Vertimus – An Art and Science Project

Karine Bonneval, Eric Badel

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We turn, we turn around, we transform ourselves

text **Karine Bonneval** and **Eric Badel**

Prima Belladonna

> I was in the shop tuning up a Khan-Arachnid orchid with the UV lamp. It was a difficult bloom, with a normal full range of twenty-four octaves, but unless it got a lot of exercise it tended to relapse into neurotic minor key transpositions which were the devil to break. And as the senior bloom in the shop it naturally affected all the others. Invariably when I opened the shop in the mornings, it sounded like a madhouse, but as soon as I'd fed the Arachnid and straightened out one or two pH gradients the rest promptly took their cues from it and dimmed down quietly in their control tanks, two-time, three-four, the multi-tones, all in perfect harmony.
> – JG Ballard, "Prima Belladonna", *Vermilion Sands*[1]

I don't live in Vermilion Sands, "an exotic suburb of my mind" according to Ballard, but in a small village in Cher, France, where I have never heard orchids sing. In this land of mists and witches, the trees sing in the wind, their branches swaying as though they were alive. On the Atlantic coast (where I was born), you can see this movement as though it were imprinted in the maritime pines that hang off the edges of the limestone cliffs. Apart from the *Mimosa pudica*, which closes its leaves if it is brushed against, or the carnivore Venus flytrap, we don't usually see plants – anchored to the ground – move by themselves. Plants are in constant motion, but in a different temporality (which must also have pleased J. G. Ballard). Today, I am trying to find imperfect and poetic translations of how non-humans are different. This is what Baptiste Morizot, in his recent book, *Manières d'être vivant* (Ways of Being Alive) calls our "alien kins".

In 2017, Natacha Duviquet invited me to meet Eric Badel, INRAE researcher in tree biomechanics at the PIAF laboratory in Clermont-Ferrand[2]. Natacha Duviquet is a regular working partner of mine. She works alongside Studio Décalé, an organisation that facilitates meetings between artists, scientists and actors in new technologies.

I had already worked with a tree ecophysiology team in 2015, more precisely with Claire Damesin from the Ecology, Systematics and Evolution Laboratory of the Paris-Sud University in Orsay[3]. Together, we developed a project on how we share our breathing cycle with that of trees: *Dendromacy*, meaning "intimacy with trees". We don't share sensory faculties with plants, but we breathe the same air! This first collaboration gave rise to a video shot by means of a thermal camera with a cooled objective and to an installation about the possible mingling between our physiology and that of trees, about our invisible exchanges[4].

How do these collaborations work? Very simply, through meetings with the referent scientist, the teams, and the laboratory. Eric Badel showed me tools, videos and "translators" created by scientists who observe and analyse the movements of plants in a much faster time frame adapted to the human eye. In his laboratory, they investigate questions about plant behaviour that seemed incredibly new and complex to me.

Vertimus

How do plants evolve in their environment? We say they "grow", but we should rather say that they "develop"; their stems and branches extend, thicken and even bend in order to change the direction they are growing in. At the PIAF laboratory, I was shown how plants perceive their environment, whether climatically (temperature, light, water) or mechanically (the action of wind, touch, gravity). Plants even perceive their own form! How? How do plants manage to perceive external stimuli? How do they respond to them and modulate their development, adjusting themselves to acclimatise to external changes[5]? For example, let's consider the Earth's gravitational pull that each of us experiences every day. Which parts of the plants can sense it? What are the sensors? Where are they? Do they perceive the force of gravity or simply an angle of inclination? A whole florilegium of questions that involve biology and physics. Do they know the limits of their bodies and can they adjust them if physiological changes are necessary? Can they differentiate a one-off event from a permanent solicitation ? Do they remember what they went through? Do they get used to the constraints imposed on them by their fluctuating growth environment? If so, how?

We have known for a long time that plants have tropisms; that is, they orient their growth in response to external factors. Which child has not observed the tropism of lentils that, when placed on a cotton pad soaked in water, grow systematically towards the window? It is of course phototropism, to which plants are responsive, that we are talking about here. Another important tropism is governed by the Earth's gravitational force. We have observed trees straighten up slowly to regain their verticality after being tilted by a storm. Is the response of the tree the result of a clever combination of gravitropism and phototropism? Not just that! Thanks to a recent discovery made in our laboratory, we now know that plants also have a perception of their own form – proprioception – which leads them to modulate the curvature of their axes and makes them straighten up.

How can we distinguish these three perceptions and their physiological responses? How can the researcher study these three processes separately? In the case of small plants that are a few days old and only take a few hours to react, it is relatively easy to suppress their phototropism by immersing them in darkness. What about gravity? Since we can't experiment in space, we have to make do! Rotating the plant continuously on itself makes it lose its notion of top and bottom because its internal tilt sensors need time to take a measurement.

The idea of building spheres comes from the fact that trees grow very, very slowly. It takes long weeks – sometimes even months – to observe their growth process and be able to measure it. Suppressing phototropism cannot be done simply by switching off the light, because trees need this energy every day in order to grow. The originality of spheres is their ability to create an environment of isotropic light; that is, an environment where light shines in the same way in all directions. Therefore, with appropriate programming, we can create a day-night rhythm where a tree receives light energy from the top, bottom and all sides. Phototropism is no longer possible! How does a tree move in such an environment, after losing one of the main factors of environmental tropism, and with only the perception of gravity and proprioception left?

The spheres were coloured white, using a slightly transparent resin. They actually consist of two half-spheres that can be assembled for the duration of the experiments. Dozens of circular neon lamps are fixed all around and distributed regularly over the surface in order to produce uniform lighting. A purpose-made tree support was also created: it allows the pot to be tilted horizontally while keeping in the nourishing soil, and guarantees the regular irrigation necessary for transpiration and photosynthesis throughout the experiment.

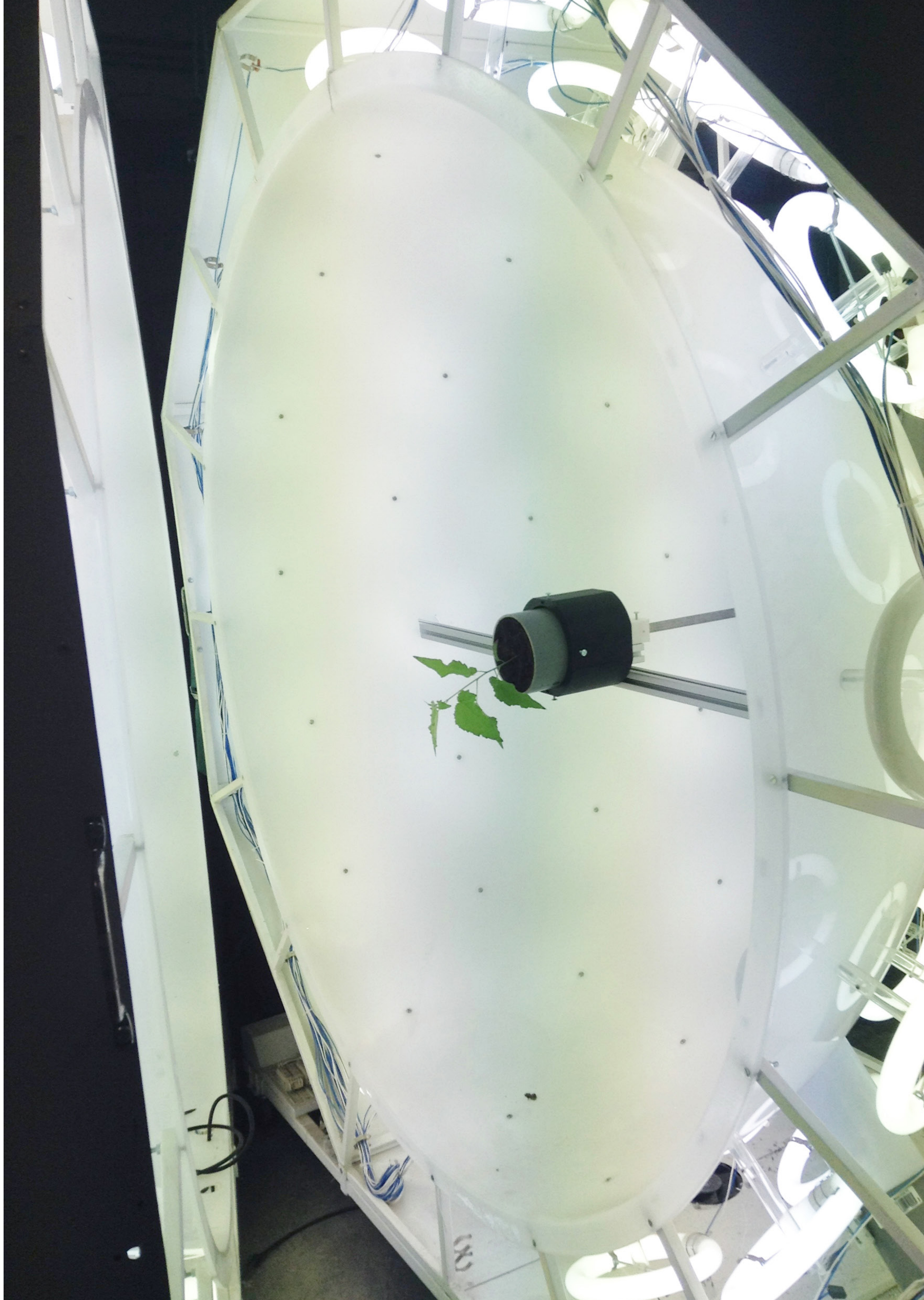
Finally, a digital camera fitted in a small hole in the sphere, and controlled by a computer, allows the recording of images of our tree's slow movements in time-lapse, i.e. at a regular rate, in order to make the film which will then be analysed.

The sphere served as the starting point for a collaborative work: a long tilting experiment with a poplar tree illuminated at 360 degrees. This required adjustments such as the customisation of some parts in order to accommodate a camera, and the creation of a rotating, automatically watered mechanism. Then, since we were working with a plant, we had to wait for the right time: the season when the trees grow and can therefore straighten up. The conclusive experiment finally took place in June 2019.

In parallel, the (deceptively simple) idea I had developed was to compare the plant's perception of the boundaries of its own form and gravitational pull with human perception of the same physiological phenomena.

Emilie Pouzet is a performer and curator of the dance and performance programme of the Emmetrop association in Bourges. In discussion with her, it emerged that the notions of proprioception and gravity were part of several current methods used in contemporary dance.

Using archive images, Emilie acquainted herself with the movements of a shrub straightening itself up (rendered possible by a sequence of stop-motion photography) in order to transform them into human movements. An almost impossible task, since our bodily structure is obviously very



different from that of a poplar tree. The performer must mentally project herself into this movement, try to grasp its complexity and to enter a different time, since a sequence of movements made by the human body in about four minutes for the *Vertimus* film lasted more than two weeks for the plant (at the rate of one image every ten minutes).

After some rehearsals, the "human" sequence – based on the stop-motion sequence of a poplar tree straightening up at the PIAF – was shot by Bandit-Mages, an organisation that offers a platform for residencies, production, experimentation, research, dissemination and awareness in the wider field of contemporary media, such as video, cinema and sound, as well as electronic and digital objects, in Bourges.

Thanks to symmetrical digital editing of the two sequences, the respiration/pulsation shared by the two beings – human and plant – can be experienced by the spectator.

Soon added to the idea of the two-channel video projection was the principle that the spectator of the experiment should also experience a change in their own gravitational pull. The primary source of inspiration was a metal tool, "a chaise longue for plants", found in the laboratory. Two ficus trees were tilted in order to instigate the straightening-up process; they accompany the spectator, who has become an actor in the straightening-up process.

Taking on the life of a plant in order to understand its movement involves improbable tests in the meeting room, to understand if humans, when leaning too far, also feel – like the plant when suddenly placed horizontally – that their position is not correct and that the body must react in order to ensure stability.

The apparatus functions in a simple manner, by disturbing our inner ear and alerting our senses, our vertigos, although the angle here is only 35°, while the ones created at the PIAF can tilt the plant to an extreme degree – to the horizontal position. They make us feel that, if we do not stiffen our entire body, the position will become impossible to uphold and inevitably result in a fall to the ground. It is the same for plants which, in order to remain upright, have to quickly develop specific new tissues – veritable muscles capable of tensing, that allow them to hold a stable position, and also to bend in order to recover the verticality they seek for their mechanical comfort. The apparatus also makes us feel the vital need to anchor ourselves to the ground. The Earth's gravity does its work by exerting a vertical force towards the centre of the Earth, against which the root system spread out in the ground struggles. Earth action, root anchor reaction: over the course of this long experiment that follows the life of a continuously growing tree, who will prevail? Because unlike adult humans, trees continue to grow, to synthesise biomass that accumulates in their trunk and branches, and get heavier. The adjustment of mechanical reactions is therefore a permanent constraint for all trees, from the smallest to the oldest and largest redwoods.

Synclinal forest

Among the first things Eric Badel showed me were cross sections of tree trunks. Their rings revealed how the trees had, very asymmetrically, adjusted the production of their wood to adapt to a permanent inclination. Evolution has selected two main strategies for tilted trees to manage their uncomfortable mechanical situation. Hardwoods build on the upper side of the trunk fibres, capable of pulling like guy-wires, while softwoods build on the underside of the trunk fibres, capable of pushing like hydraulic cylinders, and try to slowly straighten up the stem, day by day.

Following the same principle of a tree's straightening movements as it adapts to a permanent inclination, *Synclinal Forest* is a ceramic tripod where three softwood trees grow in a tilted gres pot. In geology, a syncline is a fold that is concave upward. This formation is often created by the collision of two tectonic plates. Trees growing on these inclined and concave spaces have to adapt to this geographic singularity. In this piece, a bonsai-scale forest grows by straightening up in a slow movement involving gravitropism, phototropism and proprioception.

Listen to the Soil

Stefano Mancuso, Professor at the University of Florence, Italy, and founder of the International

Plant Neurobiology Laboratory (LINV) said in *Le Temps* magazine, 2018:

> Now I'm going to be provocative by saying that plants are the only organisms that really solve their problems, because us animals think we are solving our problems but we generally use movement to avoid them: it's cold, so we go to a warmer place and vice versa; if there is a predator, we run away; if there is no more food, we move on. Plants face the same problems but have to solve them without moving. They are therefore much more intelligent than animals![6]

We mentioned this above, too: plants move in their own way, by pushing and adapting to external stimuli. Plant movement simply does not feature on the human time scale. Thanks to stop-motion devices, the movement of plants above ground can be seen to unfold in human time.

But what's going on under our feet? It is a dimension that escapes our common perception above ground, where our senses operate. We all know that a large part of a plant's organism grows underground. On this subject, in one of my previous works, *Listen to the Soil*, I collaborated with bio-acoustician Fanny Rybak and Matthias Rillig, Director of the Rillig Lab[7]; we designed an installation of ceramics that would broadcast sound recordings of invertebrate activity in soils from different places. Indeed, healthy soil is noisy: the sound sequences allow us to hear the movement of small animals that live in various types of soil collected from different places (worms, larvae, arthropods...).

But these bio-acoustic devices do not allow us to listen to the roots growing. Out of our sight, a large part of the plant grows underground, without us paying much attention. However, the plants' root systems are also very skilled at analysing their environment.

We return to the PIAF in Clermont-Ferrand, to discuss roots. In order to maintain its anchoring and nutritional functions, the root system has to keep developing. It therefore matches the growth of the plant's aerial part. The roots make their way through the soil, first becoming longer, then increasing in thickness. The mechanical characteristics of the soil through which they extend fluctuate both spatially and temporally. Spatially, because of the natural heterogeneity of the different soil horizons or the presence of impenetrable rocks. Temporally, since climatic conditions can play an important role by supplying the plant with water, or conversely, depriving the plant of it in the event of a drought. How do roots react when they suddenly come into contact with a denser, harder environment that is more difficult to penetrate? Do they persist in trying to puncture the obstacle, looking for a porosity they can engage with, or bypass it entirely? Roots perceive variations in their environment and adjust their progression so that they can continue to grow as much as necessary to develop the structure of their underground system. Just like the responses of the aerial part of the plants to fluctuations in their environment, these root system growth responses are also studied in the PIAF laboratory, in artificial environments where their mechanical properties are monitored. These environments are transparent, so that the slow progression of the roots can be monitored with cameras in order to elucidate why certain genotypes persist and perforate the obstacle, while other genotypes immediately take the path of circumvention[8]. The studies also seek to understand the mechanisms of perception of these soil properties: which cells are doing the sensing, where are they located and how do they perceive things? Many questions remain unanswered and are the object of ongoing research.

RRR: Rhizotron Roots Rock

Inspired by Monica Gagliano's 2017 work, which shows that roots are sensitive to sound, this piece attempts a dialogue with the root systems of various plants by playing music[9].

Rhizotrons are transparent devices of different shapes and sizes which are used to study root systems. Here, it takes the form of a round acrylic glass container resting on three feet, which is filled with either translucent hydrophilic gel or soil, depending on the version. Each leg is equipped with a speaker that plays music. Three pieces of human-made music, presenting melodies of differ-

ent styles to the roots. A musical proposal to test if the vibrations will influence the direction the root grows in, to see if these pieces of music can attract or repel the roots. A human invitation to the underground movement of the plants.

The spectator perceives this "movement" by the direction of growth of the roots, attracted or repelled by certain melodies or frequencies. It is a living piece in constant evolution: the audience sits, listening to the music played to the plants, at the same time as the plants perceive it; they can see for themselves if the form of the various root systems is affected by the music. One of the samples is from Jan Grünfeld's album *Music for Plants* (an example among many of music designed for plants and supposed to stimulate their growth), another is a traditional Taiwanese song for plants, while the last one is the rather punk rock song "Les Insectes" by Pest Modern.

In a first version where the system had been left to evolve for six months, the Taiwanese song seemed to be the most successful among the plants, while the techno-punk song appeared to have caused avoidance movements.

RRR is a non-scientific attempt of collaboration, an invitation for plants to dance, in their own time and with their own ways of moving, *in crescendo*.

"Se planter"

The French expression "se planter" (literally, "to plant oneself") has a rather negative connotation: it means to be wrong or to fail. However, as Stefano Mancuso says, since plants are anchored to the ground, they have had to develop living strategies that are different to those of animals because they cannot go looking for food, nor can they flee from a predator or protect themselves from heat or the cold by moving away from it. The ceramic piece takes on a hybrid form of gloves and roots, inviting us to plant our hands in the ground. Metaphorically, it is an attempt to experience for a moment what it is like to live in the earth; an attempt to project oneself into a form of terrestrial and subterranean life. Echoing the research carried out at the PIAF on the development of roots, our hands become sensors that help us perceive the heterogeneity of

the soil, and the constraints it imposes on us when we try to sink into it.

Paco Calvo is the Director of the MINT_{lab} in Murcia (the world's first laboratory in the philosophy of plant signaling and behavior, i.e. plant neurobiology)[10]. During a panel discussion in April 2019 at the Forum for Philosophy in London, he showed us an extraordinary video of an experiment placing a climbing bean alone in a room, with a stake – the ideal support for its growth – sticking out of the ground, but positioned too far away from the plant[11]. In this stop-motion sequence, it is fascinating to watch the stalk spin around in a spiral for a while and then sort of "set its sight" on the stake. The plant throws its stem, with the leaves acting like a pendulum, to catch hold of it as one would with a fishing rod. We see the plant position itself, stretch out and "aim" at the stake until it finally wraps around the support[12].

Plants have a broad perception of their environment. Currently we believe that they are capable of fifteen different ways of perceiving their living environment in order to adapt to it . Something to think about when picking a flower or observing a potted plant at home ... And between the sites of perception of the environment and the growing organs that are able to respond and to modify their development, there must be channels of communication and transfers of information through the plant. How can mechanical stress at the base of a stem, or the burning of a leaf, cause a growth stop at the terminal bud on a branch? There are currently a number of hypotheses.

At the PIAF in Clermont Ferrand, we worked with physicists from the University of Marseille on the hypothesis of a hydraulic signal: the vascular system, a network of conduits that supply organs with water and nutriments, is potentially a privileged communication channel. We were able to demonstrate that the application of mechanical stress to the base of the trunk, for example bending, generates hydraulic overpressures in the channels[14]. This overpressure, which we reproduced in artificial biomimetic systems, is capable of propagating very rapidly, like a wave, reaching distant organs such as terminal buds. But other hypotheses are also tested, e.g. electrical signalling. New, ongoing extracellular electrophysiology experiments aim to characterise these electrical signals and their mode of propagation through the plant. A whole scientific field yet to be explored.

And we researchers are not finished with the behaviour of plants. How do they perceive environmental factors, how do they transport information, how do they respond? Are the physiological responses relevant, in the sense that they allow plants to adjust efficiently to their environment in order to continue their sustainable development?

Research in the animal world has found most of the answers to these questions: we have a good understanding of how an eye captures light, how the image is formed on the retina and how this light signal is transmitted in the form of electrical impulses to the brain. Similarly, we also have a good understanding of the functioning of the inner ear for the perception of our position, of how olfactory receptors work, etc. Surprisingly, it is only very recently that we are witnessing renewed interest in the plant world and, day after day, we are making progress in this wold of fascinating questions, realizing that there is still a long way to go before we understand all these mechanisms. In laboratories like the PIAF, we need to revisit the concepts with new tools, and most importantly with new multidisciplinary approaches that combine ecophysiology, molecular biology and physics – and challenge or even undermine a number of paradigms, so that we can start considering plants as living beings that are ultimately very (re)active!

This artistic research, in collaboration with laboratories and teams of scientists, is only at the beginning. I like to think that, by collaborating in this way in our respective fields, we are like couriers, passing on what we see, hear, and experience. To quote Baptiste Morizot again, together we try to invent "adjusted considerations", an "interspecies diplomacy"[15]. It is now a question of immersing oneself in the living tissue to understand it from the inside... And maybe one day, we too will be able to hear the plants sing, as in Ballard's Vermilion Sands.

Karine Bonneval *is a visual artist based in the Centre region in France. Her work relies on the resources of nature and science to nourish a research on alternative ways to see and perceive them, revealing at once the possibility of using new tools to artists, and peculiar or unexplored dimensions of their research to scientists. She is especially interested in the way in which plant and animal forms constitute a repertoire of references of all times exploited. She holds a degree from the ESAD, Strasbourg, and exhibited in France, Germany, Denmark, Lettonia, United States, Argentina, Sri Lanka. She won, together with Eric Badel and Natacha Duviquet the Daniel and Nina Carasso grant Composing Knowledge for the* Vertimus *project.*
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Eric Badel *is a INRAE senior scientist at the at the Integrative Physics and Physiology of Trees in Fluctuating Environments laboratory (PIAF). In the past, he worked as a specialist of wood, studying the relationships between its microscopic structure and technical properties, while his current research investigates the biomechanics of living trees and their development in fluctuating environments. His works are based on an interdisciplinary approach that mixes physics, physiology and molecular aspects. He focuses on the way trees feel the external mechanical constrains like gravity or wind, transport this signal through their organs, and adjust their development accordingly in order to ensure their sustainability for centuries.* eric.badel@inrae.fr
www6.ara.inrae.fr/piaf_eng/About/Teams/MECA

Notes

1. "Prima Belladonna" is an early short story by J. G. Ballard. First published in a popular sci-fi magazine (*Science Fantasy*, Vol. 7, No. 20, Dec 1956), and reprinted in the collection *Vermilion Sands*, Berkley Books, 1971. All the stories in the collection are set in an imaginary seaside town called Vermilion Sands.

2. INRAE is the French National Research Institute for Agriculture, Food and the Environment.

3. In 2020 the University of Paris-Sud has been replaced by the University of Paris-Saclay.

4. Bourse Diagonale Paris-Saclay, https://www.ladiagonale-paris-saclay.fr/curiositas/portfolio-items/dendromite

5. B. Niez, J. Dlouha, B. Moulia, E. Badel, "Water-stressed or not, the mechanical acclimation is a priority requirement for trees", *Trees – Structure and Function*, Springer Verlag, 2019, 33 (1), pp.279-291. https://hal.archives-ouvertes.fr/hal-02019962v1(accessed on 4 Aug 2020).

6. Pierre Barthélémy, "Les plantes sont beaucoup plus intelligentes que les animaux", *Le Temps*, 19 April 2018, https://www.letemps.ch/sciences/plantes-beaucoup-plus-intelligentes-animaux (accessed on 4 Aug 2020).

7. About Fanny Ribak cf. Neuro-Psi, Neuro-Sciences Institute, Paris Saclay, http://neuro-psi.cnrs.fr/spip.php?article94. About Matthias Rillig and his lab cf. https://rilliglab.org (accessed on 4 Aug 2020).

8. J. Roue, H. Chauvet-Thiry, N. Brunel-Michac, F. Bizet, B. Moulia, E. Badel et al., "Root cap size and shape influence responses to the physical strength of the growth medium in Arabidopsis thaliana primary roots"., *Journal of Experimental Botany*, Oxford University Press (OUP), 2019, 12 p. https://hal.archives-ouvertes.fr/hal-02394664v1 (accessed on 4 Aug 2020).

9. M. Gagliano, M. Grimonprez, M. Depczynski, M. Renton, "Tuned in: plant roots use sound to locate water", *Oecologia*, 2017;184(1):151-160. https://pubmed.ncbi.nlm.nih.gov/28382479 (accessed on 4 Aug 2020).

10. https://www.um.es/web/minimal-intelligence-lab/

11. Recordings of the discussion can be found here https://blogs.lse.ac.uk/theforum/plants (accessed on 4 Aug 2020).

12. Michael Pollen, "Plant Neurobiology – Commentar", The New Yorker Youtube channel, https://youtu.be/MPql1VH-bYl4 (accessed on 4 Aug 2020).

13. Cf. Daugey (2018), *L'intelligence des plantes – Les découvertes qui révolutionnent notre compréhension du monde végétal,* Ulmer. An English translation hasn't been published yet.

14. JF Louf, G. Guéna, E. Badel, Y. Forterre, "Universal poroelastic mechanism for hydraulic signals in biomimetic and natural branches", *Proceedings of the National Academy of Sciences of the United States of America* , National Academy of Sciences, 2017, 114 (42), 6 p. https://hal.archives-ouvertes.fr/hal-01613620v1

15. Baptiste Morizot, *Manières d'être vivant* , Actes Sud, 2020, https://www.actes-sud.fr/catalogue/sciences-humaines-et-sociales-sciences/manieres-detre-vivant (accessed on 4 Aug 2020).

Images

Fig 1-2, p. 18: *Dendromité,* 2017. Stills from video. Above: Geodesic dome around the tree . Below: Claire Damesin breathing. Supported by Diagonale Paris-Saclay and Atelier 105. © Karine Bonneval

Fig. 3, p. 21: A young poplar tree in the PIAF sphere with isotropic lighting. © Eric Badel

Fig. 4-5, p. 23: *Vertimus*, 2019. With Emilie Pouzet. Still from Video. Supported by Carasso Foundation © Karine Bonneval

Fig. 6, p. 24: *Vertimus***,** 2019. Installation view at *Basculement des mondes***,** Maison des Arts Plastiques Rosa Bonheur, Chevilly Larue, 2019. © Karine Bonneval

Fig. 7, p. 26 above: *Synclinal Forest*, 2019. © Karine Bonneval

Fig. 8, p. 26 below: Tree rings in the cross section of different species in Eric Badel's office, 2018. © Karine Bonneval

Fig. 9-10, p. 27: *Listen to the soil*, 2018. Above: installation view at *L'âme des écorces*, Galerie Louise Michel, Poitiers, 2018. Below: installation view at *Sometime I hear the plants whisper*, Botanical Museum, Berlin, 2018. © Karine Bonneval

Fig. 11-12, p. 28: *RRR*, 2019. Above: Detail of roots "escaping" from the vibrations of the Pest Modern's track. Below: roots going straight down the tube where the barred owl song is playing, detail from the installation. © Karine Bonneval

Fig. 13, p. 29: *RRR*, 2019. Installation view at *Dé-jardiner,* Gr_und, Berlin, 2019. © Karine Bonneval

Fig. 14, p. 31 above: *Se planter*, 2019. Installation view at *Dé-jardiner,* Gr_und, Berlin, 2019. © Karine Bonneval

Fig. 15, p. 31 below: Controlled mechanical stimulations of young poplar trees in climatic chamber, PIAF, 2019. © Karine Bonneval

Fig. 16, p. 33: "Flagpole" tree in the wind, Beal Pass (Auvergne-Rhone-Alpes, France), original photo © Eric Badel, composition by Karine Bonneval, 2018.