Dialectics of Nature

Metabolic Architectures Meet Intelligent Guerrilla Beehives

DENNIS DOLLENS AND **ANNEMARIE MAES**

ABSTRACT

Between realms of cellular life, city occupation and technology, AnneMarie Maes's Intelligent Guerrilla Beehive project and Dennis Dollens's metabolic architectures share a theoretical lineage and form-finding curiosity, subscribing to the view that species' intelligence and their built environments can contribute to experimental art and architecture. Microbe, plant, animal and machine intelligences then root our research considering bees, microbes and computational simulation as participants in generative design and technological communication, AI and community. The article discusses sculptural, architectural and theoretical logic/design as it draws from nature to hybridize types of intelligences spanning matter, phenomena and life.

BIOREMEDIATING INSTALLATIONS AND ARCHITECTURES

The philosophical lessons of civil disobedience from Thoreau, the Civil Rights Movement, Paris '68, Vietnam War protests and antinuclear demonstrations still resonate in social policies, production of the arts and individuals' psyches. In recent times the Arab Spring, #MeToo, Greenpeace, Occupy and COVID-19 lockdowns continue cultural evolution and spread tactical thinking that enrolls new populations to face environmental realities that include species eradication, climate change and artificial intelligence (AI).

Rarely grouped together, these and other movements interface the arts, science and technology as subjects of thinking, computing and cognitive extension [1] communicated with the intelligence of living organisms, smartphones and AI neural nets. Human thinking extended from revolutionary and technological movements is then an epigenetic [2] part of global DNA, coding new patterns of assessment that cognitively and technologically underwrite an expanded conceptualization of life, urban occupation and environmental justice we treat in hybrid theory, installations, sculpture and architectures.

In consequence, we—Maes and Dollens—identify species intelligence with social justice to underpin forms of artistic expression and expand our understanding of organisms, matter and natural forces through research by design. That approach is encapsulated in artist production interlacing biological and technological theories indexed in relation to philosophy and biocomputation. To instigate methods of biological input for technological art and architecture (Figs 1,2), we identify metabolic and synthetic intelligences communicating in wild and urban environments. Those intelligences inaugurate dialectical reasoning to explore microbial life, botanic communities, signaling (as in the dance of bees) [3] and AI's increasing potential to learn on its own [4]. This dialogue distinguishes forms of life, communication and intelligence performed by living and AI agents in:

> nature populated by intelligence of bees and plants and machines and buildings, [in which] a collective matrix emerges . . . in order for behaviors of organisms (beehives) and machines (also beehives) to be understood as genuine attributes of physical intelligence, where, in Langton's [5] sense of ALife and AI, intelligence requires us to "organize a population of machines in such a way that their interactive dynamic is 'alive'" [6].

In this article, aspects of biointelligences (including machines/AI) meet animal architectures potentially delivering the intelligence of biofilms to fablab-built components generated through plant algorithms. Algorithmic generation is thereby grounded in L-systems, a coding language for simulating plant/tree growth and development [7]. These biocomponents are highlighted for realizing art/design through observational and digitally simulated lineages of microbe, insect or plant organisms.

Relatedly, as a parable from *The Overstory*, Richard Powers [8] portrayed ecowarriors attempting to save thousand-year-old trees from clear-cutting. These trees and their homeland

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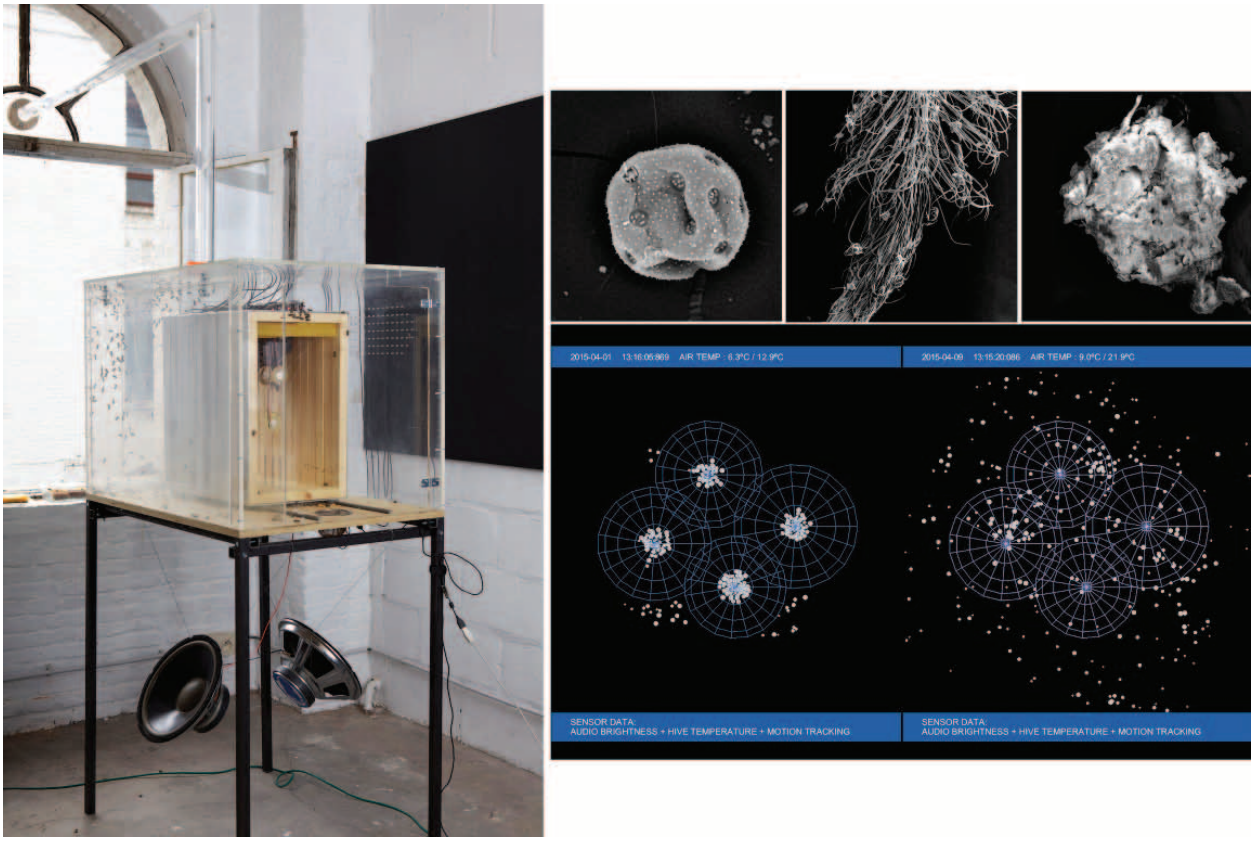

Fig. 1. AnneMarie Maes, *The Transparent Beehive*, 2013–2014. A bee colony lives in a hive that houses piezo microphones, temperature sensors and webcams. Top right: These Scanning Electron Micrographs focus on the entanglement of the honeybees with their environment: (SEM) of a *Mentha* (mint) pollen grain (×3400), SEM micrograph of the lower tip of the proboscis (×150) and SEM micrograph of a fine dust particle (×250). Bottom right: Artistic visualization of audio, temperature and bee-traffic data gathered in the beehive. (© AnneMarie Maes)

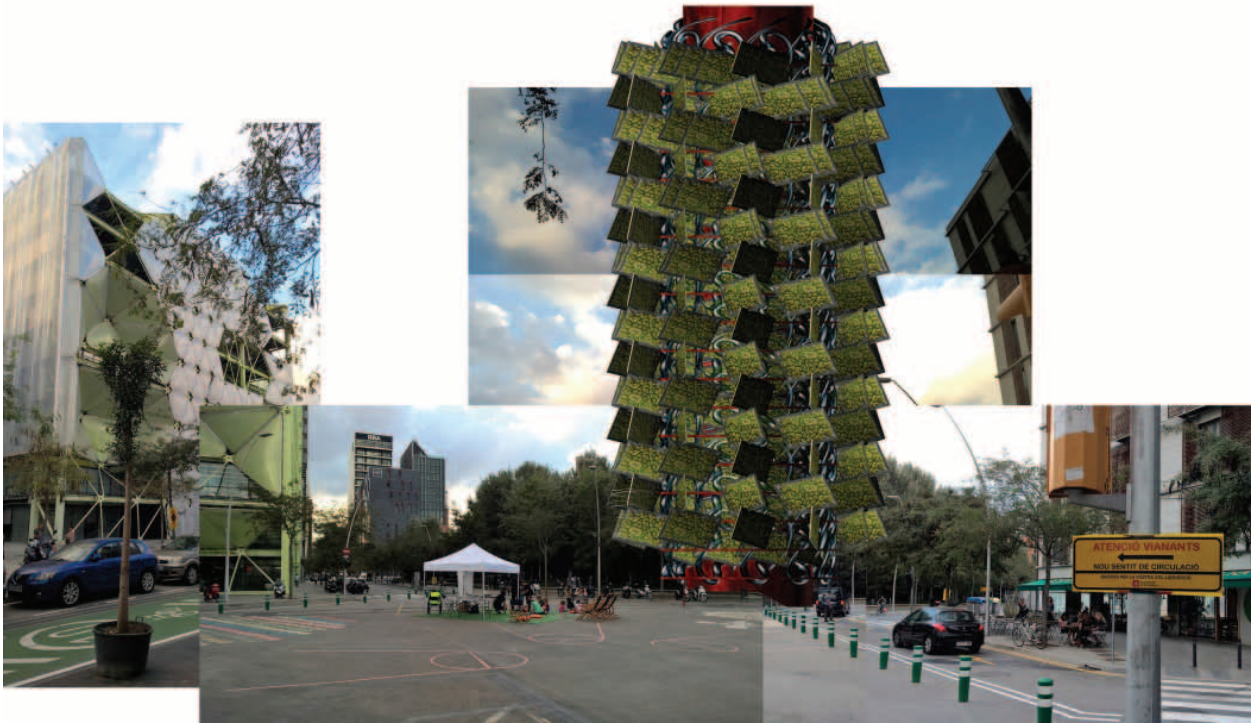

Fig. 2. Dennis Dollens, *BCN MicrobeTower*, 2015–. The structure of this building is algorithmically grown as simulated trees whose branches irregularly fuse to engage truss-like strength. The panels are hybridized microbial intelligences managed by AI for homeostatic, bioremedial performance. (© Dennis Dollens)

forests had been scientifically demonstrated to be communicating with each other and forest-soil communities. They are arboreal and microbial citizens using biochemical signaling enacted between leaf pheromonic signaling and/or bacterial root systems [9]. In the minds of Powers' protestors, forest intelligences were not only endangered, but *entitled*—by species rights—to protection from ecocide deforestation. The correlation with Maes's Intelligent Beehive project and Dollens's BioTowers is in a convergence of differing species intelligence with human intention and artistic/technological potential leading to environmental collaboration between species.

Discussion of radical science/technology or politically charged issues surrounding environmental, urban and/or artistic practice is not unusual in *Leonardo* [10]. Here we establish a context in past and present political action, theory and history while looking forward in our work to interfacing biology, technology and cognition.

Maes seeks artistic and media expression through sculptural, technological and biological installations to communicate urban bee, bacteria and human habitation. Dollens posits the role of microbial intelligence for bioremedial buildings. For us both, issues of ontology and morphology, along with typologies of intelligence, drive systems thinking from autopoiesis [11] as it theoretically aids the development of pathways to distinguish living cognition and/or single-cell intelligence. Applied in this realm of thinking, works are anchored in, for example, Thoreau's proto-autopoietic thought: "Shall I not have intelligence with the earth? Am I not partly leaves and vegetable mould myself?" [12].

SHOUT-OUT: THE WORDS/WORKS

Our questions oscillate around art/architecture in spheres of nature and technology (Figs 3 and 4). Some research questions are de facto propositions manifested in images, models or texts conceptually exploring realms of scales, materials and communication. To convey their visions, Maes favors exhibitions and Dollens favors theory. We both use the format of artist books—most recently, Maes in *The Transparent Beehive* [13] and then *Alchimia Nova* [14], and Dollens in *Autopoietic Architecture: Can Buildings Think?* [15] and *Metabolic Architectures: Turing, Sullivan, Autopoiesis & AI* [16].

Our recent books function as artistic propositions and, sometimes, as proof-of-concept documents, establishing direct artistic observation as a strategy for probing dialectical questions integrating intelligence, AI and life into the production of art/architecture. Our publication tactic is carefully paired with advocacy to give voice to urban culture and technological/artistic potentials for near-future designing. Our respective research acts as catalysts nurturing current projects. For example, Maes continues to work with biofilms she initiated in 2016–2017 (see online supplemental material). This research is a central component of the *Intelligent Guerrilla Beehive* (Fig. 3), and that work, a branch of the earlier *Transparent Beehive* (Fig. 1),

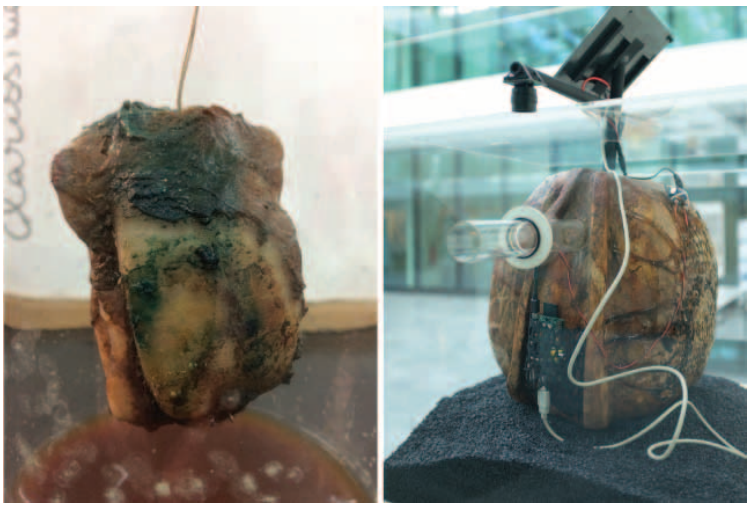

Fig. 3. AnneMarie Maes, *The Intelligent Guerrilla Beehive*, 2016–2017. Left: 3D printed model of the beehive, clad with microbial cellulose skin and inoculated with *Lactobacillus plantarum* bacteria growing into a biofilm. Right: Installation shot at the Leonardo da Vinci Science and Technology Museum, Milano, Italy. (© AnneMarie Maes)

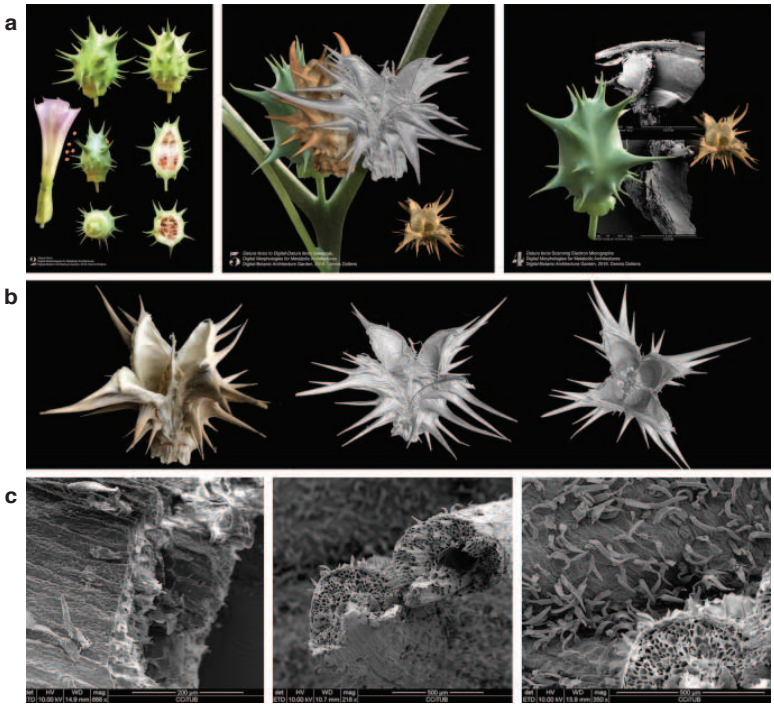

Fig. 4. *BioTower Seedpod Morphology*, 2016–. (a) *Datura ferox* botanic prints. (b) A dried biological seedpod at left, indistinguishable from two high-resolution CT scans at center and right. (c) SEM images of *Datura ferox*. Left: spike and surface (668×); center: split spike, cellular reticulation (218×); right: spike section (350×). (© Dennis Dollens)

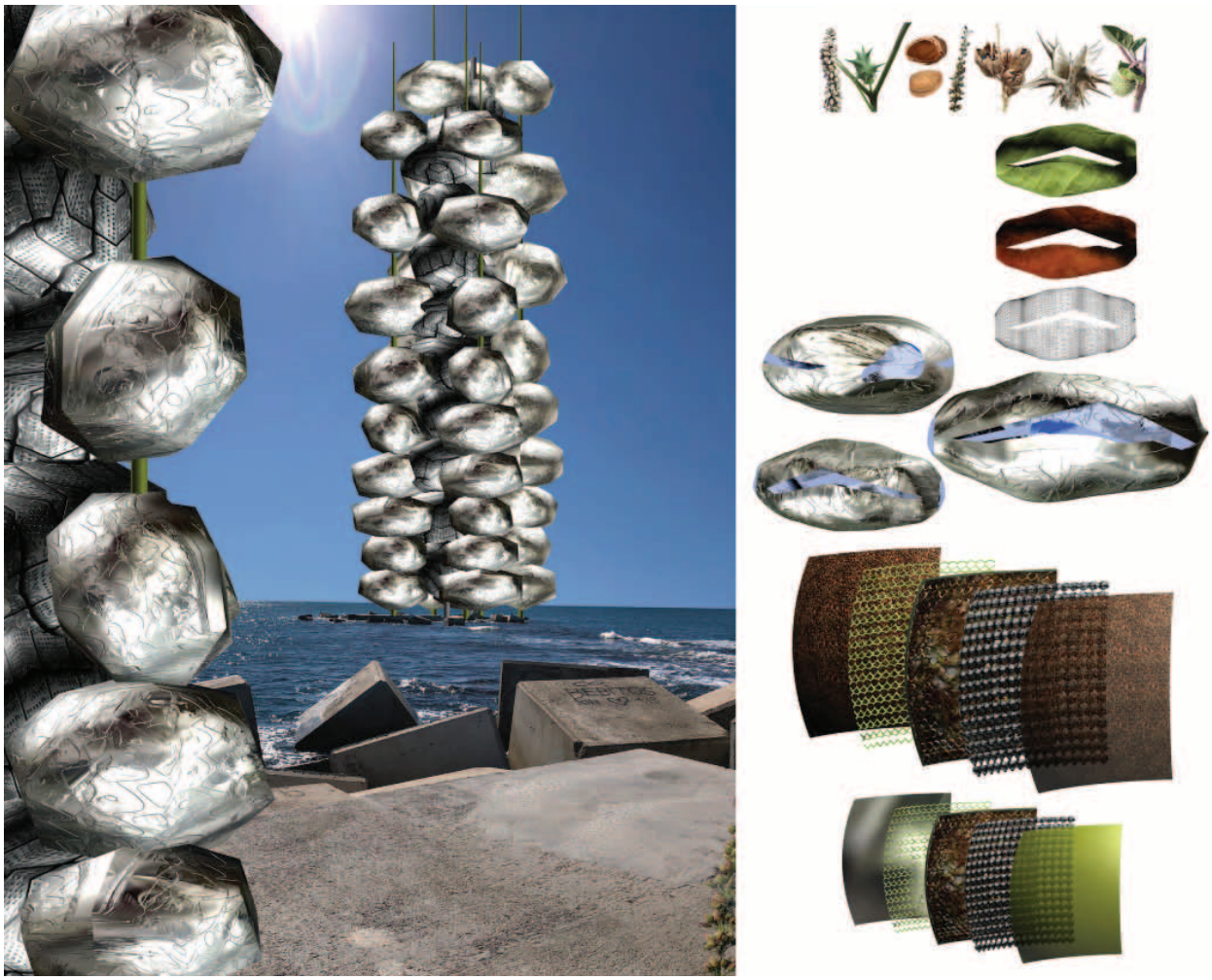

Fig. 5. Dennis Dollens, *BioRemediating PodTower*, Barcelona, 2018. Right: Algorithmically grown, *penstemon palmeri*–inspired forms based on seedpods nurture and signal inner biofilm panels as living agents metabolizing pollution. Left: Digital studies for transforming data from plant observations, SEM and CT scans (Fig. 4) into architectonic pods, panels and infrastructures. (© Dennis Dollens)

evolved through her research on an alternative architecture appropriate to endangered species. Dollens blogged that *The Transparent Beehive* book is an:

> introduction to how Maes's research operates between experimental urban horticulture, scientific research, and metabolic architectures. It's a guide to her artistic vision and ways she evolves processes to realize forms, materials, and biological monitors [sensors]. . . . By engaging complexity, Maes builds into the project first-hand observation, laboratory probes, and digital monitoring for testing in research gardens, overgrown urban lots, and rooftop apiaries [17].

The blog post points out continuity in current work emerging in experiments with color (dye) potentials produced by living biofilms [18]. And those experiments expand research into realms of pigment attributes and spectral signaling differing between species. Together we are considering the use of bacterial signals as sensors and living biochemical actuators with a view to biofilm panels enacting pollution remediation for BioTowers (Fig. 5). For the past few years, Dollens has been theorizing microbe-to-AI interactions by asking: Can AI and microbes be hacked for architecture-to-environment goals? Our individual research projects consequently overlap. Where Maes is prototyping bacterial performance to evolve beehive morphology—sculpture—biologically intent on inoculating beehives against microbial predators (Fig. 3), Dollens is taking the mathematics and morphology of plants and trees (Fig. 2) to generate buildings for which biofilm/microbial panels support bacterial agents metabolizing (eating) airborne carbon.

> Thinking of building intelligent beehives with living substances, Maes . . . initiated laboratory experiments involving the growth of bacterial and yeast skins (scoby skins), with "leather-like cellulose" properties, for prototype constructions. Matrix-like, these striated biofilms are projected to function as environmental sensors while providing the bees with probiotic resistance to fight-off mites. . . . By extension, similar bio-research processes are in line with designing materials and infrastructures, pertinent to metabolic architectures [19].

An analogy emerges—Maes's beehives are, to Dollens, experimental architectures. The relationship is in how we dialectically perceive working with microbial/plant intelligences different from human intelligence. Nature extrapolated through science and direct observation thus guides our

research to question what is natural and ethical to support environmental/social change in the flux of city life. For articulation of design intentions, one form of dialectics emerges where installations, art, texts and buildings interconnect with and transform each other.

Frederick Engels, in the *Dialectics of Nature*, wrote: "The general nature of dialectics [is] to be developed as a science of interconnections" where "transformation of quantity and quality—mutual penetration of polar opposites and transformation into each other . . . [is developed] through contradiction and negation of the negation" [20]. With "negation of the negation" corresponding to resolving questions, we contemplate fusions of organic life with hybrid materiality and AI. Engels's transformations then constitute a process of working with matter and phenomena underpinning our partnerships with wildlife, art and technology. We strive thus to address toxic strife and species diversity in urbanisms while seeking to collaborate with science to synchronize biotechnological potentials of, for example, smart cities before it is too late to debate/research nature-to-technology partnerships.

DISTRIBUTED MICROBIAL/PLANT INTELLIGENCE

Returning to *The Overstory*, the point we take away is that ecological activism eventually informs government policies—and has resulted, to cite two cases, in Ecuador's 2008 constitutional amendment recognizing the Rights of Nature and a Māori legal victory in 2017 when a sacred river was "granted the same legal rights as a human being" [21]. Powers chronicles 1990s activists questioning how nature, in this case trees—but, by the same principle, oceans, wetlands and wildlife (such as bees)—could be granted legal rights administered by legal guardians. The guardians could then represent trees or mountains or rivers in court proceedings against oil pipelines, offshore drilling, strip mining, ocean dumping, forest clear-cutting or exclusionary city zoning.

The justification in such cases is that if corporations have legal rights, nature too should have legal standing to live free of pollution. In order to explore the logics involved in such propositions, Christopher D. Stone's text "Should Trees Have Standing?" [22] reads like a manifesto for contemplating and protecting nature as living intelligences using legal case studies to invoke how living species, science and technology can be folded into autopoietic [23] and social domains of nature. On a theoretical level, Stone's concerns may now be applied to metabolic art/architectures as well as to human-centered AI and machine consciousness [24].

If Stone's essay is considered in relation to microbe/plant [25] actions in buildings, a conceptual network emerges to support modeling biotechnology and algorithmic simulation with artistic and theoretical practice. That cognitive/biodigital network becomes foundational for ecological collaboration, in our case with AI and cellular intelligences. In response, we read "Should Trees Have Standing?" in tandem with *Dialectics of Nature* [26] as scaffolding to situate questions surrounding endangered species and climate change into research protocols.

Some of these inquiries concern both of us in our use of imaging technology to make visible the microscopic, as in Maes's books or her 2018 exhibition at the Miró Foundation in Barcelona, where five large scanning electron micrographic images [27] greeted visitors (Fig. 1). Dollens too uses SEM images (Fig. 4) along with CT scans to investigate seedpod morphology for coded tree growth in L-systems—what he calls eTrees [28]. Design research and its resulting art/architecture now suggests to us biofilm substrates as panel components to detect and react to industrial toxins. Both our projects are then similarly imbued with the conviction that species—bees, plants, microbes, urban/wild lands, etc.—have rights to be considered in artistic production.

In this realm, the rooftop beehives Maes maintains at her Brussels studio—certified neonicotinoid pesticide free by the EU—demonstrate bee-human urban compatibility [29]. For Dollens, his *Datura ferox* and *Datura stramonium* cultivation beds are realms for observing phase changes from living organisms to dried pods, with consequent morphological data later extracted from CT and SEM pod scans (Fig. 4).

Likewise, while beehives and seedpods have spatial, form, material and social analogies with cities and buildings, a parallel correlation emerges in microbial life. Biofilm bacteria are now known to build infrastructures displaying urban-like organization. In the *Journal of Bacteriology*, Paula Watnick and Roberto Kolter wrote: "The natural biofilm is less like a highly developed organism and more like a complex, highly differentiated, multicultural community much like our own city" [30]. In this scenario, Watnick/Kolter describe biofilm exopolysaccharide structures (carbohydrate starch, cellulose or glycogen), as microscopic 3D space frames built by resident bacteria. This corresponds with Maes's research that biofilm bacteria continuously renew themselves. Their cellulose skin acts as a crust that disintegrates under each new layer of bacteria. As a skin/crust laminate enabling biorenewal and bioremedial materialization, it may be applied to an *Intelligent Guerrilla Beehive* or a BioTower's inner panel as a sensory membrane of living cells feeding off previous generations (Figs 6 and 7). Alternatively, breakthroughs with engineered *E. coli* suggest hybrid potential for both projects dealing with bioactive panels that detect/eat/metabolize CO_2 [31]. The aspect we focus on is that living engineering, intelligence and materialization exists at bacterial scales—and, as with beehives and forest-tree communities, microbes, plants, soils and fungi have lessons for art and design requiring recognition of urban and wild bioremediation.

With biofilms and biopanelization, we investigate joining/laminating living organism with design functions, technological materials and AI programming. This sets the stage for evolving Intelligent Guerrilla Beehives and BioTowers to include living microbial performance. Research then locates biofilm panels incorporating living functions with AI-monitored self-maintenance as supporting microbe or plant intelligence for bioremedial, and biosurveillance, tasks. From this collaboration, biofilm membranes provide organic life to architectural curtain walls and pod-skin materializations (Figs 5–7). As living sensors, biofilms may detect, ingest and metabolize pollution while other "microorganisms produce

Fig. 6. Left: AnneMarie Maes, *Resonances II*. Left: Exhibition at the EU Joint Research Center, Ispra, Italy, 2017. Experiment with microbial cellulose for biofilms. Fluctuations in temperature, Ph and ultrasound were observed over 6 weeks and the results were made audible and visual on a small DIY device. Right: Installation at *Sensorial Skin*, Brussels, 2016. (© AnneMarie Maes)

Fig. 7. Dennis Dollens, *FeroxTower*, Barcelona, 2018–. Hybrid AI and microbially intelligent agents sense, respond and metabolize atmospheric CO_2 via computationally augmented bioremediation. L-system grown eTree tower and 3D, CT-scanned *Datura ferox* pods (Fig. 4, row c) embody microbial agents and direct-air capture machines. (© Dennis Dollens)

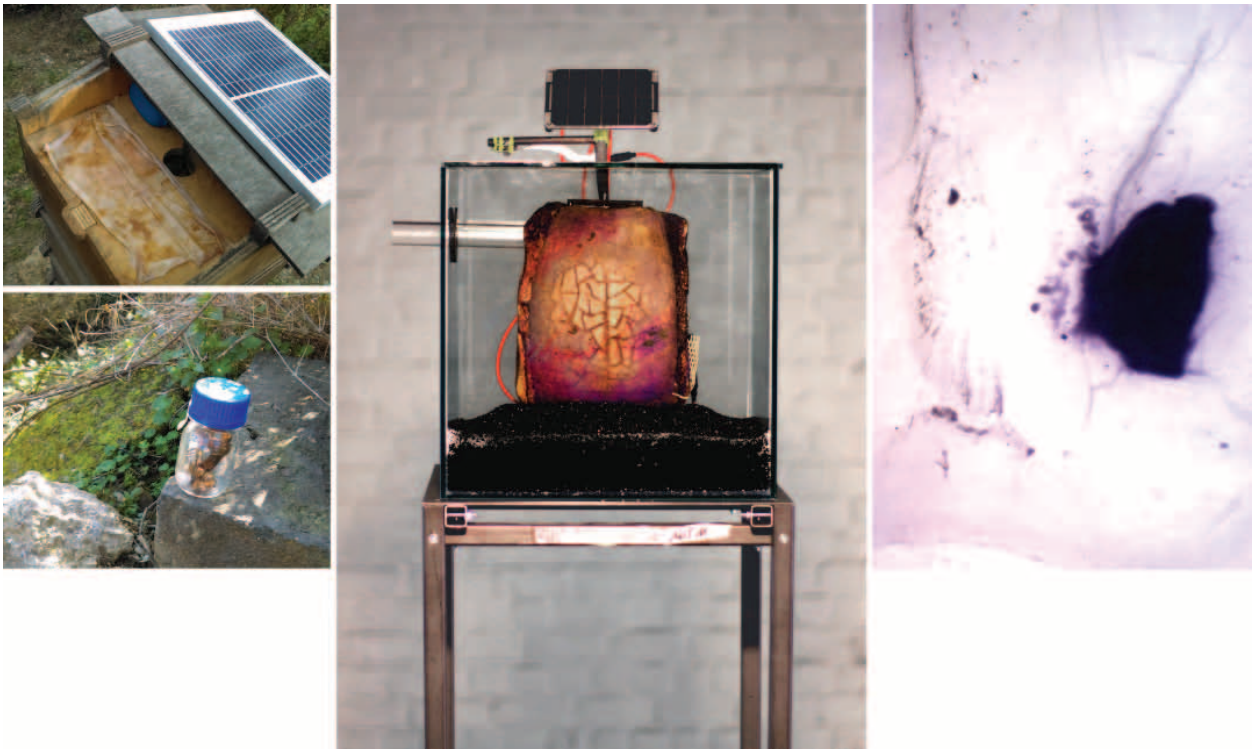

Fig. 8. Left: Hunting bacteria in the apiary. Wet cellulose fabric is positioned in the top of the beehive to collect environmental bacteria and to isolate and culture useful microbial colonies from it in the lab, 2017. Photos © Núria Condé Pueyo. Middle: AnneMarie Maes, *The Intelligent Guerrilla Beehive* as a sculptural biofilm construction, at Ars Electronica, Linz, 2017. (© AnneMarie Maes) Right: A biofilm of *Janthinobacterium lividum* microbes is developing on a wet microbial skin, 2018. (© AnneMarie Maes)

diverse secondary metabolites such as antibiotics, antifungals, and siderophores [iron binder/transporter for microorganisms], that mediate communication, competition, and interactions with other organisms and the environment" [32].

From the above we posit that aggregated intelligences living in biofilms constitute "villages"—bacterial neighborhoods—participating in communal activities even as they build inhabitable structures. Applied to beehives or architectures they are cities-within-cities—proximate intelligences available for inclusion in bioperformative art/architecture (Figs 7, 8). Maes's descriptions for Intelligent Guerrilla Beehives speak to BioTowers and the necessity for research that entail biofilms surviving outside of a laboratory. In that description Maes sets up analogies useful for architectural functions.

> The design of the Guerilla Beehive is inspired by nature. The content (± 40 liters) responds to the nest-needs of a bee colony living in the wild, and the mobile architecture makes it easily deployable on different spots in public space. . . . The beehive has been enhanced with a sensor network in order to monitor the health of the colony [33].

These conditions—referenced to beehives or architectural panels—facing years of exposure to urban environments, suggest pairing with AI-learning to guide bioremediation and homeostasis in urban hives or tall buildings. Subsequent ongoing challenges for Maes exist in searching for living biofilm potential (Fig. 8) with performative environmental abilities; for Dollens, challenges exist in searching biomechanical and bioAI infrastructures in order to chart pathways to metabolic architectures. That said, we both emphasize a dialectic approach—collaborative debate—involving community and scientific input realized as environmental advocacy in art, design and teaching [34].

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