublin Castle, the Printworks Building, the "curtain" is made of 16 modules which wrap a large portion of the main façade spanning two floors. Each module functions as a "photobioreactor", a digitally designed and custom-made bioplastic container of living microalgae cultures.

"Dirty" urban air is introduced at the bottom and while bubbles naturally rise through the jellified medium they come into contact with voracious microbial cells. CO2 molecules and pollutants from the air are captured and stored within the algal body, thus contributing to their growing biomass; this can be harvested and used in the production of more bioplastic raw material. Freshly photosynthesized oxygen is finally released at the top of each module and into the urban microclimate.

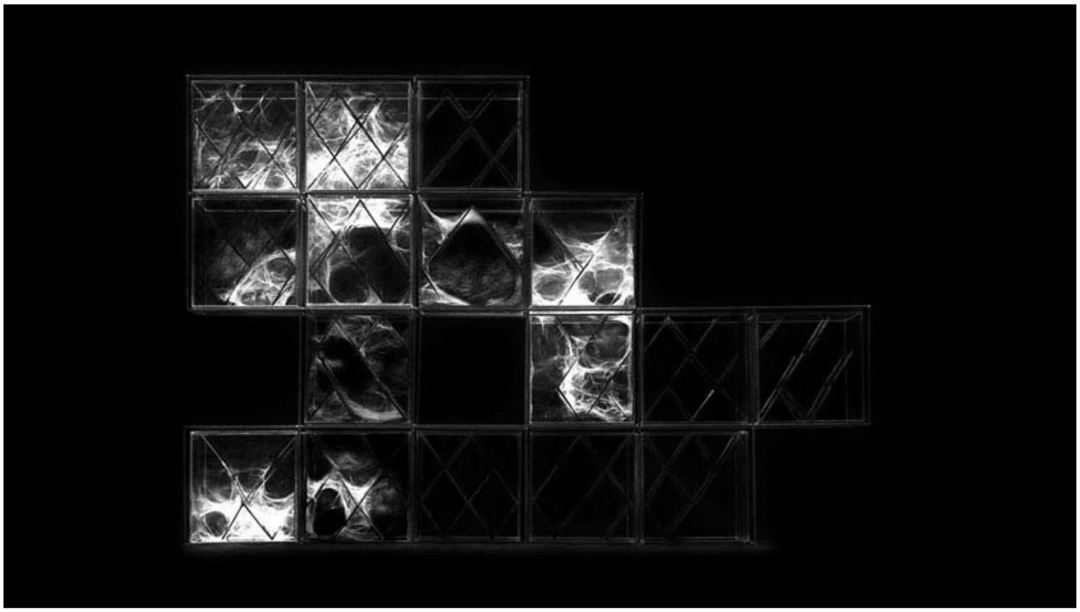

Figure 10.10 XenoDerma, building skin prototype. Front view of the 1:1 scale prototype under construction. The image illustrates empty units, 3D-printed substratum units, units currently inhabited by silk spinning Asian Fawn tarantula and units completed with both structure and silk cladding.

Source: Copyright Urban Morphogenesis Lab, UCL London, 2018

The project involves the contribution of human and non-human stakeholders, thus elevating them to the role of co-creators of the actual solutions in their becoming. In this sense it is less important whether the design medium includes algae, bacteria or other kinds of digital systems. All these forms of intelligence are dragged into the creative process, managed and mediated by architecture and its protocol. This is how, by releasing control of the actual definition of architectural morphology and its future evolution, we simultaneously gain in scope and in the ability to influence its morphogenesis at a more profound level.

In XenoDerma, one of our recent research-based speculative projects developed at the Urban Morphogenesis Lab in UCL London, we propose this new-found level embodies a productive form of alienation where spiders, more specifically a breed of tarantula named Asian Fawn, act as autonomous agents of architectural production (Figure 10.10). As we discovered, spiders' minds do not completely reside in their body, as their web constitutes a form of spatial thinking. Information from their web becomes an integral part of their cognitive system. The web provides a medium of interaction with embedded intelligence. In XenoDerma its morphogenesis is interfered with by an alien spatial scaffolding (algorithmically designed and machine printed). The result is ambiguous, the product of an alien intelligence that resides somewhere at the intersection of the biological, digital and spatial realms.

In conclusion,

> Through experimenting with biological organisms and digital apparatus we envision a new generation of bio-digital 'designed prototypes' with transformative agency for an architectural discipline yet to come.
>
> *(Pasquero and Zaroukis, 2016)*

A future bio-tech architecture that is plural, collective and mutant. Defined by the trans-scalar nesting of heterogeneous systems, each composed of individually interacting units immersed in a changing environment. Within this new paradigm performance is a generative force of spatial and material articulation, a morphogenetic force. Adaptation to a world of scarce resources will lead to richness and diversity of forms and increased material intelligence.

It is a process that has no beginning and no end; rather, it evolves in time from conception to construction and beyond during its useful life cycle. This notion suggests moving away from ideas of responsive or adaptive environments to develop participatory frameworks where the observer is no longer a mere user but becomes an active co-creator of the spaces he or she is inhabiting. This shift makes novelty possible as a new kind of spatial conversation emerges with unexpected consequences on the way space is perceived and utilized. Ultimately computational design strategies are re-cast into a broader practice of embedding bio-digital intelligence into physical space. This effort represents an attempt to culturalize the inhuman, that is to re-describe the boundaries of generative design practices beyond human rationality and creativity.

Architecture thus begins to operate at multiple interconnected scales at once, from the micro-regimes of algae cells to the macro-behaviours of smart urban infrastructures, expanding both its scope and reach. It provides the spatial substratum for a new emergent form of "bio-citizenship", recognizing the expanded role played by inhuman entities in the Anthropocene Age. Any architectural protocol in the future shall seek to enable this extended participation and shall embody its artificial intelligence. A form of intelligence that is distributed into the fabric of the spaces we inhabit and that is co-evolutionary to them.

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